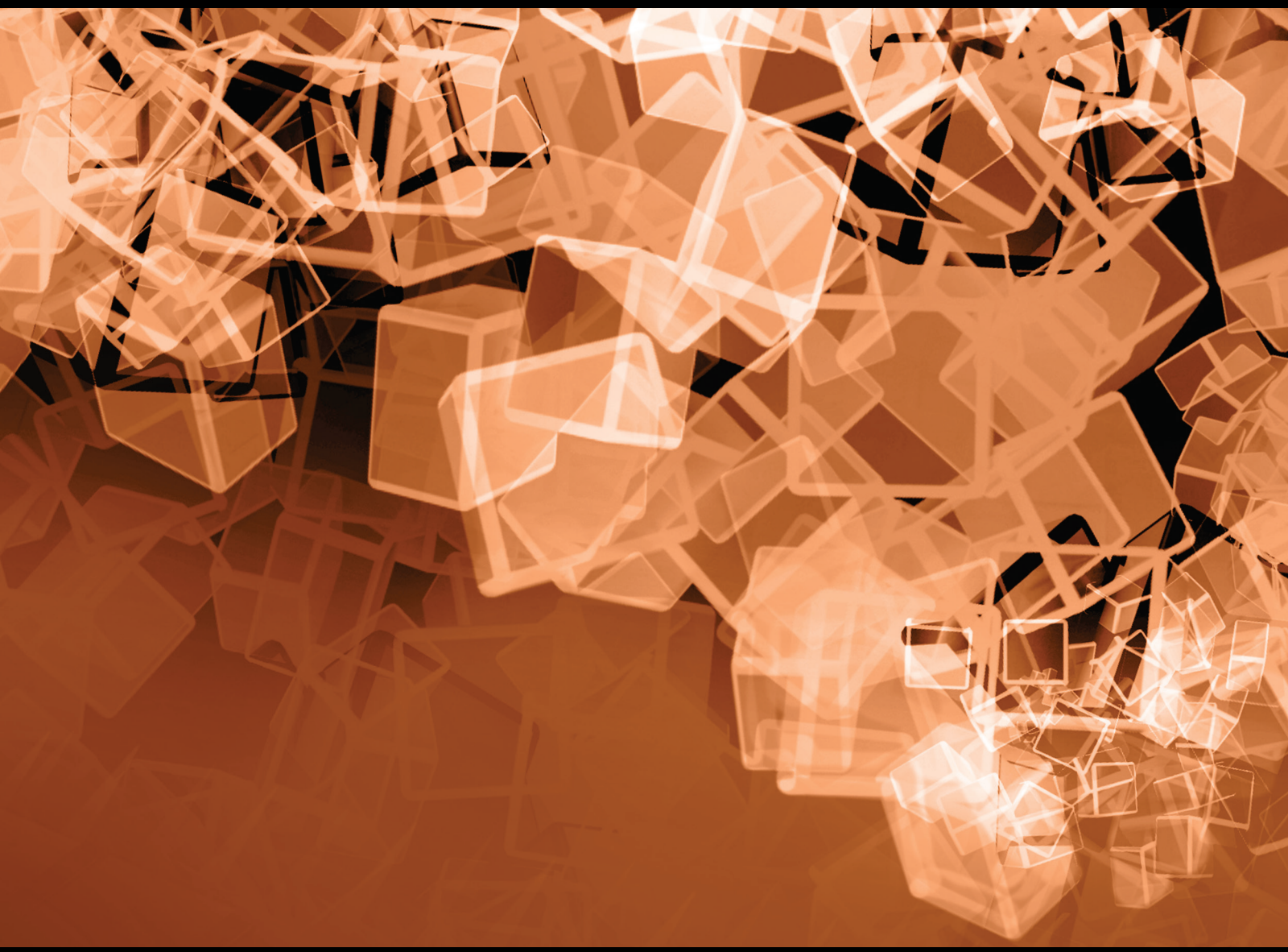
Discrete Dynamics in Nature and Society

Advanced Multi-Criteria Decision Making for Complex Production Systems under Uncertain Information

Lead Guest Editor: Zaoli Yang
Guest Editors: Yuchen Li and Ibrahim Kucukkoc



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https://doi.org/10.1155/2024/9869785

Retraction

Retracted: Key Frame Extraction Method for Minors' Participation in Online Short-Form Video from the Perspective of Government Administration

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[1] Q. Wu, "Key Frame Extraction Method for Minors' Participation in Online Short-Form Video from the Perspective of Government Administration," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 8985219, 9 pages, 2022.

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Discrete Dynamics in Nature and Society
Volume 2024, Article ID 9856106, 1 page
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Hindawi
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Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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Research Article

How to Evaluate the Efficiency of Green Economy and Its Regional Differences: Evidence from China

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Green economy is environmentally friendly economy, which is important for the sustainable economic development and environmental protection. Based on the panel data of 30 provinces and cities in China, a three-stage super-efficient SBM-DEA (slack-based model-data envelopment analysis) model is constructed to evaluate the efficiency of green economy and analyze its regional differences. The results show that, first, the random error factor and external environmental conditions significantly affect the efficiency of green economy. Second, the green economic efficiency in China from 2010 to 2019 is stable and needs to be further improved. Third, through regional comparison, it is found that the green economy efficiency in eastern China is higher than those in central and western China and the green economy efficiency in northeast China is the lowest. Finally, green economy efficiency does not simply depend on the economic development, the regional differences of green economy efficiency results from the combined effects of different geographical resources endowment, different economic development characteristics, and different environmental protection policies in different regions of China. Based on the research findings, corresponding policy suggestions are put forward to improve the efficiency of green economy.

1. Introduction

Since the reform and opening-up in 1978, China's economy has grown rapidly, and its economic strength and people's living standards have improved significantly. However, the economic growth of China used to be characterized by high input, high energy consumption, high emissions, and high pollution. The problems of resource waste and environmental pollution are becoming increasingly prominent, and the green economy is inefficient. With China's GDP (gross domestic product) exceeding 100 trillion in 2020, it is estimated that the average economic loss of 190 cities caused by environment pollution in China in 2014–2016 was 0.3% of GDP [1]. At the same time, in recent years, the traditional driving force of China's economy has gradually weakened, and the economic growth rate has shown a downward trend. China urgently needs to transform its economic development model, improve the efficiency of resource utilization, reduce pollution, and reduce social losses caused by environmental pollution. Green development is an important part of high-quality economic development and a necessary requirement to build a high-quality modern economic system [2, 3]. The Chinese government attaches great importance to the development of green economy and proposes to implement the concept of green development. At the same time, with the deepening of regional coordinated development strategy, scientific evaluation of green economic efficiency in different regions of China is the key to better implement the concept of green development. What are the levels about the green economic efficiency in each region of China? What are the characteristics of regional differences? In-depth studying these issues is of practical significance to improve the efficiency of green economy and promote regional coordinated development.

This paper is structured as follows: Section 2 is the literature review about efficiency of green economy. Section 3

illustrates the methods and data sources, followed by the research results in Section 4. Section 5 presents the conclusions, including policy implications.

2. Literature Review

The efficiency of green economy is an important indicator to measure whether economic development is sustainable under the dual pressure of resources and environment. Green economic efficiency was first put forward by Hall in 1989, who believed that economic development should not destroy the ecological environment by blindly pursuing growth of GDP, nor cause economic stagnation by depleting resources, and economic development must be limited within the range that natural resources can bear [4]. In recent years, many scholars have made a similar definition of the concept about green economic efficiency, and its connotation includes economic growth, resource consumption, and environmental pollution [5–7]. At present, the methods to evaluate green economic efficiency mainly include three types.

The first type is data envelopment analysis (DEA) of nonparametric method. For example, Yang Qing et al. introduced the comprehensive environmental pollution index on the basis of the traditional DEA model to analyze the provincial green development efficiency in China and studied its evolutionary mechanism [8]. Ho, C-T Ho used hybrid model of GRA-DEA (gray relational data envelopment) to calculate the efficiency of green economy and analyzed the regional differences of the efficiency of green economy from the aspects of technical efficiency and scale efficiency [9]. Some scholars put forward its need to consider the unexpected output when studying the efficiency of green economy. In the early stage, variable or numerical conversion was generally adopted. For example, Scheel calculated the efficiency of green economy by incorporating environmental pollution into output variables [10]. Seiford took the negative number of the undesirable output and converted it to positive indicator through the intermediate number [11]. At present, it is common to consider the negative impact of undesired output on economic growth and introduce the undesired output and expected output into the model research by using slacks-based model (SBM). For example, Chen Fang et al. used "carbon emissions" as single nonexpected output index to measure the green economic efficiency of all provinces in China [12]. Xia Yongqiu et al. used the SBM to calculate China's green economic efficiency by taking the industrial three wastes emission index as multiple undesired outputs and discovered that the national average annual green economic efficiency was 0.7, yielding an inverted U-shaped evolution process [13]. The second type is SFA (stochastic frontier analysis). Zhang Caiqing and Chen Panyu used the SFA model to measure the panel data of the Yangtze River Economic Belt and found that the overall level of green economic efficiency was in a state of inefficiency [14]. Zhang Sheng et al. took panel data of 21 prefecture-level cities in Guangdong Province as samples and used stochastic frontier model and logarithmic Cobb–Douglas production function to analyze the growth of green economic efficiency [15]. Wu DJ used stochastic frontier model to estimate the efficiency of China's marine green economy and tested the effects of per capita GDP, urbanization rate, industrial structure, foreign trade, and energy consumption structure on the efficiency of China's marine green economy [16]. The third category is three-stage DEA model. On the basis of combining the characteristics of parametric method and nonparametric method, the three-stage DEA model is introduced which considers how to separate the random errors in the nonparametric method. Waldhoff S et al. used the three-stage model to study the damage caused by four greenhouse gases such as carbon dioxide and methane to the efficiency value of global green economy [17]. Kupika et al. studied the efficiency of green economy in central Zimbabwe and took the interview results of experts on green economy and climate change as the source data of the second stage of the study; then, the results are more authentic and reliable [18]. Wu MR measured the green technology innovation efficiency of 30 provinces in China from 2008 to 2017 by constructing a three-stage super-efficiency DEA model including undesired output. The study found that the overall performance of regional green technology innovation efficiency in China was poor in the past decade, and there was still a lot of room for improvement [19]. In addition, other methods such as cluster analysis, technique for order preference by similarity to an ideal solution model, and translogarithmic random boundary analysis model are also shown in the literature about green economic efficiency [20–26].

3. Research Design

3.1. Research Methods. DEA is a nonparametric technical efficiency analysis method first proposed by Charnes et al. which is used to evaluate the relative efficiency of decision-making units with multiple inputs and outputs [27]. Due traditional DEA model has the defect of the input data and output data are enlarged or reduced the same proportion [28]. Tone introduced super-efficiency SBM to remedy this defect, but ignored uncontrollable factors such as external environment and random interference [29]. Fried et al. studied how to introduce environmental factors and random factors into DEA model and proposed three-stage DEA model [30]. Considering the characteristics of statistical data, random error, and the impact of environmental factors, this paper combines DEA model and super-efficiency SBM to establish a three-stage super-efficiency SBM-DEA model.

The specific steps are as follows.

In the first stage, the super-efficiency SBM is adopted to consider both expected output and unexpected output. The model to calculate the initial efficiency value is shown in

$$\rho = \min \frac{(1/t)\sum_{i=1}^{t}(\overline{x}/x_{ik})}{(1/s_1 + s_2)\left(\sum_{r=1}^{s1}\overline{y^d}/y_{rk}^d + \sum_{q=1}^{s2}\overline{y^u}/y_{qk}^u\right)},$$

$$\text{Subject to } \overline{x} \geq \sum_{j=1\neq k}^{n} x_{ij}\lambda_j, i = 1, \ldots, t,$$

$$\overline{y^d} \geq \sum_{i=1+t}^{n} y_{ij}^d \lambda_j, r = 1, \ldots, S_i,$$

$$\overline{y^u} \geq \sum_{j=1\neq k}^{n} y_{qj}^u \lambda_j, q = 1, \ldots, S_2,$$

$$\lambda_j \geq 0, j = 1, \ldots, n, j \neq 0,$$

$$\overline{x} \geq x_k, i = 1, \ldots, t; \overline{y^d} \geq y_k^d, r = 1, \ldots, S_1;$$

$$\overline{y^u} \geq y_k^u, q = 1, \ldots, S_2, \quad (1)$$

where $X = (X_y)$, $(i = 1,\ldots,t, \quad j = 1,\ldots,n)$, $1,\ldots,s;$ $j = 1,\ldots,n)$, $Y^d = (y^d{}_{rj})$, $(i = 1,\ldots,s_1; \quad j = 1,\ldots,n)$, $Y^u = (y^u{}_{qj})$, $(i = 1,\ldots,s2; j = 1,\ldots,n)$. t represents inputs, n represents departments, s represents outputs, S_1 represents expected outputs, and S_2 represents unexpected outputs. The constant vector λ represents the weight of decision-making unit. P represents the efficiency value.

In second stage, in order to exclude the influence of random error and environmental factors, the random frontier SFA method is adopted in the second stage to find out the random errors and environmental factors with the greatest influence. The regression expression of random frontier is shown in

$$S_{ik} = f(Z_i; \beta_k) + v_{ik} + \mu_{ik}, \quad (2)$$

where $i = 1, 2, 3, \ldots, t; k = 1, 2, 3, \ldots, n;$ and S_{ik} are the slack variable and represent the input difference of the i-th input in the k-th decision unit. Z_k is the environment variable. β is the parameter to be estimated corresponding to environmental variables. $f(Zi;\beta k)$ has a stochastic machine and is used to represent the influence of environmental factors on S_{ik}. V_{ik} stands for random error, roughly normal distribution. U_{ik} represents the inefficiency of management, presenting a truncated normal distribution. V_{ik} and U_{ik} are independent of each other, and $V_{ik} + U_{ik}$ is a mixed error term. According to the values of V_{ik} and U_{ik}, the input index and output index of efficiency value are adjusted, and the adjusted results are shown in

$$X_{ik}^* = X_{ik} + \left[\max\left(f\left(Z_k; \widehat{\beta}_n\right) - f\left(Z_k; \widehat{\beta}_n\right)\right)\right] + \left[\max\left(v_{ik}\right) - v_{ik}\right], \quad (3)$$

X_{ik} is the original input, and the new input value $X^*{}_{ik}$ is obtained by (3).

In the third stage, $X^*{}_{ik}$ value excluding the influence of environmental and random factors in the second stage is brought into the super-efficiency SBM to calculate the relative efficiency, and the result obtained is more objective and accurate.

3.2. Design of Index System. On the basis of comprehensive consideration of the scientific, systematic, and operable selection of indicators, this paper builds an index system of green economy efficiency (see Table 1). The index system constructed in this paper consists of input variables, output variables, and external environment variables.

3.2.1. Input Variables. According to the production function, labor, capital, and land are essential inputs, and energy consumption is the main source of nondesired output. This paper takes labor, capital, land, and energy as input factors. Referring to the research of Zeng Gan et al., labor input is expressed by the average annual number of employees per unit, capital input is expressed by the actual capital stock, land input is expressed by built-up area, and energy input is expressed by water supply and total social electricity consumption [26]. Since the data of actual capital stock cannot be obtained directly, this paper uses the perpetual inventory method proposed by Pittman to calculate the capital stock [31]. The calculation formula is as follows: $K_t = (1-\delta)K_{t-1} + I_t$, where K_t and K_{t-1} represent the capital stock of period t and $t-1$, respectively. δ is the depreciation rate. This paper refers to the practice of Zhang Jun et al. [32] and takes $\delta = 9.6\%$, $I_t = I_0/(\delta + g)$, I_0 is the fixed assets investment in 2005, and g is the average growth rate of new fixed assets in the whole society from 2010 to 2019.

3.2.2. Output Variables. In this paper, output variables are composed by GDP and industrial waste. The expected outputs used include gross domestic product (GDP), industrial added value, total retail sales of social consumer goods, green coverage area of built-up areas, etc. In this paper, GDP is selected as expected output. When measuring output, not only social benefits but also ecological benefits should be considered. In order to avoid single undesired output index and improve the accuracy of measurement results, this paper selects industrial sulfur dioxide emissions, industrial wastewater emissions, and industrial smoke (powder) dust emissions as undesired output.

3.2.3. External Variables. The factors that drive and restrict the efficiency of the green economy focus on several aspects, such as economic development, technology innovation, investment environment, industrial structure, and opening to the outside world on the basis of comprehensive consideration of the scientific, systematic, and operable selection of indicators. In this paper, the per capital GDP, the proportion of technology and education expenditure in GDP, the proportion of environmental protection expenditure in GDP, the proportion of secondary industry in GDP, and the

Table 1: Index system of green economic efficiency.

Destination layer	Criteria layer	Indicator name (unit)
The input variables	Capital input	Capital stock (100 million yuan)
	Labor input	Total number of employed persons (ten thousand)
	Energy input	Water supply (100 million cu·m)
		Electricity consumption (100 million kw·h)
		Land for construction (1000 hectares)
The output variable	Desirable output	GDP (100 million yuan)
	Undesirable output	Industrial wastewater discharge (ten thousand tons)
		General solid waste emissions (ten thousand tons)
		Industrial sulfur dioxide emissions (ten thousand tons)
The extraneous variable	Economic development	Natural logarithm of per capital GDP (ten thousand yuan)
	Self-dependent innovation	Proportion of technology and education expenditure in GDP (%)
	Environmental investment	Proportion of energy conservation and environmental protection expenditure in GDP (%)
	Industrial structure	Proportion of secondary industry in GDP (%)
	Open door to the outside world	Proportion of total imports and exports to GDP (%)

proportion of total import and export in GDP are selected as external variables.

3.3. Data Source. The data in this paper are from China Statistical Yearbook (2010–2019), China Environmental Statistical Yearbook(2010–2019), and China Energy Statistical Yearbook (2010–2019). In order to facilitate regional comparison, 30 provinces and cities are divided into eastern region, northeastern region, central region, and western region.

4. Results

Green economic efficiency is the comprehensive economic efficiency considering the cost of resources and environment, and it is an important index to measure the level of green development. The evaluation results of green economic efficiency by using three-stage DEA model are more consistent with reality.

4.1. SBM Analysis of Initial Super-Efficiency in the First Stage. According to the index system of green economic efficiency (Table 1), input and output variables are selected and the super-efficiency SBM is adopted to calculate the efficiency of green economy about 30 provinces and cities in China from 2010 to 2019. The results are in Table 2 and Figure 1.

From Table 2 and Figure 1, there are obvious regional differences in China's green economy efficiency from 2010 to 2019, the eastern region has the highest green economy efficiency, with an average efficiency level of 0.822, the green economic efficiency in central China is 0.507, the average value of green economic efficiency in northeast China is 0.505, and western China has the lowest green economic efficiency, with an average of 0.415. This is because the eastern region is at the forefront of China's reform and opening up. Its unique geographical advantages and good policies given to the eastern region by the central government have made its economic development in a leading position. In addition to technology and education, capital and other elements gathered have promoted the economic transformation and upgrading in the eastern region, so the green economic efficiency is much higher than other area. The central region and the western region benefit from the strategy of western development and the rise of the central region. After accepting the industrial transfer from the east region, the economic production efficiency is greatly improved. Moreover, most of the industries are pollution industries, so there is big gap in green economic efficiency between central region, western region, and eastern region. The economic level of northeast region was once in the forefront of the country. However, in recent years, its economic structure problems have been exposed continuously, and the lack of cultivation of new economic industries has led to a sustained downturn in economic development. As a result, its green economic efficiency has declined rapidly and has been surpassed by the central region and western region.

4.2. SFA Regression Analysis in the Second Stage. In second stage, the relaxation variable of the input index calculated from the super-efficiency SBM in the first stage was taken as the dependent variable and the external environmental variables. In Table 1, they were taken as the independent variables to establish the SFA regression model. The results are listed in Table 3.

It can be found from Table 3 firstly the relationship between economic development and capital, labor, energy, and land is significant. The increase in labor, water supply, and land inputs can promote the economic development. Capital investment is not conducive to the level of economic development, but it is consistent with the actual situation of the current transformation development in China. At present, China's economy has not completely transformed into a green economic development model, which is basically driven by the supply of land and high consumption of water. Secondly, the improvement of technology and education can promote the utilization rate of labor force, water supply, and land factors. Thirdly, except for the negative

Table 2: Green economic efficiency in all regions from 2010 to 2019.

Region	Province year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Eastern China	Beijing	1.222	1.212	1.205	1.205	1.208	1.212	1.205	1.202	1.195	1.316
	Tianjin	1.106	1.093	1.096	1.098	1.104	1.097	1.109	1.098	1.095	1.000
	Hebei	0.469	0.504	0.450	0.429	0.408	0.406	0.418	0.444	0.440	0.463
	Shanghai	1.094	1.034	1.027	1.028	1.020	1.026	1.040	1.073	1.062	1.041
	Jiangsu	1.044	1.076	1.080	0.628	0.589	0.628	0.620	1.005	1.019	1.040
	Zhejiang	0.573	0.601	0.597	0.551	0.545	0.551	0.615	1.000	0.603	1.025
	Fujian	1.016	1.007	1.001	0.530	0.537	1.002	1.023	1.022	1.032	1.045
	Shandong	0.591	0.589	0.565	0.537	0.525	0.517	0.499	0.517	0.506	1.005
	Guangdong	1.058	1.056	1.049	1.042	1.034	1.024	0.683	0.570	0.632	0.531
	Hainan	0.571	0.610	0.600	0.541	0.542	0.470	0.460	0.470	0.431	0.430
	Mean	0.874	0.878	0.867	0.759	0.751	0.793	0.767	0.840	0.801	0.890
Central China	Shanxi	0.400	0.432	0.381	0.351	0.324	0.317	0.305	0.330	0.336	0.270
	Anhui	0.418	0.441	0.429	0.402	0.399	0.397	0.400	0.407	0.384	0.586
	Jiangxi	0.438	0.443	0.429	0.408	0.406	0.394	0.396	0.381	0.383	0.395
	Henan	0.457	0.449	0.440	0.410	0.415	0.409	0.419	0.420	0.436	0.506
	Hubei	0.500	0.506	0.514	0.475	0.467	0.485	0.505	0.488	0.490	1.019
	Hunan	0.556	0.585	0.613	1.006	1.004	1.015	1.020	1.017	1.010	1.017
	Mean	0.462	0.476	0.468	0.509	0.502	0.503	0.508	0.507	0.507	0.632
Northeastern China	Liaoning	0.460	0.457	0.460	0.436	0.425	0.425	0.306	0.323	0.340	0.303
	Jilin	1.004	1.009	0.461	1.006	1.005	1.007	1.000	0.407	0.390	0.246
	Heilongjiang	0.423	0.433	0.414	0.397	0.401	0.378	0.353	0.335	0.324	0.235
	Mean	0.629	0.633	0.445	0.613	0.610	0.603	0.553	0.355	0.351	0.261
Western China	Inner Mongolia	0.508	1.030	1.038	1.033	1.022	1.013	0.415	0.328	0.338	0.355
	Guangxi	0.395	0.437	0.420	0.402	0.401	0.408	0.409	0.365	0.354	0.317
	Chongqing	0.435	0.463	0.493	0.466	0.479	0.482	0.522	0.514	0.474	1.020
	Sichuan	0.456	0.475	0.495	0.469	0.465	0.448	0.463	0.455	0.451	0.601
	Guizhou	0.336	0.339	0.347	0.351	0.352	0.379	0.396	0.378	0.378	0.398
	Yunnan	0.353	0.341	0.353	0.372	0.361	0.368	0.359	0.353	0.344	0.572
	Shanxi	1.008	1.022	1.010	0.489	0.481	0.459	0.439	0.438	0.451	0.440
	Gansu	0.308	0.313	0.308	0.289	0.272	0.257	0.241	0.231	0.240	0.212
	Ningxia	0.256	0.275	0.269	0.257	0.246	0.247	0.254	0.253	0.258	0.236
	Qinghai	0.321	0.334	0.337	0.314	0.309	0.305	0.298	0.287	0.294	0.250
	Xinjiang	0.309	0.307	0.294	0.273	0.263	0.248	0.228	0.226	0.238	0.235
	Mean	0.426	0.485	0.488	0.429	0.423	0.420	0.366	0.348	0.347	0.421
Nationwide	Mean	0.600	0.630	0.601	0.574	0.568	0.579	0.547	0.541	0.527	0.597

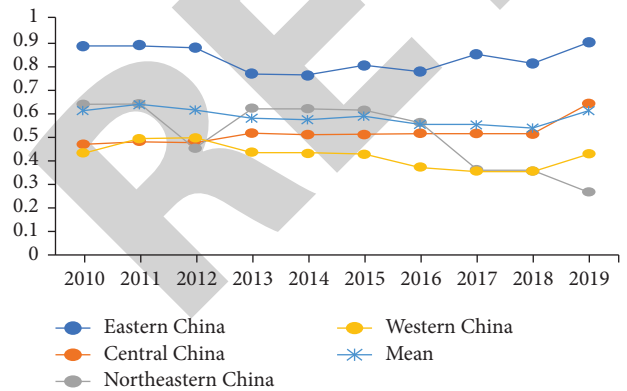

Figure 1: The variation of green economic efficiency in different regions from 2010 to 2019.

impact of environmental investment on capital factors, environmental investment has positive impact on employed persons, total water supply, total electricity, and built-up area, and it shows that the increase of energy conservation and environmental protection expenditure can improve ecological environment, reduce pollutant emissions, improve energy utilization rate, increase energy conversion, and promote the efficiency of green economic development. Fourth, the industrial structure can promote the input of capital, energy, and land factors, and this shows that the development of China's secondary industry has not been free from the dependence on energy consumption, land, and capital. At the same time, in recent years, the intelligent level of China's secondary industry has been improved, and the demand for human capital has been weakening. Finally, the coefficient of capital investment relaxation caused by opening to the outside world is positive, which also indicates that capital is waste and more redundancy is generated in the process of capital introduction by opening to the outside world. The regression coefficient of the investment relaxation on land and energy is negative, which indicate that the improvement of the level of opening-up not only increases the consumption of land and energy, but also promotes employment.

In conclusion, there are differences in the influential factors of economic efficiency in different regions and the direction and magnitude of their influence, which can lead to

Table 3: Second-stage random frontier regression results.

	Real capital stock	Number of employed persons	Total water supply	Total electricity	Built-up area
Constant term	−12.383 (−1.269)	14.022*** (3.317)	216.090*** (4.291)	393.651 (1.331)	527.305*** (4.737)
Ln (PGDP)	6.102*** (2.692)	−6.278*** (−5.258)	−50.192*** (−3.316)	198.886** (1.997)	−75.046** (−1.991)
Expenditure on technology and education share of GDP	58.311*** (3.367)	−42.968*** (−3.559)	−214.090* (−1.729)	241.913 (0.255)	−340.536** (−1.979)
Expenditure on energy conservation and environmental protection share of GDP	58.186 (0.871)	−127.887*** (−2.942)	−1318.317*** (−2.931)	−3171.728*** (−3.085)	−3302.647*** (−2.664)
The second industry share of GDP	−113.504*** (−9.851)	17.128*** (3.042)	−61.826 (−0.956)	−1248.703*** (−2.825)	−587.677*** (−3.539)
Total import and export share of GDP	21.690*** (4.235)	−0.505 (−0.209)	−137.415*** (−3.450)	−832.836*** (−3.447)	−108.409 (−1.141)
$\sigma\sigma\sigma\ ^{2}22$	2337.279*** (3.173)	56.104*** (5.105)	28005.398*** (15442.383)	707671.550*** (37838.040)	222112.090*** (89727.844)
$\gamma\gamma\gamma$	0.978*** (135.076)	0.579*** (4.471)	0.901*** (105.085)	0.778*** (40.306)	0.916*** (120.750)
The log function value	−1085.726	−952.783	−1664.048	−2266.027	−1960.665
LR unilateral check value	145.288	39.257	348.971	172.724	368.040

Note. ***, **, and * show significance at the 1% level, 5% level, and 10% level, respectively.

Table 4: Green economic efficiency in all regions from 2010 to 2019.

Region	Province year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Eastern China	Beijing	1.222	1.212	1.205	1.205	1.208	1.212	1.205	1.202	1.195	1.316
	Tianjin	0.576	0.605	1.011	1.017	1.022	1.018	1.002	0.596	0.567	0.271
	Hebei	1.002	1.005	1.011	1.005	1.000	0.550	0.542	1.036	1.007	0.427
	Shanghai	1.076	1.019	1.014	1.022	0.753	0.739	1.018	1.063	1.056	1.030
	Jiangsu	1.041	1.055	1.067	1.027	1.018	1.024	1.026	1.037	1.035	1.058
	Zhejiang	1.014	1.009	1.011	1.006	1.002	1.016	1.018	1.016	1.014	1.012
	Fujian	0.565	0.515	0.573	0.657	1.006	0.628	1.003	0.664	1.005	1.016
	Shandong	1.088	1.081	1.086	1.091	1.078	1.090	1.082	1.082	1.069	1.015
	Guangdong	1.079	1.070	1.066	1.072	1.059	1.050	1.052	1.057	1.054	1.048
	Hainan	0.192	0.210	0.218	0.217	0.223	0.211	0.210	0.206	0.196	0.179
	Mean	0.886	0.878	0.926	0.932	0.937	0.854	0.916	0.896	0.920	0.837
Central China	Shanxi	0.346	0.372	0.370	0.354	0.341	0.352	0.319	0.333	0.339	0.293
	Anhui	0.422	0.420	0.443	0.476	0.489	0.469	0.444	0.462	0.459	0.503
	Jiangxi	0.367	0.364	0.383	0.409	0.425	0.406	0.381	0.379	0.379	0.374
	Henan	0.627	0.646	0.652	0.624	1.007	0.608	1.001	0.668	0.734	0.594
	Hubei	0.501	0.482	0.518	0.575	0.581	0.590	0.608	0.601	0.677	1.011
	Hunan	0.495	0.512	0.549	0.570	1.003	1.011	1.023	1.003	1.002	0.582
	Mean	0.460	0.466	0.486	0.501	0.641	0.573	0.629	0.574	0.598	0.559
Northeastern China	Liaoning	0.594	0.553	0.581	0.622	0.599	0.569	0.392	0.395	0.386	0.340
	Jilin	0.352	0.338	0.384	0.386	0.384	0.368	0.380	0.351	0.341	0.231
	Heilongjiang	0.374	0.351	0.355	0.383	0.394	0.365	0.325	0.327	0.326	0.240
	Mean	0.440	0.414	0.440	0.464	0.459	0.434	0.366	0.357	0.351	0.270
Western China	Inner Mongolia	0.447	0.434	1.014	0.509	0.447	0.415	0.422	0.341	0.334	0.291
	Guangxi	0.327	0.360	0.369	0.404	0.417	0.419	0.394	0.354	0.358	0.334
	Chongqing	0.350	0.380	0.437	0.454	0.459	0.459	0.479	0.478	0.456	0.434
	Sichuan	0.561	0.554	0.622	0.715	0.623	0.592	1.007	0.607	0.646	1.006
	Guizhou	0.283	0.261	0.290	0.328	0.334	0.356	0.368	0.366	0.362	0.334
	Yunnan	0.347	0.316	0.353	0.402	0.409	0.395	0.355	0.375	0.373	0.414
	Shanxi	0.428	0.434	1.004	0.544	0.613	0.488	0.455	0.475	0.487	0.407
	Gansu	0.222	0.208	0.230	0.249	0.254	0.239	0.209	0.210	0.213	0.204
	Ningxia	0.087	0.095	0.103	0.106	0.110	0.113	0.116	0.111	0.108	0.103
	Qinghai	0.084	0.090	0.097	0.100	0.110	0.108	0.103	0.103	0.105	0.099
	Xinjiang	0.218	0.209	0.220	0.232	0.242	0.232	0.207	0.215	0.221	0.225
	Mean	0.305	0.304	0.431	0.368	0.365	0.347	0.374	0.331	0.333	0.350
Nationwide	Mean	0.541	0.536	0.604	0.589	0.618	0.568	0.601	0.567	0.580	0.541

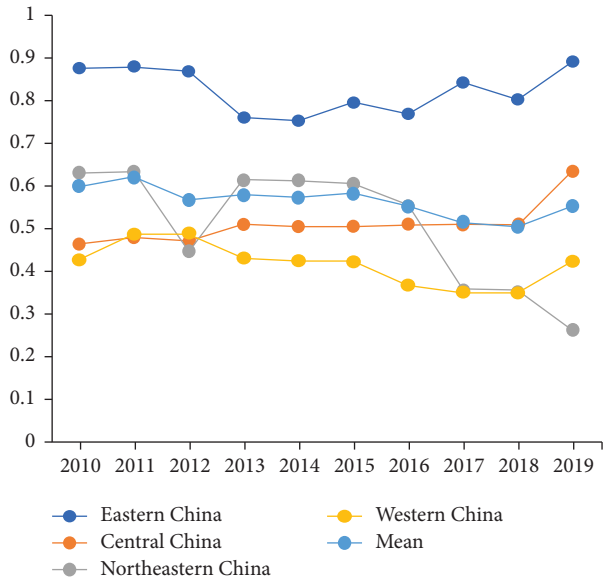

Figure 2: Average change of efficiency in the third stage from 2010 to 2019.

deviations in the assessment of the efficiency of the green economy. Therefore, it is necessary to eliminate the influence of environmental variables and recalculate green economy efficiency.

4.3. Efficiency Analysis after Input Adjustment in the Third Stage. After adjusting the original input value, the input data and original output data after eliminated random errors and environmental variables are substituted into the super-efficiency SBM again. The calculation results are listed in Table 4.

Overall, as shown in Table 4 and Figure 2, the efficiency value in the third stage compared with efficiency value calculated in the first stage has significant changed, indicating that external environmental factors and random factors can promote the efficiency of green economy. The adjusted efficiency value from 2010 to 2019 is more stable, which is different from the large fluctuation of the efficiency value in the first stage. It shows that thanks to the gradual improvement and implementation of the national green economic efficiency policy, the continuous increase of environmental protection input, and the gradual enhancement of residents' environmental awareness, the green economic efficiency develops steadily. In addition, the green economic efficiency in the third stage of each province and city has changed greatly from 2010 to 2019, and the regional imbalance shows that green economic efficiency is highest in the eastern region, second in the central region, third in the northeast region, and lowest in the western region. It is concluded that geographical advantage plays an important role in the efficiency of green economy. Beijing, Tianjin, the Yangtze River Delta, and the Pearl River Delta serve as "leading regions." The province of Jiangxi, Chongqing, Gansu, and Guizhou has the function of connecting the east region with the west region, connecting the north region with the south region. The northwest region and northeast region are marginal regions with the lowest green economic efficiency. Secondly, the efficiencies of green economy in different regions are influenced by a variety of factors, and differences of geographical environment and economic development have significant effect.

5. Conclusions

By using the three-stage super-efficiency SBM-DEA model and constructing the index system of green economic efficiency, this paper evaluates the green economic efficiency of China from 2010 to 2019 and analyzes its regional differences. The conclusions are drawn. Firstly, random error factors and external environmental conditions can significantly impact on the efficiency of China's green economy and they can promote the efficiency of green economy. Although economic development can improve the utilization rate of labor force and energy, the investment of capital factors is not conducive to the development of economy, leading to a result that it is easy to produce a lot of redundancy. Industrial structure can enhance the demand for capital and increase consumption of energy and land. Technology and education have positive effect on the utilization rate of land, labor, and energy, but negative effect on capital. Secondly, excluding random error and external environment, the efficiency of China's green economy rose steadily from 2010 to 2019. Third, from the perspective of regional differences, green economic efficiency in the eastern region is higher than that in the central and western regions, with the lowest in the northeast region. The province of Beijing, Guangdong, and Shandong has the highest green economic efficiency, and the province of Ningxia, Qinghai, and Hainan has the lowest green economic efficiency; in addition, the green economic efficiency of developed regions is not necessarily high. These regional differences are mainly due to the joint effects of different geographical resources endowments, different economic development characteristics, and different environmental protection policies.

Based on the research findings, the policy suggestions are proposed. First, strengthen technology and education investment to enhance the development of technology and education, and the development of technology and education is not only beneficial to the transformation and upgrading of economic development, and to create more employment opportunities. Second, further speed up opening to the outside world and strengthen the capital investment in the field of environmental protection, which is beneficial to the transformation of economic development, and develop green economy. Third, allocate economic resources appropriately and bridge the development gap in different regions.

Data Availability

The data used to support the findings of this study can be obtained from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

X. D. and K. Z. contributed to the conceptualization and the research design; M. M. T. prepared the original draft; K. Z. reviewed and edited the manuscript. All authors have read and agreed to the published version of the manuscript.

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Research Article

Private-Sector Partner Selection for Public-Private Partnership Projects Based on Improved CRITIC-EMW Weight and GRA -VIKOR Method

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When the government decides to use the public-private partnership (PPP) in projects, such as infrastructure construction, selecting a private-sector partner that meets the project's needs is one of the key factors for successful implementation, but this is ignored in existing research. On this basis, this paper proposes a GRA-VIKOR method based on the combined weight of the improved CRITIC-entropy weight method (EWM). The traditional CRITIC method is improved by combining it with EWM. The combined weights are measured, which reduces the limitations of the single weight. Considering the inherent correlation of evaluation indicators, the VIKOR method is combined with the grey relational analysis (GRA), which makes the results of the selection assessment more reasonable. This paper carries out a case study of the first inland navigation PPP project in China. Through preliminary tracking studies, it tests the effectiveness of the proposed method, the superiority of which is demonstrated by comparing the evaluation results with those of the traditional GRA methods, VIKOR, and TOPSIS.

1. Introduction

As China's economy enters a new normal, the demand for infrastructure is increasing, while the traditional direct investment and construction by the government can hardly meet the public requirement for quality infrastructure [1]. The proposed public-private partnership (PPP) provides a new approach for the government to alleviate the debt pressure, broaden financing channels, and improve public services, thus is widely adopted in China [2]. According to the annual report, by the end of 2021, China's cumulated PPP projects reached 13,359, and the total investment amount reached 193,758.837 billion yuan, an increase of 9.89%. Among them, there are 4,439 government-paid projects in total and 1,658 user-paid projects. In recent practice, a large number of PPP projects have failed due to poor financing, lack of experience, and unsatisfactory operation of the social capital [3, 4]. The root cause of this phenomenon is that the government does not rationalize the selection of social capital partners according to the characteristics of the project, which leads to a mismatch between supply and demand and fails to achieve the expected cooperation effect. In recent years, the Chinese government has paid more attention to this issue. For example, the Ministry of Finance promulgated Implementation Opinions on Promoting the Standardized Development of Government-Social Capital Cooperation in March 2019. Li et al. considered the selection of private-sector partners is one of the key factors to guarantee the successful implementation of the PPP project [5, 6]. Inappropriate partners are the prominent risk factors for PPP projects, which is precisely the most neglected problem [7]. Therefore, it is of great practical significance to study the partner selection for PPP projects.

So far, few studies have been carried out on private-sector partner selection in PPP projects, and most of the studies focus on the application of PPP in infrastructure construction. Private-sector partner selection is essentially

an integrated ranking of multiple alternatives under multiple evaluation criteria. Therefore, it is a multicriteria decision-making (MCDM) problem. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) and VIKOR method are used as effective tools to solve MCDM problems [8]. The VIKOR method is an effective tool for private-sector partner selection. However, the premise of the traditional VIKOR decision is limited information, which has the disadvantage of information omission [9]. Although existing studies have investigated the private-sector partner selection from various perspectives using different MCDM methods and achieved certain results, there are still limitations that need further improvement, which is reflected in the following two aspects: (1) the multiple attribute decision-making method applied in existing research does not consider the inherent correlation between the evaluation indicators of the selection, which cannot be solved by traditional MCDM methods. Thus, the information-digging of the indicators is insufficient, affecting the accuracy of the evaluation results; (2) the single method of determining the weights of the evaluation indicators ignores its own defects, which makes the weight allocation of the indicators not sufficiently reasonable.

To fill the shortage of existing research, this paper introduces the grey system theory into multiple attribute decision-making. Grey relational analysis (GRA) is used to explore the inherent correlation of decision indicators, and the grey relation is used to modify the aggregation function of the VIKOR method. It establishes a new GRA-VIKOR method to deal with private-sector partner selection. In terms of weight determination, the traditional CRITIC method uses standard deviation to measure the intensity of conflict among indicators, which leads to inconsistency in the base unit and the order of magnitude; thus, measurement distortion occurs [10]. The Gini coefficient is a reflection of the comparative intensity of indicators in MCDM, measuring the conflicting nature of each indicator [11]. In this paper, the improved CRITIC method is obtained by replacing the standard deviation with the Gini coefficient, which is used to measure the intensity of conflict among indicators. To avoid the limitations of a single weight, the improved CRITIC method is combined with the EWM to determine the combined weights of evaluation indicators, which solves the problem of insufficient rationality.

This paper is organized as follows: Section 2 reviews the relevant literature on the main research methods for multiple attribute decision-making and identifies the main contributions of this paper; Section 3 presents the specific steps of the proposed method; Section 4 conducts a case study of the first PPP project on inland waterway shipping in China to test the validity of the method and make a comparative analysis with traditional MCDM methods; Section 5 draws the conclusion.

2. Literature Review

Throughout the years, scholars have achieved certain results in studying private-sector partner selection for public-private partnership (PPP) projects, but the research in this field is still relatively insufficient. As described in Section 1, private-sector partner selection is a multicriteria decision-making (MCDM) problem. Therefore, the relevant research on MCDM problems is closely related to this study. The commonly used MCDM methods are Tomada de Decisão Iterativa Multicritério (TODIM), multiattributive border approximation area comparison (MABAC), the technique for order performance by similarity to ideal solution (TOPSIS), and VlseKriterijuska Optimizacija I Komoromisno Resenje (VIKOR).

MABAC is the multiattribute border approximation area comparison, which ranks the alternatives for merit by comparing the distance of the alternatives to the border approximation area. Zhang and Wang [12] combined the Bayesian method with the Markov chain Monte Carlo (MCMC) method, applied them to the selection ranking, and validated this method by numerical examples. Zhang et al. [13] introduced an extended MABAC method to evaluate and select the optimal supplier in under picture fuzzy environment. Ghadikolaei et al. [14] proposed to select partners based on the decision made in a grey environment, using the combination of DEMATEL-based analytic network process (DANP) and MABAC techniques to establish a grey DANP-MABAC method for selection.

TODIM is based on the value function of prospect theory, which compares a solution with another one, calculates the relative superiority, and selects the optimal solution according to the superiority degree. Zhao et al. [15] applied the TODIM method to stock decision selection under uncertain information. Liu et al. [16] determined the criterion weights through the analytic network process (ANP) and applied TODIM to the selection of suppliers for nuclear power equipment. Tian et al. [17] applied the TODIM method to select green suppliers considering the ambiguity of evaluation information and the psychological state of decision makers during the selection.

TOPSIS is an objective selection method that ranks the choices by performing distance measures with the best and worst solutions. Venkatesh et al. [18] used the fuzzy analytic hierarchy process (FAHP) to calculate criterion weights and to establish a fuzzy AHP-TOPSIS-based selection. Due to the complexity and uncertainty of alternatives and the fuzziness of information, fuzzy sets were introduced, and a TOPSIS-based multipartner classification model [19] was proposed. Wu et al. [20] proposed an integrated decision-making model from a sustainable perspective by applying the TOPSIS method using trapezoidal fuzzy numbers to calculate the weights of different decision makers. The combination of the GRA with the TOPSIS method has also been effectively applied. Naseem et al. [21] designed a GRA-TOPSIS selection evaluation method. Wang et al. [22] introduced the fuzzy theory and used the FTOPSIS model to rank the alternatives.

VIKOR is a compromise ranking method to rank alternative decisions by maximizing group utility and minimizing individual regret, which is also an effective method to study multicriteria decision making (MCDM) problems. Yin and Li [23] introduced the fuzzy prospect theory, calculated criterion weights by entropy evaluation, and applied VIKOR

Table 1: Principles and characteristics of main research methods.

No.	Methods	Principles	Characteristics
1	TODIM	By comparing any two solutions, the dominance matrix is constructed. The dominance of individuals is assembled to form the overall dominance, and the ranking is based on the dominance	The effect evaluation must be a specific value. It cannot evaluate the situation where the effect value is an interval value
2	MABAC	The border matrix is calculated based on the decision matrix. Then, the distance of each alternative from the border approximation area is used to rank the alternatives for selection	The computational process is simple, and the results are stable. It is easy to combine with other methods and does not reflect the decision maker's preference
3	TOPSIS	It is a sequential selection ranking technique of ideal similarity, which obtains the optimal selection by determining the solution with the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution	It has the advantages of robust logical structure, simple computation, and considering both ideal and negative-ideal solutions. It is suitable for multiple attribute decision-making based on the full rationality of decision makers
4	VIKOR	A compromise ranking method that determines positive and negative-ideal solutions. It performs compromise ranking of finite decision alternatives by maximizing group utility and minimizing individual regret	With the characteristics of considering both group utility maximization and individual regret minimization and incorporating decision makers' subjective preferences, it has higher stability and credibility of the ranking

for selection sort. Garg and Sharma [24] proposed a combined model based on best-worst evaluation and ranking and used VIKOR for the final selection of partners. As the research progressed, some extensions were gradually developed. Lam et al. [25] combined entropy evaluation with the VIKOR method. Zhou et al. [26] combined the best-worst method (BWM) and information entropy for subjective and objective assignment and used the VIKOR method to assemble and rank the evaluation information for selection. As shown in Table 1, the VIKOR method has the advantage of considering both the maximization of group utility and the minimization of individual regret and incorporating the subjective preferences of decision makers. Therefore, it has higher ranking stability and credibility.

Based on existing research results, TOPSIS and VIKOR are the two main multi-criteria decision-making (MCDM) methods, and a large number of studies have proved their effectiveness. Different types of PPP projects have different requirements for partners, which makes decision makers have different preferences. The characteristics of the research methods in Table 1 show that VIKOR best fits the private-sector partner selection studied in this paper. Therefore, this paper chooses VIKOR as the main research method to study private-sector partner selection in public-private partnership (PPP). At present, no research in this field has considered the inherent correlation between the selection evaluation indicators. Based on previous studies, this paper combines VIKOR with the GRA to establish a new GRA-VIKOR decision-making method to solve the private-sector partner selection problem in PPP projects. In terms of determining the weights of indicators, combine the CRITIC method and EWM to verify the effectiveness of combined weights [27, 28]. But neither of them considered the inconsistency in the base unit and the order of magnitude due to standard deviation. On this basis, this paper improves the CRITIC method by introducing the Gini coefficient to replace the standard deviation, and a new CRITIC-EWM is obtained, which is then used as the method for determining the weights of the indicators.

3. Methodology

3.1. Research Framework. To investigate private-sector partner selection for public-private partnership (PPP) projects, this paper proposes an improved CRITIC-entropy weight method (EWM) and GRA-VIKOR method. The research framework consists of three parts, as shown in Figure 1. The first part reviews and summarizes existing research results and proposes the research method. In the second part, the improved CRITIC-EWM is used to calculate the weights of evaluation indicators. In the third part, the GRA-VIKOR method is developed to make a selection sort.

3.2. Normalization of Indicators. Suppose the selection evaluation system contains n objects and m indicators. The former constitutes the set of options $E = \{E_1, E_2, \cdots, E_n\}$, and the latter constitutes the set of indicators $F = \{F_1, F_2, \cdots, F_m\}$. The attribute value of the indicator F_j corresponding to the object E_i is $c_{ij}, i = 1, 2, \cdots, n; j = 1, 2, \cdots, m$. The evaluation matrix is $C = \{c_{ij}\}_{n\times m}$. The decision matrix $S = \{s_{ij}\}_{n\times m}$ can be obtained by normalizing c_{ij}, and it is calculated as follows:

$$\text{Benefit} - \text{based indicators } s_{ij} = \frac{c_{ij} - \min\limits_i c_{ij}}{\max\limits_i c_{ij} - \min\limits_i c_{ij}} \quad (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m), \tag{1}$$

$$\text{Cost} - \text{based indicators } s_{ij} = \frac{\max\limits_i c_{ij} - c_{ij}}{\max\limits_i c_{ij} - \min\limits_i c_{ij}} \quad (i = 1, 2, \cdots, n; j = 1, 2, \cdots, m). \tag{2}$$

3.3. Combined Weight Calculation. CRITIC is an objective weighting method that can measure the intensity of

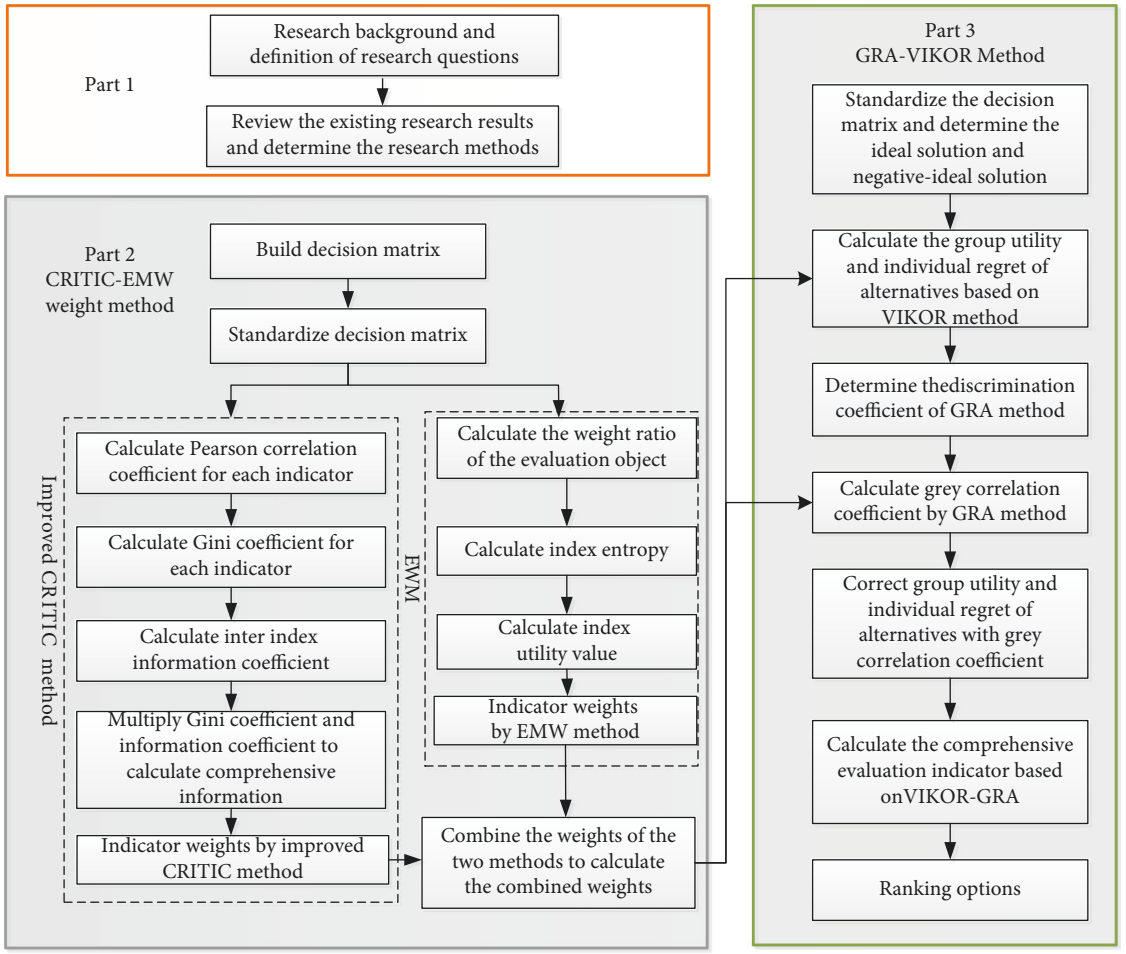

Figure 1: Research framework.

comparison between indicators but not the effect of dispersion [29]. Precisely, the entropy weight method (EWM) determines the weight of an indicator based on the degree of dispersion among the indicators. The combination of the two methods reflects the indicator weights more reasonably. Therefore, in this paper, we choose to combine the improved CRITIC method and EWM to determine the combined weights of grey relations.

3.3.1. The Improved CRITIC Method. The CRITIC method reflects the variability and inherent conflict among indicators through the standard deviation and correlation coefficient. Traditionally, the correlation coefficient may be negative, which leads to wrong results. When the base unit and order of magnitude of the data are different, there will be distortion in the calculation results. To solve the above problems, this paper takes the absolute value of the correlation coefficient and introduces the Gini coefficient instead of the standard deviation to measure the conflict between indicators and obtains the improved CRITIC weight calculation method.

Step 1. Calculate the correlation coefficient matrix.

Suppose $X = \{x_{ij}\}_{n\times m}$ is the correlation coefficient matrix calculated, and x_{ij} is the Pearson correlation coefficient. It is calculated as follows:

$$x_{ij} = \frac{\sum_{k=1}^{n}(s_{ik} - \bar{s}_i)(s_{jk} - \bar{s}_j)}{\sqrt{\sum_{k=1}^{n}(s_{ik} - \bar{s}_i)^2} \cdot \sqrt{\sum_{k=1}^{n}(s_{jk} - \bar{s}_j)^2}}, \quad (3)$$

where $\bar{s}_i, \bar{s}_j$ are the average of indicators i and indicators j, respectively.

Step 2. Calculate the Gini coefficient.

Suppose ε_j is the Gini coefficient used to measure the indicator information distribution. It is calculated as follows:

$$\varepsilon_j = \frac{\sum_{i=1}^{n}\sum_{k=1}^{n}|s_{ij} - s_{kj}|}{2n\sum_{i=1}^{n} s_{ij}} \ (j = 1, 2, \ldots, m). \quad (4)$$

It can be seen from the equation that $\varepsilon_j \in [0, 1]$. The closer ε_j is to 1, the more unbalanced the information distribution is, and the more information it contains; the closer ε_j is to 0, the more balanced the information distribution is, and the less information it contains.

Step 3. Calculate the information coefficient.

Suppose γ_j is the information coefficient. There are positive and negative correlations between indicators. To ensure calculation accuracy, it takes the absolute value of the Pearson coefficient, which is then brought into the calculation of the information coefficient. It is calculated as follows:

$$\gamma_j = \sum_{i=1}^{n}\left(1 - \left|x_{ij}\right|\right) (j = 1, 2, \ldots, m). \tag{5}$$

Step 4. Calculate the general quantities of information of indicators.

Suppose η_j is the general quantities of information of indicators j. It is calculated as follows:

$$\eta_j = \varepsilon_j \cdot \gamma_j (j = 1, 2, \ldots, m). \tag{6}$$

Step 5. Calculate the weight of indicators as follows:

$$W_j^1 = \frac{\eta_j}{\sum_{j=1}^{m} \eta_j} (j = 1, 2, \ldots, m), \tag{7}$$

where $\sum_{j=1}^{m} W_j^1 = 1$, $0 \le W_j^1 \le 1$

3.3.2. The Entropy Weight Method (EWM)

Step 1. Calculate the weight ratio of the object.

Suppose the weight ratio is f_{ij}. It is calculated as follows:

$$f_{ij} = \frac{s_{ij}}{\sum_{i=1}^{n} s_{ij}} (i = 1, 2, \ldots, n; j = 1, 2, \ldots, m). \tag{8}$$

Step 2. Calculate the entropy.

Suppose the entropy is e_j. It is calculated as follows:

$$e_j = -\frac{1}{\ln m} \cdot \sum_{i=1}^{n} s_{ij} \ln s_{ij} (j = 1, 2, \ldots, m). \tag{9}$$

Step 3. Calculate the weight

Use EWM to calculate the weight of indicators j as follows:

$$W_j^2 = \frac{1 - e_j}{\sum_{i=1}^{n}\left(1 - e_j\right)} = \frac{1 - e_j}{m - \sum_{i=1}^{n} e_j} (j = 1, 2, \ldots, m), \tag{10}$$

where $\sum_{j=1}^{m} W_j^2 = 1$ and $0 \le W_j^2 \le 1$.

3.3.3. Combined Weights. The combined weight of W_j^1 and W_j^2 is the following:

$$W_j = \frac{W_j^1 \cdot W_j^2}{\sum_{j=1}^{m} W_j^1 \cdot W_j^2} (j = 1, 2, \ldots, m), \tag{11}$$

μ is the coefficient of the weight combination, where $\mu \in [0, 1]$. In this paper, it is set as $\mu = 0.5$

3.4. The GRA-VIKOR Method. VIKOR is a multicriteria decision-making (MCDM) method based on ideal ranking. The premise of the traditional VIKOR method is limited information, which has the disadvantage of information omission. In order to fully explore the data of the indicators, this paper adopts grey relational analysis (GRA) to explore the inherent rules of the decisive indicators, considers the inherent correlation between the evaluation indicators, and combines the grey relational coefficient with the group utility value and individual regret value of the VIKOR method to improve the accuracy of the evaluation results.

Step 1. Calculate the ideal sequence.

Assume that s_{0j}^{+} and s_{0j}^{-} are the ideal solution and negative-ideal solution, respectively; they are composed of cost-based indicators and benefit-based indicators in the decision matrix as follows:

$$\begin{aligned} S^{+} &= \left(s_1^{+}, s_2^{+}, \cdots, s_m^{+}\right) S^{-} = \left(s_1^{-}, s_2^{-}, \cdots, s_m^{-}\right) \\ s_j^{+} &= \left\{\max_i s_{ij} | j \in I, \min_i s_{ij} | j \in O\right\} \\ s_j^{-} &= \left\{\max_i s_{ij} | j \in O, \min_i s_{ij} | j \in I\right\}, \end{aligned} \tag{12}$$

where I is the benefit-based indicator and O is the cost-based indicator.

Step 2. Calculate the group utility and individual regret of alternatives as follows:

$$Q_i = \sum_{i=1}^{n} w_j\left(s_j^{+} - s_{ij}\right) / \left(s_j^{+} - s_j^{-}\right), j = 1, 2, \ldots, m, \tag{13}$$

$$R_i = \max_j \left\{w_j\left(s_j^{+} - s_{ij}\right) / \left(s_j^{+} - s_j^{-}\right)\right\}, j = 1, 2, \ldots, m. \tag{14}$$

The higher the value of Q_i is, the lower the group utility of the alternative firms is; the higher the R_i value is, the lower the individual regret of the alternative firms will be.

Step 3. Determine the discrimination coefficient of the grey relation.

In most grey relational models, the coefficient of discrimination is fixed at 0.5. However, it reflects the influence of the maximum difference between the two extremes of the indicator on the grey relational coefficients, which will be different depending on the value of the coefficient of discrimination. If the derived grey relation values are similar, it is difficult to distinguish them if the differentiation of the comparative series is small. The principle of selecting the discrimination coefficient should be to make the grey relational values as large as possible. In this paper, the discrimination coefficient is determined by setting a range of the coefficient using absolute deviation.

Assume that Δ_s is the average absolute deviation, B_Δ is the ratio of absolute deviation to the maximum absolute deviation, and ρ is the discrimination coefficient. They are calculated as follows:

$$\Delta_s = \frac{1}{nm}\sum_{i=1}^{n}\sum_{j=1}^{m}\left|s_{0j} - s_{ij}\right|,$$
$$B_\Delta = \frac{\Delta_s}{\max_i \max_j \left|s_{0j} - s_{ij}\right|}. \quad (15)$$

Value range of resolution coefficient ρ:

When $B_\Delta < 1/3$, $\rho \le 1.5\Delta_s$; when $B_\Delta \ge 1/3$, $\rho > 1.5\Delta_s$,

Step 4. Calculate the grey relational coefficient as follows:

$$\xi_{ij}^{+} = \frac{\min_i \min_j \left|s_{ij} - s_j^{+}\right| + \rho \max_i \max_j \left|s_{ij} - s_j^{+}\right|}{\left|s_{ij} - s_j^{+}\right| + \rho \max_i \max_j \left|s_{ij} - s_j^{+}\right|}$$
$$(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m),$$
$$\xi_{ij}^{-} = \frac{\min_i \min_j \left|s_{ij} - s_j^{-}\right| + \rho \max_i \max_j \left|s_{ij} - s_j^{-}\right|}{\left|s_{ij} - s_j^{-}\right| + \rho \max_i \max_j \left|s_{ij} - s_j^{-}\right|} \quad (16)$$
$$(i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m).$$

Step 5. The group utility and individual regret based on GRA are $\widetilde{Q}_i$ and $\widetilde{R}_i$, respectively, as follows:

$$\widetilde{Q}_i = Q_i \sum_{j=1}^{m} \xi_{ij}^{+} \cdot w_j \,(i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m), \quad (17)$$

$$\widetilde{R}_i = R_i \max_j \xi_{ij}^{-} \cdot w_j \,(i = 1, 2, \cdots, n;\ j = 1, 2, \cdots, m). \quad (18)$$

Step 6. Calculate the comprehensive evaluation indicator based on VIKOR-GRA as follows:

$$\widetilde{T}_i = \theta\left(\frac{\widetilde{Q^*} - \widetilde{Q}_i}{\widetilde{Q^*} - \widetilde{Q^-}}\right) + (1-\theta)\left(\frac{\widetilde{R^*} - \widetilde{R}_i}{\widetilde{R^-} - \widetilde{R*}}\right), i = 1, 2, \ldots, n, \quad (19)$$

where $\widetilde{Q^*} = \max_i \widetilde{Q}_i$, $\widetilde{Q^-} = \min_i \widetilde{Q}_i$, $\widetilde{R^*} = \max_i \widetilde{R}_i$, $\widetilde{R^-} = \min_i \widetilde{R}_i$, θ is the preference coefficient, which satisfies $\theta \in [0, 1]$, and generally has $\theta = 0.5$.

Step 7. Determine the ranking of alternative enterprises.

Assume that the best cooperative enterprise is P_1 and the second best is P_2, ranked according to the maximum group utility $\widetilde{Q}_i$. The optimal solution is when the enterprise meets the following two conditions:

Condition I: $\widetilde{T}(P_1) - \widetilde{T}(P_2) \ge GT, GT = 1/(n-1)$

Condition II: the optimal cooperative enterprise P_1 at least ranks the first in one of $\widetilde{Q}_i$ and $\widetilde{R}_i$

The determination of the optimal cooperative enterprise is based on the above two conditions, and the criteria are as follows:

(1) If both Conditions I and II are true, P_1 is the optimal enterprise.

(2) If only Condition I holds, both P_1 and P_2 are the best choices.

(3) If only Condition II holds, any alternatives that do not satisfy Condition I are optimal choices.

4. Case Study

4.1. Case Profile and the Evaluation Indicators Construction. The Xiaoqinghe River Recovery of Navigation Project is the first inland navigation PPP project in China. It is the first water conservancy project with a single investment of more than 10 billion yuan ever in Shandong Province. The project adopts the public-private partnership for operation. In the early stage, the government negotiated with several enterprises, four of which became alternatives. Scientific and reasonable indicators are the key factor for the selection and evaluation of cooperative enterprises. Under the basic principles of simplicity, systematicity, and pertinence, the government sets evaluation indicators from the perspectives of enterprise operation, economic rationality, and social recognition according to the characteristics and needs of this project. Relevant information is shown in Table 2.

The data of the cases in this paper were obtained from government research on the situation of each alternative enterprise, as shown in Table 3.

4.2. The Process and Results of Selection and Evaluation

4.2.1. Data Processing. The evaluation indicators of the decision matrix were analyzed. Q1, E4, and S2 were cost-based indicators; the smaller, the better. Q2, Q3, Q4, E1, E2, E3, and S1 were benefit-based indicators; the larger, the better. The decision matrix was normalized according to equation (1).

The ideal solution and negative-ideal solution are as follows:

$$S = \begin{bmatrix} 0.5055 & 0.2824 & 0.3181 & 0.5406 & 0.4788 & 0.5147 & 0.3811 & 0.4976 & 0.1676 & 0.3604 \\ 0.4676 & 0.6217 & 0.7262 & 0.7433 & 0.5456 & 0.4922 & 0.7342 & 0.5290 & 0.8941 & 0.6350 \\ 0.5252 & 0.4633 & 0.2317 & 0.2027 & 0.4624 & 0.3880 & 0.4043 & 0.4657 & 0.1397 & 0.3947 \\ 0.5000 & 0.5649 & 0.5637 & 0.3379 & 0.5092 & 0.5850 & 0.3902 & 0.5056 & 0.3912 & 0.5578 \end{bmatrix}. \quad (20)$$

Table 2: The evaluation indicator system of each alternative enterprise and interpretations.

No.	Categories	Indicators	Interpretations	Attribute
1	Quality indicators (Q)	Q1: Debt-to-assets ratio (%)	Reflecting the assets of the enterprise	−
2		Q2: The number of implemented water conservancy projects	Reflecting the enterprise's experience in similar projects	+
3		Q3: Times of winning the bid for 5-billion-scale PPP projects	Reflecting the enterprise's experience in similar modes	+
4		Q4: The number of qualifications owned	Reflecting whether the enterprise has the comprehensive strength to implement the project	+
5	Economic indicators (E)	E1: The scale of financing required for the project (billion yuan)	Reflecting the enterprise's capital gap	+
6		E2: The amount of credit granted by financial institutions (billion yuan)	Reflecting the confidence of financial institutions in the enterprise	+
7		E3: The amount of annual newly signed contract (billion yuan)	Reflecting the overall business scale of the enterprise	+
8		E4: Cumulative government subsidies during the operation period (billion yuan)	Reflecting the cost of government expenditure	−
9	Social recognition indicators (S)	S1: Times of winning the annual national quality engineering awards	Reflecting the recognition of the community and industry	+
10		S2: Number of environmental accident penalties	Water conservancy projects have high requirements for environmental protection. This indicator reflects the environmental compliance of the enterprise	−

Table 3: Initial evaluation indicators of each alternative enterprise.

No.	Alternative enterprises	Q1	Q2	Q3	Q4	E1	E2	E3	E4	S1	S2
1	P_1	75.6	164	92	8	51.25	80	10561	129.7	6	42
2	P_2	69.93	361	210	11	58.4	76.5	20344	137.9	32	74
3	P_3	78.55	269	67	3	49.5	60.3	11204	121.4	5	46
4	P_4	74.77	328	163	5	54.5	90.93	10812	131.8	14	65

Table 4: Weight coefficients of each evaluation indicator.

No.	Weight	Indicators									
		Q1	Q2	Q3	Q4	E1	E2	E3	E4	S1	S2
1	W_j^1	0.0637	0.0858	0.0712	0.0780	0.0671	0.0977	0.0821	0.179	0.0714	0.2041
2	W_j^2	0.0815	0.0644	0.0942	0.0848	0.0927	0.0662	0.2125	0.0772	0.1453	0.0812
3	W_j	0.0726	0.0751	0.0827	0.0814	0.0799	0.0819	0.1473	0.1281	0.1080	0.1426

The ideal solution and negative-ideal solution are as follows:

$$s_j^+ = \{0.4676, 0.6217, 0.7262, 0.7433, 0.5456, 0.5850, 0.7342, 0.4657, 0.8941, 0.3604\}$$
$$s_j^- = \{0.5252, 0.2824, 0.2317, 0.2027, 0.4624, 0.3880, 0.3811, 0.5290, 0.1397, 0.6350\}. \quad (21)$$

4.2.2. Calculate the Weight of CRITIC-EWM. According to equations (2)–(11), the weight coefficients of the CRITIC method and the entropy weight method (EWM) were calculated, respectively, to determine the combined weight, which measures the importance of each evaluation indicator. The calculation results are shown in Table 4.

4.2.3. Calculate Relevant Data Based on the GRA-VIKOR Method. According to equations (13)–(18), the group utility value and individual regret value of the traditional VIKOR method and the GRA-VIKOR method were calculated, as shown in Table 5.

Table 5: Relevant data of the VIKOR-GRA model.

Alternative enterprises	Data of the VIKOR-GRA model			
	Q_i	R_i	$\widetilde{Q}_i$	$\widetilde{R}_i$
P_1	0.7338	0.1373	0.7691	0.1473
P_2	0.1445	0.0751	0.1322	0.0726
P_3	0.8577	0.1473	0.8605	0.1439
P_4	0.4328	0.1055	0.4980	0.1460
Max	0.8577	0.1473	0.8605	0.1473
Min	0.1445	0.0751	0.1322	0.0726

4.2.4. Result Analysis. The data of each indicator of the model were brought into (19) to derive the evaluation results as a basis for the government to select partners. The results are shown in Table 6.

Table 6: Evaluation results.

Case calculation results	Alternative enterprises			
	P_1	P_2	P_3	P_4
$\widetilde{T}_i$	0.9372	0.000	0.9774	0.7425
Selection sort	3	1	4	2

Table 7: Sensitivity analysis of the decision coefficient.

No.	θ	Alternative enterprises				Selection sort
		P_1	P_2	P_3	P_4	
1	0.0	1.0000	0.0000	0.9545	0.9826	$P_2 > P_3 > P_4 > P_1$
2	0.3	0.9624	0.0000	0.9681	0.8385	$P_2 > P_4 > P_1 > P_3$
3	0.5	0.9373	0.0000	0.9772	0.7424	$P_2 > P_4 > P_1 > P_3$
4	0.7	0.9122	0.0000	0.9863	0.6464	$P_2 > P_4 > P_1 > P_3$
5	1.0	0.8745	0.0000	1.0000	0.5023	$P_2 > P_4 > P_1 > P_3$

Table 8: Comparative analysis of the methods.

No.	Alternative enterprises	GRA		TOPSIS		VIKOR		GRA-VIKOR	
		Analysis results	Selection sort	Analysis results	Selection sort	Analysis results	Selection sort	Analysis results	Selection sort
1	P_1	0.6950	3	0.2861	4	0.9331	3	0.9373	3
2	P_2	0.9090	1	0.6600	1	0.5000	2	0.0000	1
3	P_3	0.6194	4	0.2892	3	1.000	4	0.9772	4
4	P_4	0.7125	2	0.2994	2	0.2381	1	0.7424	2

From Table 6, it can be concluded that P_2 is the best partner in this selection. Its evaluation result can be interpreted as that under the evaluation indicator system set by the government, the overall performance of P_2 best fits the project demand, making it the potential partner among all the enterprises evaluated by the government.

4.3. GRA-VIKOR Examination

4.3.1. The Influence of the Decision Coefficient θ on Results. The value of the decision coefficient θ represents the decision maker's preference. If $\theta > 0.5$ the decision maker prefers maximum group utility; if $\theta < 0.5$, the decision maker prefers minimum individual regret; if $\theta = 0.5$, the decision maker prefers a compromised solution. In order to analyze the influence of θ on the results, this paper selects different values $[0, 1]$ and conducts a sensitivity analysis. The results are shown in Table 7.

From the above results, it can be seen that, in this case, the value of the decision coefficient θ does not affect the ranking of alternative enterprises; that is, this ranking is not sensitive to the value of the decision coefficient and is stable.

4.3.2. Comparative Analysis of the Methods. In order to verify the superiority of the method proposed in this paper, this example is compared with the gray relational analysis (GRA), the TOSPSIS method, and the traditional VIKOR method. The results of the comparative analysis are shown in Table 8.

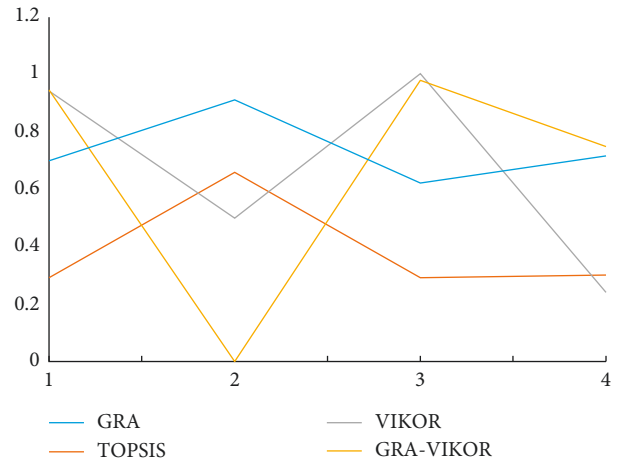

Figure 2: Comparative analysis of the results of different decision-making methods.

On the whole, many indicators of P_2 are the best among the alternative enterprises, making it most consistent with the government's demand, which is also verified by different evaluation methods. The four evaluation methods have basically consistent results, which proves the effectiveness of the method used in this paper. A comparative analysis (Figure 2) of the results of the four decision methods in Table 8 shows that the GRA-VIKOR method proposed in this paper has the greatest differentiation of the optimal solution, and the ranking is more reasonable considering the inherent correlation of the evaluation indicators. It verifies

the superiority of the proposed method in this paper over the traditional evaluation method.

5. Conclusion

This paper investigates the selection of potential social capital cooperation by the government before the implementation of public-private partnership (PPP) projects and proposes the GRA -VIKOR decision-making method based on the combined weights of the improved CRITIC-entropy weight method (EWM). The advantageous combination of VIKOR and grey relational analysis (GRA) solves the problem of correlation of evaluation indicators that cannot be solved by the traditional VIKOR method and makes multicriteria decision making (MCDM) more reasonable. The improved method realizes the full utilization of evaluation information, has more reasonable weights and provides an effective solution for the government to select cooperative enterprises in PPP projects. The main findings of this study are as follows:

(1) From the perspective of practical management, this paper aims to select the partner that best fits the PPP project and solve the problem of lacking a systematic and reasonable way of selecting social capital by the government before the implementation of the project. Based on the research results, the government can design a more suitable implementation plan and alternative social capitalist resource base to lay the foundation for the successful implementation of subsequent projects.

(2) At a theoretical level, the improved CRITIC method is combined with the entropy weighting method (EWM) to determine the combined weights, reduce the one-sidedness of single weighting, and obtain more reasonable weights. Using the advantages of grey relational analysis (GRA) in digging the information of evaluation indicators, we combine GRA with VIKOR to establish a new GRA-VIKOR method, which can make up for the shortcomings of VIKOR and provide an effective MCDM method.

(3) As for application and promotion, the first inland navigation PPP project in China is analyzed in this paper to prove the effectiveness of the proposed method. The superiority of the proposed method is verified by comparing the results with traditional MCDM methods. In addition, the proposed method can be applied not only to the selection problems studied in this paper but also to other fields, such as scheme comparison, safety assessment, and selection for supply chain partners. Meanwhile, using the research idea of this paper for reference, future studies can combine TOPSIS, TODIM, and MABAC with GRA, which needs further supplementation and improvement.

Data Availability

The data supporting the findings of the study are included within the paper.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

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Retraction

Retracted: Design of Moral Education Management System for Higher Vocational Students Based on Multisource Sensing Data Fusion

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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Research Article

Design of Moral Education Management System for Higher Vocational Students Based on Multisource Sensing Data Fusion

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Based on the specific circumstances of colleges and universities, this study presents the moral education management system and leverages multisource sensor data and other technologies to develop an information system in line with the moral education management of modern college students. Using multisource sensor data fusion and learning data definition, the fused education data is expressed in a standardized way, resulting in a common and standard data interchange format. This foundation is used to build a shareable and reusable data management system that enables data sharing and interchange across multiple heterogeneous data sources, aids the intelligent education system in obtaining more comprehensive and complete recorded data, and improves data sharing timeliness. As a result, learning behavior analysis results are more objective, immediate, and accurate, allowing the intelligent education system's response to be more prompt and intelligent. This study, which is based on multisource sensor data fusion, also discusses platform selection, system architecture, database design, and methods and suggestions for overcoming critical challenges and can be used as a reference for other university information management systems with vast amounts of data.

1. Introduction

Higher education is responsible not only for the transmission of knowledge but also for the establishment of moral education and the cultivation of socialist builders and successors with socialist core values and comprehensive development of moral, intellectual, physical, and aesthetic qualities [1, 2]. Many schools have established moral education management systems to assist higher vocational students in developing a correct worldview, outlook on life, and values, developing correct scientific moral cognition, moral behavior, legal consciousness, learning behavior, and interpersonal behavior, and quantifying the results of moral education [3, 4]. China has witnessed the rapid development of higher vocational education, particularly since the Ministry of Education launched a special project on higher vocational expansion in 2019 to meet the growing demand for technical skill talents for industrial upgrading and economic restructuring and to develop higher vocational education as a strategic move to relieve current employment pressures and solve the shortage of highly skilled talents. The moral education management system based on traditional IT technology of centralized data storage + relational database appears to be inadequate in terms of data retrieval storage and efficiency as the number of higher vocational students in China has increased on a larger scale, and the amount of data to be handled has dramatically increased, and the moral education management system based on traditional IT technology of centralized data storage + relational database appears to be inadequate in terms of data retrieval storage and efficiency [5, 6].

In this context, this paper designs a moral education management system for college students based on multisource sensing data to solve the problem of big data storage and retrieval.

2. Difficulties of Moral Education Management in Higher Vocational Institutions

It focuses on improving the impact and degree of moral education, encouraging students to develop accurate conceptions that can regulate their behavior, establishing professional moral quality, patriotic spirit, and having a serious and responsible attitude toward their own behavior. [7, 8]. Currently, understudies commonly neglect discipline during moral education management in many institutions, and executives' ethical instruction techniques are in reverse. They are unable to assist guardians and endeavors in establishing an acceptable upright training improvement climate for understudies, which may result in a decreased moral schooling board influence, particularly throughout the development of organizational innovation. The attributes of understudy moral training, board rules, and other reasonable exploitation of organizational innovation are not included in higher professional foundations [9, 10]. Especially during the development of network technology, higher vocational colleges do not use network technology and software technology reasonably with the characteristics and laws of students' moral management, and it is difficult to enhance the management effect when the technology is backward.

Most higher education institutions also struggle with moral education management, as they are unable to update various data information and moral education management contents in real time and accurately, making it difficult to improve moral education management effectiveness through high-quality and orderly means. The following is a reasonable proposal for an information-based and data-driven stage for moral training executives and the construction of ethical schooling the board framework, with the goal of increasing the impact of moral training executives.

3. Data Fusion Analysis of Multisource Heterogeneous Education Data

3.1. Analysis of Multisource Data Fusion Methods. Data fusion was first applied in the military field, which is a multilevel and multifaceted data processing process [11, 12]. It is used to process multisource information and naturally identify, join, correspond, gauge, and blend data, basically to accomplish more precise position deduction and personality assessment and afterward make an opportune and complete assessment of war zone conditions, danger level, and significance level. It was later applied and developed in many fields such as sensors, geospatial and intelligence analysis, and so on. Especially, in the Internet era, multisource data fusion has gradually become an important research direction in the field of big data. Through multisource sensing data fusion, the cross-corroboration of multisource information can be realized; mutual compensation of data information can be achieved; and the amount of data can be effectively reduced to obtain definite data and deep semantic knowledge [13, 14]. The biology of training vast amounts of data is progressively being shaped during the age of computerized reasoning education. The massive amount of training data has multisource heterogeneous attributes. The multisource information combination strategy offers another approach for resolving the sharing and interoperability of vast amounts of training data in the modern day, as well as a potentially valuable viewpoint for creating reusable and shared instruction data models.

The common multisource data fusion methods are mainly data-level fusion, feature-level fusion, and decision-level fusion. Data-level fusion is the lowest level of data fusion, which is to directly correlate and fuse the original data after simple preprocessing and only after fusion for data feature extraction. Feature-level fusion is to first extract the data features and then correlate and fuse the data. By comparing these three data fusion methods, it can be seen that although data-level fusion can retain the maximum extent of the original. Decision-level fusion is to first make decisions for each data source, then correlate and fuse these decisions, and finally obtain an overall consistent decision result. Although decision-level fusion has high fault tolerance and timeliness, it is a data fusion with specific decision needs as the starting point, and it is difficult to make specific decisions for data fusion in the face of the complex and changing educational big data environment in the era of AI education [15]. The feature-level fusion, on the other hand, may provide immediacy while simultaneously providing the maximum amount of idiosyncratic information needed for decision-making, and its fusion outcomes are also quite accurate. The feature-level fusion method fits well with the requirements of educational big data analysis in the era of artificial intelligence education since educational big data does not have the same high fusion accuracy as picture data.

3.2. Extraction of Shared Data Features of Heterogeneous Multisource Education Data. In order to improve the data reuse after data fusion, the multisource education data fusion method in this paper is to perform feature-level data fusion by extracting the data sharing characteristics of each heterogeneous data source. The process of extracting shared data characteristics is in essence the process of extracting learning context characteristics from the learning behavior data generated by learners from each heterogeneous data source. Throughout the previous descriptions of information characteristics of learning contexts, different scholars have classified contextual information characteristics into different types from different perspectives. The following are relevant ones.

According to Dey et al. [16], contextual information includes explicitly perceived contextual information such as location, time, and surroundings, as well as implicitly perceived contextual information such as social relationships, habits, consumption levels and preferences, and so on. Kwilinski et al. [17] divided the context into three major aspects: user context, environmental context, and application context, among which user context includes an activity. Chaaya et al. [18] divided the context into user context, environment context, and application context, where user

context includes activity, location, and description; environment context includes time, brightness, temperature, weather, resources, and other contexts; and application context includes function, maintenance, energy, and other contexts. Mattila et al. [19] divided the contextual information into three categories: natural environment, device environment, and user environment. From the user-centered perspective, Sarker [20] divided the contextual information into computing scenarios, user contexts, physical contexts, temporal contexts, and social contexts. The learning data from different data sources in the era of AI education have obvious spatial and temporal characteristics and the learning data from different data sources.

The learning data from different data sources in the era of AI education have obvious spatial and temporal characteristics, and the learning interaction of learners cannot be supported by devices. Based on the above contextual information characteristics analysis, the article extracts the shared data characteristics of each heterogeneous data source into five dimensions: learner context, time context, location context, device context, and event context, through statistical analysis of research samples (see Figure 1).

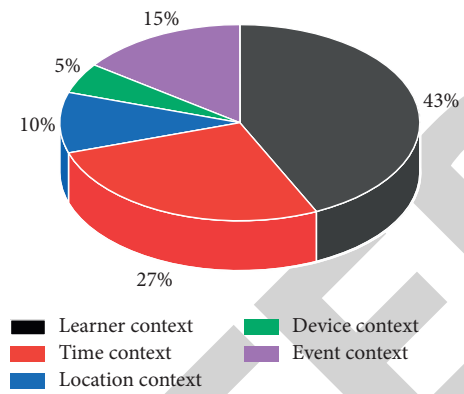

Figure 1: Pie chart of the proportion of four heterogeneous data sources.

3.3. Feature-Level Data Fusion Based on Shared Data Characteristics. The above five dimensions of learning context information characteristics well characterize the shared data characteristics of each heterogeneous data source, and through these five shared data characteristics, the real learning life scenarios of learners in each heterogeneous data source can be accurately described, and then the seamless connection between heterogeneous data can be well realized. These five shared data features represent five data dimensions, which can be combined to form a real learning scene of learners: "learner context + time context + location context + device context + event context learning scene," which describes "learners, when, where, based on what device, and what they did." Based on these five data dimensions, the feature-level data fusion method is used to fuse educational data. The feature-level data fusion mainly goes through a hierarchical extraction of the semantic features of each data dimension, hierarchical semantic feature-level data fusion, and cross-dimensional and cross-layered correlated semantic feature-level data fusion.

The main goal of hierarchical semantic feature extraction for each data dimension [21] is to extract the semantic features of these five different data dimensions hierarchically, determine the semantic attributes of each data dimension, and determine the multilayer semantic logical relationships of each data dimension semantically at the same level and at the upper and lower levels. For example, the semantic attributes of the time dimension can be separated into broad semantic information about working days and vacations, and working days can be differentiated into semantic information about classroom study time and self-study time at varying levels of granularity.

The main goal of highlight-level information combining progressive semantics is to entangle instructional data from several heterogeneous data sources. The comparative fine-grained combination technique is used to build scene information, as represented by the progressive semantic order and element-level information combination. These data can accurately depict students' learning characteristics, eliminate irregularity and overt repetition within data structures, and perform a similar semantic agglomeration at a similar granularity.

4. Hardware Design

4.1. Establishing Multisource Data Signal Sensor. To construct a multisource information signal sensor, first, the design of the multisource information signal sensor is investigated. The information stream connection point is planned by the presentation necessities of the sign detecting framework and the sensor engineering. The sensor structure is planned through the information stream structure, and the system of information keen examination is illustrated. The information keen examination multisource information signal sensor is set as a various leveled design to store and preprocess the multisource information signals. The control information signal streams to the multisource information handling layer and is yielded at the handling layer after information checking and stockpiling. The sensor data flow interface is thus constructed, as shown in Figure 2.

According to the sensor data flow interface analysis, it can be seen that the data signal flows to the multisource data processing layer and the sensor data is delivered through the cloud server. Therefore, there are mandatory requirements for multisource data signal sensors to be able to transmit data signals accurately. Accordingly, the packet loss rate of the data state signal is calculated, and the data transmission rate is monitored. The source data transmission reference standard is developed according to the data state of the application layer, as shown in Figure 3.

The data sensing content is determined based on the developed data state to source data transmission standard and the reference value, and the sensing content is analyzed in parallel with the data sending delay to form a multisource data signal sensor structure, as shown in Figure 4.

By forming a multisource data signal sensor, the multisource data signal is preprocessed and the data signal features are extracted. The data intelligent analysis results for

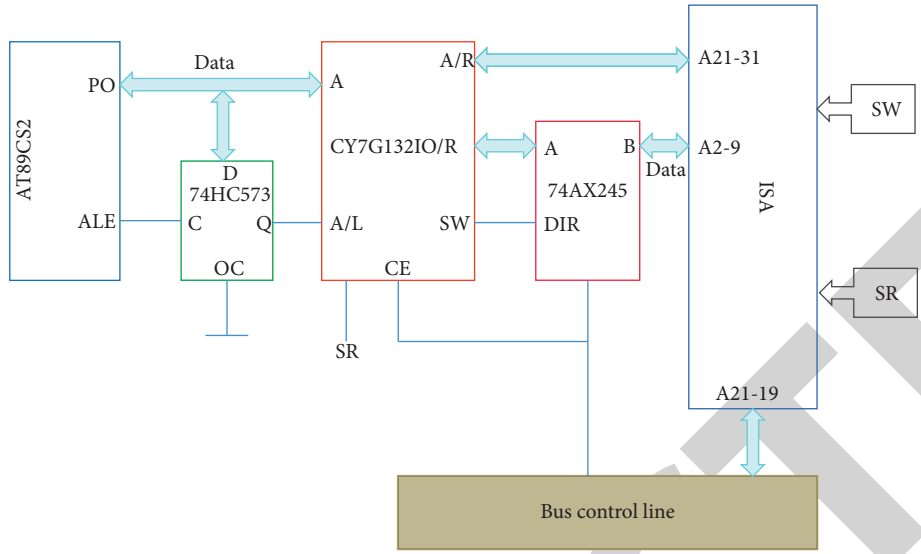

Figure 2: Diagram of sensor data flow interface.

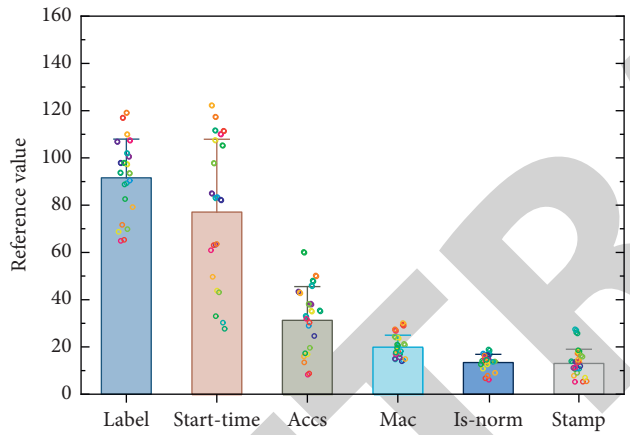

Figure 3: Columnar scatter diagram of reference standard value of source data transmission.

multisource data fusion are stored, and the data content is updated in time, so as to achieve the purpose of judging the intelligent analysis of data delay demodulation.

4.2. Building Data Intelligent Analysis Circuit. In order to ensure the data intelligent analysis rate and better storage of machine learning data, the load of the data intelligent analysis circuit is adjusted. The historical data analysis output process of the intelligent circuit is long, so the circuit update timing is constructed, as shown in Figure 5.

According to the circuit update timing diagram, the data types transmitted by the circuit are intelligently classified, and the data types transmitted by the circuit are summarized. The data intelligent analysis circuit is constructed according to the circuit transmission data type. In order to ensure that the influx of data listening packets corresponding to the data intelligent analysis does not exceed the load range of the data intelligent analysis circuit [22], the size of the data analysis packet needs to be calculated in advance with the following formula:

$$A = A_1 + A_2 + A_3,$$
$$S = \sum_{i=1}^{n} S_i, \quad (1)$$
$$T_i = \frac{S}{A},$$

where the first three values of the parameter in the packet are A_1, A_2, A_3; n is the length of the first packet of data transmission; and S_i is the packet transmission byte of the data intelligent analysis circuit. Using the size of the data analysis packet, the load fluctuation range during the packet influx is calculated as follows:

$$Y = 5q \int_{i-1}^{i+1} l_i^4 \mathrm{d}i, \quad (2)$$

where q is the standard value of line load and l_i is the length of the i^{th} packet, the load fluctuation range is established based on the data vector, and the line type of the data intelligent analysis circuit is selected accordingly to ensure the safety of data transmission.

The data intelligent analysis circuit is used to intelligently analyze the data fused from multiple sources and share the transmission pressure of the main data transmission line. And, in the range of data vector load fluctuation, determine the byte fluctuation range of data transmission, while avoiding the influx of data packets overload caused by data line short circuit.

5. Software Design

5.1. Acquisition of Multisource Intelligent Sensing Data Signals. The multisource data signal sensor is used to capture the multisource intelligent sensing data signal. To begin, control the information procurement and transmission layer by prehandling multisource clever detecting information, control astute investigation guidelines

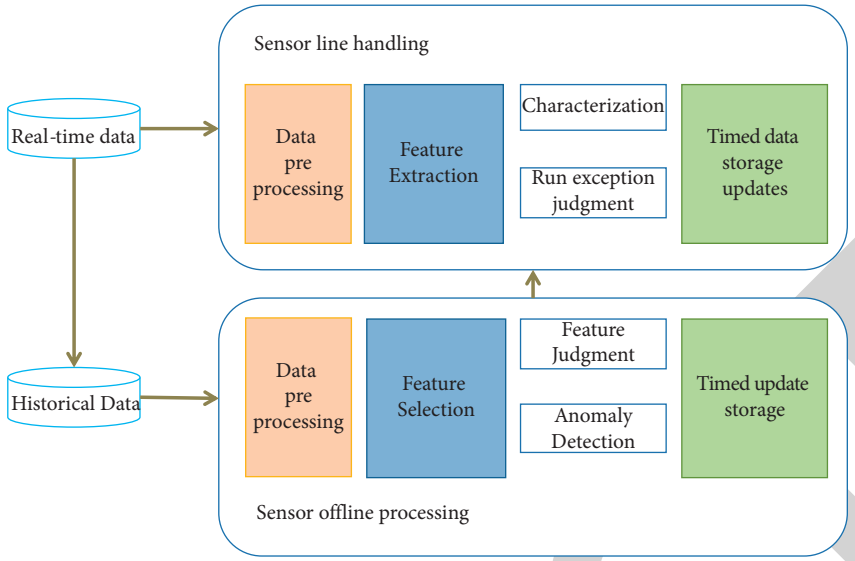

Figure 4: Multisource data signal sensor structure schematic.

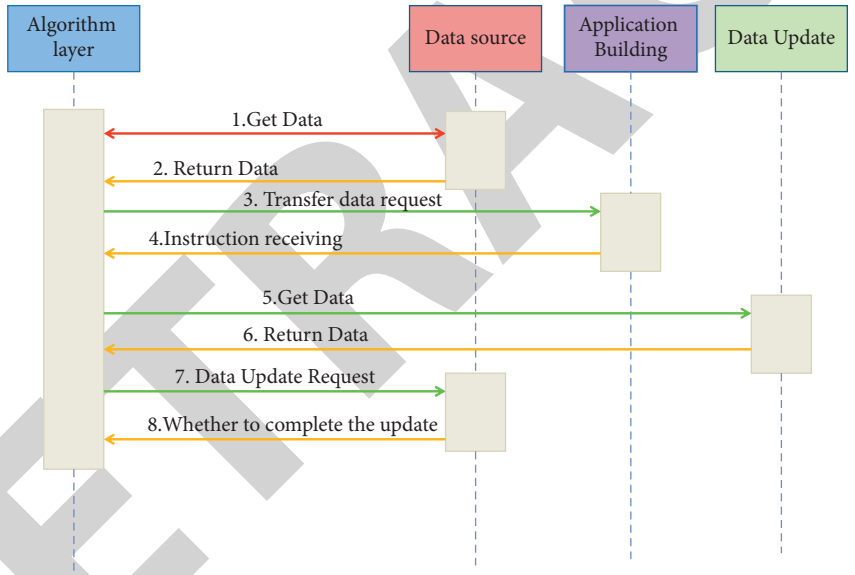

Figure 5: Circuit update timing.

through signal prehandling, and use the association between the application layer of multisource shrewd detecting information to accomplish correspondence associations by prehandling signal calculation. In addition, use the top PC to manage the data transmission arrangement and enter the first phase of the inborn rationale data prehandling application layer.

The computer control data of multi-source sensitive detection information is processed in a decentralized manner, and the basic principles of detection signals are summarized. The detection information is classified and troubleshooting according to the information types transmitted by circuits. Decide on the troubleshooting information's question area right away and inquire about and count the multisource shrewd detecting information as indicated by the consensus for the ensuing investigation. Accordingly, we get the multisource intelligent sensing data termination matching report and truncate the report to organize the termination matching report of circuit transmission data types, as shown in Figure 6.

When the data type termination mismatch is known to exist in the matching result, the termination data types of the termination matching report are excluded, and the matching circuit data types are collated, and the set of multisource intelligent sensing data signal acquisition categories [23] is set as C_i ($i = 1, 2, \ldots, C$) according to the matching result, and the set of data categories with the total number of N_i is screened, and for some of the screened data sets, the initial entropy value is calculated by the following formula:

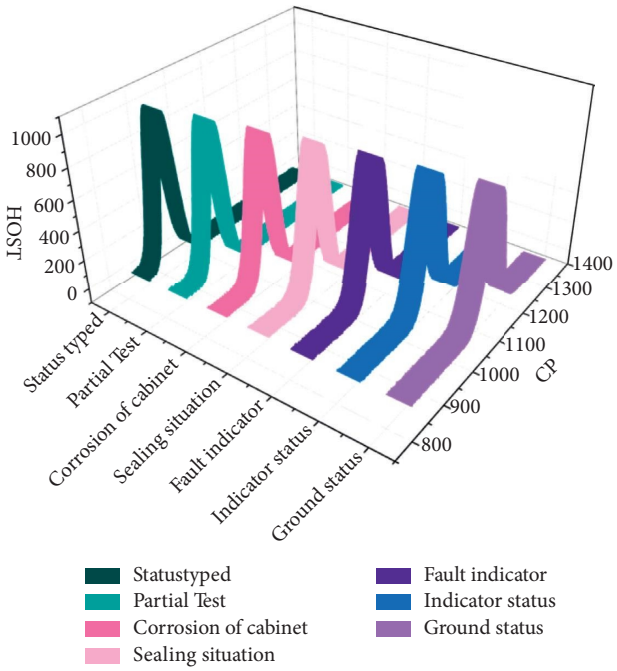

FIGURE 6: Matching data distribution diagram of different circuit transmission data types.

$$P_t = \left(\frac{N_i}{C_i}\right)\log_2\left(\frac{N_i}{C_i}\right),$$

$$S(I) = \sum_{t=1}^{c} P_t, \tag{3}$$

$$S(I) = \sum_{t=1}^{c}\left(\frac{N_i}{C_i}\right)\log_2\left(\frac{N_i}{C_i}\right),$$

where t is the sensing data signal acquisition time and P_t is the circuit matching termination power. The initial entropy value of the screened data set is used to determine the clustering center of the multisourced intelligent sensing data, and the collection interval of the sensing data is calculated as follows:

$$U = \left|S(I) - \overline{m}_i\right|^2,$$

$$d(i,j) = \sqrt{U}, \tag{4}$$

$$d(i,j) = \sqrt{U} = \sqrt{\left|S(I) - \overline{m}_i\right|^2},$$

where m_i is the clustering center of the data set with k as sample points. By determining the acquisition interval of sensing data, the multisource intelligent sensing data signal is acquired; the multisource data signal is structured and processed within the interval; and the multisource data signal structured analysis algorithm is designed for the structured processing.

5.2. Designing Multisource Data Signal Structuring Analysis Algorithm. According to the multisource intelligent sensing data signal, the structured analysis algorithm of the multisource data signal is designed. First, set the analysis procedure of the multisource data signal structured analysis algorithm.

Use the multisource data downstream to self-check and divide the data attribute structure; reason the multisource data signal structure in reverse by linking relationships [24]; when there is reverse logical feedback, extract the data signal and carry out structured analysis; and at this time, the expression of linking relationship is as follows:

$$Z_i = \frac{1}{2}\left(z_1^2 + z_2^2 + \cdots + z_i^2\right). \tag{5}$$

By modifying the multisource data sensing signal, the relationship matrix of the multisource data signal structure is obtained, and the formula is as follows:

$$M_i = \begin{Bmatrix} z_{11} & z_{12} & \cdots & z_{1i} \\ z_{21} & z_{22} & \cdots & z_{2i} \\ \vdots & \vdots & \cdots & \vdots \\ z_{n1} & z_{n2} & \cdots & z_{ni} \end{Bmatrix}. \tag{6}$$

Through the relationship matrix of the multisource data signal structure, establish the multisource data signal link relationship, label the signal data through the link relationship, accordingly control the position of the multisource data signal in the data signal structure, analyze the multisource data signal through link jumping, and read the content of the multisource data signal to analyze the multisource data signal structure.

5.3. Complete Data Intelligent Analysis. Use multisource data blend and format data touchy identification project. Then, by adding data perusing cooperation focuses, the servers at the two terminations of the data overview are related to facilitating the client study data. At last, the data limit is given; the wise examination method of data handling is taken on; the data keen application layer is gathered and organized; and the data examination results are shown by the last connection report. Information investigation shows content, information smart examination upgrading, and wise examination of multisource information, according to the conclusion association report. The content of the multisource data signal is exported according to the predetermined inner logic, and the preset processing logic is exported by independently evaluating the self-tested data type when the overall analysis progress decompression result of the data package appears. Simultaneously, data kinds that do not match the end connection report are separated, and the background compressed file data signal is used to match the end connection report upload once more, completing the intelligent data analysis. So far, the design of the sensor data

intelligent analysis system based on multisource data fusion is completed.

6. Create a Standardized Platform for Moral Education Management

Higher vocational institutions can create a standardized platform for moral education management through network technology and software technology, which can be used to enhance the standardization of students' speech and behavior and play a certain restraint so that students can form a correct concept of compliance with discipline.

6.1. Construction of a Standardized Platform for Behavior. In the process of designing the platform, the "moral education reward and punishment point system" should be used as the basic part so that all moral education personnel can use the platform to make the adjustment to students' behavior scores while visualizing and quantifying students' behavior. The software allows moral staff to change student behavior scores, add or delete points, and administer consequences. To improve the binding force of student management, software technology should be used to push the content of behavior record data for students once a day during the platform's design so that students can consciously regulate their own behavior, discipline their own behavior, abide by the law, and play a good moral education management role through the platform.

6.2. Designing an Interactive Platform. Higher vocational institutions can use network technology to create interactive platforms for moral education management, including parents' and teachers' ends, where parents and teachers can discuss moral education topics and communicate with one another, and students' ends, where students can understand the behavior and information of excellent students in mobile terminals, thereby increasing the influence of all students unintentionally.

Students can learn about the behavior and information of good students in mobile terminals and enhance the behavior management ability and self-management ability of all students under the influence of good students' role models [25]. Higher education institutions also need to pay attention to the standardization of moral education activities in the platform and use the database system to store students' daily information and then release it on the platform to enhance students' self-confidence in moral education learning and make them have the pride of standardizing themselves. In terms of the platform's normative release of various information, it should also pay attention to the normative release of school recruitment data information and enterprise recruitment data information; provide students with employment information, professional ethics information, job work rules and regulations information, and so on; and design corresponding modules to guide students to understand the professional skills they need to master for future job work and the ethical norms and rules and regulations they need to abide by, so as to cultivate students' moral qualities. The module is designed to guide students to understand the professional skills, moral codes, and rules and regulations that need to be observed in their future jobs, so as to cultivate their moral and professional qualities.

7. Improve the Modules of Moral Education Management in Higher Vocational Institutions

So far, school personnel, plan operation staff, and board teachers have waived the authority to make adjustments to teachers and class educators when most professional undergraduates disobey these rules. This shows that tutors' and head teachers' management data is burdensome and chaotic, and they are unable to sort out the behavior data of substitute pupils in an ideal and correct manner, implying that they lack multisensor data. Simultaneously, they find it difficult to truly summarize and interpret behavioral data (a type of multisensor data), reducing the influence of alternative data on executives and making them unable to engage in certain actions. It is difficult to summarize and deal with it effectively, which leads to a decrease in the effectiveness of student information management and the inability to play the role of behavior management and moral management. In view of this situation, it is suggested that important departments of schools and colleges use data innovation and programming innovation to improve the volume and quality of multisensor data, take their own moral training as the board module, and set up special modules for educators, managers, experts, and coordination factor instructors, as shown in Figure 7. Simultaneously, employees from all departments should gradually record replacement behavior data and violation data (a sort of multisensor data) in accordance with module prerequisites so that managers' moral counseling may accurately comprehend the conduct of various substitutes. With a single click, the software may retrieve information about a student's behavior. As a result, behavior control and moral education management may be carried out effectively using in-depth mining of multisensor data, highlighting the role and benefits of information technology and digital moral education management.

7.1. Designing Moral Education Management System of Home-School Cooperation. The fundamental measure for moral education management of college students in higher education institutions is home-school cooperation. It not only can improve the moral education management level with parental support but also can encourage college students to govern their own behavior and build good moral quality and superb quality in all aspects. As a result, it is suggested that higher education institutions strengthen home-school cooperation and establish a moral education management system in terms of home-school cooperation by using network technology and software technology to record students' performance data and moral education data in real

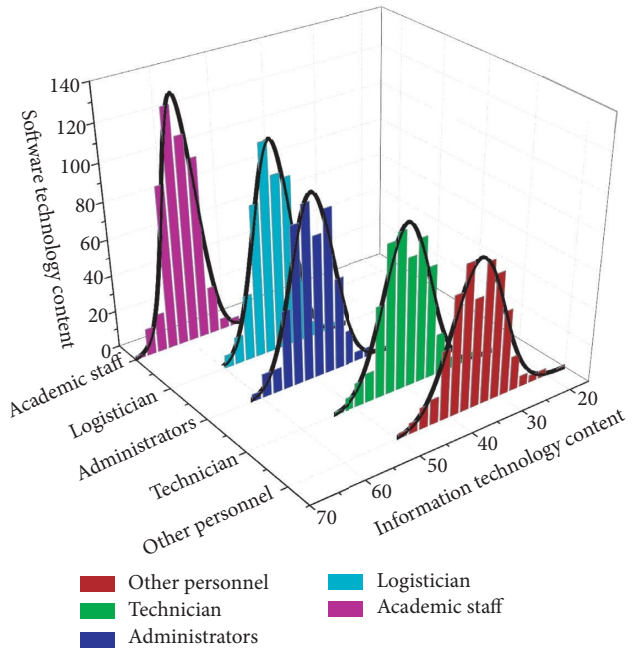

Figure 7: Curve of teaching personnel, management personnel, technicians, and logistics personnel applying information technology and software technology.

time, allowing moral education managers to improve the moral education effect during parent-teacher collaboration.

7.2. Designing a Module to Record Students' Growth Information in Real Time. It is suggested that higher vocational institutions design modules that can record students' growth information in real time on the platform and summarize the data information of the modules into the database system to facilitate the implementation of moral education management. Many parents are too busy to provide moral education for their children, particularly for some residential students, and parents are unable to communicate effectively with students, and there is little time for communication between parents and teachers, so they are unable to fully comprehend their children's daily performance and behavior. During the design of the moral education management platform, it is necessary to include a module for recording students' growth information, as well as the input of students' daily behavior and learning data so that parents can grasp and understand their children's situation through the module and then learn how to conduct moral education in the limited time they have with them under the guidance of teachers' communication.

7.3. Designing the Module of Real-Time Feedback Information. Higher vocational institutions can apply network technology and software systems to design real-time feedback modules for home-school cooperation in the moral education management platform, in which parents are required to communicate with school moral education managers and give feedback on students' behavior. Parents can get real-time student behavior information on the platform, and if communication with teachers is not effective, they can leave messages for the school on the platform, and the school's moral education management department can provide parents with fast and accurate feedback to help parents clarify how to regulate student behavior and solve behavior problems, forming an interactive feedback model. At present, some parents cannot actively communicate with schools and moral education management personnel because they do not recognize the importance of moral education. In this case, higher education institutions should explain to parents that students' bad behavioral habits are linked to family education and the growing environment to some extent and that once moral education is neglected in families, it is difficult for higher education institutions to complete related education work independently. In this approach, a huge quantity of feedback information can be offered in the moral education management platform with the help and understanding of parents, and moral education management can be carried out efficiently to improve the effectiveness of home-school cooperation.

7.4. Designing Moral Education Management System of School-Enterprise Cooperation. Higher vocational colleges and universities will lead students to study vocational skills, job work practice operation knowledge, and technology to enhance the development of students' vocational ability through school-enterprise cooperation in the process of fostering talents. During this time, it is suggested that higher vocational institutions design a moral education management system of school-enterprise cooperation in a moral education platform and collaborate with enterprises to cultivate students' professional moral quality and professional cultivation, in order to cultivate composite talents with professional skills, innovation ability, moral quality, and a sense of social responsibility with the help of good moral education management.

7.4.1. Designing the Moral Education Module of "Craftsmanship". Therefore, in the process of cooperation between higher education institutions and enterprises, the moral education module of "craftsmanship" should be designed, in which it is clear that the enterprises need to provide students with professional skills, innovation, moral quality, and responsibility through craftsmen. Therefore, in the process of cooperation between higher education institutions and enterprises, the moral education module of "craftsmanship" should be designed, in which it is clear that enterprises need to lead students to learn and get in touch with more professional ethical behaviors and comply with rules and regulations through technicians with craftsmanship so that students can improve their behavioral concepts and have good moral quality and professionalism under the influence of technicians' subtle influence.

7.4.2. Designing the Moral Education Module of Enterprise Intuitive Management. When designing moral education modules with advanced technology, higher education

institutions should also pay attention to designing modules for enterprises to manage moral education intuitively so that enterprises can complete the task of moral education management for students in the process of cooperation with higher education institutions. In the module, a database of students' behavioral information should be set up, in which students' data on rewards and punishments in school, professional ability, and career potential should be entered so that companies can provide students with moral management according to various information. At the same time, enterprises can also select outstanding talents to work in enterprise positions by understanding students' situation in the module system, which not only can improve the employment rate of students' talents but also can meet the talent demand of enterprises, achieving a win-win situation.

7.4.3. Designing Moral Education Modules in Employment. It is suggested that higher vocational colleges and enterprises should jointly study how to design employment modules and guidance platforms for students, especially for college students who are confused about the direction of employment, and should set up relevant employment guidance modules and management systems for them in a targeted way. Firstly, in the module, a system introducing information about different employment enterprises should be designed for students so that students can know the job information, work information, and skill requirement information of future employment enterprises through mobile terminals, and employment enterprises can also know students' information in the platform so that the management mode of employment guidance can be formed in the case of two-way selection of students and enterprises' employment. Secondly, in the digital platform of moral education management, it is also necessary to set up a moral education management module for fixed-term internships, a moral education management module for practical tutorials, a moral education management module for employment information, a moral education management module for registration interview, a moral education management module for the presigning list, and so on. In this way, the quality of moral education management can be promoted with the help and support of various modules.

8. Conclusion

The primary goal of higher vocational education is to build moral education, and moral education plays a significant role in daily classroom activities. Building a reusable and shareable data management system to standardize multisource heterogeneous education data in the artificial intelligence education environment and achieve high sharing of multisource sensing data is one of the urgent problems to be solved in the development of education in the era of artificial intelligence education.

In this paper, the design of a moral education management system is done in the context of the specific circumstances of higher education schools, and an information system based on the moral education management of modern college students is built using multisource sensor data and other technologies. The fused education data is described in a standardized way through multisource sensing data fusion combined with learning data specification, resulting in a common and standard data exchange format, on which a shareable and reusable data management system is built to realize data sharing and exchange among various heterogeneous data sources, allowing the intelligent education system to obtain more comprehensive and complete record data to enhance. The immediacy and intelligence of the intelligent education system reaction are enhanced by the timeliness of data exchange, which makes the outcomes of learning behavior analysis more objective, timely, and correct. This paper also includes recommendations for platform selection, system architecture, database design, and other difficulties, as well as methodologies and suggestions for resolving significant issues, all of which can be useful for other university information management systems with enormous data volumes.

Data Availability

The data set can be accessed upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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Retraction

Retracted: Construction and Application of College English Blended Teaching System Based on Multidata Fusion

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] A. Pan, "Construction and Application of College English Blended Teaching System Based on Multidata Fusion," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 4990844, 7 pages, 2022.

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Research Article

Construction and Application of College English Blended Teaching System Based on Multidata Fusion

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With the rapid development of educational information technology, "online and offline" hybrid teaching has become the main trend of foreign language teaching reform in colleges and universities. The blended teaching mode integrates the traditional teaching mode with modern educational technology and reconstructs the traditional college English teaching mode in the aspects of teaching object, teaching content, teaching method, teaching environment, and teaching evaluation. Based on the multisource data such as students' learning situation, learning duration, and academic performance, this paper builds a student English learning analysis system that realizes the integration of multisource data, completes the unified processing and analysis of multisource data, and then displays it through the interface. The system helps English teachers to guide students in different degrees according to the students' English learning situation and academic performance, so that English teachers have a clearer and more comprehensive understanding of students' learning and living conditions and timely guide students with incorrect learning attitudes, so as to avoid students' detours.

1. Introduction

The blended teaching mode of college English pays more attention to the individuality of the teaching object. In the traditional teaching mode, teachers uniformly organize and arrange the teaching progress and content. Teachers are the main body of teaching, and the learning content is dominated by teachers and professors, while students' learning interests and individual needs are often ignored [1–3]. However, the development of modern educational technology provides realistic possibilities for the satisfaction of the individual needs of students. Abundant online teaching resources make students' choices more diversified and close to their personal needs [4,5]. The combination of "online and offline" teaching mode can provide students with more choice space according to the individual needs of students. The hybrid teaching mode realizes the effective combination of classroom teaching and independent learning, meets the personalized learning of students in a multimodal environment, and greatly improves the teaching efficiency and learning effect [6–11]. The teaching content of college English blended teaching mode is closer to reality, richer, and more three-dimensional. In the traditional teaching mode, the teaching content is only based on the selection of established texts, which has a certain lag in time and can not fully reflect the changes in reality. The rich teaching resources on the Internet provide an excellent supplement to traditional teaching and become an important part of the blended teaching content, as well as an important source of materials to cultivate students' awareness of practical care. Online teaching resources are close to reality and have a variety of topics, covering different fields such as economy, society, culture, and history, enabling students to start from reality and examine the relationship between individuals, society, and the world from a diversified perspective [12–15]. In addition, the development of modern educational technology also promotes the booming of online courses, covering many professional fields, increasing the autonomy of students to choose, and enabling students to choose appropriate online courses according to individual needs as a beneficial extension and supplement of classroom teaching content, thus expanding the breadth and depth of teaching

content. Through knowledge acquisition tasks, the blended teaching model encourages students to help each other learn, encourages students and extremely to participate in different forms of learning tasks and in the process of mutual discussion, debate, answer questions, or inspire, in the peer influence of the development of critical thinking ability [15]. The enhancement of interaction also helps to deepen the feelings between students, easy to form a harmonious vice consistent, positive collective atmosphere, so that students promote each other, and common development, and promote students' moral, intellectual, and physical development in an all-round way. The blended teaching mode of college English realizes the interaction between students and knowledge.

Big data teaching refers to the use of big data in teaching by schools and teachers to build an informationized and personalized teaching environment and provide teachers and students with a resource pool to achieve common progress between teachers and students [16–20]. In big data teaching, teachers can use relevant software to build the teaching environment and make full use of the big data function. Teachers categorize the resources that students will use in learning, compile guiding outlines, guide students to establish their own learning garden, and build a ubiquitous learning platform [21–25]. Under the guidance of teachers, students use massive resources to learn actively and use big data to carry out discussions and exchanges to promote their own progress. Big data is to generate a large number of field attribute data with research significance in a relatively short period of time and use the relevant technologies involved in big data to analyze the massive data in order to mine the meaningful information and explore the expanded application of big data in college English teaching.

2. Big Data Technology

2.1. Hadoop Platform. Hadoop is an open-source framework developed by Apache based on the Java language. It is an open-source implementation of distributed computing framework studied by foreign scholars according to the paper of Google. Users can build Hadoop cluster infrastructure without understanding its underlying principles, make full use of the advantages of distributed high-speed computing, and combine the advantages of Hadoop's large storage to develop applications. As a platform for mining and analyzing massive data, Hadoop involves the following core technologies: HDFS, MapReduce, and YARN. An ecosystem is made up of many different subsystems. In the whole ecosystem, each system framework is only used to solve a certain kind of problem, certainly not all the problems can be solved, and to a certain extent, the whole ecosystem is in a stable and highly available state. Hadoop is a computing platform used to process and analyze large-scale data. Its main task is to store and calculate big data. Hadoop is composed of the distributed file management system (HDFS) and distributed computing system (MapReduce). HDFS supports unified file management on distributed servers. Because the initial data is mixed and unstructured, it has high fault tolerance requirements. It is suitable for storing massive data sets and can be deployed on inexpensive hardware. MapReduce is a parallel processing framework for task decomposition and scheduling. It is suitable for splitting tasks into multiple subtasks and combining the calculation results of massive data sets to speed up data processing. Hadoop is suitable for offline batch data processing with low real-time performance and can be used for offline analysis of massive data, large-scale web information search, and data-intensive parallel computing. Figure 1 shows the Hadoop framework.

2.2. Clustering Algorithm. The clustering algorithm is the most widely used method based on statistical analysis in unsupervised learning, which can be used to explore the division of samples or indicators. The partition method refers to the method of splitting the data set with N sample attributes into K clusters, each cluster is represented as a cluster, and K is less than N. For a given K value, two conditions are met. First, each data cluster contains at least one record. Secondly, each record can only be grouped into a cluster. Algorithms based on the partition method are generally divided according to distance. A partition-based algorithm is to perform initial cluster clustering on the cleaned data set, divide the data set into K clusters, and then adjust the cluster division through repeated iterative technology, so that the adjusted cluster is more accurate than the previous cluster, that is, to make the data of the same cluster as similar as possible. However, the data of different clusters are irrelevant or separated from each other as far as possible.

K-means algorithm is the most commonly used and the most basic and effective method to deal with a large amount of data in an unsupervised learning clustering algorithm. The algorithm uses the partition method to cluster the given N data objects into K groups and makes the samples of the same group have the maximum possible correlation, while the samples of different groups have the maximum possible correlation. The correlation of clusters is calculated using the center of mass obtained from the sample mean of each cluster. The processing process of the K-Means algorithm is particularly easy, and the speed of processing data is also very fast, which is suitable for processing large amounts of data. In addition, the algorithm has nothing to do with the order of data processing. It can divide a large amount of data into several small data sets for processing and then summarize the results. However, in the K-Means algorithm, it is necessary to set an appropriate K value for the data set in advance, and it adopts the method of obtaining K original clustering centers randomly so that the selection of different K values and different clustering centers has a great influence on the clustering result. In addition, the K-Means algorithm is very sensitive to noise data and isolated point data, such as maximum or minimum values which will lead to a large error in the results.

The working process of the K-Medoids algorithm is very similar to that of K-Means, but the difference lies in the selection of the initial cluster center. K-Means algorithm mainly adopts the means in the sample data to obtain the initial clustering center, and the clustering center in the

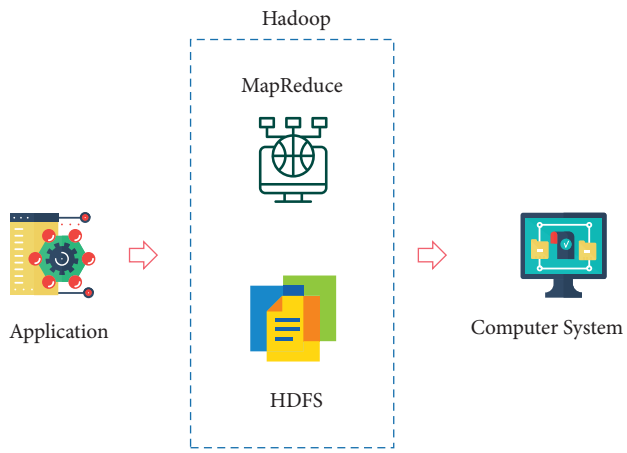

Figure 1: Hadoop framework.

cluster is not necessarily the sample point. However, *K*-Medoids uses the center point in the sample data as the clustering center, which reduces the negative impact caused by noise data to some extent. However, it has a large amount of computation and consumes more system performance compared with the *K*-Means algorithm.

CLARA algorithm is mainly based on sampling to process large sample data. The core idea of the CLARA algorithm is to extract multiple sample sets from a large-scale data set and then use the *K*-Medoids algorithm to perform cluster analysis on the sampled sample data. The CLARA algorithm does not need to consider the entire dataset but rather extracts a portion of it as a sample dataset. CLARA has the advantage of processing large data sets, but its clustering effect is closely related to the size of the sample set extracted, so it may not get the best result. CLARANS is a combination of sampling technology and PAM technology, which is no longer limited to certain fixed samples but randomly sampled data at each step of the search.

2.3. Keyword Extraction Algorithm. The TF-IDF algorithm is a very efficient algorithm for numerical statistics and is used to extract attributes or features that best represent or describe unclassified documents. TF-IDF further emphasizes that it is intended to reflect the relevance of a particular term in a particular document. Relevance means that it is related to the amount of information it provides about the context, be it a sentence, document, or corpus. The most relevant terms are those that help humans better understand the entire document, even without having to read everything. TF-IDF works by assigning weights to each document item, which is reflected in the TF-IDF matrix. The intuition behind TF-IDF is that if a term appears more than once in one or several documents, then that term is relevant or necessary and should have a higher TF-IDF score. However, when a term appears more than once in all or most documents, the term is considered typical and has a low TF-IDF score. TF-IDF algorithm mainly extracts keywords through word frequency statistics, which is a relatively simple algorithm. Term Frequency (TF) refers to the frequency with which a word appears in a text. However, words like "today," "of," "yes," "middle," and "you" still account for a large proportion of the text. In addition, the situation where multiple words appear in the text for the same number of times also occurs for a long time. Therefore, it is necessary to assign different weights to different words through the inverse document frequency (IDF). To select attributes or features that best represent unclassified documents. TF-IDF algorithm is the product of TF and IDF; that is, the larger the TF-IDF value is, the higher its importance to the document is proved.

TF is used to measure the frequency of terms appearing in documents. For the word t_i in a document d_i, TF of t_i can be expressed as

$$\mathrm{tf}_{i,j} = \frac{n_{i,j}}{\sum_1^k n_{k,j}}, \tag{1}$$

where $n_{i,j}$ represents the number of times that the word t_i appears in document d_j, and $n_{k,i}$ represents the number of all words that appear in document d_j.

IDF is used to measure the importance of terms. When TF is calculated, all terms are considered to be equally important. IDF formula is shown in

$$\mathrm{idf}_i = \log \frac{N}{N_i + 1}, \tag{2}$$

where N represents the total number of documents, N_i represents the number of documents that contain the term t, and $N_i + 1$ ensures that the denominator is not zero.

The common formula of the TF-IDF algorithm is the product of TF and IDF, and the TF-IDF value is the characteristic value of the word t_i, as shown in

$$\mathrm{tf} - \mathrm{idf}\,(t_i) = \mathrm{tf}_{i,j} * \mathrm{idf}_i = \frac{n_{i,j}}{\sum_1^k n_{k,j}} * \log \frac{N}{N_i + 1}. \tag{3}$$

3. System Design

We build a hybrid English teaching system, analyze the needs of students and teachers in online teaching, and optimize the teaching model. Now, the architecture model of the system is designed, and the architecture model is shown in Figure 2 in combination with reasonable technology selection. As can be seen from Figure 2, the system is mainly divided into a data access module, data processing and analysis module, and data display module.

3.1. System Structure. HDFS, a distributed file management system on the Hadoop platform, has high throughput and storage capacity of TB and PB levels, requiring only common servers. The HDFS framework can automatically restore the lost core files of the HDFS cluster, thus ensuring the automatic recovery of the lost core files of the HDFS cluster. The system adopts the Hadoop framework to store massive data. This module is used to import a large amount of data of user information into HDFS of the Hadoop platform through the Flume framework, clean the isolated point or

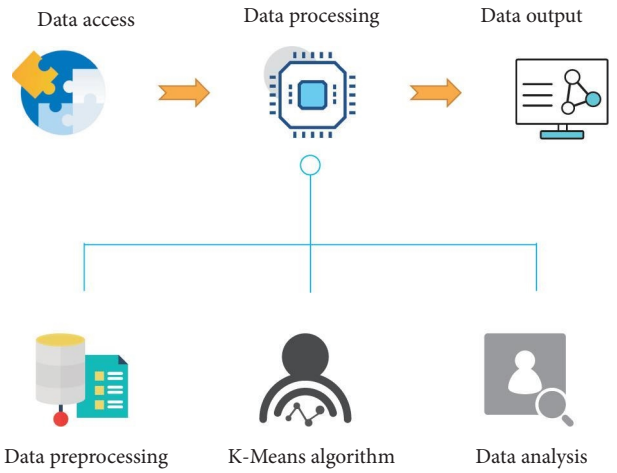

Figure 2: Construction of system architecture.

missing value data, and then associate and match the user's performance information and other data with the user's online log information. This module lays a solid foundation for data preprocessing and data analysis and processing in the data processing module.

In the data processing module, the obtained original data is preprocessed, the noise points in the data are removed through data cleaning, integration transformation, weighted normalization, and other operations, and the data is converted into a format suitable for data analysis. Statistical methods are used to analyze users' online preferences, online duration, and user behavior trajectory, and a clustering algorithm is used to analyze heavy Internet users to judge their impact on students' class efficiency and exam scores. Finally, the analysis result data is stored in the relational database MySQL through the Hive framework. The data processing and analysis module is the core part of the user behavior analysis system of the whole campus network.

The data output module mainly outputs the student information analysis function, involving the student's favorite plate, the student's habitual behavior, the student's ability, and other types of information. In the analysis of student information, the system analyzes students' behavior habits from different aspects, so as to understand the behavior habits of students in online English education as a whole. Through data analysis and statistics, online teaching helps students to learn English, which is convenient for teachers to have a comprehensive understanding of students' learning situations. Data output module through visual tools displays pages, etc.; the readability of data analysis output is convenient from different perspectives for students to analyze and timely guide.

3.2. Algorithm Optimization. *K*-Means clustering algorithm selects the original clustering center by random selection, so the clustering result error is generally large, so the accuracy of this algorithm is extremely low. In order to solve the problem of low accuracy, this paper makes full use of the improved *K*-Means algorithm to solve the problem of low accuracy of *K*-Means. The biggest difference between the improved *K*-Means algorithm and the *K*-Means algorithm is the different selection methods of the initial clustering centers, which is to increase the interval between the initial clustering centers as much as possible so that the distance of each clustering center can be as far as possible. The core idea of the improved *K*-Means algorithm is that it is assumed that N sample data have been selected as the initial clustering center. Then, when selecting the next clustering center, it is necessary to calculate the interval between other sample points and their selected clustering center first and then take the data sample point with the farthest interval as the clustering center of this time. The detailed calculation steps of the improved *K*-Means algorithm are shown in Figure 3.

Since the improved *K*-Means algorithm needs to select the initial clustering center through repeated iteration, thus increasing the time cost, the algorithm ensures the distance between *K* clustering centers as far as possible, thus compensating for the error caused by the random selection of the centroid of the *K*-Means clustering algorithm.

The traditional TF-IDF algorithm is mainly used to extract keywords from the web page text for the whole article, and the statistics are the words with high frequency in the text, which cannot accurately summarize the keywords of the text. Therefore, the algorithm needs to be optimized. Generally speaking, the keywords in the text will be reflected in the title, the first paragraph, the end paragraph, or the summary, such as "in summary," "summary," and other important words, so the use of keywords in different positions gives different weight. Considering that the text to extract keywords is mainly web page text, and web page text is mainly the structural features of HTML, tags in HTML can reflect the expression degree of words to the whole text to different degrees, and their weight ratio is also different. Different coefficients are given to words in different positions to improve the accuracy of keyword extraction. The specific steps are as follows:

(a) Enter the web page text collection $C = \{c_1, c_2, c_3 \ldots c_n\}$, web page title text set $T = \{t_1, t_2, t_3 \ldots t_n\}$

(b) Make text segmentation, to stop words and other operations

(c) Calculate the weight value of the i-th word $w_{i,j}$ in the j-th text. If $w_{i,j}$ is included in the corresponding title text t_j, increase the weight value. In addition, the weight value of text with different lengths is different. In order to reduce the strong coupling of the TF-IDF algorithm to the TF value, the IDF value is squared to balance the algorithm

(d) Repeat the previous step until the weight value of keywords in each text is calculated, sort, obtain the first n keywords, and save and record them

In algorithm optimization, the TF value is mainly improved. In addition, in order to balance the algorithm and reduce the dependence of the algorithm on TF, the IDF value is squared.

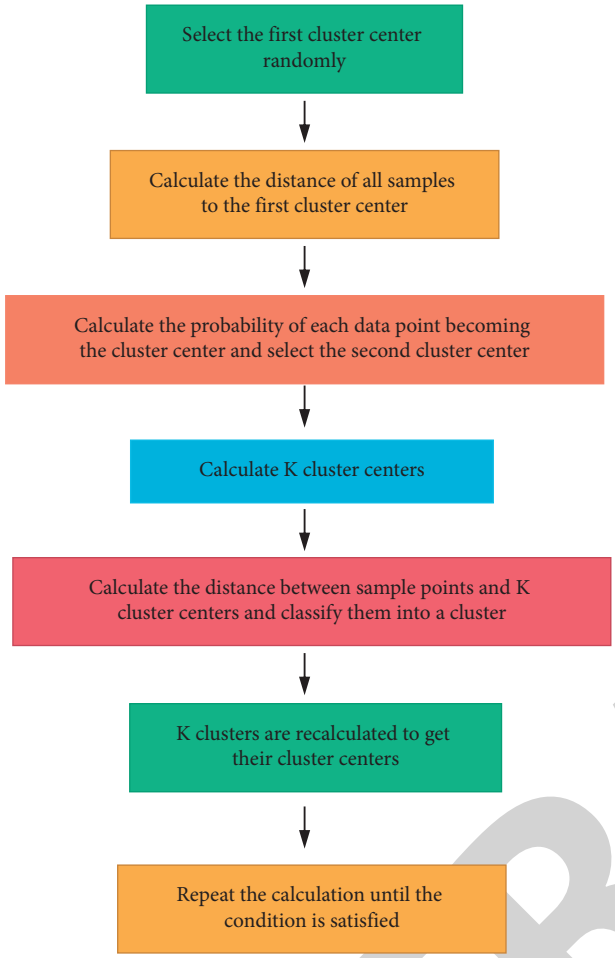

Figure 3: Improved *K*-Means algorithm.

$$tf-\mathrm{idf}(t_i) = tf_{i,j} * \mathrm{idf}_i = \frac{n_{i,j}}{\sum_1^k n_{k,j}} (1+\beta) * \left(\log \frac{N}{N_{t_i}+1}\right)^2, \tag{4}$$

where $n_{i,j}/\sum_1^k n_{k,j}$ represents the TF value of the word in the text, $\beta n_{i,j}/\sum_1^k n_{k,j}$ represents the TF value of the word in the title, and $(\log N/N_{t_i}+1)^2$ represents the IDF value.

When the number of web pages is less than 300 and the β value is greater than 1.5, the selection of keywords depends too much on keywords in the title, and the accuracy decreases. When the number of pages is between 300 and 600, the value of β is 2. When the web page text number is greater than 600, β value 3 is appropriate. The base coefficient in β value is set to 1, and the coefficient dynamically increases by 1 for every 300 words. The value of TF is expressed by $tf_{i,j}$, and the calculation formula is as follows.

$$tf_{i,j}(w_i) = tf_{i,j-c}(w_i) + (1+\alpha) tf_{i,j-t}(w_i), \tag{5}$$

where $tf_{i,j-c}(w_i)$ represents the TF value of the word w_i in the text, and $tf_{i,j-t}(w_i)$ represents the TF value of the word w_i in the title.

3.3. Data Access Module Design. The data access module mainly collects data from multiple data sources, transforms the data, and writes the data to the specified storage. If all data is stored on only one server, memory may be insufficient. In addition, once a single point of failure occurs, data may be lost and cannot be recovered. Therefore, the data access module uses a Hadoop cluster to store massive data. The data access module is used to import large data volumes such as student learning logs and traffic logs into HDFS of the Hadoop platform through the Flume framework, perform data cleaning operations on isolated points or missing values, and then associate and match data such as student performance information and student learning log information. The data access module lays a solid foundation for the data preprocessing and data analysis in the data processing module.

3.4. Data Processing Module Design. Data preprocessing includes two parts of data preprocessing, including multisource data preprocessing and web content analysis preprocessing. Data preprocessing is due to the fact that the data collected is unlikely to be very regular and all are subject to data errors, inconsistent data, incomplete data, incorrect data formats, and other miscellaneous data. The main purpose of data collation is to organize the jumbled data in the dataset in order to improve the quality of the data. The data collation process is shown in Figure 4.

After data collation, further data processing is needed. Combined with the characteristics of the original data set and the content of preanalysis, the latitude reduction strategy is adopted in the data reduction module to remove the unimportant data and improve the mining efficiency, and then the data is normalized. The amount of data sets in the system is very large, and different data attributes are different. For learning duration attributes, min-Niax standardization is used to transform them, and for IP field attributes, Z-Core standardization is used to transform them, so as to put the data in a small range and maintain the inherent relationship between field attributes. Finally, the weighted normalization of the data makes the data have a good analysis.

3.5. Data Output Module Design. It is difficult to find and understand the relationship and rule characteristics between data in data analysis conclusions. Data analysis results can be presented in the form of bar charts, scatter charts, pie charts, etc., so as to observe and analyze the information contained therein more intuitively. The system will have students' learning preferences, learning hours, analysis of students' learning habits, and students' personal portraits through visual display, more intuitive analysis of students' learning habits, and timely correction of online learning arrangements. The system uses HTML, CSS, JavaScript, and so on to display the front-end interface of multisource data analysis results, mainly through the conventional bar chart, scatter chart, and so on display, so as to analyze the conclusion.

3.6. System Environment Setup. The amount of original data used for data mining analysis is relatively large, which may

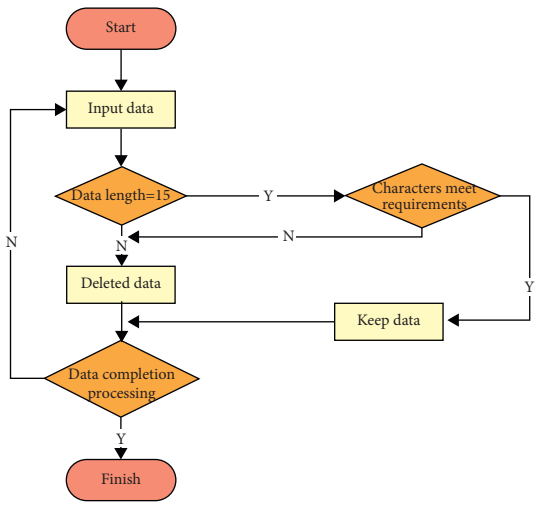

Figure 4: Data integration process.

not meet the storage requirements if a single machine is used and even lead to poor computing performance. Linux server is adopted to mine and analyze the large-scale data set collected in the online learning system by using big data-related technology, so as to analyze the students' learning habits and discover the hidden connections in the data, which can assist the English teaching of teachers and also help to carry out blended learning to mediate and control decisions. In order to complete the construction of the system, a Hadoop cluster is needed. The construction of the Hadoop cluster mainly uses a Linux host server to be more stable and faster, so as to support the requirements of the Hadoop cluster for server performance indicators.

3.7. System Implementation. This system mainly uses three servers to build a Hadoop cluster and uses Hive to do big data processing and analysis. The main work of the data access module is to collect and store the students' learning time and habits in the HDFS file operating system through Flume and store the students' scores and other types of information in the file server through file uploading. Students' learning time, learning habits, and basic information uploaded from the front end are mirrored from the system gateway. The data access module mainly conducts data processing according to requirements by analyzing and studying the format of user data acquired, using MapReduce technology. Although MapReduce is a lightweight framework, its performance is especially fast when it runs on hundreds of servers. It can easily process TERabytes of big data and meet the requirements of increasingly massive data visualization and analysis.

For the realization of the data processing and analysis module, the data is preprocessed to convert it into a format suitable for analysis, and then the data processing theory and front-end tools are used to analyze the results, mining the characteristics of students' learning behavior, and find out the students who do not have enough learning time; that is, the learning time is less than the normal learning time. Finally, the results of the study time are not enough for the ranking analysis, to master the situation of students. The system extracts the student account number, online time, learning time, and other data through data preprocessing for further analysis. Through the observation of the data, it is found that each data contains multiple access attribute information. For the current system, not all attributes will be used, and there is some redundant data information. The original data with a large amount of data always has more or less error information or missing information. Therefore, the first step is to clean the initial data, delete the error information in the original data or useless data that cannot reflect students' behavior, and then transform and standardize the data.

To realize data collation, MapReduce can be implemented quickly. Text files are read by line through Java, each line is converted into an array, field formats in each data are screened by regular matching and other methods, and the number of disorderly data is recorded. Finally, the proportion of disorderly data is visualized. Data set may contain a variety of different properties, but for data mining, many properties are superfluous, the original data set is chaotic and wants to have effectiveness analysis of data, and a lot of data attribute is useless, so the system will adopt the way of latitude to reduce redundancy field processing and improve the performance of data analysis and processing.

The standardization method adopted in this paper is the commonly used Z-Core method. In addition, due to the different size values of data attributes, the data interval after processing is not fixed, so the data attributes of the original band of the initial data are retained. In addition, the data after data standardization has completed the dimensionalization of the data, and different attribute values have comparability. After data standardization, closely related and noncomparable data can be combined in a weighted way to make the data analytical. MapReduce is used to sort out useless data or error information. Map processing is relatively complex and requires data calculation, while Reduce is the simplest method that does not require any data calculation and only combines the Map calculation results.

4. Conclusion

The rapid development of computer technology has brought a new model to college English teaching. Using the K-Means clustering algorithm and weighted technology of information retrieval and data mining, this paper analyzes and processes college students' English learning habits, learning time, and scores, constructs the system to achieve the initial data in advance screening, and analyzes the basic information for teachers to understand the learning situation, so as to pay more effective and timely attention to the psychological changes of students and quickly make corresponding solutions. The construction of the system provides a new direction for college English blended teaching and enriches the college English teaching model.

Data Availability

The dataset can be obtained from the author upon request.

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Retraction

Retracted: Deep Learning-Based Detection and Identification Method for Sports Health Video Dissemination

Discrete Dynamics in Nature and Society

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

In addition, our investigation has also shown that one or more of the following human-subject reporting requirements has not been met in this article: ethical approval by an Institutional Review Board (IRB) committee or equivalent, patient/participant consent to participate, and/or agreement to publish patient/participant details (where relevant).

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] Y. Pang, "Deep Learning-Based Detection and Identification Method for Sports Health Video Dissemination," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 1628165, 9 pages, 2022.

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Research Article

Deep Learning-Based Detection and Identification Method for Sports Health Video Dissemination

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Sports health is gradually attracting attention, and computer vision technology is integrated into sports health to improve the quality of sports and increase the motivation of athletes. A deep learning sports health video propagation detection and recognition system is built through the mode of video propagation to provide real-time training information for sports and scientific body index parameters and exercise data for sports health programs. An athletics action estimation network (AAEN) is promoted, which initially obtains the correlation features and depth features between human skeleton key points through partial perception units. Then, all the joint point features are classified and correlated based on the affinity field range through the confidence map of the human skeletal node region. All video frames are then fused with similar joint features at the temporal level to extract motion key points in the time scale, and human posture prediction is achieved by fitting between the motion features and the dynamic database. To show the high efficiency of our method, we select three main databases for validation, and the results prove that AAEN outperforms by 13.96%, 16.90%, and 15.10% in precision, *F*1 score, and recall compared to the SOTA in sports health video detection and recognition. Our method also performs better overall in the same type of algorithms.

1. Introduction

With the improvement of living standards, physical health is gradually gaining attention. Most people value physical health because they want to keep their body in balance on the dietary and exercise levels. Proper physical activity promotes body metabolism, while physical health indicators can be used as a guide for assessing a person's physical health status. Based on the different parameters of the indicators, the specialist can determine the cause of the patient's illness and suggest a detailed set of sports rehabilitation tables based on rehabilitation science. For professional athletes, sports health can test the physical limits of the athlete and prevent the athlete from developing organismic injuries during the training process [1–3]. Sports health contains a variety of physical assessment parameters, such as real-time heart rate, respiratory rate, blood pressure, muscle stretch, and bone tolerance, based on which the athlete can receive more scientific training recommendations [4, 5].

Physical fitness is the most fundamental code in the field of sports. The effectiveness of training in sports will be directly proportional to the results of the assessment of training intensity and sports health. Physical training programs can have a huge impact on the physiological performance of athletes. According to our preliminary research, regarding athletes with more thorough physical fitness programs, the actual performance of athletes with better physical fitness programs is better than that of other athletes. Targeted strength training is also essential, depending on the sport. The effects of sports health planning are reflected in athlete field technique, mental fitness, physical strength, and tactical planning. In addition to prioritizing a prudent training process, good coaches will consider adding supplementary training facilities, such as computer-aided training systems and computer vision systems, to the training process [6, 7]. Only by incorporating real-time training data into the training program can a sustainable physical fitness program be scientifically developed.

The key performance of the sport health assessment is reflected in the initial training period, special period, competition period, peak period, and rest period. In the initial training period, the physical fitness of the athletes is the main concern. Through the indicators of training ability, training intensity, and cycle analysis, the basic fitness of the athletes will be understood, and scientific training plans will be formulated for the subsequent phases. In the special period, the training capacity and training intensity will be appropriately increased based on the data from the previous phase to complete the transition from adaptive training to competition-related intensity training. The most important part of this period is the issue of improving physical fitness in sports health planning of athletes. The main purpose of the competition period is to improve technical difficulty and learn competition tactics [8, 9]. The competition period usually lasts about 15 weeks and is carried out in phases. This phase of training can be effective in improving competition performance. The peak period usually lasts about one month and is the precompetition training phase. The intensity of training in this phase is gradually reduced to reserve strength and energy for the actual competition. This phase usually employs the taper rule, using a combination of 8/25/45 taper and program retention features, using fitness fatigue training to maximize recovery and maintain peak. Rest periods are postcompetition rest periods where training intensity and volume are reduced to one-third of the peak. The aim is to recover sufficiently to prepare the body for the next phase of training.

With the growth of people's demand for sports health, the combination of sports health industry and video has become the best model. It is difficult for the sports health planning model to meet the motivation and participation of people in sports. It makes athletes unable to grasp the essentials of sports quickly, resulting in low sports results. With the upgrade of computer vision technology, posture estimation techniques can be applied to track and field training [10]. The development of these technologies is often accompanied by video communication techniques that directly contribute to the athletic effectiveness of sports health and improve the understanding and interaction of the public with sports. The introduction of the sports health management system under the video communication system can achieve a win-win situation in sports quality and sports popularity [11]. Understanding the relationship between different sports and health is a prerequisite for health planning. There are many movements in sports health assessment, including athletes who need to understand the focus of technical movements. Therefore, deep learning methods under video dissemination system can learn sports action features and provide people with detailed action guidance and suggestions in sports health system.

The rest of the paper is organized as follows. Section 2 presents work related to different human pose recognition methods. Section 3 introduces the implementation process of detection and recognition of sports health video propagation paths based on deep learning network. Section 4 presents the experimental dataset and the analysis of the experimental data, and Section 5 summarizes the full paper, analyzing the shortcomings of the study and indicating future research directions.

2. Related Work

The most commonly used deep learning model for sports health video dissemination is the human pose prediction model. The most important aspect of human posture research is the estimation of spatial coordinates of joint points, yet this aspect is greatly influenced by the appearance of the human body [12]. Sports health video detection and recognition technology can provide real-time visual display and complete exercise data for sports. With this as a reference, doctors can tailor a scientific exercise plan and health cycle arrangement for each athlete. The core algorithm of sports health video detection technology is human action recognition algorithm, which is divided into single-player action recognition and multiplayer action recognition according to the number of people faced. After a large number of researchers, experimental verification can be seen; the more people, the worse the video action detection effect, where the single person action recognition is the preferred algorithm for most action recognition industry because of its good model stability and high robustness. For multiperson action recognition, video action detection results are affected by unstructured factors [13]. Some researchers in multiperson action experiments have found that crowd occlusion, overlapping light streams, and dynamic dark scenes can cause poor recognition results. It generally occurs that some human bones cannot be captured, resulting in spatial features and temporal features that cannot be connate, and human behavioral features cannot be matched with the action database. Although the efficiency of multiperson action recognition is not high, but considering that our research faces a large number of people for video detection, therefore, we choose to optimize on the basis of multiperson action recognition to improve the efficiency of multiperson video detection.

Sports health video detection has different effects when faced with multiplayer detection using different detection methods. Researchers in the literature [14] have focused their research on multitask action detection around top-down approaches. The authors used a convolutional neural network as the base network to capture the outer contours of the human body through center-of-mass localization. In the case of multiple people, the outer contours share a feature extraction layer and different people correspond to different center-of-mass contours, then the number of people is determined based on the number of centers of mass, and different numbers of people are divided into different pose estimation units, each of which contains a human skeleton segmentation algorithm that automatically assigns human skeletons to the people whose centers of mass are determined. The temporal relationship between the human skeletal nodes of the premise of the action recognition algorithm, the authors determined by this method to deal with the problem of skeletal segmentation of multiple people, and the experiments proved that the overall efficiency of the method is better, but it is affected by the human detector.

Researchers in the literature [15] proposed the heat map gradient method to detect multiperson gestures, and the authors found in their experiments that different gesture actions have different ways of heat map representation, and threshold range restrictions can segment the heat maps of different actions into broad categories of actions, and different network classes output different heat maps, and different categories of actions can be obtained according to the mapping between heat maps and human actions. For control of the number of people, the authors used the convolutional bit-pose algorithm to estimate the pixel weights of different people in the video, and the matching between people and poses is accomplished by the weights and the size of the heat map area.

Other researchers used stacked pyramid networks to improve the perceptual domain of human skeletal joint points and fuse the characteristics of different body parts by cascading them to improve the extension of action categories [16, 17]. In the literature [18], to solve the problem of inconsistent scales of multiperson action characteristics, the authors proposed a feature Atlas preprocessing method to effectively resolve the differences between action characteristics. The researcher in the literature [19] proposed a combined skeletal key point planning method that can compensate for the difference between features and improve the accuracy of skeletal recognition. Some other researchers have tried to use a linear regression neural network algorithm to localize skeletal points before moving to a dynamic joint algorithm of skeletal points to predict action classes [20, 21]. Researchers in the literature [22] found in their experiments that a bottom-up video action detection method is more effective, and the authors started with joint coordinate points of multiple individuals, whose joint point vectors are not oriented in the same direction for different individuals, and used this as a criterion to categorize each individual's joint points as a way to complete skeletal point segmentation, followed by video action recognition. The researchers in the literature [23] incorporated a residual network [24] into the video action recognition network and used adaptive image constraints to perform linear regression on skeletal points, but this method requires high hardware conditions, which leads to high experimental costs. Considering the experimental cost and computational complexity, researchers in the literature [25] performed clustering analysis of human skeletal joint points by video single-frame pixel embedding, and the clustering results at different levels mapped different video action classes.

In addressing the efficiency of video multiplayer action recognition, some researchers have tried to start with tracking algorithms that mimic the pixel tracking principle to achieve dynamic tracking of skeletal points as a way to analyze their behavioral action categories. Researchers in the literature [26], inspired by the flower pollination algorithm, set adaptive search windows by using the human center of mass of each frame of the video as a tracking point. This method improves the video detection accuracy of the human skeleton and achieves the target tracking of actions at the temporal level. The researchers in the literature [27] proposed an energy optimization strategy, and to reduce the influence of the experimental environment on the experimental results, the authors built a linear invariant system, and the experimental results showed that the method achieved 87% of the video action recognition accuracy. The researchers in the literature [28] found in a study of badminton escort robots that the derivative evolutionary algorithm can migrate learning to video action recognition and maintain dynamic skeletal point feature sharing at the temporal level, which facilitates the differentiation of differences between multiplayer actions.

3. Methods

3.1. Partial Perception. For video input, the human body is divided into skeletal nodes with each image frame of size $w \times h$. The deep neural network divides the body into different parts, each corresponding to a different joint confidence map H, and a body part affinity field (PAF) L, where L represents the number of joints. The number of frame rates of joint skeletal confidence maps $H = (H_1, \ldots, H_J)$ in video motion capture is J, where $H_j \in \mathbb{R}^{w \times h \times 2}$, $j \in \{1, \ldots, J\}$, H_j^{GT} represents the position of joint skeletal points in each frame of the video. Ifmmc1 is the video motion capture that starts from the overall level of human joints, and the labels of each joint part can be automatically generated by linear functions. For PAFs $L = (L_1, \ldots, L_c)$, C represents the total number of vectors of joint skeletal points, and different joints map different vector domains, where $L_c \in \mathbb{R}^{w \times h \times 2}, c \in \{1, \ldots, C\}$, L_c^{GT} represents the true unit vector of independent joints in the composition of skeletal points, each joint skeleton maps an independent unit vector j_1, j_2, the range of joints in each frame of the video consists of a combination of rectangular boxes, and the direction of vector j_1 within each rectangular box is consistent as j_2. Assuming a label of $y_{GT} = (H^{GT}, L^{GT})$, a model function of $P = (H, L)$, and an error parameter of $E_{L2}(P, y_{GT})$, the mathematical equations are expressed as follows:

$$E_{L2}(P, y_{GT}) = \sum_{j=1}^{J} \sum_{p} W(p) \| H_j(p) - H_j^{GT}(p) \|_2^2 + \sum_{c=1}^{C} \sum_{p} W(p) \| L_c(p) - L_c^{GT}(p) \|_2^2, \quad (1)$$

where P represents the pixel coordinates of joint skeletal points in each frame of the video, and W represents the dynamic mask of joint points, which is used to call function $W(p) = 0$ for optimizing video motion capture with

nonstructural factors in the case of abnormal experimental environment and multiple overlapping people. During the training process, the real features are easily deleted by mistake due to occlusion and ambient lighting. To solve this problem, we set an independent supervised self-loop f in each feature extraction layer to adaptively compensate gradient errors and prevent gradient explosion [29], which is mathematically expressed as follows:

$$f = \sum_{t=1}^{T_p} f_L^t + \sum_{t=T_p+1}^{T_p+T_c} f_S^t. \tag{2}$$

In order to reasonably match the skeletal joints with the corresponding parts of the body, a set of linear regression functions was used. In the vector domain generated by the skeletal joint points, the group of joint points is filtered according to the vector direction. The linear combination of the skeletal vectors with the corresponding body part domains was evaluated using confidence maps as the criteria. After the joints are matched with the body parts, the weight scores are then calculated, and the confidence weight values depend on the mapping rules between the skeletal points and the joint groups. The effect of the action of the joint affinity field is shown in Figure 1. When associating the dancer's left arm at the same time, different people will have different directions of affinity vectors for labeling.

3.2. Confidence Correlation. To explain the equation f mentioned in the previous section at a mathematical level, we label each skeletal point in the pixel coordinate system of the video frame and generate the corresponding joint confidence map S^*. The confidence map is generated from the joint group, so each confidence contains a direction vector information and a pixel coordinate information. The position changes of different skeletal points on the pixel coordinates can be converted into video motion capture information. In human motion detection experiments, each limb consists of a joint group and a skeletal point, and different combinations correspond to different peak ranges. Each person has a different peak range, so the peak range can be used to divide most people into independent individuals j. Each independent individual k is defined in the peak range or generates k confidence atlases $S_{j,k}^*$, where $x_{j,k} \in \mathbb{R}^2$ represents the real information of body part j of individual k in each frame of the video. Assuming $p \in \mathbb{R}^2$, then $S_{j,k}^*$ has the following mathematical expression.

$$S_{j,k}^*(p) = \exp\left(-\frac{\left\|p - x_{j,k}\right\|_2^2}{\sigma^2}\right), \tag{3}$$

where σ represents the joint combination peak, the video action recognition network starts with a single confidence map to resolve the action type of a single individual and then migrates to learn from multiple individuals, and the joint group confidence map range can filter the action category weights between different individuals.

$$S_j^*(p) = \max_k S_{j,k}^*(p). \tag{4}$$

The joint group confidence peaks in the video multiplayer hands-on recognition experiments limit the action trade-offs between individuals, and to maintain accuracy, we chose the mean value as the limiting condition. The confidence correlation process is shown in Figure 2, taking the athlete's hand confidence correlation as an example, and each hand appears with an infinite number of confidence correlation baselines. The association between the hands of the same person is the internal correlation, and the association with others is the external correlation. In the internal correlation, the correlation of the same hand is an internal positive correlation (shown as red dashed line), and the correlation between different hands is an internal negative correlation (shown as yellow dashed line).

3.3. Mapping and Association. In the first layer of the video multiplayer action recognition network, each frame of the video is characterized on-demand based on joint groups and skeletal points. Referring to the Google VGG network, we set VGG-19 as the base feature extraction network and select the joint group PAF $L^1 = \phi^1(F)$ in the skeletal feature initialization stage, where ϕ^1 denotes the joint features are denoted after the first stage of initialization. Each round of feature F is iteratively updated until the PAF logic criterion is satisfied before it can be output to the next action feature capture stage. The mathematical expressions are shown as follows:

$$L^t = \phi^t\left(F, L^{t-1}\right), \quad \forall 2 \le t \le T_p, \tag{5}$$

where ϕ^t represents the prediction result of the video action recognition network at stage t, and T_p indicates the number of iterations of the PAF. According to the internal logic of the PAF, the confidence map generated by each local joint iteration will be passed as a set of skeletal points, and the form of the pass is converted once after each T_p iterations.

$$\begin{aligned} S^{T_p} &= \rho^t\left(F, L^{T_p}\right), \quad \forall t = T_p, \\ S^t &= \rho^t\left(F, L^{T_p}, S^{t-1}\right), \quad \forall T_p \le t \le T_p + T_c, \end{aligned} \tag{6}$$

where ρ^t represents the action prediction result in the confidence iteration phase t , and T_c represents the number of skeletal confidence parameters for the joint group. Researchers in the literature [14] also refined the association of confidence maps with joint groups in their study of PAF, but the refinement led to halving of parameters and a significant reduction in the prediction of affinity fields. Therefore, in our network design, we used cluster analysis to adopt linear clustering for each joint group and bone, and different individual joint groups can be discriminated according to PAF channel logic. The experimental results demonstrate that our method is less effective in obtaining the connection between the confidence map and the action of the body as a whole, and for the extraction of fragmented features of body parts.

Figure 3 shows the effect of different iterative levels of PAFs between joint groups and bone points. As in the case of the athlete's leg node, the first stage is the refinement of the

Figure 1: Principle of joint affinity field action.

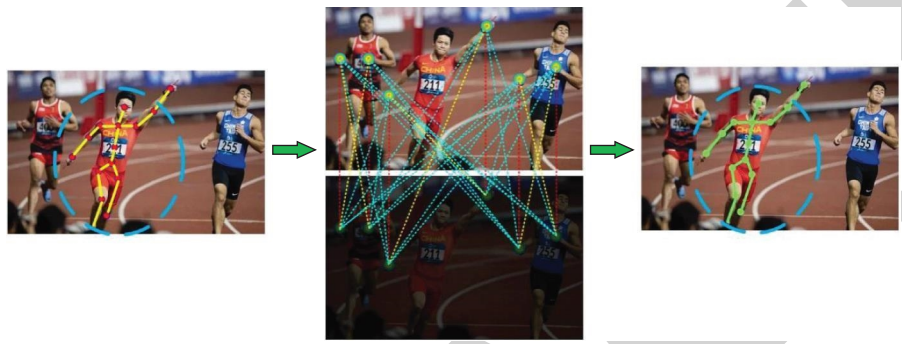

Figure 2: Confidence correlation process.

Figure 3: The effect of part affinity fields at different stages.

affinity field between the starting point and the endpoint. The second stage will connect the start point with the endpoint and refine the intermediate points. The third stage is the overall feature node refinement. The joint group PAF predictions of different individuals all share the same input of the network layer. To facilitate feature traversal of the joint group confidence map in the same individual, all network layers use the same parameter settings to prevent video frame pixel bias during traversal to properly guide the convolutional neural network to assign different features to different parts of the body during the iterative process. To prevent the confidence bias of the PAFs of the branch network and the backbone network, an additional L_2 loss function is added at the end of each video action recognition network. When matching real action features with labels, we added spatial loss functions in 3D for spatial location localization of individual mass centers. In addition, for the additional skeletal point features, we used data optimization and data padding to filter out the features with higher weights and then padding them into the real feature set.

3.4. Athletics Action Estimation Network. In order to meet the development needs of the sports and health industry, we propose a human action video recognition network, named Athletics Action Estimation Network (AAEN), with the network structure shown in Figure 4. The whole network of AAEN is divided into two stages, and the first stage of network iteration is to obtain the confidence features of the joint group confidence features ρ^t and match them with the individual skeletal affinity field ϕ^t. The network structure of the second stage is an optimization of the first stage, and the number of network iterations is adaptively selected according to time t. Each iteration updates the joint group confidence and skeletal affinity field, and when the parameter weights reach the specified values, then the output values are optimized in a continuous layer for feature optimization, where $t \in \{1, \ldots, T\}$ represents the supervised self-loop in the network layer.

We optimize based on the human pose estimation network proposed in the literature [30]. We design the network with more strata, and the number of strata is related to the time t, which is determined by the confidence of the joint group and the matching of the skeletal affinity field. When the weights reach the specified range, then the update iterations are stopped to output the action classification results. In the optimization of the network layer, we refer to the optimization strategy of Google VGG network and use conv 3×3 instead of conv 7×7 to increase the network width and improve the feature extraction limit of the

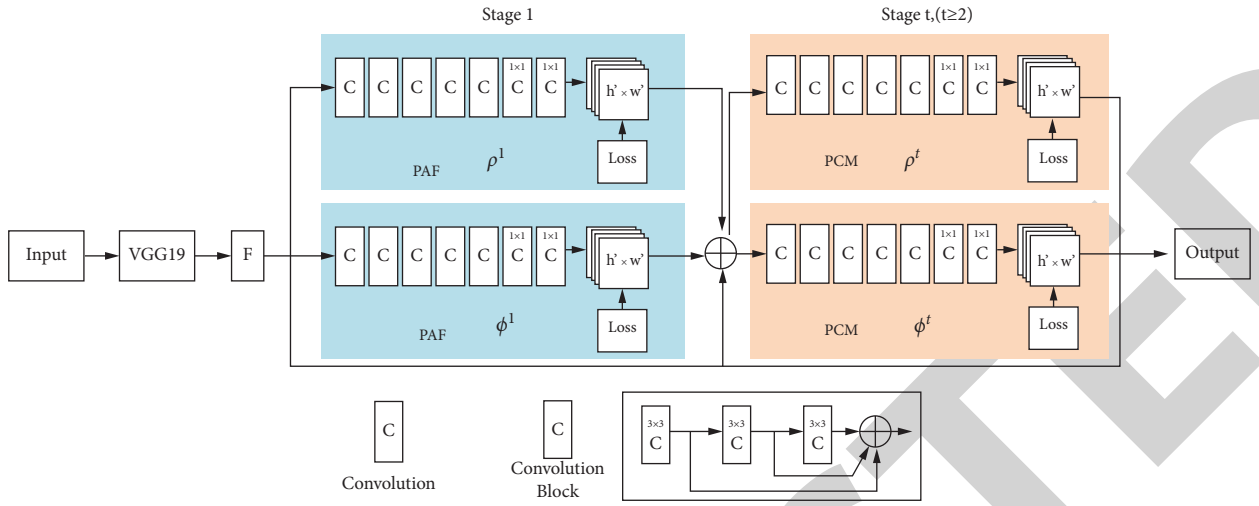

Figure 4: Athletics action estimation network.

network. We design the whole network as a sparse structure, and the initial and final layers of the network use residual connections for feature sharing, which solves the problem of parameter redundancy and overfitting. In addition, in the design of the network layer of the skeletal point affinity field, we add nonlinear units to extract high-level action features without affecting the extraction of low-level features by this network layer. Such a network design reduces the computational cost and improves the robustness of the video action recognition model.

4. Experiment

4.1. Dataset. To validate the performance of AAEN in sports video propagation detection, we performed experimental validation in the public datasets KTH [31], OSD [32], and UCF-Sports [33]. The KTH dataset was collected from 25 volunteers according to the actions specified. Each sample segment has a duration of 4 seconds and a pixel resolution of 160×120. The jogging and running datasets were chosen for the experiments to fit the research topic of sports health assessment. The OSD dataset is an Olympic sport-based dataset that contains all Olympic sports. The UCF-Sports dataset is a combination of sports videos from video websites and national channels, and this dataset is mainly oriented towards action recognition and human localization studies. We selected some data related to track and field sports for our experiments. The details of the three public datasets mentioned above are shown in Table 1.

4.2. Analysis of Results. We compared three methods, SVM [34], CNN [35], and OpenPose [36]. To ensure that the action recognition methods perform optimally independently in the experiments, we take a reset system approach for each method. In the method evaluation, we chose precision (P), $F1$ score, and recall (R) as the evaluation criteria. Each sports health detection metric is fed to each metric in the dataset, and the association between the metrics can indicate the performance of the sports health video propagation detection system and then the sports gesture prediction output with the help of motion joint feature classifier. Data labels can also be compared to react to the accuracy of human pose recognition. The performance of the sports health video propagation detection system in different public datasets is shown in Table 2.

The results in Table 2 indicate that the machine learning algorithms have poor performance in video recognition of human poses. Among the deep learning class of methods, CNN is the most widely used method, but video human pose recognition is not as accurate as the OpenPose algorithm. OpenPose's hierarchically interconnected network structure obtains better efficiency of action recognition, which allows for local perception and maximum fusion of memory information. Our approach AAEN adds an articulation group channel and a skeletal feature channel to the base model, starting from local fragmented information from the body to obtain bidirectional feature information. Therefore, the AAEN outperforms by 13.96%, 16.90%, and 15.10% in precision (P), $F1$ score, and recall (R) compared to the OpenPose algorithm.

Due to the low accuracy of SVM method in video human action recognition, it seriously affects the video human pose estimation in the second stage. We only keep the deep learning method as a comparative method for video human pose estimation. Before performing the video human action recognition work, according to the targeted experimental objectives of the three datasets, we will develop the optimization of the three datasets in order to be more adapted to the action recognition of sports health. Due to the large amount of data, we evaluated the datasets in terms of skeletal feature matching rate (SFMR), joint point matching rate (JPMR), and time node distribution rate (TNDR), and the results are shown in Table 3.

In Table 3, UCF-S maintains above 80% in both the skeletal feature matching rate and the node matching rate, and the recognition performance of the KTH is lower than that of the other two datasets in terms of the distribution rate

Table 1: Number of training sets and test sets.

	Datasets		
	KTH	OSD	UCF-S
Train	1332	1647	753
Test	232	315	106
Total	1564	1962	859

Table 2: Comparison of the accuracy of different methods of identification.

	KTH			OSD			UCF-S		
	P	*R*	*F*1	*P*	*R*	*F*1	*P*	*R*	*F*1
SVM	0.53	0.53	0.57	0.63	0.62	0.59	0.55	0.53	0.57
CNN	0.65	0.71	0.69	0.70	0.59	0.60	0.70	0.63	0.60
OpenPose	0.72	0.80	0.78	0.73	0.70	0.70	0.80	0.75	074
Ours	**0.86**	**0.91**	**0.81**	**0.83**	**0.80**	**0.82**	**0.87**	**0.92**	**0.92**

Table 3: Experimental results for different motion datasets.

	KTH	OSD	UCF-S
SFMR	0.72	0.75	0.84
JPMR	0.67	0.82	0.89
TNDR	0.43	0.66	0.57

Table 4: Comparison of the accuracy of human pose estimation in different sports events.

	1000 m race	Triple jump	Pole vault	Marathon
CNN	0.68	0.55	0.53	0.61
OpenPose	0.78	0.68	0.73	0.76
Ours	**0.95**	**0.86**	**0.91**	**0.94**

Figure 5: Results of human pose estimation based on AAEN for track and field events in the racing category.

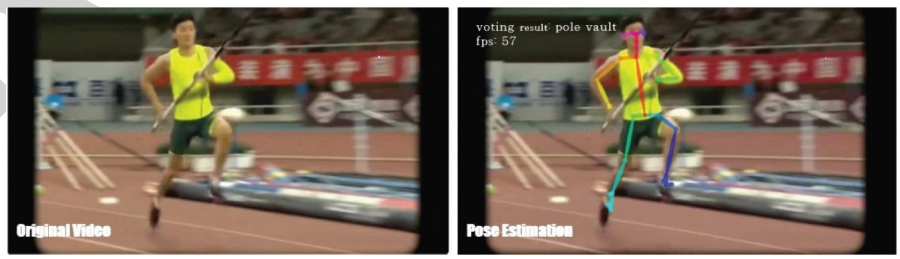

Figure 6: Results of human pose estimation based on AAEN for pole vault category track and field events.

of the temporal nodes. In order to maintain the balance between temporal and spatial features, we finally choose OSD as the validation dataset for video human pose estimation. We prioritized four representative sports, 1000-meter running, triple jump, pole vault, and marathon and compared the human action recognition video performance

of various methods. The results are shown in Table 4. And the results of our video body pose estimation method adopted AAEN in competition sports and pole vaulting-type sports are shown in Figures 5 and 6.

Table 4 shows that the video human pose estimation by CNN is not as effective as the OpenPose method, and our method is the most efficient, with an average accuracy of over 20 percentage points higher than the OpenPose algorithm. Therefore, human pose estimation is more suitable for running sports health video detection projects, such as 1000 m race and marathon. This is because running sports are simpler in terms of action characteristic dimension. In contrast, for triple jump events, the overall movement is more complex, the movement characteristics are more difficult to capture, and the prediction of pose at the temporal level is more difficult, so it is more effective than running sports.

5. Conclusion

In this paper, we investigate the details of the evaluation of sports health and find that the sports model is inefficient. To further improve the quality of sports and the motivation of athletes, we integrate deep learning human pose estimation algorithms into sports and build an integrated sports health video detection and recognition system that incorporates computer vision techniques and deep learning algorithms. An athletics action estimation network (AAEN) is promoted, which initially acquires position features and orientation features between key points of the human skeleton through partial perception units. Then, all nodal features are classified and correlated based on the affinity field range through the confidence map of the human skeletal node region. All video frames are then fused with similar joint features at the temporal level to extract motion features in the time scale, and video human action recognition is achieved by fitting between motion features and the dynamic database. We screened three main datasets for validation, and the results prove that our method is more efficient than machine learning methods. Our method also performs better overall in the same type of algorithms. To further validate the adaptability of our method to specific athletic events, we selected four sports, and the results prove that our method performs better in running-type sports.

Experiments from video propagation tests of sports events show that our method performs poorly in complex sports events. To solve this problem, in future research, we will consider starting from the mapping relationship between part and whole, borrowing the bidirectional loop structure of LSTM algorithm to highlight the fuzzy action features and weaken the noise features to achieve the effect of feature balance.

Data Availability

The dataset used to support the findings of the study can be accessed by contacting the author.

Conflicts of Interest

The author declares that they have no conflicts of interest.

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Research Article

Decision Analysis Approach Based on 2-Tuple Linguistic m-Polar Fuzzy Hamacher Aggregation Operators

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This research article is devoted to presenting the concept of 2-tuple linguistic m-polar fuzzy sets (2 TL m FSs) and introducing some fundamental operations on them. With 2 TL m FSs, we shall be able to capture imprecise information with high generality. With the appropriate operators, we shall be able to apply 2 TL m FSs in decision-making efficiently. The aggregation operators that we propose are the 2 TL m F Hamacher weighted average (2 TL m FHWA) operator, 2 TL m F Hamacher ordered weighted average (2 TL m FHOWA) operator, 2 TL m Hamacher hybrid average (2 TL m FHHA) operator, 2 TL m F Hamacher weighted geometric (2 TL m HWG) operator, 2 TL m Hamacher ordered weighted geometric (2 TL m HOWG) operator, and 2 TL m F Hamacher hybrid geometric (2 TL m FHHG) operator. We investigate their properties, including the standard cases of monotonicity, boundedness, and idempotency. Then we develop an algorithm to solve multicriteria decision-making problems formulated with 2 TL m F information. The 2 TL m F data in multiattribute decision-making are merged with the help of aggregation operators, and we consider the particular instances of the 2 TL m FHA and 2 TL m FHG operators. The influence of the parameters on the outputs is explored with a numerical simulation. Moreover, a comparative study with existing methods was performed in order to show the applicability of the proposed model and motivate the discussion about its virtues and advantages. The results confirm that the model here developed is reliable for decision-making purposes.

1. Introduction

With its large display of different approaches, multiattribute decision-making (MADM) is a collective enterprise that aspires to deal with complex situations in the presence of multiple attributes. The choice of a decision-making approach plays a vital role in the selection of desirable alternatives. Also, the representation of the information is crucial because the formulation of problems with real-valued attribute endowments is a rarity in decision sciences. For this reason, Zadeh [1] introduced the idea of fuzzy sets (FSs), a mathematical tool that easily tackles MADM, being a mutated form of crisp set theory. Yager [2, 3] presented the less stringent concept of Pythagorean fuzzy sets (PFSs) for which the condition $\mu + \nu \leq 1$ imposed by IFSs is relaxed to $\mu^2 + \nu^2 \leq 1$. FS has a pathbreaking structure that allows it to account for vagueness for the first time. But it is not a totally general framework for the mathematical treatment of partial knowledge. To enlarge its scope, Atanassov [4] introduced intuitionistic fuzzy sets theory (IFSs), a simple modification that can tackle uncertain and vague data more precisely.

Aggregation operators (AOs) play a crucial role in converting different datasets into a single result and dealing with collective decision-making problems. A very popular tool for aggregating data was introduced by Yager [5] under the name of ordered weighted averaging aggregation (OWA) operators. Yager [6] contributed to quantifier guided aggregation using OWA operators. Xu [7] first gave intuitionistic fuzzy set-based aggregation operators. Then Xu and Yager [8] studied geometric aggregation operators and

produced some real-life applications. Alcantud et al. [9] first produced AOs that operate on infinitely many intuitionistic fuzzy sets. Improvements to IFSs appeared, and AOs were produced in these new models too. Since there is often a counterpart for each attribute of the alternatives, bipolarity has been used as a conceptual tool for the representation of dual attributes. Wei et al. [10] came forward with hesitant bipolar fuzzy weighted aggregation operators as arithmetic and geometric operators. With the help of hesitant bipolar fuzzy weighted aggregation operators and geometric operators, Xu and Wei [11] gave dual hesitant bipolar fuzzy weighted aggregation operators and geometric operators. In other frameworks, AOs have been studied too. For example, Garg [12] gave a framework for linguistically prioritized aggregation operators.

More sophisticated aggregation operators were developed to improve the accuracy of the subsequent applications. For example, based on algebraic and Einstein t-conorm and t-norm [13], Hamacher t-conorm and t-norm [14] were developed to aggregate data for decision making. Peng and Luo [15] presented decision-making for China's stock market bubble warning. Aggregation operators based on Hamacher operations produce a transparent result in decision-making. Thus, inspired by these operators, Wei et al. [16] developed some induced geometric aggregation operators with intuitionistic fuzzy information and showed their applications to group decision making. Liu [17] proposed aggregation operators for interval-valued intuitionistic fuzzy fields. Further contributions were made by Akram et al. [18] with the introduction of a decision-making model using complex intuitionistic fuzzy Hamacher aggregation operators. Huang [19] put forward the idea of intuitionistic fuzzy Hamacher aggregation operators and illustrated their application in multiattribute decision making. After that, Hamacher aggregation operators were extended so that they could operate on Pythagorean fuzzy sets. Wu and Wei [20] presented the Pythagorean fuzzy Hamacher aggregation operators and their application to multiple attribute decision making. Akram et al. [21] used these operators in the complex fuzzy field and developed the idea of a hybrid method for complex Pythagorean fuzzy decision making. Akram et al. [22] designed a decision-making model with the help of complex picture fuzzy Hamacher aggregation operators. After that, bipolar fuzzy Hamacher arithmetic and geometric operators were also developed by Wei et al. [23]. Akram et al. [24] developed q-rung orthopair fuzzy graphs under Hamacher operators.

As many real-life situations contain multiinformation, Chen et al. [25] developed the m-polar fuzzy (m F) set, which enables decision-makers to manipulate multipolar data for the purpose of decision-making. Further, Jana and Pal [26] presented the m-polar fuzzy operators and their application in the multiple-attribute decision-making process. Hwang and Yoon [27] presented the concept of multi-objective decision making-methods with applications. Nevertheless, Hamacher operations were not originally designed to collect information in the form of intuitionistic fuzzy numbers (IFNs), Pythagorean fuzzy numbers (PFNs), bipolar fuzzy numbers [28], or m F numbers (m FNs). Waseem et al. [29] used Hamacher operators to aggregate data in a m-polar fuzzy setting. Akram et al. [30, 31] adapted respective mathematical models to approach decisions in m-polar fuzzy environments.

Most people want to express themselves with common terms like "magnificent," "superb," "best," "better," "poor," and "worst" to gauge some attributes. These assessments of an object's properties should then be used in MADM. Thus, the aggregation operators that collect information in a linguistic form are crucially essential. By using the 2-tuple linguistic (2 TL) tool, we can prevent the loss of data and get more transparent results in decision making. Firstly, Herrera and Martinez [32] introduced the idea of 2 TL representation, which is the most successful tool to take on linguistics decision-making issues. For further notions and applications, the readers are suggested to [33–40]. The main goal of this article is the aggregation of 2-tuple linguistic information by using Hamacher operators and their application in decision-making.

1.1. Motivation and Contribution. The motivation of this work is described as follows:

(i) The justification of any reliable choice in a problem formulated with 2 TL m F information is a highly complicated MADM issue. Nevertheless, the proposed MADM model provides significant results through convincing arguments.

(ii) The field of application of 2 TL m FS is enormous, as this model combines the benefits of both 2 TL and m-polar fuzzy sets. However, the treatment of linguistic techniques with multipolar fuzzy situations, particularly the 2 TL m F MADM approach, remains a challenge that we take up in this article.

(iii) The toolbox that helps us for this purpose includes aggregation operators. Taking this into consideration, aggregation operations are capable of providing valid data combinations in the form of 2 TL m Fs.

(iv) Hamacher aggregation operators are a straightforward tool, easy to apply to real-life MADM problems based on the 2 TL m F environment.

(v) The previously existing techniques, which are designed to take over MCDM problems, are restricted to dealing only with the m-polar fuzzy information. These techniques are unable to take into account linguistic information. So, this may cause a loss of information, which typically leads to undesired results. Thus, existing technical hindrances can be sorted out by using the newly proposed work.

Thus, to choose the best alternative, our 2 TL m F methodology relies on Hamacher AOs. As compared to other plans of action, the developed operators have three major advantages. Firstly, we can make use of 2 TL m F information, which is an asset in decision-making problems as explained above. Secondly, a single parameter suffices to

make the methodology flexible while preserving its transparency and simplicity. Further, the decision-making issues are not affected by varying the parameters. Thirdly, the use of Hamacher aggregation operators for 2 TL m F information in MADM produced significant results. To operate in complicated situations with a real background, as in the case of the selection of the best place for a thermal power station, the proposed operators are very affordable.

The major contributions of this research paper are

(i) The generalization of m F Hamacher operators to 2 TL m F Hamacher operators. Some fundamental properties are given, including their proofs and explanations. These operators are more flexible and produce transparent results by aggregating m-polar fuzzy data with linguistic information.

(ii) In order to undertake decision-making problems, an algorithm is developed for 2 TL multipolar information.

(iii) Lastly, the validity, versatility, and traits of the proposed operators are investigated by a comparative study with existing techniques.

1.2. Structure of Paper. The structure of this research work is as follows: in Section 2, we perform a basic revision of some concepts about 2 TL and m F sets, which are properly described. Section 3, contains the study of some operators, namely 2 TL m FHWA, 2 TL m FHOWA, and 2 TL m FHHA, with some basic properties. In Section 4, we investigate additional operators like 2 TL m FHWG, 2 TL m FHOWG, and 2 TL m FHHG. Again, their fundamental properties are studied, and examples are given. In Section 5, a procedure is developed to tackle multicriteria decision-making issues that involve 2 TL m F information. The procedure takes advantage of the 2 TL m FHA and 2 TL m FHG operators. In the next Section 6, numerical work is done for the selection of the best location for a thermal power station by using 2 TL m FHA and 2 TL m FHG operators. It also includes a study about the influence of parameters on the decision. Section 7 contains a comparative study with previously existing methods, which shows the applicability and strength of our method. It also outlines the advantages and limitations of the proposed work. Section 8 contains some concluding remarks with future research directions. The structure of the proposed research article is displayed in Figure 1.

2. Preliminaries

This section reviews some basic definitions that are necessary for this paper.

Definition 1 (see [32, 34]). Let a set $S = \{s_i | i = 0, 1, \ldots, t\}$ of odd numbers of linguist terms, where s_i indicates the probable linguistic term for the linguistic variables. For instance, a linguistic term set S having seven terms can be described as follows:

$S = \{s_0 = \text{none}, s_1 = \text{very low}, s_2 = \text{low}, s_3 = \text{medium}, s_4 = \text{high}, s_5 = \text{very high}, s_6 = \text{perfect}\}$.

If $s_i, s_k \in S$, then the set S meets with the following characteristics:

(i) Ordered set: $s_i > s_k$, if and only if $i > k$.

(ii) Max operator: $\max(s_i, s_k) = s_i$, if and only if $i \geq k$.

(iii) Min operator: $\min(s_i, s_k) = s_i$, if and only if $i \leq k$.

(iv) Negation: Neg $(s_i) = s_k$ such that $k = t - i$.

Herrera and Martinez [32], introduced 2 TL representation model based on the idea of symbolic translation, which is useful for representing the linguistic assessment information by means of a 2-tuple (s_i, ρ_i).

where

(i) s_i is a linguistic label for a predefined linguistic term set S.

(ii) ρ_i is called symbolic translation and $\rho_i \in [-1/2, 1/2)$.

Definition 2 (see [32]). Let φ be the result of an aggregation of the indices of a set of labels assessed in a linguistic term set S, i.e., the result of a symbolic aggregation operation, $\varphi \in [1, t]$, where t is the cardinality of S. Let $i = \text{round}(\varphi)$ and $\rho = \varphi - i$ be two values, such that, $i \in [1, t]$ and $\rho \in [-1/2, 1/2)$ then ρ is called a symbolic translation.

Definition 3 (see [32]). Let $S = \{s_i | i = 1, \ldots, t\}$ be a linguistic term set and $\varphi \in [1, t]$ be a number value representing the aggregation result of linguistic symbolic. Then the function Δ used to obtain the 2-tuple linguistic information equivalent to φ is defined as

$$\Delta: [1, t] \longrightarrow S \times \left[-\frac{1}{2}, \frac{1}{2}\right),$$

$$\Delta(\varphi) = \begin{cases} s_i, i = \text{round}(\varphi), \\ \rho = \varphi - i, \rho \in \left[-\frac{1}{2}, \frac{1}{2}\right), \end{cases} \tag{1}$$

Definition 4 (see [32]). Let $S = \{s_i | i = 1, \ldots, t\}$ be a linguistic term set and (s_i, ρ_i) be a 2-tuple, there exists a function Δ^{-1} that restores the 2-tuple to its equivalent numerical value $\varphi \in [1, t] \subset R$, where

$$\Delta^{-1}: S \times \left[-\frac{1}{2}, \frac{1}{2}\right) \longrightarrow [1, t],$$

$$\Delta^{-1}(s_i, \rho) = i + \rho = \varphi, \tag{2}$$

Definition 5 (see [32, 34]). Let us consider (s_k, ρ_1) and (s_l, ρ_2) be two 2 TL values. Then,

(1) For $k < l$, we have, (s_k, ρ_1) is less than (s_l, ρ_2)

(2) If $k = l$, then

(i) For $\rho_1 = \rho_2$, implies that (s_l, ρ_1) and (s_k, ρ_2) are same.

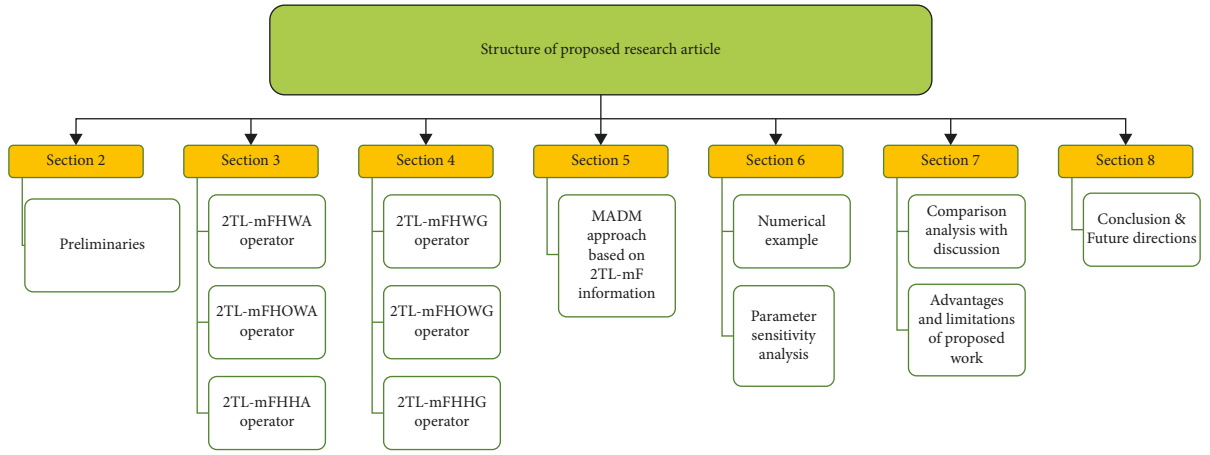

Figure 1: Structure of the proposed research work.

(ii) For $\rho_1 < \rho_2$, implies that (s_l, ρ_1) is less than (s_k, ρ_2)

(iii) For $\rho_1 > \rho_2$, implies that (s_l, ρ_1) is greater than (s_k, ρ_2)

Chen et al. [25] first considered the notion of m-polar fuzzy sets. The membership grade of m-polar fuzzy set belongs to the interval $[0,1]^m$, and it stands for m different divisions of an attribute.

Definition 6 (see [25]). An mF set C on a nonempty set X is defined as a mapping C: $X \longrightarrow [0,1]^m$. The representation of membership value for every element $x \in X$ is denoted as

$$C = \left(p_1 \circ C(x), p_2 \circ C(x), \ldots, p_m \circ C(x)\right). \tag{3}$$

Here $p_i \circ C$: $[0,1]^m \longrightarrow [0,1]$ is the i–th projection mapping.

Notice that, $[0,1]^m$ (m-th power of [0, 1]) is a Poset with the pointwise order $\leq$, where m is an arbitrary ordinal number (we make the convention that $m = \{n | n < m\}$ when $m > 0$), $\leq$ is defined by $x \leq y \Leftrightarrow p_i(x) \leq p_i(y)$ for each $i \in m$ $(x, y \in [0,1]^m)$, and p_i: $[0,1]^m \longrightarrow [0,1]$ is the i–th projection mapping ($i \in m$). Where in $[0,1]^m$, the greatest value is $1 = (1, 1, \ldots, 1)$ and the smallest value is $0 = (0, 0, \ldots, 0)$. For convenience, $\widehat{C} = (p_1 \circ C, \ldots, p_m \circ C)$ is the representation of mF number.

Definition 7 (see [25]).The accuracy function H of an mFNs, $\widehat{C} = (p_1 \circ C, \ldots, p_m \circ C)$ is defined as

$$H(\widehat{C}) = \frac{1}{m}\left(\sum_{r=1}^{m} (-1)^r \left(p_r \circ C - 1\right)\right), H(\widehat{C}) \in [0,1], \tag{4}$$

Thus, arbitrarily, for any m-polar fuzzy numbers $\widehat{C}$, $S(\widehat{C}), H(\widehat{C}) \in [0,1]$.

Definition 8 (see [25]). Let $\widehat{C}_1 = (p_1 \circ C_1, \ldots, p_m \circ C_1)$, and $\widehat{C}_2 = (p_1 \circ C_2, \ldots, p_m \circ C_2)$ be two m-polar fuzzy numbers. Then

(1) $\widehat{C}_1 < \widehat{C}_2$, if $S(\widehat{C}_1) < S(\widehat{C}_2)$.

(2) $\widehat{C}_1 > \widehat{C}_2$, if $S(\widehat{C}_1) > S(\widehat{C}_2)$.

(3) $\widehat{C}_1 = \widehat{C}_2$, If $S(\widehat{C}_1) = S(\widehat{C}_2)$ and $H(\widehat{C}_1) = H(\widehat{C}_2)$.

(4) $\widehat{C}_1 < \widehat{C}_2$, if $S(\widehat{C}_1) = S(\widehat{C}_2)$, but $H(\widehat{C}_1) < H(\widehat{C}_2)$.

(5) $\widehat{C}_1 > \widehat{C}_2$, if $S(\widehat{C}_1) = S(\widehat{C}_2)$, but $H(\widehat{C}_1) > H(\widehat{C}_2)$.

The nomenclature of the proposed research terms is given in Table 1.

3. 2 TL m F Hamacher Aggregation Operators

We first define the concept of 2-tuple linguistic m-polar fuzzy sets and some basic operations.

Definition 9. A 2TLmFSs Ψ on a nonempty set Y is defined as

$$\widehat{\Psi} = \left\{ < y, \left(\left(s_{\psi_1}(y), \rho_1(y)\right), \left(s_{\psi_2}(y), \rho_2(y)\right), \ldots, \left(s_{\psi_m(y)}, \rho_m(y)\right)\right) > : y \in Y \right\}, \tag{5}$$

where $(s_{\psi_i}(y), \rho_i(y))$, represent the membership degrees, with the conditions $s_{\psi_i}(y) \in \Psi$, $\rho_i(y) \in [-0.5, 0.5)$, $0 \leq \Delta^{-1}(s_{\psi_i}(y), \rho_i(y)) \leq t, i = 1, 2, \ldots, m$. For convenience, we say $\xi = ((s_{\psi_1}, \rho_1), (s_{\psi_2}, \rho_2), \ldots, (s_{\psi_m}, \rho_m))$, a 2-tuple linguistic m-polar fuzzy number, where $0 \leq \Delta^{-1}(s_{\psi_i}, \rho_i) \leq t$, $i = 1, 2, \ldots, m$.

Definition 10. The *score function* S of a 2 TL m-polar fuzzy number $\xi = ((s_{\psi_1}, \rho_1), (s_{\psi_2}, \rho_2), \ldots, (s_{\psi_m}, \rho_m))$, is defined as

$$S(\widehat{\xi}) = \Delta\left(\frac{t}{m}\sum_{r=1}^{m}\left(\frac{\Delta^{-1}\left(s_{\psi_r}, \rho_r\right)}{t}\right)\right), \Delta^{-1}(S(\widehat{\xi})) \in [0, t], \tag{6}$$

Table 1: Nomenclature of proposed terms.

Abbreviation	*Description*
2TL m FN	2-Tuple linguistic m-polar fuzzy number
2TL m FHWA	2-Tuple linguistic m F Hamacher weighted average operators
2TL m FHOWA	2-Tuple linguistic m-polar fuzzy Hamacher ordered weighted average operators
2TL m FHHA	2-Tuple linguistic m-polar fuzzy Hamacher hybrid average operators
2TL m FHWG	2-Tuple linguistic m-polar fuzzy Hamacher weighted geometric operators
2TL m FHOWG	2-Tuple linguistic m-polar fuzzy Hamacher ordered weighted geometric operators
2TL m FHHG	2-Tuple linguistic m-polar fuzzy Hamacher hybrid average geometric
(s_{ψ_m}, ρ_m)	2-Tuple linguistic m-polar fuzzy number
$S(\widetilde{\xi})$	Score function of a 2 TL m-polar fuzzy number
$H(\widetilde{\xi})$	Accuracy function of a 2 TL m-polar fuzzy number
A_k	Alternatives
ζ_i	Attributes
ϕ_j	Weight of attributes

Definition 11. The *accuracy function* H of a 2TLm-polar fuzzy number $\xi = ((s_{\psi_1}, \rho_1), (s_{\psi_2}, \rho_2), \ldots, (s_{\psi_m}, \rho_m))$, is defined as

$$H(\widehat{\xi}) = \Delta\left(\frac{t}{m}\sum_{r=1}^{m}(-1)^r\left(\left(\frac{\Delta^{-1}\left(s_{\psi_r}, \rho_r\right)}{t}\right) - 1\right)\right), \left(\Delta^{-1}H(\widetilde{\xi})\right) \in [0, t]. \tag{7}$$

Definition 12. Let $\xi_1 = ((s_{\psi_1^1}, \rho_1^1), (s_{\psi_2^1}, \rho_2^1), \ldots, (s_{\psi_m^1}, \rho_m^1))$, and $\xi_2 = ((s_{\psi_1^2}, \rho_1^2), (s_{\psi_2^2}, \rho_2^2), \ldots, (s_{\psi_m^2}, \rho_m^2))$, be two 2-tuple linguistic m-polar fuzzy numbers. Then we define operations on 2-tuple linguistic m-polar fuzzy numbers as follows:

(1) $\xi_1 \oplus \xi_2 = (\Delta(t(\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t + \Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t - \Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/\ t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)), \ldots (\Delta(t(\Delta^{-1}(s_{\psi_m^1},\ \rho_m^1)/t + \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t - \Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t.\Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)))$

(2) $\xi_1 \otimes \xi_2 = (\Delta(t(\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)), \ldots, \Delta(t(\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t.\ \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)))$

(3) $\alpha\xi = (\Delta(t(1 - (1 - \Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha})), \ldots,\ \Delta(t(1 - (1 - \Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha}))),\ \alpha > 0,$

(4) $\xi^{\alpha} = (\Delta(t(\Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha}), \ldots, \Delta(t(\Delta^{-1}(s_{\psi_m},\ \rho_m)/t)^{\alpha})),\ \alpha > 0,$

(5) $\xi^{c} = (\Delta(t - \Delta^{-1}(s_{\psi_1}, \rho_1)), \ldots, \Delta(t - \Delta^{-1}(s_{\psi_m}, \rho_m))),\ \alpha > 0,$

(6) $\xi_1 \subseteq \xi_2$, if and only if $\Delta(t(\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t \leq\ \Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)), \ldots, \Delta(t(\Delta^{-1}\ (s_{\psi_m^1}, \rho_m^1)/t \leq \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)),$

(7) $\xi_1 \bigcup \xi_2 = \Delta(t(\max(\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t, \Delta^{-1}\ (s_{\psi_1^2}, \rho_1^2)/t))),\ \ldots, \Delta(t(\max\ (\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t, \Delta^{-1}(s_{\psi_m^2},\ \rho_m^2)/t))),$

(8) $\xi_1 \cap \xi_2 = \Delta(t(\min(\Delta^{-1}(s_{\psi_1^1},\ \rho_1^1)/t, \Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)), \ldots, \Delta(t(\min(\Delta^{-1}\ (s_{\psi_m^1}, \rho_m^1)/t, \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)).$

We now define Hamacher operations for 2-tuple linguistic m-polar fuzzy numbers.

Definition 13. Let $\widetilde{\xi_1} = \left\{(s_{\psi_1^1}, \rho_1^1), \ldots, (s_{\psi_m^1}, \rho_m^1)\right\}$, $\widetilde{\xi_2} = \left\{(s_{\psi_1^2}, \rho_1^2), \ldots, (s_{\psi_m^2}, \rho_m^2)\right\}$ and $\widetilde{\xi} = \left\{(s_{\psi_1}, \rho_1), \ldots, (s_{\psi_m}, \rho_m)\right\}$ be 2-tuple linguistic m-polar fuzzy numbers. Then, the basic Hamacher operations for 2-tuple linguistic m-polar fuzzy numbers with $\lambda > 0$ is defined as

(1) $\xi_1 \oplus \xi_2 = (\Delta(t((\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t + \Delta^{-1}\ (s_{\psi_1^2}, \rho_1^2)/t - \Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t + (1 - \lambda)\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)/(1 - (1 - \lambda)\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t))), \ldots$

$\Delta(t((\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t + \Delta^{-1}\ (s_{\psi_m^2}, \rho_m^2)/t - \Delta^{-1}(s_{\psi_m^1}, \rho_m^1)\ /t.\ \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t - (1 - \lambda)\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t.\ \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)/(1 - (1 - \lambda)\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t.\Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t))))$,

(2) $\xi_1 \otimes \xi_2 = (\Delta(t((\Delta^{-1}\ (s_{\psi_1^1}, \rho_1^1)/t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)/(\lambda + (1 - \lambda)(\Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t + \Delta^{-1}(s_{\psi_1^2},\ \rho_1^2)/t - \Delta^{-1}(s_{\psi_1^1}, \rho_1^1)/t.\Delta^{-1}(s_{\psi_1^2}, \rho_1^2)/t)))\ \ldots \Delta(t((\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t.\Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)/(\lambda + (1 - \lambda)(\Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t + \Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t - \Delta^{-1}(s_{\psi_m^1}, \rho_m^1)/t.\Delta^{-1}(s_{\psi_m^2}, \rho_m^2)/t)))),$

(3) $\alpha\xi = (\Delta(t((1 + (\lambda - 1)\Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha} - (1 - \Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha}/(1 + (\lambda - 1)\Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha} + (\lambda - 1)(1 - \Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha})), \ldots \Delta(t((1 + (\lambda - 1)\Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha} - (1 - \Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha}/(1 + (\lambda - 1)\Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha} + (\lambda - 1)(1 - \Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha}))),\ \alpha > 0$

(4) $\xi^{\alpha} = (\Delta(t(\lambda(\Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha}/(1 + (\lambda - 1)(1 - \Delta^{-1}(s_{\psi_1}, \rho_1)/t))^{\alpha} + (\lambda - 1)(\Delta^{-1}(s_{\psi_1}, \rho_1)/t)^{\alpha})), \ldots \Delta(t(\lambda(\Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha}/(1 + (\lambda - 1)(1 - \Delta^{-1}(s_{\psi_m}, \rho_m)/t))^{\alpha} + (\lambda - 1)(\Delta^{-1}(s_{\psi_m}, \rho_m)/t)^{\alpha}))),\ \alpha > 0$

Example 14. Let $\xi_1 = \{(s_3, 0.2), (s_2, 0.5), (s_4, 0.0)\}$ and $\xi_2 = \{(s_3, 0.8), (s_4, 0.0), (s_2, 0.6)\}$ be 2-tuple linguistic 3-polar fuzzy numbers. Then for $\lambda = 3$,

$$\xi_1 \oplus \xi_2 = \left(\Delta\left(4\left(\frac{\Delta^{-1}(s_3, 0.2)/4 + \Delta^{-1}(s_3, 0.8)/4 - \Delta^{-1}(s_3, 0.2)/4.\Delta^{-1}(s_3, 0.8)/4}{1 - (1-3)\Delta^{-1}(s_3, 0.2)/4.\Delta^{-1}(s_3, 0.8)/4} \right) \right) \right)$$

$$\Delta\left(4\left(\frac{\Delta^{-1}(s_2, 0.5)/4 + \Delta^{-1}(s_4, 0.0)/4 - \Delta^{-1}(s_2, 0.5)/4.\Delta^{-1}(s_4, 0.0)/4}{1 - (1-3)\Delta^{-1}(s_2, 0.5)/4.\Delta^{-1}(s_4, 0.0)/4} \right) \right) \tag{8}$$

$$\Delta\left(4\left(\frac{\Delta^{-1}(s_4, 0.0)/4 + \Delta^{-1}(s_2, 0.6)/4 - \Delta^{-1}(s_4, 0.0)/4.\Delta^{-1}(s_2, 0.6)/4}{1 - (1-3)\Delta^{-1}(s_4, 0.0)/4.\Delta^{-1}(s_2, 0.6)/4} \right) \right)$$

$$= \{(s_4, -0.0158), (s_4, 0.000), (s_4, 0.01)\}.$$

Thus, $\xi_1 \oplus \xi_2$ is again a 2-tuple linguistic 3-polar fuzzy number. So, the closure law is satisfied.

Thus, in a similar pattern, the closure law is verified for all the above-defined Hamacher operations for 2-tuple linguistic m-polar fuzzy numbers.

Definition 14. Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers, where $j = 1, 2, \ldots, n$. Then, an 2 TL m F Hamacher weighted average operator is a mapping $2TL$ m FHWA: $\widehat{\xi}^n \longrightarrow \widehat{\xi}$, whose domain is the family of 2 TL m F numbers $\widehat{\xi}^n$, which is defined as,

$$2TLm\text{FHWA}_\phi\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \oplus_{j=1}^n \left(\phi_j \widehat{\xi}_j\right), \tag{9}$$

where $\phi = (\phi_1, \phi_2, \ldots, \phi_n)^T$ is the weight vector representation for $\widehat{\xi}_j$, for each 'j', $j = 1, 2, \ldots, n$, with $\phi_j > 0$ and $\sum_{j=1}^n \phi_j = 1$.

Example 1. Let $\widehat{\xi}_1 = \{(s_3, 0.2), (s_2, 0.5), (s_4, 0.7), (s_1, 0.3)\}$, $\widehat{\xi}_2 = \{(s_3, 0.8), (s_4, 0.6), (s_2, 0.6), (s_1, 0.4)\}$, and $\widehat{\xi}_3 = \{(s_6, 0), (s_2, 0.2), (s_3, 0.4), (s_1, 0.5)\}$ be 2-tuple linguistic 4-polar fuzzy numbers with a weight vector $\phi = (0.3, 0.5, 0.2)^T$. Then, for $\lambda = 3$,

$$2TLmFWA_\phi\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \oplus_{j=1}^n \left(\phi_j \widehat{\xi}_j\right),$$

$$= \left(\Delta\left(t\left(1 - \prod_{j=1}^n \left(1 - \frac{\Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j\right)}{t} \right)^{\phi_j} \right) \right), \Delta\left(t\left(1 - \prod_{j=1}^n \left(1 - \frac{\Delta^{-1}\left(s_{\psi_2^j}, \rho_2^j\right)}{t} \right)^{\phi_j} \right) \right), \ldots, \right.$$

$$\left. \Delta\left(t\left(1 - \prod_{j=1}^n \left(1 - \frac{\Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j\right)}{t} \right)^{\phi_j} \right) \right) \right). \tag{10}$$

Theorem 1. *Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers, where $j = 1, 2, \ldots, n$. The assembled values of these 2 TL m F numbers using the 2 TL m FHWA operator is also 2 TL m F numbers, given as*

$$2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\oplus_{j=1}^{n}\left(\phi_j\widehat{\xi}_j\right),$$
$$=\left(\Delta\left(t\left(\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t^{\phi_j}-\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}/\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t^{\phi_j}+(\lambda-1)\right.\right.\right.$$
$$\left.\left.\left.\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}\right)\right),\ldots$$
$$\Delta\left(\left(t\left(\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t^{\phi_j}-\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}/\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t^{\phi_j}+(\lambda-1)\right.\right.\right.$$
$$\left.\left.\left.\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}\right)\right)\right) \tag{11}$$

Proof. We use mathematical induction to prove it. □

Case 1. Let us take $n=1$, by using *Equation* (4), we obtained

$$2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\widehat{\xi} \tag{12}$$

Thus, (10) holds for $n=1$.

Case 2. Next, we suppose that the result is true for $n=$ k, where $k\in\mathbb{N}$ (N: natural numbers), we obtain

$$\widehat{\xi}^{-}\le 2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)\le\widehat{\xi}^{+}, \tag{13}$$

for $n=k+1$,

$$2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi_{k+1}}\right)=\oplus_{j=1}^{k}\left(\phi_j\widehat{\xi}_j\right)\oplus\left(\phi_{k+1}\widehat{\xi_{k+1}}\right),$$

$$2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)\le 2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1^{'},\widehat{\xi}_2^{'},\ldots,\widehat{\xi}_n^{'}\right). \tag{14}$$

Thus, (10) holds for $n=k+1$. Conclusively, the result holds for any $n\in\mathbb{N}$.

Remark 1. For $\lambda=1$, 2TLmFHWA operator reduces to 2 TL m F weighted averaging (2 TL m FWA) operator given as follows:

$$2TLmFWA_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\oplus_{j=1}^{n}\left(\phi_j\widehat{\xi}_j\right),$$
$$=\left(\Delta\left(t\left(1-\prod_{j=1}^{n}\left(1-\frac{\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)}{t}\right)^{\phi_j}\right)\right),\Delta\left(t\left(1-\prod_{j=1}^{n}\left(1-\frac{\Delta^{-1}\left(s_{\psi_2^j},\rho_2^j\right)}{t}\right)^{\phi_j}\right)\right),\ldots,\Delta\left(t\left(1-\prod_{j=1}^{n}\left(1-\frac{\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)}{t}\right)^{\phi_j}\right)\right)\right). \tag{15}$$

2. For $\lambda=2$, 2 TL m FHWA operator reduces to 2TLmF Einstein weighted averaging (2 TL m FEWA) operator as follows:

$$2TLm\text{FEWA}_{\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\oplus_{j=1}^{n}\left(\phi_j\widehat{\xi}_j\right)$$
$$=\left(\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}-\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}}{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}+\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}}\right)\right),\ldots$$
$$\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}-\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}}{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}+\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}}\right)\right)\right). \tag{16}$$

Theorem 2. *Idempotency. Let* $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ *be a set of 2 TL m F numbers, where* $j = 1, 2, \ldots, n$. *If all these numbers are equal, that is,* $\widehat{\xi}_j = \widehat{\xi}$, $\forall$ *'j' varies 1 to n, then we have*

$$2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \widehat{\xi}. \tag{17}$$

Proof. Since $2TLm\text{FHWA}_{\phi}((s_{\psi_1^j}, \rho_1^j), (s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_1^j}, \rho_1^j)) = \widehat{\xi}$, where $j = 1, 2, \ldots, n$, then by using *equation* (4), we get

$$2TLm\text{FEOWA}_{w}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \oplus_{j=1}^{n}\left(w_j\widehat{\xi_{\sigma(j)}}\right),$$

$$= \left(\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j} - \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j} + \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right), \ldots \tag{18}$$

$$\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j} - \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1+\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_{\sigma(j)}} + \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right).$$

Hence, $2TLm\text{FHWA}_{\phi}(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n) = \widehat{\xi}$ holds only if we use $\widehat{\xi}_j = \widehat{\xi}$ where $\forall j = 1, 2, \ldots, n$

Further, we will discuss the remaining properties, namely, boundedness and monotonicity, and their proofs are directly followed by definitions. □

Theorem 3. *Let* $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$, *be a set of 2 TL m F numbers, where 'j' varies from 1 to n,* $\widehat{\xi}^{-} = \cap_{j=1}^{n}\widehat{\xi}_j$ *and* $\widehat{\xi}^{+} = \cup_{j=1}^{n}\widehat{\xi}_j$, *then*

$$\widehat{\xi}^{-} \leq 2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) \leq \widehat{\xi}^{+}, \tag{19}$$

Theorem 4. *Let* $\widehat{\xi}_j$ *and* $\widehat{\xi}_j'$, $j = 1, 2, \ldots, n$ *be the two sets of 2 TL m F numbers. If* $\widehat{\xi}_j \leq \widehat{\xi}_j'$, *then*

$$2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) \leq 2TLm\text{FHWA}_{\phi}\left(\widehat{\xi}_1', \widehat{\xi}_2', \ldots, \widehat{\xi}_n'\right). \tag{20}$$

We now propose the 2 TL m F Hamacher ordered weighted average (2 TL m FHOWA) operator.

Definition 15. Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be the set of 2 TL m F numbers where $j = 1, 2, \ldots, n$. Then, a 2 TL m FHOWA operator is a mapping $\widehat{\xi}^n \longrightarrow \widehat{\xi}$ with a weight vector

$w = (w_1, w_2, \ldots, w_n)^T$, $w_j \in (0, 1]$ and $\sum_{j=1}^{n} w_j = 1$. Then,

$$2TLm\text{FHOWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \oplus_{j=1}^{n}\left(w_j\widehat{\xi}_{\sigma(j)}\right), \tag{21}$$

where $(\sigma(1), \sigma(2), \ldots, \sigma(n))$ is the permutation of the indices $j = 1, 2, \ldots, n$, for which $\widehat{\xi}_{\sigma(j-1)} \geq \widehat{\xi}_{\sigma(j)}$,

$\forall j = 1, 2, \ldots, n$.

Theorem 6. *Let* $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ *be a set for 2 TL m F numbers, where 'j' varies from 1 to n. Then the assembled values of these 2 TL m F numbers using the 2 TL m FHOWA operator is again 2 TL m F numbers, given as*

$$2TLm\text{FHOWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \overset{n}{\underset{j=1}{\oplus}}\left(w_j\widehat{\xi}_{\sigma(j)}\right)$$

$$= \left(\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1+(\lambda-1)\right)\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)^{w_j}/t - \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1+(\lambda-1)\right)\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t^{w_j} + (\lambda-1)\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right), \ldots \tag{22}$$

$$\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1+(\lambda-1)\right)\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_{\sigma(j)}\right)/t^{w_j} - \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1+(\lambda-1)\right)\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_{\sigma(j)}\right)/t^{w_j} + (\lambda-1)\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right).$$

Proof. The proof of the theorem is directly followed by the similar arguments as used in Theorem 3.9, as mentioned above. □

Remark. 1. For $\lambda = 1$, 2 TL m FHOWA operator reduce to 2 TL m FOWA operator as follows:

$$2TLm\text{FOWA}_w\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \overset{n}{\underset{j=1}{\oplus}}\left(w_j \widehat{\xi}_{\sigma(j)}\right)$$

$$= \left(\Delta\left(t\left(1 - \prod_{j=1}^{n}\frac{\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)^{w_j}}{t}\right)\right), \Delta\left(t\left(1 - \prod_{j=1}^{n}\frac{\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)^{w_j}}{t}\right)\right), \ldots, \Delta\left(t\left(1 - \prod_{j=1}^{n}\frac{\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)^{w_j}}{t}\right)\right)\right). \tag{23}$$

2. For $\lambda = 2$, 2 TL m FHOWA operator reduce to 2 TL m FEOWA operator given as follows:

$$2TLm\text{FEOWA}_w\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \overset{n}{\underset{j=1}{\oplus}}\left(w_j \widehat{\xi_{\sigma(j)}}\right)$$

$$= \left(\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1 + \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j} - \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1 + \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j} + \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right), \ldots \right.$$

$$\left.\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1 + \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j} - \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1 + \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_{\sigma(j)}} + \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right). \tag{24}$$

Theorem 7. *Idempotency. Let us consider* $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ *a collection of 2 TL m F numbers, where* $j = 1, 2, \ldots, n$. *For the equality of all these numbers, in other words,* $\widehat{\xi}_j = \widehat{\xi}$, *where,* $\forall j = 1, 2, \ldots, n$, *then we have*

$$2TLm\text{FHOWA}_w\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \widehat{\xi}. \tag{25}$$

Proof. Since $2TLm\text{FHOWA}_w((s_{\psi_1^j}, \rho_1^j), (s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_1^j}, \rho_1^j)) = \widehat{\xi}$, where $j = 1, 2, \ldots, n$. Then by using *Equation* (11), we obtain

$$2TLm\text{FEHA}_{w,\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \oplus_{j=1}^{n}\left(w_j \widetilde{\widehat{\xi}}_{\sigma(j)}\right),$$

$$= \left(\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1 + (\lambda - 1)\right)\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t^{w_j} - \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1 + (\lambda - 1)\right)\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t^{w_j} + .\prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right), \ldots \right.$$

$$\left.\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1 + (\lambda - 1)\right)\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t^{w_j} - \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(1 + (\lambda - 1)\right)\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t^{w_j} + \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right) \tag{26}$$

Hence, $2TLm\text{FHOWA}_\phi(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n) = \widehat{\xi}$ holds only if $\widehat{\xi}_j = \widehat{\xi}$, $\forall j = 1, 2, \ldots, n$.

We state boundedness, monotonicity, and commutative properties without their proofs. □

Theorem 8. *Let* $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$, *be a collection of 2 TL m F numbers, where* $j = 1, 2, \ldots, n$, $\widehat{\xi}^- = \cap_{j=1}^{n}\widehat{\xi}_j$, *and* $\widehat{\xi}^+ = \cap_{j=1}^{n}\widehat{\xi}_j$, *then*

$$\widehat{\xi}^- \leq 2TLm\text{FHOWA}_\phi\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) \leq \widehat{\xi}^+. \tag{27}$$

Theorem 9. *Let $\widehat{\xi}_j$ and $\widehat{\xi}'_j$, $j = 1, 2, \ldots, n$ be two sets of 2 TL m F numbers. If $\widehat{\xi}_j \leq \widehat{\xi}'_j$, then*

$$2TLm\text{FHOWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) \leq 2TLm\text{FHOWA}_{\phi} \cdot \left(\widehat{\xi}'_1, \widehat{\xi}'_2, \ldots, \widehat{\xi}'_n\right), \tag{28}$$

Theorem 10. *Let $\widehat{\xi}_j$ and $\widehat{\xi}'_j$, $j = 1, 2, \ldots, n$ be two sets of 2 TL m F numbers, then*

$$2TLm\text{FHOWA}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = 2TLm\text{FHOWA}_{\phi} \cdot \left(\widehat{\xi}'_1, \widehat{\xi}'_2, \ldots, \widehat{\xi}'_n\right), \tag{29}$$

where $\widehat{\xi}'_j$ is the arbitrary permutation of $\widehat{\xi}_j$.

Remark (i). In Definition 15 and 5, we observe that 2 TL m FHWA operators and 2 TL m FHOWA operators with 2 TL m F numbers and ordered arrangements of 2 TL m F numbers, respectively. (ii) We now propose another operator, namely 2 TL m F Hamacher hybrid averaging operator which combines the qualities of 2 TL m FHWA operator and 2 TL m FHOWA operator.

Definition 16. Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers, where $j = 1, 2, \ldots, n$. Then, a 2 TL m F Hamacher hybrid averaging (2 TL m FHHA) operator is defined as

$$2TLm\text{FHHA}_{w,\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \oplus_{j=1}^{n}\left(w_j \widehat{\xi_{\sigma(j)}}\right), \tag{30}$$

where $w = (w_1, w_2, \ldots, w_n)^T$ represent the associated weight vector of the 2 TL m F numbers $\widehat{\xi}_i$, instead of weighting the experts, for each 'i' varies from 1 to n, with $w_i \in (0, 1]$ and $\sum_{i=1}^{n} w_i = 1$, $\widehat{\xi_{\sigma(j)}}$ is the jth biggest 2 TL m F numbers of the $\widehat{\xi}_i (i = 1, 2, \ldots, n)$ with $\widetilde{\widehat{\xi}}_{\sigma(i)} = (n\phi_i)\widehat{\xi_{\sigma(i)}}$, $(i = 1, 2, \ldots, n)$, $\phi = (\phi_1, \phi_2, \ldots, \phi_n)^T$ is the weight vector for the ordered arguments, with $\phi_j \in (0, 1]$, $\sum_{j=1}^{n} \phi_j = 1$ and n serves as the balancing coefficient.

The 2 TL weighted average operators integrate the importance of linguistic arguments. where 2 TL ordered weighted aggregation operators increase the worth of ordered positions of the linguistic arguments. There are different techniques to evaluate the weight vectors. For this, [6] proposed an interesting approach to evaluate the weight vector. In particular, we assign weight values to linguistic terms according to their importance in real-life issues.

Remark. We notice that, if we have $w = (1/n, 1/n, \ldots, 1/n)^T$, then 2 TL m FHHA operator convert into 2 TL m FHWA operator, when $\phi = (1/n, 1/n, \ldots, 1/n)^T$, then 2 TL m FHHA operator degenerates into 2 TL m FHOWA operator. Therefore, 2 TL m FHHA operator is the generalization of the operators, namely, 2 TL m FHWA and 2 TL m FHOWA, which explains the degrees and ordered arguments of the given 2 TL m F values.

Theorem 11. *Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers, where $j = 1, 2, \ldots, n$. Then the assembled values of these 2 TL m F numbers using the 2 TL m FHHA operator is again a 2 TL m F numbers, which is given as*

$$\begin{aligned}
&2TLm\text{FHHA}_{w,\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \overset{n}{\underset{j=1}{\oplus}}\left(w_j \widetilde{\widehat{\xi}}_{\sigma(j)}\right) \\
&= \left(\Delta\left(t\left(\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t^{w_j} - \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}\right) \Big/ \prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t^{w_j}\right.\right. \\
&\quad \left.\left. + (\lambda-1)\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)}\right)/t\right)^{w_j}\right)\right) \ldots \\
&\quad \cdot \Delta\left(t\left(\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t^{w_j} - \prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}\right) \Big/ \prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t^{w_j}\right. \\
&\quad \left.\left. + (\lambda-1)\prod_{j=1}^{n}\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)}\right)/t\right)^{w_j}\right)\right)
\end{aligned} \tag{31}$$

Proof. The proof of the theorem is directly followed by similar arguments as used in Theorem 1. □

Remark 1. For $\lambda = 1$, 2 TL m FHHA operator reduces to 2TL m F hybrid averaging (2 TL m FHA) operator as follows:

$$2TLm\text{FHA}_{w,\phi}(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n) = \oplus_{j=1}^{n}(w_j \widetilde{\widehat{\xi}}_{\sigma(j)}),$$

$$= \left(\Delta\left(t\left(1 - \prod_{j=1}^{n}\left(1 - \frac{\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)} \right)}{t} \right)^{w_j} \right) \right), \Delta\left(t\left(1 - \prod_{j=1}^{n}\left(1 - \frac{\Delta^{-1}\left(s_{\psi_2^{\sigma(j)}}, \rho_2^{\sigma(j)} \right)}{t} \right)^{w_j} \right) \right), \ldots, \Delta \right.$$
$$\left. \cdot \left(t\left(1 - \prod_{j=1}^{n}\left(1 - \frac{\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)} \right)}{t} \right)^{w_j} \right) \right) \right). \tag{32}$$

2. For $\lambda = 2$, 2 TL m FHHA operator reduce to 2 TL m FEHA operator as follows:

$$2TLm\text{FEHA}_{w,\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n \right) = \overset{n}{\underset{j=1}{\oplus}}\left(w_j \widetilde{\widehat{\xi}}_{\sigma(j)} \right)$$
$$= \left(\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(1 + (\lambda - 1) \right)\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)} \right)/t^{w_j} - \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)} \right)/t \right)^{w_j}}{\prod_{j=1}^{n}\left(1 + (\lambda - 1) \right)\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)} \right)/t^{w_j} + . \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_1^{\sigma(j)}}, \rho_1^{\sigma(j)} \right)/t \right)^{w_j}} \right) \right), \ldots \Delta \right.$$
$$\left. \cdot \left(t\left(\frac{\prod_{j=1}^{n}\left(1 + (\lambda - 1) \right)\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)} \right)/t^{w_j} - \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_{\sigma(j)} \right)/t \right)^{w_j}}{\prod_{j=1}^{n}\left(1 + (\lambda - 1) \right)\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_m^{\sigma(j)} \right)/t^{w_j} + \prod_{j=1}^{n}\left(1 - \Delta^{-1}\left(s_{\psi_m^{\sigma(j)}}, \rho_{\sigma(j)} \right)/t \right)^{w_j}} \right) \right) \right). \tag{33}$$

4. 2 TL m F Hamacher Geometric Aggregation Operators

We now propose 2 TL m FHWG operators, 2 TL m FHOWG operators, and 2 TL m FHHG operators.

Definition 17. Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers, where $j = 1, 2, \ldots, n$. Then, an 2 TL m FHWG operator is a mapping, $2TL$ m FHWG : $\widehat{\xi}^n \longrightarrow \widehat{\xi}$, whose domain is the set of 2 TL m F numbers, is defined as follows:

$$2TLm\text{FHWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n \right) = \otimes_{j=1}^{n}\left(\phi_j \widehat{\xi}_j \right)^{\phi_j}, \tag{34}$$

where $\phi = (\phi_1, \phi_2, \ldots, \phi_n)^T$ represent the weight vector of $\widehat{\xi}_j$, for each 'j' vary from 1 to n, with $\phi_j > 0$ and $\sum_{j=1}^{n} \phi_j = 1$.

Example 2. Let us consider $\widehat{\xi}_1 = \{(s_1, 0.5), (s_2, 0.3), (s_3, 0.2)\}$, $\widehat{\xi}_2 = \{(s_2, 0.4), (s_1, 0.6), (s_5, 0.1)\}$, and $\widehat{\xi}_3 = \{(s_4, 0.3), (s_2, 0.1), (s_1, 0.3)\}$ be 2TL3FNs with the weight vector $\phi = (0.2, 0.4, 0.1)^T$, and we take $\lambda = 3$. Then, the assembled result can be calculated as follows:

$2TL$ m FHWG$_{\phi}(\xi_1, \xi_2 \ldots \xi_n) = \otimes_{j=1}^{3}(\phi_j \xi_j)^{\phi_j}$.

Theorem 12. *Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers where 'j' varies from 1 to n. The assembled values of these 2 TL m F numbers using the 2 TL m FHWG operator is again a 2 TL m F numbers, given as follows:*

$$2TLm\text{FHWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n \right) = \overset{n}{\underset{j=1}{\otimes}}\left(\phi_j \widehat{\xi}_j \right)^{\phi_j}$$
$$= \left(\begin{array}{l} \Delta\left(t\left(\dfrac{\lambda \prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j \right)/t \right)^{\phi_j}}{\prod_{j=1}^{n}\left(1 + (\lambda - 1) \right)\left(1 - \Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j \right)/t \right)^{\phi_j} + (\lambda - 1)\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j \right)/t \right)^{\phi_j}} \right) \right), \ldots \\ \Delta\left(t\left(\dfrac{\lambda \prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j \right)/t \right)^{\phi_j}}{\prod_{j=1}^{n}\left(1 + (\lambda - 1) \right)\left(1 - \Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j \right)/t \right)^{\phi_j} + (\lambda - 1)\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j \right)/t \right)^{\phi_j}} \right) \right) \end{array} \right) \tag{35}$$

Proof. The proof can be followed easily by using mathematical induction.

We now state idempotency, boundedness, and monotonicity properties for 2 TL m FHG aggregation operators without their proofs. □

Theorem 13. *Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m FNs where $j = 1, 2, \ldots, n$. For the equality of all these numbers, that is, $\widehat{\xi}_j = \widehat{\xi}$, $\forall$ 'j' varies from 1 to n, then we have*

$$2TLm\text{FHWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \widehat{\xi}, \tag{36}$$

Theorem 14. *Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$, be a set of 2 TL m FNs where $j = 1, 2, \ldots, n$ and $\widehat{\xi}^- = \cap_{j=1}^n \widehat{\xi}_j$, $\widehat{\xi}^+ = \cup_{j=1}^n \widehat{\xi}_j$, then*

$$\widehat{\xi}^- \leq 2TLm\text{FHWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) \leq \widehat{\xi}^+, \tag{37}$$

Theorem 15. *Let $\widehat{\xi}_j$ and $\widehat{\xi}_j'$, where 'j' varies from 1 to n, be a set of 2 TL m FNs. If $\widehat{\xi}_j \leq \widehat{\xi}_j'$, then*

$$2TLm\text{FHWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) \leq 2TLm\text{FHWG}_{\phi} \cdot \left(\widehat{\xi}_1', \widehat{\xi}_2', \ldots, \widehat{\xi}_n'\right), \tag{38}$$

Remark 1. For $\lambda = 1$, 2 TL m FHWG operator reduces to $2TL$ m F weighted geometric (2 TL m FWG) operator as follows:

$$2TLm\text{FWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \overset{n}{\underset{j=1}{\otimes}} \left(\phi_j \widehat{\xi}_j\right)^{\phi_j} = \left(\Delta\left(t \prod_{j=1}^{n} \left(\frac{\Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j\right)}{t}\right)^{\phi_j}\right), \Delta\left(t \prod_{j=1}^{n} \left(\frac{\Delta^{-1}\left(s_{\psi_2^j}, \rho_2^j\right)}{t}\right)^{\phi_j}\right), \ldots, \Delta\left(t \prod_{j=1}^{n} \left(\frac{\Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j\right)}{t}\right)^{\phi_j}\right)\right). \tag{39}$$

2. For $\lambda = 2$, 2 TL m FHWG operator reduces to 2TLmF Einstein weighted geometric (2 TL m FEWG) operator as follows:

$$2TLm\text{FEWG}_{\phi}\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \overset{n}{\underset{j=1}{\otimes}} \left(\phi_j \widehat{\xi}_j\right)^{\phi_j} = \left(\Delta\left(t\left(\frac{2\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j\right)/t\right)^{\phi_j}}{\prod_{j=1}^{n}\left(2 - \Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j\right)/t\right)^{\phi_j} + \prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^j}, \rho_1^j\right)/t\right)^{\phi_j}}\right)\right), \ldots = \left(\Delta\left(t\left(\frac{2\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j\right)/t\right)^{\phi_j}}{\prod_{j=1}^{n}\left(2 - \Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j\right)/t\right)^{\phi_j} + \prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^j}, \rho_m^j\right)/t\right)^{\phi_j}}\right)\right). \tag{40}$$

We now propose 2 TL m FHOWG operators.

Definition 18. Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m FNs, where $j = 1, 2, \ldots, n$. Then, an (2 TL m FHOWG) operator is a mapping $\widehat{\xi}^n \longrightarrow \widehat{\xi}$ with the weight vector $w = (w_1, w_2, \ldots, w_n)^T$, where $w_j \in (0, 1]$ and $\sum_{j=1}^n w_j = 1$. Thus,

$$2TLm\text{FHOWG}_W\left(\widehat{\xi}_1, \widehat{\xi}_2, \ldots, \widehat{\xi}_n\right) = \otimes_{j=1}^n \left(w_j \widehat{\xi}_{\sigma(j)}\right). \tag{41}$$

Here $(\sigma(1), \sigma(2), \ldots, \sigma(n))$ represent the permutation of the indices 'j' where $j = 1, 2, \ldots, n$, for which $\widehat{\xi}_{\sigma(j-1)} \geq \widehat{\xi}_{\sigma(j)}$,

$\forall j = 1, 2, \ldots, n$.

Theorem 16. *Let $\widehat{\xi}_j = ((s_{\psi_1^j}, \rho_1^j), \ldots, (s_{\psi_m^j}, \rho_m^j))$ be a set of 2 TL m F numbers, where $j = 1, 2, \ldots, n$. Then the assembled values of these 2 TL m F numbers using the 2 TL m FHOWG operator is also a 2 TL m F numbers, given as follows:*

$$2TLm\text{FHOWG}_W\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\overset{n}{\underset{j=1}{\otimes}}\left(w_j\widehat{\xi}_{\sigma(j)}\right)$$
$$=\left(\Delta\left(t\left(\frac{\lambda\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}(1+(\lambda-1))\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)/t\right)^{w_j}+(\lambda-1)\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right),\ldots\right.$$
$$\left.\cdot\,\Delta\left(t\left(\frac{\lambda\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}(1+(\lambda-1))\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}+((\lambda-1)\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right).\tag{42}$$

Remark 1. For $\lambda = 1$, 2 TL m FHOWG operator reduces to $2TL$ m F ordered Weighted geometric (2 TL m FOWG) operator as follows:

$$2TLm\text{FOWG}_w\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\overset{n}{\underset{j=1}{\otimes}}\left(\widehat{\xi_{\sigma(j)}}\right)^{w_j}$$
$$=\left(\Delta\left(t\prod_{j=1}^{n}\left(\frac{\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)}{t}\right)^{w_j}\right),\Delta\left(t\prod_{j=1}^{n}\left(\frac{\Delta^{-1}\left(s_{\psi_2^{\sigma(j)}},\rho_2^{\sigma(j)}\right)}{t}\right)^{w_j}\right),\ldots,\Delta\left(t\prod_{j=1}^{n}\left(\frac{\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)}{t}\right)^{w_j}\right)\right).\tag{43}$$

2. For $\lambda = 2$, 2 TL m FHOWG operator reduces to 2 TL m F Einstein ordered weighted geometric (2 TL m FEOWG) operator as follows:

$$2TLm\text{FEOWG}_\phi(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\quad\widehat{\xi}_n)=\otimes_{j=1}^{n}\quad(\widehat{\xi}_j)^{w_j},=(\Delta$$
$$(t(\prod_{j=1}^{n}(\Delta^{-1}(s_{\psi_1^{\sigma(j)}},\quad\rho_1^{\sigma(j)})/t)^{w_j}/\prod_{j=1}^{n}(2-\Delta^{-1}\quad(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)})/$$
$$t)^{w_j}+\prod_{j=1}^{n}(\Delta^{-1}(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)})/\,t)^{w_j})),\ldots,$$

$$\Delta\left(t\left(\frac{\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}\left(2-\Delta^{-1}\left(s_{\psi_m^{j}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}+\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right).\tag{44}$$

Theorem 17. *Idempotency. Let* $\widehat{\xi}_j=((s_{\psi_1^j},\rho_1^j),\ldots,(s_{\psi_m^j},\rho_m^j))$ *be a set of 2 TL m FNs, where* $j=1,2,\ldots,n$. *For the equality of all these numbers, that is,* $\widehat{\xi}_j=\widehat{\xi}$, $\forall j=1,2,\ldots,n$, *then the monotonicity property is defined as*

$$2TLm\text{FHOWG}_w\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\widehat{\xi}.\tag{45}$$

The remaining properties, namely, boundedness, monotonicity, and commutativity for the 2 TL m FHOWG operators are defined as

Theorem 18. *Let* $\widehat{\xi}_j=((s_{\psi_1^j},\rho_1^j),\ldots,(s_{\psi_m^j},\rho_m^j))$, *be a set of 2TLmF numbers, where* $j=1,2,\ldots,n$, $\widehat{\xi}^-=\cup_{j=1}^{n}\widehat{\xi}_j$ *and* $\widehat{\xi}^+=\cup_{j=1}^{n}\widehat{\xi}_j$ *then*

$$\widehat{\xi}^-\le 2TLm\text{FHOWG}_\phi\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)\le\widehat{\xi}^+.\tag{46}$$

Theorem 19. *Let* $\widehat{\xi}_j$ *and* $\widehat{\xi}'_j$, $j=1,2,\ldots,n$ *be a set of 2 TL m F numbers. If* $\widehat{\xi}_j\le\widehat{\xi}'_j$, *then*

$$2TLm\text{FHOWG}_\phi\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)\le 2TLm\text{FHOWG}_\phi\left(\widehat{\xi}_1^{\prime},\widehat{\xi}_2^{\prime},\ldots,\widehat{\xi}_n^{\prime}\right).\tag{47}$$

Theorem 20. *Let* $\widehat{\xi}_j$ *and* $\widehat{\xi}'_j$, $j=1,2,\ldots,n$ *be a set of 2 TL m FNs. If* $\widehat{\xi}_j\le\widehat{\xi}'_j$, *then*

$$2TLm\text{FHOWG}_\phi\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=2TLm\text{FHOWG}_\phi\left(\widehat{\xi}_1^{\prime},\widehat{\xi}_2^{\prime},\ldots,\widehat{\xi}_n^{\prime}\right),\tag{48}$$

where $\widehat{\xi}'_j$ *represents the permutation of* $\widehat{\xi}_j$, $j=1,2,\ldots,n$.

Now, we propose another operator, namely, 2 TL m F Hamacher hybrid averaging (2 TL m FHHA) operator, which combines 2 TL m FHWG operator and 2 TL m FHOWG operator, respectively.

Definition 19. Let $\widehat{\xi}_j=((s_{\psi_1^j},\rho_1^j),\ldots,(s_{\psi_m^j},\rho_m^j))$ be a set of 2 TL m FNs where $j=1,2,\ldots,n$. Then, a 2 TL m F

Hamacher hybrid geometric (2 TL m FHHG) operator is defined as

$$2TLm\text{FHHG}_{w,\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)=\otimes_{j=1}^{n}\left(w_j\widetilde{\widehat{\xi}}_{\sigma(j)}\right),\tag{49}$$

where $w=(w_1,w_2,\ldots,w_n)^T$ represent the associated weight vector of the 2 TL m F numbers $\widehat{\xi}_i$, instead of weighting the experts, for each '' varies from 1 to n, with $w_i\in(0,1]$ and $\sum_{i=1}^{n}w_i=1$, $\widehat{\xi_{\sigma(j)}}$ is the jth biggest 2 TL m F numbers of the $\widehat{\xi}_i(i=1,2,\ldots,n)$ with $\widetilde{\widehat{\xi}}_{\sigma(i)}=(n\phi_i)\widehat{\xi_{\sigma(i)}}$, $(i=1,2,\ldots,n)$, $\phi=(\phi_1,\phi_2,\ldots,\phi_n)^T$ is the weight vector for the ordered arguments, with $\phi_j\in(0,1]$, $\sum_{j=1}^{n}\phi_j=1$.

Theorem 21. *Let $\widehat{\xi}_j=((s_{\psi_1^j},\rho_1^j),\ldots,(s_{\psi_m^j},\rho_m^j))$ be a set of 2TLmFNs where $j=1,2,\ldots,n$. Then the assembled value of these 2 TL m FNs by using the 2 TL m FHHG operator is again a 2 TL m F numbers, given as follows:*

$$\begin{aligned}2TLm\text{FHHG}_{w,\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)&=\overset{n}{\underset{j=1}{\otimes}}\left(w_j\widetilde{\widehat{\xi}}_{\sigma(j)}\right)\\&=\left(\Delta\left(t\left(\frac{\lambda\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}(1+(\lambda-1))\left(1-\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)/t\right)^{w_j}+(\lambda-1)\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right),\ldots\right.\\&\left.\cdot\,\Delta\left(t\left(\frac{\lambda\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}}{\prod_{j=1}^{n}(1+(\lambda-1))\left(1-\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}+(\lambda-1)\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)/t\right)^{w_j}}\right)\right)\right).\end{aligned}\tag{50}$$

Proof. In order to prove this theorem, the same steps are followed as discussed above in the theorem. □

Remark 1. For $\lambda=1$, the 2 TL m FHHG operator reduces to $2TL$ m FHG operator as follows:

$$\begin{aligned}2TLm\text{FHG}_{w,\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)&=\overset{n}{\underset{j=1}{\otimes}}\left(w_j\widetilde{\widehat{\xi}}_{\sigma(j)}\right)\\&=\left(\Delta\left(1-t\prod_{j=1}^{n}\left(\frac{\Delta^{-1}\left(s_{\psi_1^{\sigma(j)}},\rho_1^{\sigma(j)}\right)}{t}\right)^{w_j}\right),\Delta\left(t\prod_{j=1}^{n}\left(\frac{\Delta^{-1}\left(s_{\psi_2^{\sigma(j)}},\rho_2^{\sigma(j)}\right)}{t}\right)^{w_j}\right),\ldots,\right.\\&\left.\cdot\,\Delta\left(t\prod_{j=1}^{n}\left(\frac{\Delta^{-1}\left(s_{\psi_m^{\sigma(j)}},\rho_m^{\sigma(j)}\right)}{t}\right)^{w_j}\right)\right).\end{aligned}\tag{51}$$

2. For $\lambda=2$, 2 TL m FHHG operator convert to 2 TL m FEHG operator as follows:

$$\begin{aligned}2TLm\text{FEHG}_{w,\phi}\left(\widehat{\xi}_1,\widehat{\xi}_2,\ldots,\widehat{\xi}_n\right)&=\overset{n}{\underset{j=1}{\otimes}}\left(w_j\widetilde{\widehat{\xi}}_{\sigma(j)}\right)\\&=\left(\Delta\left(t\left(\frac{2\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}}{\prod_{j=1}^{n}\left(2-\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}+\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_1^j},\rho_1^j\right)/t\right)^{\phi_j}}\right)\right),\ldots\right.\\&\left.\cdot\,\Delta\left(t\left(\frac{2\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}}{\prod_{j=1}^{n}\left(2-\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}+\prod_{j=1}^{n}\left(\Delta^{-1}\left(s_{\psi_m^j},\rho_m^j\right)/t\right)^{\phi_j}}\right)\right)\right).\end{aligned}\tag{52}$$

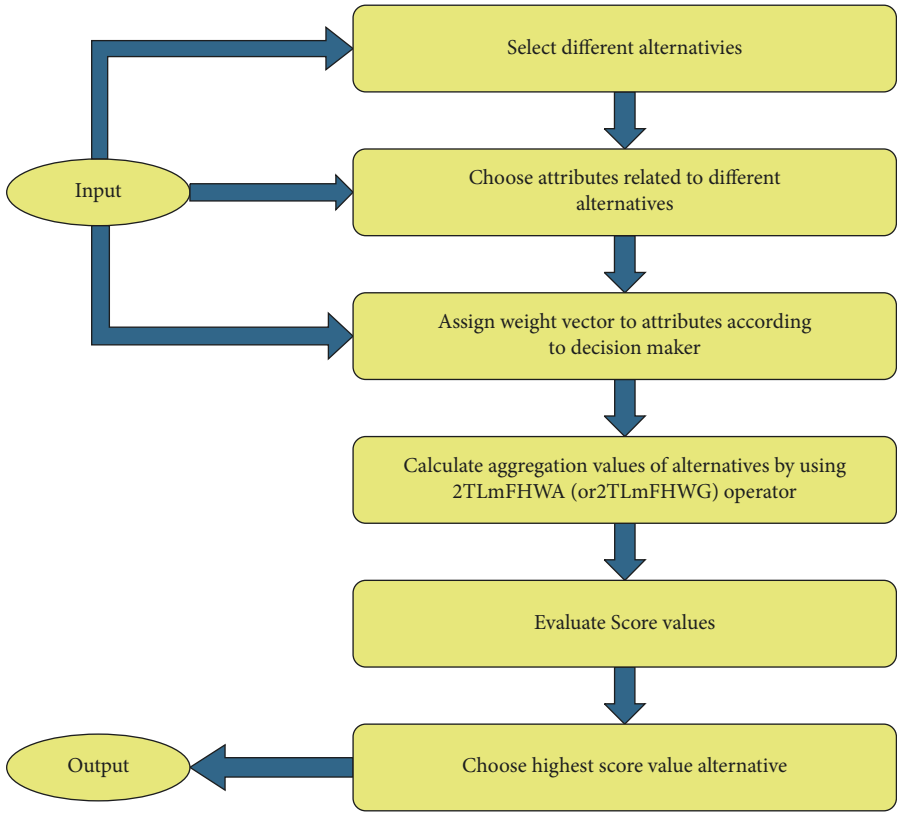

Figure 2: Flow chart for decision-making by using the 2TLmFHWA(or2TLmFHWG) operators.

(i) Input:
U, the set of discourse having k alternatives.
ζ be the set having n attributes.
$\phi = \{\phi_1, \phi_2, \ldots, \phi_n\}$, weight vector representation.

(2) In order to calculate the values in 2 TL m F decision matrix $\widehat{\beta}$, we calculate the preference values $\widehat{\beta}$, $i = 1, 2, 3, \ldots, k$, of the objects A_i, by using 2 TL m FHWA operator.

$$\widehat{p}_i = 2TL \text{ m FHWA}_{\phi}(\widehat{\xi}_{i1}, \widehat{\xi}_{i2}, \ldots, \widehat{\xi}_{in}) = \oplus_{j=1}^{n}(\phi_j \widehat{\xi}_{ij}),$$

$$= (\Delta(t(\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t^{\phi_j} - \prod_{j=1}^{n}(1-\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t)^{\phi_j}/\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t^{\phi_j} + (\lambda-1) \prod_{j=1}^{n}(1-\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t)^{\phi_j})), \ldots$$

$$\Delta(t(\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t^{\phi_j} - \prod_{j=1}^{n}(1-\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t)^{\phi_j}/\prod_{j=1}^{n}(1+(\lambda-1))$$
$$\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t^{\phi_j} + (\lambda-1)\prod_{j=1}^{n}(1-\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t)^{\phi_j}))).$$

Alternatively, if we apply 2 TL m FHWG operators, then

$$\widehat{p}_i = 2TL \text{ m } \begin{matrix} \text{FHWG}_{\phi}(\widehat{\xi}_{i1}, \widehat{\xi}_{i2}, \ldots, \widehat{\xi}_{in}) = \otimes_{j=1}^{n}(\phi_j \widehat{\xi}_{ij})^{\phi_j}, \\ = (\Delta(t(\lambda\prod_{j=1}^{n}(1-\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t)^{\phi_j}/\prod_{j=1}^{n}(1+(\lambda-1))\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t^{\phi_j} + (\lambda-1)\prod_{j=1}^{n}(1-\Delta^{-1}(s_{\psi_1^{ij}}, \rho_1^{ij})/t)^{\phi_j})), \ldots, \end{matrix}$$

$$\Delta(t(\lambda\prod_{j=1}^{n}(\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t)^{\phi_j}/\prod_{j=1}^{n}(1+(\lambda-1)(1-\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t))^{\psi_j} + (\lambda-1)\prod_{j=1}^{n}(\Delta^{-1}(s_{\psi_m^{ij}}, \rho_m^{ij})/t)^{\phi_j}))). \quad (46)$$

(3) We compute the scores $S(\widehat{p}_i)$, $i = 1, 2, 3, \ldots, k$.

(4) By using scores values $S(\widehat{p}_i)$, $i = 1, 2, 3, \ldots, k$, we make ranking for objects. If we have the same score value for two alternatives, then in order to rank the objects, we move toward accuracy function.
Output: an alternative which has the high value in Step (4) will be the decided alternative.

Algorithm 1: Procedure to tackle (MADM) problems using 2 TL m FHWA (or 2 TL m FHWG) operators.

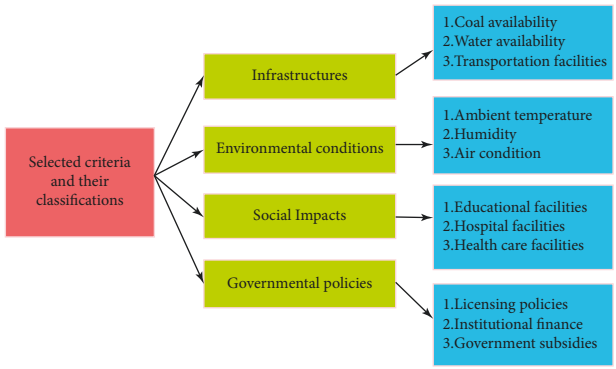

Figure 3: Criteria representation in the selected 3-polar environment.

5. Mathematical Approach for MADM Using 2 TL m F Information

In this section, we handle the multiattribute decision-making issues with 2 TL m F information by applying the 2 TL m FHA operators established in the previous sections.Let $A = \{A_1, A_1, A_2, \ldots, A_k\}$ be the set of alternatives and $\zeta = \{\zeta_1, \zeta_2, \ldots, \zeta_n\}$ be the set of attributes. Let us assume $\phi = \{\phi_1, \phi_2, \ldots, \phi_n\}$, a weight vector for the set of attributes where $\phi_j > 0$ for $j = 1, 2, \ldots, n$ and $\sum_{j=1}^{n} \phi_j = 1$.Let us take $R = (r_{ij})_{k\times n} = ((s_{\psi_1}^{ij}, \rho_1^{ij}), \ldots, (s_{\psi_m}^{ij}, \rho_m^{ij})_{k\times n}$ be a decision matrix for 2 TL m F information. Here $(s_{\psi_r}^{ij}, \rho_r^{ij})$, $r = 1, 2, \ldots, m$ represent the membership values given by the decision-makers that the alternatives assure with the attributes ζ_j, where $(s_{\psi_r}, \rho_r) \in [0, 1]$, 'r' varies from 1 to m. In order to deal with MADM issues, we explain Algorithm 1 using 2 TL m FHWA (2 TL m FHWG) operators.

Now, we elaborate the above algorithm for decision-making in the form of a flowchart, which is given in Figure 2.

6. Best Location for the Thermal Power Station: Case Study

Thermal power stations are a source of conversion of heat energy into electricity. It is selected anywhere near a water and fuel supply. Thermal power stations use fossil fuels to generate electricity, which produces pollution. By keeping all the circumstances in view, we consider the selection of the best location for a thermal power station as discussed by [26]. The best location selection plays a significant role in the economic operation of the thermal power station and the long-lasting development of the region. So, the company selects five possible areas, which are considered alternatives $A = \{A_1, A_2, A_3, A_4, A_5\}$.

The decision-maker select the best place for location under the following criteria:

ζ_1: infrastructure

ζ_2: environmental conditions.

ζ_3: social impacts.

ζ_4: governmental policies.

Where each criterion is divided into three components to form a 3-polar fuzzy set.

- Infrastructures: the development of the infrastructure involves different factors, such as the supply of water, extra high cable voltage, gas, roadways, etc. But, here we take three factors, such as the availability of coal, availability of water, and the availability of transportation facilities, to make the 3-polar fuzzy set.
- Environmental conditions: this factor means the state of the environment, including several different natural resources. Let us take the three factors of the environmental conditions which are necessary for the best location selection of the thermal power station; they are ambient temperature, humidity, and air velocities.
- Social impacts: this criterion involves the study of social challenges, which may include both beneficial and adverse effects. We consider three factors, which are education facilities, hospital facilities, and health care facilities.
- Governmental policies: this criterion includes governmental policies, which have been subdivided into three factors, such as licensing policies, institutional finance, and government subsidies. A clear vision of attribute selection in the 3-polar fuzzy environment is shown in Figure 3.

(1) In order to construct the decision matrix, the decision-makers describe their preferences for the best location of a thermal power plant in the form of linguistic terms. But if we proceed with these linguistic terms, then the assembled results may give the same linguistic term against different alternatives. So, to manage this issue, we translate it with zero symbolic translation, which converts the linguistic term data into 2 TL data in which we can rank alternatives with the same linguistic term on the basis of the symbolic translation.

The decision matrix for 2TL3-polar data is given in Table 2.

(2) The weights recommended by the experts are given as $\phi = (\phi_1, \phi_2, \phi_3, \phi_4) = (0.4, 0.3, 0.1, 0.2)$.

We now proceed to find the most suitable place for the thermal power station. The working procedure is described as follows:

Step 1. Let us take $\lambda = 3$, to assemble the 2 TL m F values. If we choose $\lambda = 1$, then the 2 TL m FHWA(2 TL m FHWG) operator reduces to 2 TL m FWA(2 TL m FWG) operator and for $\lambda = 2$, the 2 TL m FHWA(2 TL m FHWG) operator reduces to 2 TL m FEWA(2 TL m FEWG) operator. So, in the case of $\lambda = 3$, the 2 TL m FHWA(2 TL m FHWG) sustains its own nature. Therefore, $\lambda = 3$ is the most suitable value to deal with the selection of the most suitable place for a thermal power station by using operator 2 TL m FHWA.

Step 2. The 2 TL m FHWA operator is used to evaluate the assembled values, $\widehat{p}_i$ for the thermal power plant location alternatives as given in Table 3.

Step 3. Let us compute the score values $S(\widehat{p}_i)$ for all the 2TL3F numbers $\widehat{p}_i$ as in Table 4.

Table 2: Decision matrix for 2TL3F information.

	A_1	A_2	A_3	A_4	A_5
ζ_1	$((s_4,0),(s_4,0),(s_4,0))$	$((s_5,0),(s_3,0),(s_4,0))$	$((s_4,0),(s_3,0),(s_3,0))$	$((s_4,0),(s_5,0),(s_3,0))$	$((s_5,0),(s_4,0),(s_3,0))$
ζ_2	$((s_4,0),(s_5,0),(s_3,0))$	$((s_4,0),(s_5,0),(s_5,0))$	$((s_4,0),(s_5,0),(s_3,0))$	$((s_3,0),(s_4,0),(s_5,0))$	$((s_4,0),(s_6,0),(s_4,0))$
ζ_3	$((s_4,0),(s_5,0),(s_2,0))$	$((s_4,0),(s_5,0),(s_6,0))$	$((s_4,0),(s_3,0),(s_6,0))$	$((s_4,0),(s_4,0),(s_4,0))$	$((s_3,0),(s_5,0),(s_3,0))$
ζ_4	$((s_4,0),(s_3,0),(s_5,0))$	$((s_6,0),(s_3,0),(s_4,0))$	$((s_3,0),(s_4,0),(s_4,0))$	$((s_5,0),(s_2,0),(s_3,0))$	$((s_3,0),(s_4,0),(s_4,0))$

Table 3: Assembled assessment by using the 2 TL m FHWA operator.

$\widehat{p}_i$	2TL m FHWA
$\widehat{p}_1$	$((s_4,0.00000),(s_4,0.31958),(s_4,-0.1689))$
$\widehat{p}_2$	$((s_6,0.00000),(s_4,-0.0079),(s_6,0.0000))$
$\widehat{p}_3$	$((s_4,-0.1794),(s_4,-0.0499),(s_6,0.0000))$
$\widehat{p}_4$	$((s_4,-0.0039),(s_4,0.18731),(s_4,-0.1398))$
$\widehat{p}_5$	$((s_4,0.24175),(s_6,0.00000),(s_4,-0.4686))$

Table 4: Score values for all the 2TL3F numbers $\widehat{p}_i$.

Score values	2TL m FHWA
$S(\widehat{p}_1)$	$(s_4,0.05022)$
$S(\widehat{p}_2)$	$(s_5,0.33068)$
$S(\widehat{p}_3)$	$(s_5,-0.4098)$
$S(\widehat{p}_4)$	$(s_4,0.01450)$
$S(\widehat{p}_5)$	$(s_5,-0.4089)$

Table 5: Assembled assessment by using the operator.

$\widehat{p}_i$	2TL m FHWG
$\widehat{p}_1$	$((s_4,0.00000),(s_4,0.18858),(s_4,-0.3401))$
$\widehat{p}_2$	$((s_5,-0.18858),(s_4,-0.2284),(s_5,-0.4946))$
$\widehat{p}_3$	$((s_4,-0.2076),(s_4,-0.2232),(s_3,0.48176))$
$\widehat{p}_4$	$((s_4,-0.1146),(s_4,-0.0608),(s_4,-0.3258))$
$\widehat{p}_5$	$((s_4,0.08352),(s_5,-0.2833),(s_3,0.48683))$

Step 4. Alternative rankings according to their score ($S(\widehat{p}_i)$, i = 1,2, . . ., 5) values for all the 2TL3F numbers,

$A_2 > A_5 > A_3 > A_1 > A_4$.

Step 5. Conclusively, A_2 is the best place for the thermal power station.

If we use the 2 TL m FHG operator, the best alternative can be selected in the same pattern as taken above. The procedure is as follows:

Here, we take $\lambda = 3$, in order to select the most suitable place for a thermal power station by using 2 TL m FHWG operator.

Step 1. The 2 TL m FHWG operator is used to assemble the values $\widehat{p}_i$ for the best thermal power plant location alternatives selection as given in Table 5.

Step 2. Evaluate score values $S(\widehat{p}_i)$ for all the 2TL3F numbers $\widehat{p}_i$ as in Table 6.

Table 6: Scores values for all the 2TL3F numbers $\widehat{p}_i$.

Scores values	2TL m FHG operator
$S(\widehat{p}_1)$	$(s_4,-0.0505)$
$S(\widehat{p}_2)$	$(s_4,0.36276)$
$S(\widehat{p}_3)$	$(s_4,-0.3163)$
$S(\widehat{p}_4)$	$(s_4,-0.1671)$
$S(\widehat{p}_5)$	$(s_4,0.09567)$

Table 7: Alternative ranking order.

Operators	Ranking	Best alternative
2TL m FHWA	$A_2 > A_5 > A_3 > A_1 > A_4$	A_2
2TL m FHWG	$A_2 > A_5 > A_1 > A_4 > A_3$	A_2

Step 3. Alternative rankings corresponding to their scores ($S(\widehat{p}_i)$, i = 1,2,\enleadertwodots,5), for all the 2TL3F numbers,

$$A_2 > A_5 > A_1 > A_4 > A_3, \tag{53}$$

Step 4. Thus, A_2 is the best alternative. This calculation shows that A_2 is the most suitable location by using the 2TLmFA and 2TLmFG operators, the order of ranking is given in Table 7.

Now we performed the check work for the influence of the parameter $\lambda \in [0,6]$ on the ranking sequence of alternatives by using 2 TL m FWA and 2 TL m FWG operators.

6.1. Influence of the Parameter λ on Decision-Making Results. The score and ranking sequence for different values of the parameter λ are given in Tables 8 and 9, calculated by using 2 TL m FWA and 2 TL m FWG operators. In the evaluation of 2 TL m FWA, we get the same ranking for different values of λ as $A_2 > A_5 > A_3 > A_1 > A_4$ and in the evaluation of 2 TL m FWG, we get the ranking $A_2 > A_5 > A_3 > A_1 > A_4$. Thus, the proposed MADM problem shows that using different parameter λ values does not show variation in the ranking. Thus, for different parameter values, proposed operators are not much affected.

The parameter λ working influences, on the MADM problem formed on 2 TL m FHWA and 2 TL m FHWG operators are given in Tables 8 and 9. From Table 8, we conclude that when the parameter λ is varying for the 2 TL m FHWA operator, the corresponding ranking orders have no change. So, for $1 \geq \lambda \leq 6$, we have the same ranking orders

Table 8: Score values by varying λ based on the 2TLmFHWA operator.

λ	$S(\widehat{p}_1)$	$S(\widehat{p}_2)$	$S(\widehat{p}_3)$	$S(\widehat{p}_4)$	$S(\widehat{p}_5)$	Ranking order
1	$(s_4, 0.08293)$	$(s_5, 0.35560)$	$(s_5, -0.38618)$	$(s_4, 0.07355)$	$(s_5, -0.38708)$	$A_2 > A_5 > A_3 > A_1 > A_4$
2	$(s_4, 0.06035)$	$(s_5, 0.33825)$	$(s_5, -0.40259)$	$(s_4, 0.03289)$	$(s_5, -0.40223)$	$A_2 > A_5 > A_3 > A_1 > A_4$
3	$(s_4, 0.05022)$	$(s_5, 0.33068)$	$(s_5, -0.40980)$	$(s_4, 0.01450)$	$(s_5, -0.40895)$	$A_2 > A_5 > A_3 > A_1 > A_4$
4	$(s_4, 0.04441)$	$(s_5, 0.32643)$	$(s_5, -0.41386)$	$(s_4, 0.00392)$	$(s_5, -0.41276)$	$A_2 > A_5 > A_3 > A_1 > A_4$
5	$(s_4, 0.04065)$	$(s_5, 0.32370)$	$(s_5, -0.41648)$	$(s_4, -0.00297)$	$(s_5, -0.41521)$	$A_2 > A_5 > A_3 > A_1 > A_4$
6	$(s_4, 0.03800)$	$(s_5, 0.32180)$	$(s_5, -0.41830)$	$(s_4, -0.00783)$	$(s_5, -0.41692)$	$A_2 > A_5 > A_3 > A_1 > A_4$

Table 9: Score values by varying λ based on the 2 TL m FHWG operator.

λ	$S(\widehat{p}_1)$	$S(\widehat{p}_2)$	$S(\widehat{p}_3)$	$S(\widehat{p}_4)$	$S(\widehat{p}_5)$	Ranking order
1	$(s_4, -0.09709)$	$(s_4, 0.29230)$	$(s_4, -0.37132)$	$(s_4, -0.25235)$	$(s_4, 0.03175)$	$A_2 > A_5 > A_1 > A_4 > A_3$
2	$(s_4, -0.06776)$	$(s_4, 0.33370)$	$(s_4, -0.33819)$	$(s_4, -0.19843)$	$(s_4, 0.06956)$	$A_2 > A_5 > A_1 > A_4 > A_3$
3	$(s_4, -0.05053)$	$(s_4, 0.36276)$	$(s_4, -0.31638)$	$(s_4, -0.16710)$	$(s_4, 0.09567)$	$A_2 > A_5 > A_1 > A_4 > A_3$
4	$(s_4, -0.03901)$	$(s_4, 0.38489)$	$(s_4, -0.30040)$	$(s_4, -0.14627)$	$(s_4, 0.11544)$	$A_2 > A_5 > A_1 > A_4 > A_3$
5	$(s_4, -0.03070)$	$(s_4, 0.40261)$	$(s_4, -0.28794)$	$(s_4, -0.13131)$	$(s_4, 0.13126)$	$A_2 > A_5 > A_1 > A_4 > A_3$
6	$(s_4, -0.02441)$	$(s_4, 0.41732)$	$(s_4, -0.27779)$	$(s_4, -0.12000)$	$(s_4, 0.14440)$	$A_2 > A_5 > A_1 > A_4 > A_3$

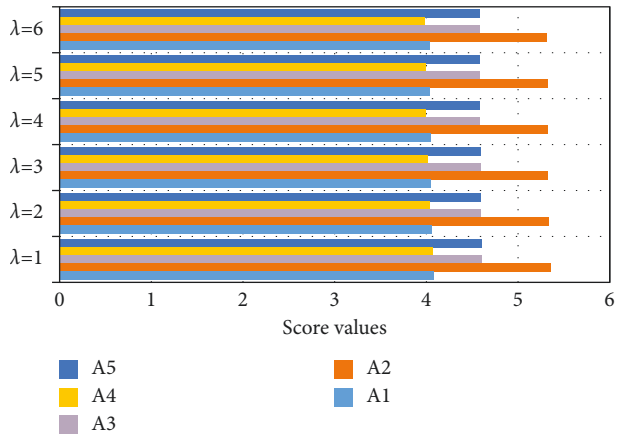

Figure 4: Score values for thermal power stations $A_k\,(k = 1, 2, \ldots, 5)$ based on the 2 TL m FHWA operator.

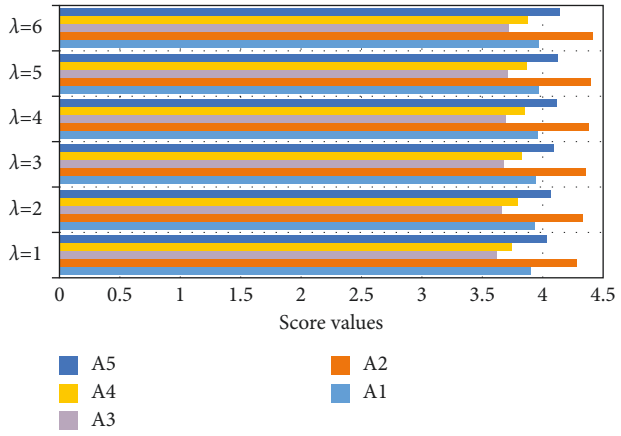

Figure 5: Score values for thermal power stations $A_k\,(k = 1, 2, \ldots, 5)$ based on the 2 TL m FHWG operator.

Table 10: Comparative analysis of proposed operators with existing ones.

Operators	Ranking	Best alternative
m FDWA [26]	$A_2 > A_5 > A_1 > A_4 > A_3$	A_2
m FDWG [26]	$A_2 > A_5 > A_1 > A_4 > A_3$	A_2
m FHWA [29]	$A_2 > A_5 > A_1 > A_4 > A_3$	A_2
m FHWG [29]	$A_2 > A_5 > A_1 > A_4 > A_3$	A_2
2TL m FHWA(proposed)	$A_2 > A_5 > A_3 > A_1 > A_4$	A_2
2TL m FHWG(proposed)	$A_2 > A_5 > A_1 > A_4 > A_3$	A_2

Table 11: Characteristics comparison of 2 TL m F operators with existing structures.

Operators Existing and proposed	Fusion of linguist data With fuzzy information	Information aggregation more flexible By a parameter λ
m FDWA [26]	×	×
m FDWG [26]	×	✓
m FHWA [29]	×	×
m FHWG [29]	×	×
2TL m FHWA(proposed)	✓	✓
2TL m FHWG(proposed)	✓	✓

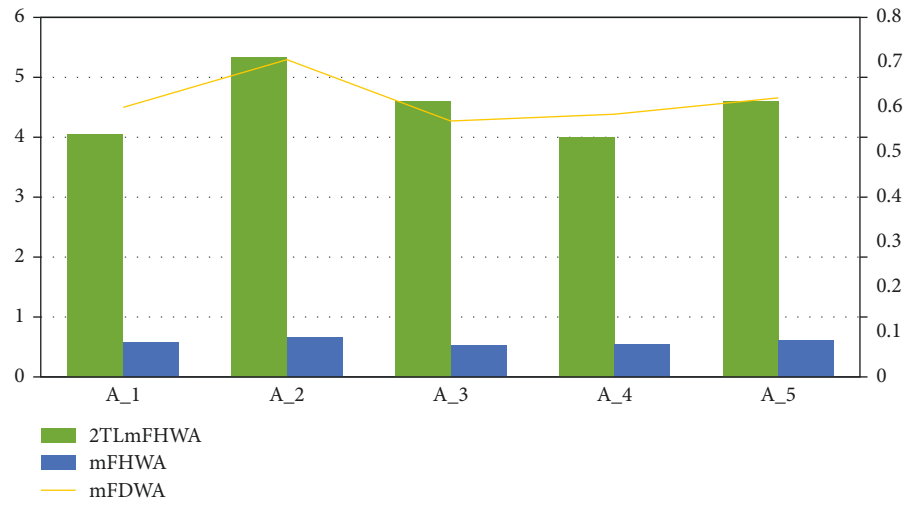

Figure 6: Comparison of proposed operator 2TLmFHWA with existing operators.

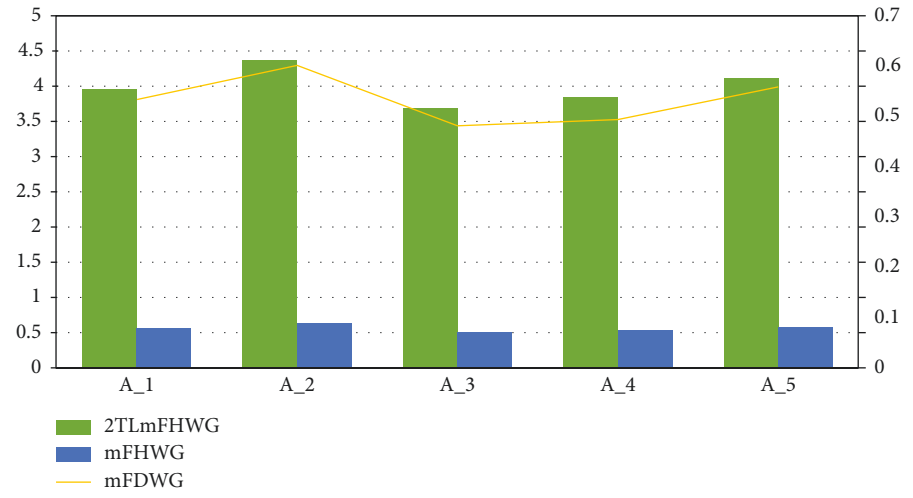

Figure 7: Comparison of proposed operator 2TLmFHWG with existing operators.

$A_2 > A_5 > A_3 > A_1 > A_4$ with the most favorable location is A_2 in all the cases.

In Table 9, when $1 \geq \lambda \leq 6$, then by using the 2 TL m FHWG operator, the order of ranking remains the same as $A_2 > A_5 > A_1 > A_4 > A_3$. Here, A_2 is again the best alternative for a suitable location of the thermal power plant. Thus, in the two situations, the most desirable alternative is A_2 with the same order sequence for $1 \geq \lambda \leq 6$. Where graphical representation of scores variation by changing the parameter λ based on 2 TL m FHWA and 2 TL m FHWG operators are represented in Figures 4 and 5, by applying Δ^{-1} on score function.

Conclusively, the developed MADM problem formed on 2 TL m FHWA and 2 TL m FHWG operators could not change the agnate ranking orders of the alternatives for different parameter values. Thus, the proposed model is reliable and has fewer upshots by λ on multiattribute decision-work.

7. Comparative Analysis

7.1. Comparison with Existing Techniques. This segment contains a comparison survey between the proposed techniques, namely, 2 TL m FHWA and 2 TL m FHWG operators, with existing. We also verify our techniques' applicability and versatility by comparison of proposed models with existing ones. The developed operators, 2 TL m FHWA and 2 TL m FHWG, and their comparison with the existing [26, 29] operators are given in Table 10. We observe that, according to the existing and proposed operators, the best location for a thermal power station is A_2, as in Table 10. Besides this, in the proposed operator 2 TL m FHWG provides the same ranking list $A_2 > A_5 > A_1 > A_4 > A_3$ as compared with the existing [26, 29] operator. But in the case of operator 2 TL m FHWA, the order list is slightly different. The characteristics comparison of 2 TL m F operators with existing structures is in Table 11.

The comparative chart representations ϕ_j of proposed techniques with existing operators are given in Figures 6 and 7.

7.2. Discussion

- The proposed operators 2 TL m FHWA (2 TL m FHWG) consider the interrelationship between the 2 TL and m-polar fuzzy data, which was not the case of the existing operators [26, 29] that only deal with m-polar fuzzy information. Thus, the proposed operators accommodate a greater amount of vagueness and provide more reliable results.
- The techniques in [26, 29], albeit designed to take over MCDM problems, are restricted to deal with m-polar fuzzy information only. They are useless in the presence of linguistic features. So, this may potentially become a cause of loss of information, which typically leads to undesired results. Our new work produces versatile operators that overcome this limitation of previous methods.
- The proposed operators not only operate with 2 TL m F data, but they also have the flexibility to switch from 2 TL m F to m F format by using the Δ^{-1}/t transformation. It is the versatility of the proposed operators, namely, 2 TL m FHWA. Thus, the proposed method is more flexible and transparent than the existing one.

After making the comparison, it has been taken into account that the proposed operators can handle 2 TL m-polar fuzzy information without any complexity. However, our proposed operators quickly describe the fusion of 2 TL and m F information. The new MADM technique for 2 TL m FHWA and 2 TL m FHWG operators improved the resilience of the utilization. Conclusively, the progress made with the help of the m F operators has produced a malleable tool to tackle 2 TL m F information for MADM problems. The ranking order derived from the proposed operators is compatible with the result from the existing operators, so our proposal is reliable and valid for MCDM. Yet more, it is prominent because no loss of data information occurs as in the linguistic information approach. Thus, numeric and linguistic information make the proposed operators more remarkable and adaptable.

7.3. Advantages and Limitations of the Proposed Work. Several aggregation operators have been suggested and put to work in decision-making. Altogether, they enable us to cope with different types of situations, and the decision-makers can select the most suitable operator for their real-world problems. Our proposed methodology is versatile enough to deem it superior as compared to other methods in the 2 TL m F environment. We list some specific advantages as follows:

- The proposed 2 TL m F sets capture descriptions of real-world problems with both quantitative and qualitative components. Because of this versatility, the proposed approach represents many situations more faithfully, and in doing so, it reduces the loss of data.
- The 2 TL m FHWA (resp., 2 TL m FHWG) operator provides more clarity and transparency of information to the decision-makers because of the fusion of 2 TL and multipolar data. This aspect provides an easy way to address MADM risk analysis.
- The proposed approach is more adaptable than other techniques as it completely addresses the interdependence of the linguistic representation with numerical multi-inputs. Therefore, it contains more general information, which gives us more reliable results. Consequently, the proposed operators have a vast range of utilization.
- The preceding strategies are limited to dealing with m-polar fuzzy information. They are rendered ineffective in the presence of linguistic traits. As a result, this might become a source of data loss, which usually results in unfavorable outcomes. Our new approach generated flexible operators that overcame the limitations of earlier methods.

Now, we list some limitations of the proposed work.

- As the proposed 2 TL m F operator collects the 2 TL data with multipolar data, when the number of poles or the subdivision of attributes has increased, this approach seems to be difficult to handle.
- The proposed approach is unable to handle the MADM approach when the decision-makers present their preferences in both positive and negative aspects.

8. Conclusions

Many real situations have a framework that contains 2 TL representations with multipolar data information. As several theoretical frameworks are developed to cover the broader range of complicated situations. Thus, the basic need is the selection of the most suitable MADM approach to tackle the complicated situation in decision making.

Thus, in this research article, we have contributed to the development of the MADM approach in the presence of 2 TL m F data. To overcome the limitations of classical MADM, we have investigated the MADM problem that suitably merges the concepts of 2 TL with Hamacher-type operators and m-polar fuzzy numbers.

Aggregation operators have become a fundamental tool for fusing data from various sources, particularly during the construction of decision-making models. In the present research work, some new aggregation operators are developed that are closely motivated by m F Hamacher operations, namely, the 2 TL m FHWA operator, the 2 TL m FHOWA operator, and the 2 TL m FHHA operator. Moreover, we have introduced the 2 TL m FHWG operator, the 2 TL m FHOWG operator, and the 2 TL m FHHG operator. We have also disclosed the various properties of these operators, namely, monotonicity, idempotency, and the boundedness property. So that, the practitioners may select the version that best serves.

We have applied these aggregation operators to enhance the applicability area of MADM in the m F environment. In the end, we have produced a comparative study of the proposed operators concerning previously existing work. This analysis speaks to the validity of the proposed operators. In our case study for the selection of the best thermal power station location, we have consistently found that A_2 is the best alternative for the location of a thermal power station. Conclusively, the significant contribution of this research article is that it combines the functions of Hamacher aggregation operators as well as the properties of 2 TL m-polar fuzzy numbers. Our proposed model of uncertain knowledge reveals its adaptability in depicting inexact, imperfect facts in complicated settings. The operators show that they are very flexible, allowing them a valuable tool that might be put to other future tasks. In future work, we plan to extend our research work to include outranking decision-making methods.

Data Availability

No data were used to support this study.

Conflicts of Interest

The authors declare that there are no conflicts of interest with this study.

Acknowledgments

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Research Article

Construction and Practice of Multiple Mixed Teaching Mode Based on Big Data Analysis: A Case Study of "International Trade" Course

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With the progress of society, the quality requirements of international business enterprises for international business talents have been improved accordingly. So, it is urgent to conduct in-depth research on the teaching model and the improvement of students' practical ability. Taking international business as an example, this paper analyzes the contradiction between the supply and demand of international business technical talents by literature research. Furthermore, the convolution neural network model is used to improve the consistency between the talent cultivation of international business major and the talent demand of enterprises by interviewing teachers and questionnaire survey of students. By studying how to implement the professional training curriculum system construction and enterprise to talented person ability training requirements cohesion, this paper in view of the secondary vocational school of international business in today's society professional training curriculum system was modified and perfected. The ultimate purpose of this paper is to meet the demand of international business for characteristic talents and constantly promote the high-quality development of international business education.

1. Introduction

The 14th Five-Year Plan emphasizes once again: international multiple contradictions and challenges faced by China will deteriorate further, Chinese enterprises will inevitably will also be further about the international market competition and the pattern of economic and social development of a subject that cannot be ignored and strength; this means that we are used to that kind of low cost, high specification models also have to go, and the direct indirect market competition will be more obvious [1, 2]. In this context, for China's international business enterprises, this is both an opportunity and a challenge, which is the most critical period of development. At the macrolevel, the scientific implementation of the five national development concepts has further mobilized the endogenous force of the international business industry and become the driving force for its sustainable development [3]. At the microlevel, there are still many deficiencies in vocational and technical education in China, which cannot keep pace with the national macropolicies [4]. Relevant surveys show that ,about 4% of graduates majoring in international business in secondary vocational schools must choose jobs corresponding to their major. However, when students enter the workplace, their lack of practical ability will be obviously manifested, and they cannot be competent for the job and meet the job needs. About 58% of the graduates choose positions related to international business major or enter other industries. More than 75% of the graduates of international business major of secondary vocational schools in 2016 choose to change jobs in the last three years, resulting in loss of most international business education resources [5].

On the one hand, now our country secondary vocational school's international business professional should also

actively explore the western orientation of CBE teaching model, effectively solve the current orientation training in international business management professionals in teaching patterns to cultivate ill-structured problems, in the international business training teaching mode in the dilemmas facing get breakthrough, and comprehensively improve the quality of international business personnel training, training practical, applied, innovative international trade personnel for the development of the international trade industry. On the other hand, from the analysis of the top-level design of national vocational education, practical training and teaching is an essential link to cultivate technical and skilled talents, and the key index to measure technical and skilled talents is also vocational ability [6, 7].

Generally speaking, now for the need of talents in our country under the changing circumstances, each secondary vocational school should update their education system in a timely manner and to timely find my own shortcomings and then improve it, so as to better adapt to the demand of the market and increase their school competitiveness in the society [8]. This paper aims to sort out the needs of international trade talents and put forward corresponding suggestions for the curriculum construction of ethnic trade specialty in secondary vocational colleges and finally achieve the purpose of adapting to social development. Teaching design ability is the core of teachers' teaching ability and also the key content of the construction of teachers' team in the future. This study tries to use the form of mixed teaching and learning mode to cultivate the ability and then, through practical research, to explore the specific effects of the training process. The specific significance of this paper is described as follows [9].

In reality, all kinds of problems are in front of us. Both learning and teaching there are serious path dependence, which means innovating teaching ideas and methods is not easy; at the same time, it also means that once the new teaching methods and means are discovered, it fully considered the student's own subjectivity, for the existence of secondary classroom teaching effectively solve the problems between the theory and practice. It builds a training system that combines quality and skill, enriches classroom teaching and practical teaching, greatly improves the teaching quality of the course, and effectively supplements the theoretical knowledge of education and teaching. Through the teaching design and the teaching implementation process of the teaching mode, it plays a guiding significance of theoretical guidance and practical demonstration to the later teaching activities and has a relatively positive role [10]. Finally, using the teaching mode in practice and feedback the study of the theory of the teaching mode, so as to provide theoretical guidance for further improve the teaching quality, it also makes that the human-oriented education concept is more and more thorough popular feeling [11].

The training of skilled talents depends on the development of secondary vocational education. However, a summary of the current teaching shows that there are still many problems in the teaching process, whether it is international business major or other applied majors. From the perspective of teaching mode, the imparting of knowledge is still a relatively single mode, mainly lectured by teachers and listened to by students [12]. From the perspective of teaching content, part of the course content is relatively backward, which does not meet the latest trends of international trade and the needs of the society and lacks attention to students' professional ability and accomplishment. From the perspective of students, most secondary school students' basic knowledge reserve is not enough, and students' cultural literacy is generally low, which is not suitable for simple theoretical knowledge learning. If theory is not combined with practice, it is difficult to ensure the teaching effect because theoretical knowledge must be tested in practice to motivate students to take the initiative to learn, and pure theoretical teaching is unlikely to bring such an incentive effect. At the same time, the combination of theory and practice is not random, but a new scientific teaching mode, which is closely combined with theory and practice and carefully studied according to students' cognitive characteristics under the consideration of students' subjectivity. This new teaching model, which includes practical elements and takes into account the cognitive characteristics of students, can motivate students to take the initiative to learn, so that students' learning efficiency is rapidly improved, and meanwhile, teachers' professional ability is further improved [13].

2. Related Work

2.1. Research Status of Deep Learning under Big Data. With the advent of the information age, the communication between people is getting closer and closer. It is in this context that big data has attracted the attention of all sectors of society. However, it is still unknown how to define the concept of big data [14, 15]. There is no unified opinion in the academic circle, which usually refers to the data set that cannot be captured, managed, and processed within a certain period of time by using conventional software tools. Big data generally has five characteristics, which refers to that the value and potential information of data depend on the size of data, which is given in Figure 1.

In-depth study is accompanied by biology of the cranial nerve system developed in the study of cognitive thinking process and was first put forward by Hinton et al, mainly according to the composition of the neurons, allowing the computer to simulate the structure and be able to study and analyze the cognitive process of human brain activity, in order to solve image, speech classification, and other tasks that require a lot of feature analysis [16, 17]. When the brain receives information from sensory organs, the information will be passed on to the layers of progressive neurons, and each layer represents the feature extraction of things, through the layers of transfer form to the cognition of things. Deep neural

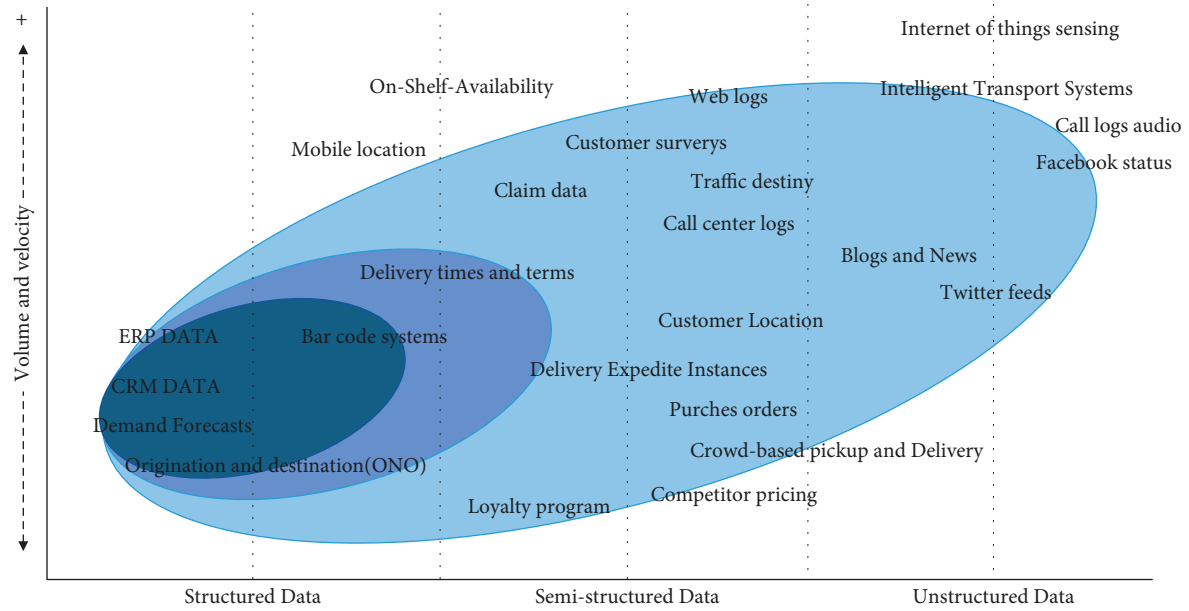

Figure 1: The development of big data sources and volumes.

networks are largely based on abstract information, with processors at each layer receiving processors at the upper and lower levels to extract deep data features [18].

A general structure consists of a visible layer that represents input information [19]. In the process of development from the encoder, because input noise makes the results are often not satisfactory, the researchers need to focus on the solution, the denoising encoder is designed, and the main working principle is in the training set artificially increase the noise data, in order to enhance the adaptability of the encoder [20].

Convolutional neural network (CNN) is a deep-seated neural network proposed by Japanese scholar Fukushima. Different from autoencoder, convolutional neural network is a supervised learning model. Because it changes the previous full-connection mode of neural network, partial connection mode is directly adopted in neurons [21]. Thus, the number of parameters to be learned in the network is reduced, the complexity of the training process is reduced, and the efficiency is improved. The structure of convolutional neural network can be artificially changed according to the actual needs. Among them, the convolution layer and the sampling layer are hidden layers, whose main task is feature mapping [22]. In the training process, the convolution layer performs operations such as convolution bias, and the sampling layer performs operations such as weighted sigmoid function. After repeated for many times, features with high abstraction are input to the full connection layer. In practice, each layer is improved according to the complexity of the problem to be solved. In addition to the above two types of deep learning algorithms, there are also deep confidence networks, convolutional decomposition neural networks and so on, and the convolutional neural networks involved in this paper is the CNN [23].

Based on the above discussion, the contributions of this paper are given as follows:

(1) Firstly, a new mixed teaching mode is proposed according to the actual needs

(2) On this basis, the new mixed teaching model is applied to the teaching of international trade courses

(3) Simulation results show the effectiveness and practicability of the proposed method

2.2. Research Status of Teaching Mode for "International Trade" Course. At present, the discussion about the mixed teaching mode is in full flow. However, due to the development time of the mixed teaching mode, we may have a misunderstanding, thinking that the mixed teaching mode is just another product of the old bottle of new wine under the development of information technology in recent years [24]. But in fact, the source of mixed teaching mode is deeply buried in the development of continuous integration of technology and teaching. Since its occurrence, hybrid teaching has rapidly become a hot spot in classroom teaching for its theoretical superiority and good effect in practice, and the hybrid teaching mode is grown in the soil of the perfect hybrid teaching, so the research on the hybrid teaching mode has to first clarify the development history of the hybrid teaching. The research of blended teaching is a

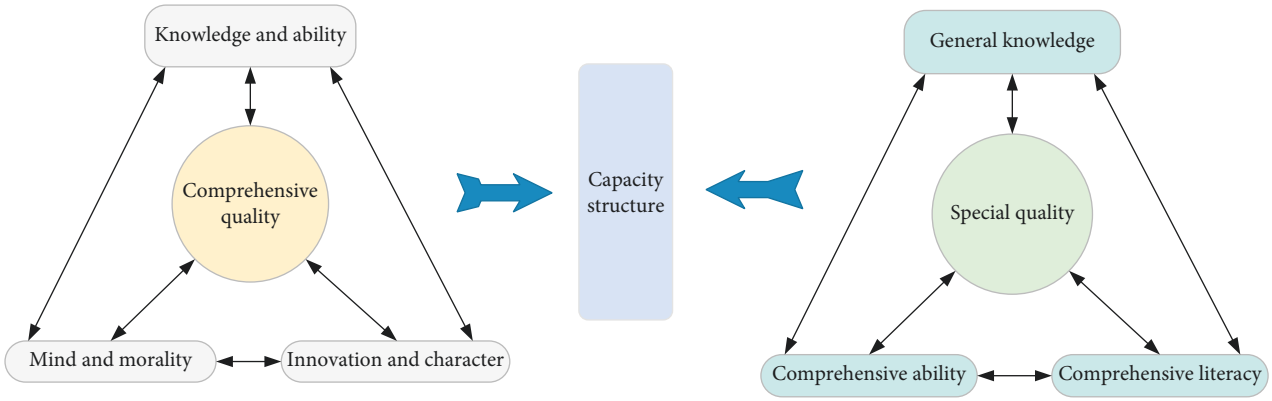

Figure 2: Ability of students majoring in international trade.

gradual process, from the germination to the mature stage, and it has gone through multiple stages of change. Sorting out the changes of its development stage and the existing research results will help us better grasp the development of blended teaching research. Therefore, we conduct a literature review in two aspects: one is the discussion on the connotation of hybrid teaching in Chinese and foreign educational circles; the other is a systematic review of the current research on hybrid teaching [25]. In addition, the main abilities are given in Figure 2.

Blended learning first appeared in enterprise training, combining online teaching with offline teaching. In 2002, foreign scholars believed that blended learning is the mixture of network technology, teaching methods, teaching technology, and classroom training. It can also be defined as a mixture of teaching techniques and teachers' work. People pay special attention to the understanding of the connotation of blended teaching, which is conducive to in-depth grasp of its essence. With the development of educational technology, its connotation has undergone multiple stages of change. First, the technology application stage (from the end of 1990s to 2006) emphasizes the core role of technology in teaching and holds that blended teaching is a simple combination of teaching and technology. Chinese scholars put forward the concept of hybrid learning in the 7th Global Chinese Conference on Computer Applications, which triggered the discussion on this concept in China. Hybrid teaching can overcome the shortcomings of traditional classroom teaching through technology. This stage is mainly regarded as "the mixture of face-to-face teaching and online teaching," and it is considered as the transitional stage between pure face-to-face teaching and pure online teaching [26].

Second is the technology combination stage (2007–2013), which went beyond the technology combination level of the previous stage. With the development of practice and research, the definition of blended teaching gradually became clear, and the appropriate use of teaching elements was emphasized to achieve the optimal learning effect [27]. Clarifying the essence of its definition is of great support to the subsequent development of theory and practice. In the third International Conference on Blended Teaching Methods (ICHL), researchers made a profound discussion on blended teaching, believing that blended teaching is not a transitional teaching method, but a flexible conversion and combination between electronic teaching and traditional teaching in order to support the needs of different learning methods of students, which is a natural teaching method. At present, the blended teaching model is considered to be more developed from the perspective of strategies and methods and mainly focuses on the change of learning environment and the frequency of interaction between teachers and students. Many scholars and experts are committed to model construction and apply it to educational technology, physics, medicine, economics, and other fields. There are abundant research achievements on the theory and practice of blended teaching [28].

Third, the Internet + stage, from 2013 to now, during which the rapid development of Internet+ has broadened the connotation of hybrid teaching and the formal application of mobile technology, which is not only the combination of traditional and online teaching forms but also the combination of technical means, objectives, and other teaching elements, which is considered to be a teaching situation combining network and classroom with the support of technology. At this stage, people gradually began to stand in the perspective of students and pay attention to the learning experience brought by blended teaching. The learning environment is student-centered [29]. Attach importance to the development of students' autonomy and personalized learning needs. Meanwhile, the development of MOOC, SPOC, and other open online courses in China has promoted the application of blended teaching in course teaching. With the development of big data technology, multiple platforms have begun to support the application of hybrid teaching, and scholars have begun to carry out the practice of hybrid teaching in an all-round way and have achieved a large number of research results [30]. Up to now, blended teaching has a richer connotation, including not only the mixture of online and offline teaching but also the mixture of teaching media, teaching methods, evaluation methods, and other teaching elements. As the new normal of

future education, blended teaching has been receiving high attention at home and abroad. Foreign hybrid teaching originated from enterprise training. In order to improve the technical level and overall quality of employees in internal training of large companies such as Intel and Microsoft, the combination of online and offline training has achieved better results than the traditional training mode, thus enabling enterprises to obtain greater benefits [31].

3. Construction of Multiple Mixed Teaching Mode by CNN

3.1. Principles of Mixed Teaching Mode. When defining blended teaching, more attention should be paid to how to help students achieve the optimal learning effect [32]. Although the above definitions start from different perspectives, they all point to the student-centered teaching concept and advocate a mixture of various elements in teaching methods. Therefore, based on the above definition, the blended teaching in this study is defined as follows: Hybrid teaching is supported by information technology, under the guidance of advanced teaching theory, breaks through the limitation of time and space, and effectively integrates the advantages of traditional teaching and network teaching. On this basis, reasonable use of various teaching elements achieves the best teaching effect of teaching methods [33].

The teaching mode is a stable framework and system of teaching activities [34]. The mixed teaching mode is a system established on the basis of the mixed teaching. According to the previous definition of the mixed teaching, the mixed teaching mode is defined as follows: break through the limitation of time and space, effectively integrate the advantages of traditional teaching and network teaching, and achieve stable teaching procedures [35]. The definition emphasizes the following: first, the mixed teaching mode is to select and use teaching technology, teaching means, teaching evaluation, and other teaching elements appropriately according to teaching needs. The ultimate goal is to achieve the maximum benefit of teaching. Second, it emphasizes student-centered and advocates the use of teaching technology, teaching means, teaching evaluation, and other elements in order to realize students' active and creative learning [36, 37].

3.2. The Proposed Recommendation Method. Due to the shallow network layer and the use of linear activation units, the early artificial neural network models are often unable to solve complex problems. So, in recent years, the CNN model is often used to solve complex image recognition problems. On the basis of the traditional full-connection layer neural network, the convolutional neural network adds convolution layer and pooling layer.

The function of the convolution layer lies in the extraction of image features. The essence of the convolution kernel is a filter matrix, which can produce many different effects on the original image. The calculation process of convolution is shown as follows:

$$x_i = \operatorname{act}\left(x_{i-1} \otimes k_i + b_i\right). \tag{1}$$

Then, the mathematical expression of sigmoid function is

$$f(x) = \frac{1}{1 + e^{-x}}. \tag{2}$$

The mathematical expression of tanh function is

$$f(x) = \frac{e^{x} - e^{-x}}{e^{x} + e^{-x}}. \tag{3}$$

The mathematical expression of ReLu function is

$$f(x) = \max(0, x). \tag{4}$$

The mathematical expression of LeakyReLu function is

$$f(x) = \begin{cases} x, & x \geq 0, \\ \alpha x, & x < 0. \end{cases} \tag{5}$$

Therefore, the efficiency of the entire network operation can be improved to a certain extent.

The output layer adopts Softmax function to normalize, and the probability value in the corresponding category is shown in the following formula:

$$h_{w,b}(x_i) = \begin{bmatrix} p(y_i = 1 | x_i; w, b) \\ p(y_i = 2 | x_i; w, b) \\ p(y_i = 3 | x_i; w, b) \\ \cdots \\ p(y_i = n | x_i; w, b) \end{bmatrix} = \frac{1}{\sum_{j=1}^{n} e^{w_j x_i + b_j}} \begin{bmatrix} e^{w_1 x_i + b_1} \\ e^{w_2 x_i + b_2} \\ e^{w_3 x_i + b_3} \\ \cdots \\ e^{w_n x_i + b_n} \end{bmatrix}. \tag{6}$$

In classification tasks, it is a common method to use cross entropy loss function to evaluate the gap between predicted value and true value. The cross-entropy formula is as follows:

$$\text{loss} = -\frac{1}{m} \sum_{j=1}^{m} \sum_{i=1}^{n} y_{ji} \log\left(\hat{y}_{ji}\right). \tag{7}$$

The error calculated from the cross-entropy function needs to be calculated by back propagation, so as to realize the newer back propagation of model parameters. The original form of the gradient descent method is

$$\theta := \theta - \alpha \frac{\partial}{\partial \theta} J(\theta). \tag{8}$$

In the experiments in the following chapters, this paper also verifies that the use of Adam has faster convergence than SGD. The mathematical expression of a common Adam optimizer is as follows:

$$m_t = \beta_1 m_{t-1} + (1 - \beta_1) g_t, \tag{9}$$

$$v_t = \beta_2 v_{t-1} + (1 - \beta_2) g_t^2. \tag{10}$$

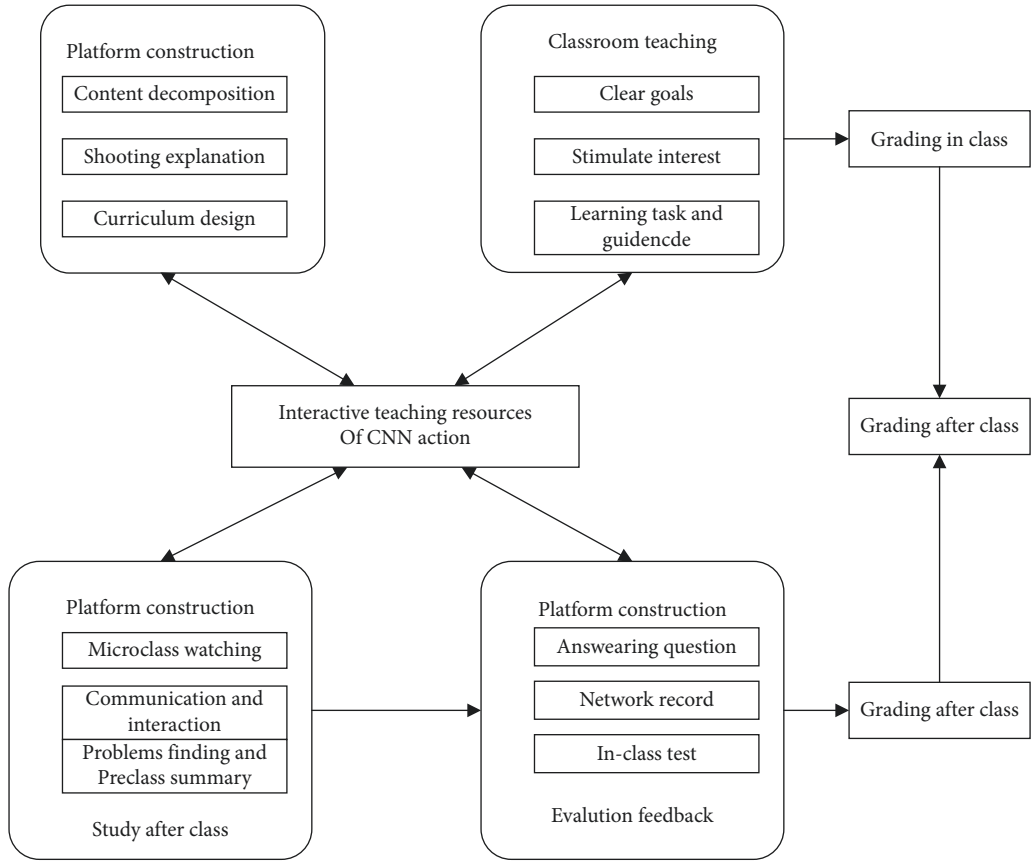

Figure 3: Schematic diagram of mixed teaching mode for international trade major students based on CNN.

Therefore, the updating rule of gradient descent is as follows:

$$\theta_{t+1} = \theta_t - \frac{\alpha}{\sqrt{v_t + \varepsilon}} m_t. \tag{11}$$

Based on the equations (1)–(11), Figure 3 gives the schematic diagram of mixed teaching mode for international trade major students based on the CNN model proposed in this paper. It mainly contains platform construction, classroom teaching, and finally, the CNN based teaching pattern is designed.

4. Experimental Results and Analysis

4.1. Experimental Data Collection and Introduction. The independent variable of this study is the mixed teaching mode, and the dependent variable is the cultivation of students' teaching design ability. Due to the limitation of the practice process, the selection of subjects cannot be randomly assigned, and the unequal group design is adopted. In the study, besides the independent variable, many factors will affect the dependent variable. In the experiment, these factors include the irrelevant variables that we need to control, including the experiment time, which is controlled to the same length. In this study, 18 class hours were taken as the criterion, and the experiment duration was strictly controlled consistent. During the experiment, experiments were carried out in the same teaching place to avoid experimental errors caused by changes in the experiment site. Therefore, the same number of teachers and assistants was used in this study to ensure the credibility of the experiment, so as to further verify the effectiveness of the proposed method. Students' existing subject knowledge, teaching knowledge, and practical knowledge will have an impact on ability training. Since the class of this study is from the natural class formed by students' independent course selection, the training situation of students with different majors, grades, and internship experiences needs to be compared and analyzed in the later analysis. The teaching data dynamic generation and processing method are shown in Figure 4.

4.2. Experimental Results. This paper uses the experimental data obtained in Section 4.1 to verify the satisfaction degree of users after using the proposed mixed teaching model. The specific experimental results are shown in Figure 5.

As can be seen from the figure, after the application of the hybrid teaching system proposed in this paper, users' satisfaction with the system reaches more than 98%. Therefore, the system is deeply loved by students and teachers and has obtained good application feedback.

Besides, the quantitative evaluation indicators results are shown in Figure 6. In the actual experiment process, we divided the students into three types, the first group is the traditional teaching mode, the second group is the

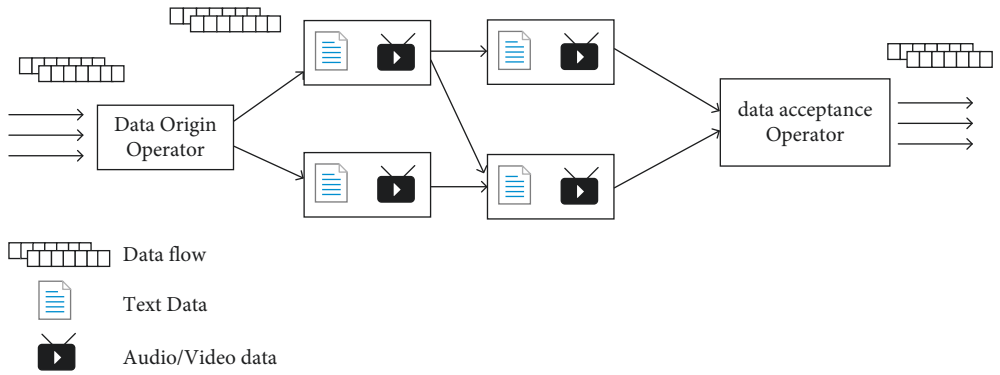

Figure 4: Teaching data dynamic generation and processing method.

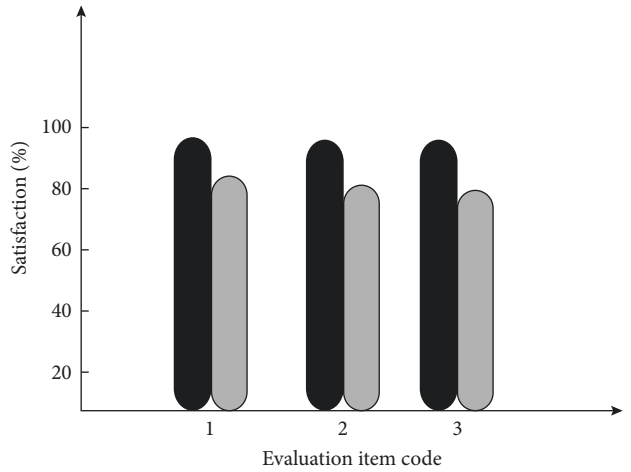

Figure 5: Satisfaction degree after using the proposed teaching model.

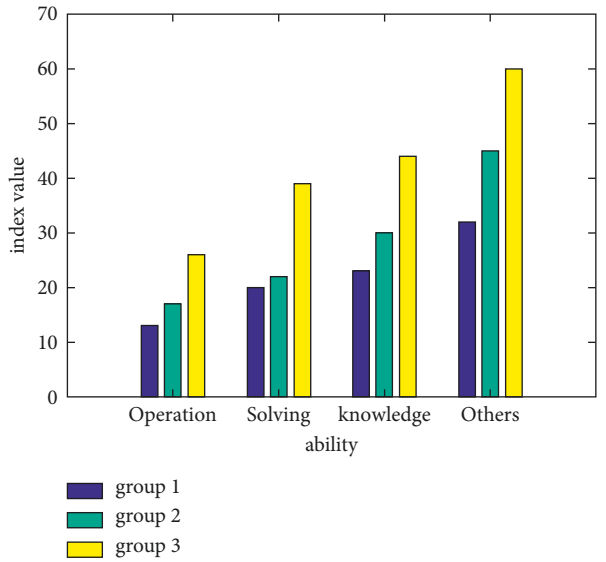

Figure 6: Results based on quantitative evaluation indicators.

simulation experiment situation, but only the basic experiment. In the third group, we conducted experiments using the proposed mixed teaching model.

This paper analyzes the test results of learning behavior of 5 students and takes attention and correct rate as quantitative indicators to demonstrate the effectiveness of

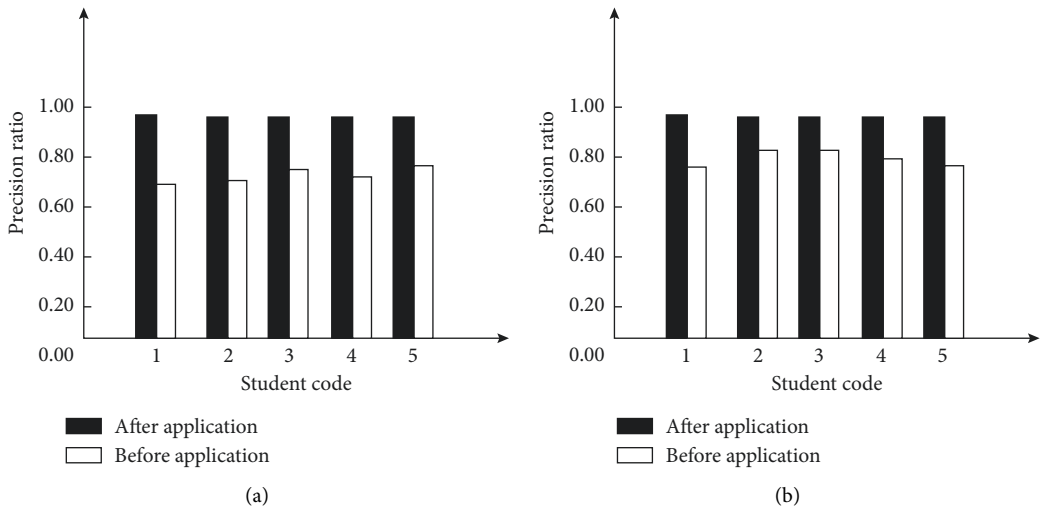

Figure 7: Teaching accurate results. (a) Attention. (b) The accuracy of the problem.

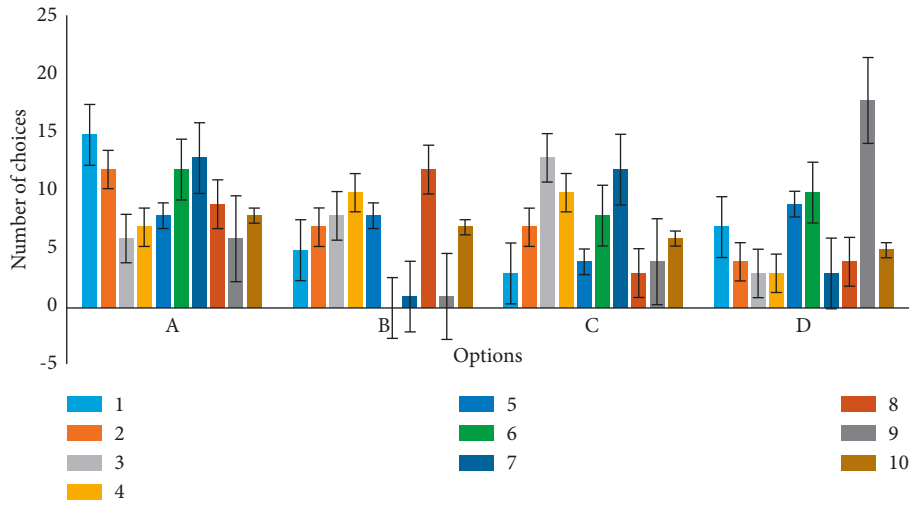

Figure 8: Visual results of students answering questions.

the proposed teaching method. The specific results are shown in Figure 7, from which it can be seen that all the proposed methods have achieved good teaching effects, and the maximum precision rate is 0.98, which also provides theoretical guidance and method reference for subsequent teaching task setting.

Figure 8 shows the comparison of the results of students taking multiple choice questions. It can be seen from the figure that the distribution of 10 students in the proposed system is relatively uniform and is consistent with the real selection results, thus proving the reliability and practicality of the proposed mixed teaching system again. Here, 10 samples were selected to conduct simulation experiments.

5. Conclusions

It is very important to cultivate talents suitable for the current social and economic development. In order to cultivate talents suitable for international trade employers, we should mainly start from the following steps: set occupation, knowledge, vocational skills, and vocational quality of the trinity of three-dimensional training vocational personnel curriculum construction, providing the design of training activities, which has a very important significance.

This paper is based on the big data processing technology: CNN model. It is of great significance to explore the applicability of mixed teaching mode in the teaching ability direction of normal university students. This paper combines theoretical research with practical research to explore the effectiveness of training. In the practical research, through text analysis and questionnaire survey, it is found that the mixed teaching mode has certain effect on the cultivation of this ability. Targeted to promote the development of students, through teaching practice to cultivate students' ability and literacy, the training process has a certain effect.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The author declares no conflicts of interest.

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Hindawi
Discrete Dynamics in Nature and Society
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Retraction

Retracted: Key Frame Extraction Method for Minors' Participation in Online Short-Form Video from the Perspective of Government Administration

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] Q. Wu, "Key Frame Extraction Method for Minors' Participation in Online Short-Form Video from the Perspective of Government Administration," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 8985219, 9 pages, 2022.

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Research Article

Key Frame Extraction Method for Minors' Participation in Online Short-Form Video from the Perspective of Government Administration

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With the progress of the Internet era, the audience scope of online short-form video and live broadcast platform is rapidly expanding. In this situation, the physical and mental health of minors is affected and harmed, and serious social problems have been caused. In view of the random images of minors participating in short online videos, the monitoring department should strengthen supervision and control and establish a good network atmosphere. The focus of surveillance is to identify short-form videos in which minors participate, monitor the content of short-form videos, and effectively identify minors. On the basis of analyzing and studying the existing methods of moving object extraction, the method of spatio-temporal information combined with geometric curve evolution is used to improve the effect of moving object extraction. Firstly, the time dynamic information of video frames is fully utilized and the initial contour of the target is segmented by high-order statistical algorithm. Based on the improved watershed algorithm, the spatial frames of the original image are segmented and the secondary contour of the target is obtained by combining the spatial and temporal information. The level set evolution algorithm is used to remove the noise and information void in the secondary target, and the final moving target is obtained. Through the extraction of key frames, it can effectively control the appearance of minors in short-form videos, which can actively guide the benign development of the platform, and put forward governance suggestions based on the perspective of government management.

1. Introduction

Short-form video is a kind of short video, which can be 15 seconds, 1 minute, 3 to 5 minutes. Short-form video is a new type of video, which can be shared in real time and seamlessly connected on social media platforms, mainly relying on mobile intelligent terminals to achieve rapid shooting, beautification, and editing. It integrates text, voice, and video, which can more intuitively and stereoscopically meet users' needs of expression and communication, and meet people's demands of display and sharing. With the development of the Internet era, the number and scope of Internet short-form video users have been expanding, among which minors account for a considerable proportion. At the same time, the network short-form video also has an important impact on minors. There are a large number of minors in the user group of online short-form video fans in China, but the cognitive ability of minors is weaker than that of adults and their self-discipline is relatively poor. Many web video publishers are using this feature to capture more attention and play. They do not hesitate to lower the moral bottom line, which leads to the status quo of the spread of short-form videos on the Internet, which presents the good and bad, and seriously endangers the social atmosphere. In addition, some publishers induce minors who lack self-control to consume through the reward function of short-form videos on the Internet and instil minors to reward their video content, taking advantage of which they collect large amounts of ill-deserved wealth [1–5].

There are a large number of minors in the user group of online short-form video fans in China, but the cognitive ability of minors is weaker than that of adults and their self-discipline is relatively poor. In the contents publicly displayed by minors in short-form videos on the Internet, it can

be seen that minor girls reveal sexual innuendo does not match their age through actions and words, and publish daily life of early marriage and pregnancy [6–8]. Underage students engage in online fights and violent fights between each other, showing off their personal behavior of dropping out of school and persuading others, minors in illegal occasions such as high consumption. Moreover, there are minors who spontaneously form so-called combinations of short-form videos on the Internet to release unhealthy video content on a large scale. These moral anomie behaviors are spread in the network short-form video, and even publicized and flaunted, which have deformed the immature three views of minors [7–10].

In view of the random images of minors participating in short online videos, the monitoring department should strengthen supervision and control and establish a good network atmosphere. The focus of surveillance is to identify short-form videos in which minors participate, monitor the content of short-form videos, and effectively identify minors. Minors belong to the key frame in the video, which can be effectively controlled by identifying the key frame [11–15]. A key frame is a key image frame that describes a shot, usually reflecting the main content of a shot. Therefore, key frame extraction technology is the basis of video analysis and video retrieval. In this paper, a fuzzy clustering algorithm is used to improve the stability of the application of key frame extraction. Firstly, the time series and dynamic information of the video can be kept through the shot detection of the video clip through the mutual information algorithm, and then the key frames in the shot can reflect the main content of the video shot better by the fuzzy clustering extraction. The initial cluster center and the number of clusters are needed for clustering calculation. In this paper, the density function method is used to determine the initial clustering center. The average entropy method is used to calculate the number of clustering, which ensures the parameterless operation of fuzzy clustering algorithm and the stability of clustering effect. Finally, the experiment proves that the key frame extracted by the system can better represent the video content and is conducive to video analysis and retrieval [16–18].

Video moving object extraction is the basis of video semantic analysis and a breakthrough to solve the problem of "semantic gap." This paper analyzes the current video motion object extraction methods in detail. On this basis, a moving object extraction method using spatio-temporal information combined with geometric curve evolution is adopted to improve the extraction effect of animation object. The final object is extracted through four steps, and the initial moving object space is obtained by high-order statistics algorithm. Aiming at the phenomenon of oversegmentation in watershed algorithm [19–21], the concept of adjacency graph is used to improve it, and the segmentation region and spatio-temporal information of video image frame are obtained. According to the proportion relation between motion and region, reserving information is determined and the quadratic moving object is obtained. The level set method is used to evolve geometric curves to obtain the final moving object. This method makes comprehensive use of time-domain and space-domain information, and retains the information of video image frame comprehensively. After the final evolution analysis, the moving object is better [22–24].

Based on the perspective of government management, this paper studies the current situation of minors' participation in online short videos and purifies the environment for minors' participation in the Internet. Through the results of key frame extraction, suggestions are put forward to manage network short video, improve the dynamic precision of government network monitoring, and help the government to consolidate and improve its management ability in network space.

2. Short-Form Video Structure

2.1. Video Hierarchy. Video is the most complex type of multimedia information. It is a comprehensive media information integrating image, sound, and text. It has the advantages of large amount of information and vivid form of expression. The video data can be structurally divided into video sequence, scene, shot, and frame from top to bottom (Figure 1). A frame is the smallest unit of video data, a still picture. The lens is the basic unit of video data. It consists of several consecutive frames of images taken continuously by a camera in time. There are two types of camera switching: abrupt change and gradual change. The mutation is a direct transition from one shot to the next. There is no time delay gradient in the middle, but some editing effect in space or time is added, and the previous shot slowly transitions to the next shot. There are mainly fade in and fade out, slow conversion and sweep conversion. A scene consists of scene of similar content, depicting the same event from different angles. Video sequences consist of many scenes and generally tell a complete story.

As can be seen from Figure 1, the higher the hierarchical structure of the video, the richer the content information contained therein, which means the higher the difficulty of processing. Therefore, top-down anatomical analysis is often used for video processing. Firstly, the video sequence is divided into multiple scenes by scene detection, and then each scene is divided into multiple scene by shot segmentation. Then, the key frame of each shot is extracted as the main content of the video sequence. In this process, scene detection, shot segmentation, and key frame extraction are involved because the lens is the basic unit of video data. At present, the more common method is to directly take the video clip as the unit, detect the shot first, and then extract the key frame without scene detection.

2.2. Extraction of Short-Form Video Key Frames. Key frame refers to the most important and representative image frame in the lens. It reflects the main content of a shot and is the basis for building a video sequence index. Using key frame technology to query, search, and browse, video database effectively can greatly reduce the amount of video data. It also provides a unified organizational framework for video processing. It also provides a unified organizational

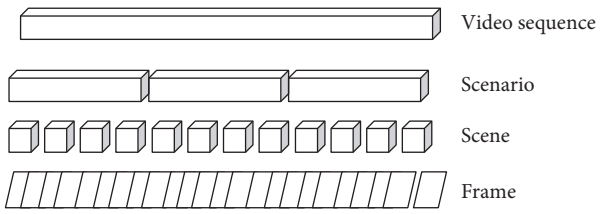

Figure 1: Hierarchical structure of video.

framework for video processing. Depending on the complexity of the shot content, one or more key frames can be extracted from a shot. Key frame extraction must be able to reflect the main content information in the shot more accurately. Secondly, the dynamic information of video sequence changes should be preserved to facilitate the indexing and management of video sequence. The traditional manual extraction method has high accuracy, but it is time-consuming and inefficient. At present, automatic detection technology is mainly used to extract key frames. Typical key frame extraction methods mainly include shot boundary-based method, content-based method, motion-based method, and clustering-based method. This paper proposes a key frame extraction method combining mutual information and fuzzy clustering. The method uses information entropy instead of Euclidean distance to calculate the similarity between frames and determines the number of clusters according to the average information entropy. The density function method is used to obtain the initial clustering center, which does not require users to input parameters related to clustering, so that the obtained key frames can not only better represent the main content of the lens, but also have good stability. Meanwhile, the time series and dynamic information of the video are maintained.

2.3. Traditional Key Frame Extraction Method. This method is based on shot boundary. In video sequences, shot boundaries are divided into two categories: shear and gradient. A shear is when a change occurs suddenly between two consecutive frames, while a gradient is when a change occurs between consecutive frames. Gradients are complex, including fading in and out, dissolving and erasing. At present, many researchers have proposed a variety of different lens boundary detection methods, such as calculating the pixel difference of the corresponding position of adjacent image frames, algorithm based on histogram difference, and method based on edge information. Through these methods, the first or last frame of the shot is taken as the key frame of the shot. The principle of this method is relatively simple, regardless of the content of the shot, the number of key frames is determined, but the effect is not stable. Since the first and last frames of each shot may not always reflect the main content of the shot, the extracted key frames are not representative enough.

The method based on content analysis is to extract key frames by changing visual information such as color and texture of each frame. The classical methods are frame average method and histogram average method. Frame averaging method is to calculate the average pixel value of all frames at a certain position in the lens and then take the frame whose pixel value is closest to the average value as the key frame. Histogram averaging method is to average the statistical histogram of all frames in a shot and then select the frame closest to the histogram as the key frame. These two methods are simple to calculate, and the selected key frames have average representative significance. However, selecting a fixed number of key frames cannot describe a shot with multiple objects moving. Zhang et al. [25] proposed to extract key frames based on the image content information such as frame color and motion. The basic idea is to use the first frame as a key frame. The other key frames are then determined according to two criteria: first, the standard based on color histogram, and the subsequent frames are sequentially compared with this frame. When the distance between the first frame and the previous key frame exceeds the value, the first frame is used as the new key frame. This is done until the last frame. Second, based on the criteria of motion, for zooming scene at least the first and last frames are selected as key frames. One shows global information, the other shows local information in focus, and for panning scene, frames where the overlapping information is less than the closed value are selected as key frames. The method is more flexible, allowing the selection of a corresponding number of key frames depending on the degree of change in the content of the footage, but the algorithm only calculates distances to adjacent frames, which is prone to missed detection and is prone to redundancy when there is a lot of camera movement.

This is an approach based on motion analysis. A representative algorithm for extracting key frames based on motion information is the optical flow method proposed by Nurse, which first calculates the optical flow for each frame and then calculates the amount of motion based on the optical flow. By finding the local minimum of the amount of motion, the frame in which it is located is used as the key frame. This method is based on the analytical calculation of the amount of motion in the footage and the selection of key frames at their local minima, reflecting the stillness of the video data.

Specifically, first the usage calculates the optical flow by summing the modes of each pixel optical flow component as the motion $M(k)$ for the kth frame, i.e.,

$$M(k) = \sum_i \sum_j \left|O_x(i, j, k)\right| + \left|O_y(i, j, k)\right|, \quad (1)$$

where $O_x(i, j, k)$ is the component X of the optical flow of pixel (i, j) in frame k and $O_y(i, j, k)$ is the component Y of the optical flow of pixel (i, j) in frame k. The local minimum of $M(k)$ is then found. Starting from $k = 0$, the $M(k)$ and k curves are scanned to find local maxima $M(k_1)$ and $M(k_2)$, requiring the values of $M(k_1)$ and $M(k_2)$ to differ by at least N % (empirically set, $N\% = 30\%$ is desirable). If $M(k_3) = \min(M(k))$, $k_1 < k < k_2$, then k_3 is taken as the key frame. The method allows the selection of the appropriate number of key frames according to the structure of the shot, but it relies on local information, is not very robust, requires a large

amount of computation, and is less time efficient, and the local minima in the method are not always accurate.

Based on clustering method, the clustering algorithm is a very effective technique widely used in pattern recognition, speech analysis, and information retrieval. The basic idea is to start with an initialized cluster, then determine whether the current frame is classified as that class or as a new class center based on the distance between the current frame and the class center, and after classifying the frames in the shot, take the frame closest to the class center in each class as the key frame. Among the many clustering algorithms, mean clustering and fuzzy mean clustering are two well-known clustering algorithms. The classification of the mean clustering algorithm is clear, with each sample being assigned to an entry belonging to only one cluster. The classification of the fuzzy mean clustering algorithm is fuzzy, with each sample having a membership function for each cluster. These clustering methods are effective in eliminating inter-shot correlations and obtaining more desirable key frames, but do not effectively maintain the temporal order and dynamic information of the image frames within the original shot.

According to the analysis of key frame extraction methods, each method has certain advantages and disadvantages. In comparison, the key frames extracted based on clustering methods are more effective, but according to the analysis of the theoretical knowledge related to fuzzy clustering, the results of clustering are usually closely related to the input parameters such as the number of clusters and the initial cluster centers. These parameters are also often difficult to decide on, especially with datasets of high-dimensional objects like images, making the quality of the clustering difficult to control. In addition, metrics using Euclidean distance are sometimes not stable enough in noisy environments, and the eye is too sensitive to the shape and size of the class.

In this research, the concept of fullness in information theory is applied to the process of fuzzy clustering classification and metrics, and an improved key frame extraction method is used. The stability of the fuzzy clustering algorithm in the key frame extraction application is improved using mutual information quantity, as shown in Figure 2.

Firstly, the shot boundary of the video sequence is detected by using the mutual information between adjacent frames, and the video fragment is divided into several subscenes. Then, the improved fuzzy clustering method is used to extract key frames in the shot. In the process of clustering analysis, there is no need of any user input parameters related to clustering model, but according to the density function method to determine the initial clustering center, and the use of the average office value to initialize clustering number, it is beneficial to maintain the stability of the clustering effect, and mesh using inter-frame office value will also be able to keep the time sequence of video and dynamic information. The obtained key frame can better represent the main content of the video sequence.

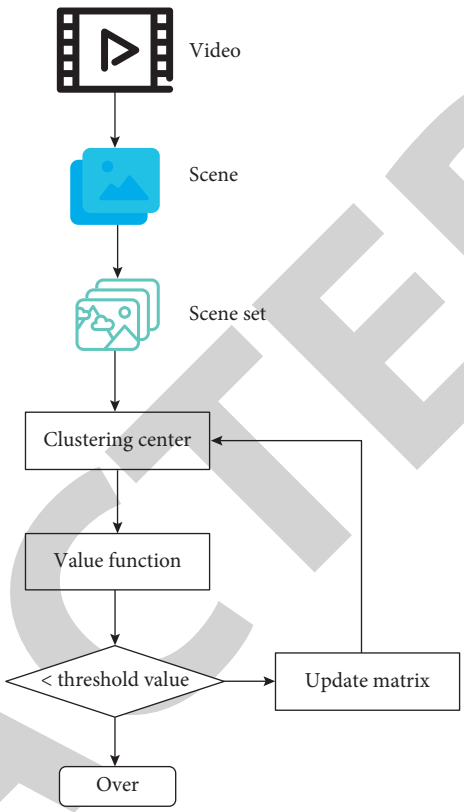

Figure 2: Key frame extraction method.

3. Motion Frame Extraction in Video

The difficulty of video moving object extraction is mainly reflected in two aspects. Due to the rich and colorful real world, the content of video scene is extremely complicated and diversified, so it is difficult to find a general method to extract moving objects from various videos. The definition of video object is a kind of high-level semantic description, which is difficult to be described by low-level visual features such as color, texture, and edge. At present, there is a "semantic gap" research bottleneck in the field of video image, which means that the current computer vision technology is far from reaching the ability of human visual recognition.

Despite the difficulties, many scholars have made great achievements in the field of video segmentation. According to the different information used in the extraction process, video object segmentation algorithms can be divided into three categories: spatial-domain segmentation technology based on within frames, temporal domain segmentation technology based on between frames, and spatial and temporal information fusion. According to the degree of manual participation, it can be divided into automatic segmentation method and semi-automatic segmentation method.

Based on inter-frame difference method, background subtraction method, and optical flow method, a moving object extraction method (IBO) combining spatio-temporal information and geometric curve evolution is proposed in this paper. Firstly, the high-order statistics algorithm is used to detect the motion regions of two adjacent frames in time domain, and the initial motion contour is extracted after morphological changes. Then, the improved watershed

algorithm is used to segment the image into regions in space domain. Finally, the better motion object contour can be obtained by combining spatio-temporal information. Finally, the contour of the moving object is taken as the initial contour of the geometric active contour model in view of the existing void, redundant or missing image information.

3.1. Geometric Curve Evolution. The time-domain information segmentation technology and spatial-domain information segmentation technology, respectively, make use of the in-frame and inter-frame information of the video. For a complete video sequence, they are only part of the information and can only reflect part of the characteristics of the video scene, so there are certain limitations. The spatio-temporal joint segmentation algorithm combines the moving object identified by time-domain segmentation and the result obtained by space-domain segmentation to get the final moving object, which has more precision and effect. Figure 3 shows a moving object extraction method using spatio-temporal information combined with geometric curve evolution.

IBO method can be divided into four steps. In the time domain, the motion information between two adjacent frames is calculated by high-order statistical method to obtain the binarized difference region, and then the morphological method is used for filtering. Finally, the initial motion contour is obtained by scanning the filled region. In spatial domain, the watershed algorithm is used to perform initial image segmentation for video frame images, and then the region fast merging method based on adjacency graph is used to reduce the oversegmentation phenomenon and get better region division effect. Combined with the comprehensive information of the previous two steps, according to the proportion value of motion information and regional information, determine the contour of the quadratic moving object. Aiming at the problems of image noise and redundant information of the quadratic moving object, the geometric active contour model combined with the spatial edge information is used to evolve the accurate moving object.

3.2. Frame to Frame Difference Method. In IBO method, the difference between frames is used to extract the information of moving objects. Frame difference method is a segmentation algorithm based on changing region detection. In the image sequence, the background of two adjacent frames is relatively unchanged, while the moving object changes. Frame difference method is an image segmentation method that separates the moving object from the stationary background by detecting the changing and invariant regions of the adjacent frames of the image sequence. The outstanding feature of IBO method is that it is simple to implement and fast to calculate, but inter-frame difference method is less affected by illumination changes because the ambient brightness changes between adjacent frames are very small.

Assume that two consecutive frames of image I_{k-1} and I_k, and the grayscale of their pixel points are, respectively, represented by $G_{k-1}(x, y)$ and $G_k(x, y)$; then, the frame difference image of these two frames can be expressed as follows:

$$D_k(x, y) = \left|G_k(x, y) - G_{k-1}(x, y)\right|. \tag{2}$$

Binarize the obtained frame difference image $D_k(x, y)$:

$$R_x(x, y) = \begin{cases} 255, & D_k(x, y) > T, \\ 0, & \text{others}, \end{cases} \tag{3}$$

where T is the threshold value. In binary difference images, a pixel with a gray value of 255 is considered as a point on a moving object.

Simple thresholding method can roughly separate moving target and background, but it requires presetting min value and poor flexibility, and it is difficult to filter noise interference, so it needs the next processing to separate moving target. If the grayscale difference between consecutive frames is nonzero, there may be two reasons for moving target changes and background noise. Under the condition of video pause, background noise mainly includes random noise, brightness change, slow change of background texture, etc. These noises have smaller amplitude compared with the gray value of non-noise image reflected by the target being photographed.

In addition, the random process distribution of thermal noise, photoelectronic noise, and photosensitive particle noise is a stationary random process with ergodicity in theory, so the statistics of these noises all conform to Gaussian characteristics, and the moving target has a strong structure. Therefore, the problem of separating moving object and background can be transformed into the problem of separating non-Gaussian data from Gaussian data.

Set the small window of 3×3 centered on (x, y) in frame difference graph $D_k(x, y)$; then, the fourth moment $m_d^{(4)}(x, y)$ and second moment $m_d^{(2)}(x, y)$ of point (x, y) are defined as follows:

$$m_d^{(n)}(x, y) = \frac{1}{3 \times 3} \sum_{(s,t) \in \eta(x,y)} \left(D_k(s, t) - m_d(x, y)\right)^n, \tag{4}$$

where $\eta(x, y)$ represents the 3×3 field centered on the current pixel and m_d is the average value of the differential gray image between frames in the window.

$$m_d(x, y) = \frac{1}{3 \times 3} \sum_{(s,t) \in \eta(x,y)} D_k(s, t). \tag{5}$$

In general, direct estimation of the fourth-order cumulants of random distribution variables is tedious, so the relationship between the fourth-order cumulants and the fourth-order moments $m_d^{(4)}(x, y)$ and two moments $m_d^{(2)}(x, y)$ can be used to solve the problem.

$$\mathrm{HOS}_4(x, y) = \begin{cases} 0, |\mathrm{HOS}_4(x, y) \le \mathrm{TH}, \\ 1, \text{ others}, \end{cases} \tag{6}$$

where TH is the set threshold, as shown in the following formula.

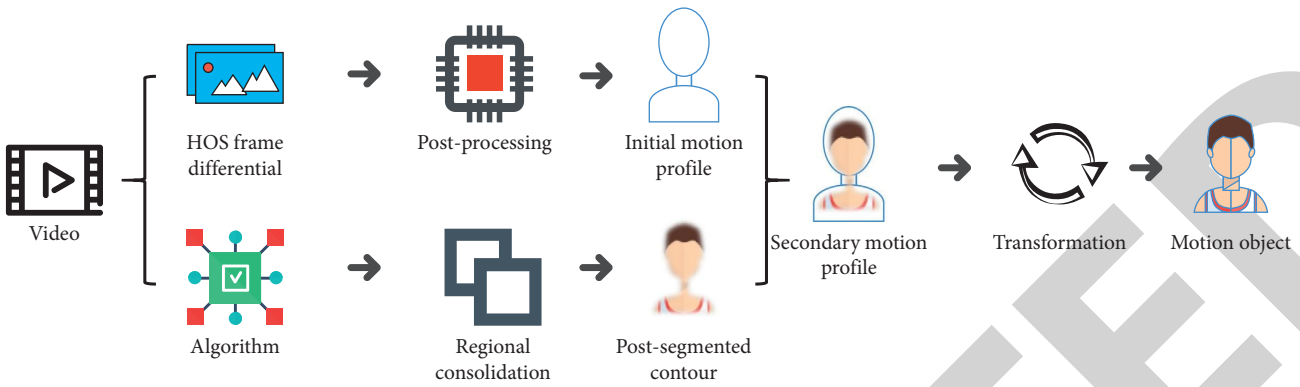

Figure 3: Moving object extraction process.

$$\mathrm{TH} = c \times \frac{1}{N} \sum_{i=1}^{N} \mathrm{HOS}_4, \tag{7}$$

where N is the number of pixels in the whole image and c is the scale factor.

3.3. Region Fast Merging Algorithm. Watershed segmentation algorithm has a wide range of applications and good segmentation results when the SNR and consistency of images are satisfied. However, due to the existence of image noise and the local irregularity of gradient, the image after watershed segmentation is easy to produce excessive; that is, the segmentation is too detailed. In this paper, a similar region merging algorithm is used to deal with over-scraping phenomenon. The algorithm is based on the assumption that each pixel is an independent image region or belongs to a segmented region, and the region is adjusted and merged by the similarity degree of the histogram of the region, so that the similarity degree between the regions is kept at a certain distance.

Make μ_i, σ_i $(i = 1, 2, \ldots, m)$, respectively, represent the mean and standard deviation of pixels in the region, and Ni is the number of pixels in the region. Then, the standard for the combination of two adjacent regions based on statistics is as follows:

$$|\mu_1 - \mu_2| \le \alpha, \tag{8}$$

$$S = \frac{|\mu_1 - \mu_2|}{\sqrt{\sigma_p^2 \left((1/n_1) + (1/n_2)\right)}} \le \beta, \tag{9}$$

where α and β are the setting parameters given in advance by the statistical characteristics of the image. If $\sigma_p^2 = 0$, any two regions satisfying equation (8) are considered similar; if $\sigma_p^2 = 0$, the two regions satisfying equation (9) are considered similar.

If there is more than one similar adjacency region, the most similar adjacency region is merged. Then, a new region is selected from the remaining regions that did not participate in the merging until all similar adjacent regions in the image are merged.

However, due to the large number of regions obtained by initial watershed segmentation, the common similar region merging algorithm is limited in speed due to the large amount of computation in the process of seeking the optimal merging region through iterative operation. In order to improve the speed of region merging, a region merging algorithm based on adjacency graph is adopted in this paper on the basis of image gradient preprocessing to avoid iterative operation and corresponding data update and reduce the complexity of region merging. Each connection in a region adjacency graph has two states, which determine the adjacency relationship between a region and the current processing region. The image region adjacency graph is stored in a table that is updated with the region adjacency relationship during region merging. The update process is shown in Figure 4.

As can be seen from Figure 4, regions A and B are relatively similar. A∗ is the new region of A and B, so the adjacent region will be changed accordingly.

Curve evolution is an effective method for image segmentation and video object tracking. The active contour algorithm was proposed in the early stage, but the model itself has some defects, such as sensitivity to the initial position, easy to fall into local extremum, and cannot automatically carry out topological transformation. Although people have made some improvements to the basic active contour model, it has not fundamentally solved the problem. A geometric active contour model based on level set, also called curve evolution model, is based on the theory of curve evolution and the idea of level set. Its principle is to express the plane closed curve implicitly as the level set of three-dimensional surface function, that is, the set of points with the same function value, and then solve the curve evolution implicitly through the evolution of the surface. The most important characteristic of this model is that it does not depend on the parameterization mode of active contour model, so it can deal with the change of topological structure of curve naturally. However, these characteristics are inseparable from level set theory. Geometric active contour model and level set method complement each other.

Figure 4: Adjacency diagram before and after merging.

4. System Construction

A portal-based content-based key frame extraction system is constructed using VC6.0 platform, and the system structure is shown in Figure 5.

As can be seen from Figure 5, the system is mainly composed of five parts: video decoding, shot detection, key frame extraction, video playing, and shot playing, among which the first three modules are video core processing modules. Video playback and shot broadcast are the auxiliary functions of the system, mainly for the convenience of users to browse and view when using the system. The former is responsible for playing the whole video sequence, while the latter mainly plays and browses for a certain shot segment or the shot selected according to the key frame. In the core module, the video decoding first decodes the newly added MPEG-4 (compression coding standard) compressed video stream, then segments the whole video sequence to get the video shot set, and then extracts the key frames of each shot to get the main content of this shot.

The moving object extraction method using spatio-temporal information combined with geometric curve evolution adopted above builds a moving object extraction subsystem through the platform, and its system structure is shown in Figure 6.

As can be seen from Figure 6, the subsystem of moving object extraction is mainly composed of contour extraction, watershed segmentation, and geometric curve evolution. Contour extraction means that in the time domain of video sequence, the frame difference image between two adjacent frames is calculated by high-order statistics, and then the binarization moving contour is obtained by morphological processing and connectivity scanning filling, which is mapped to the original image frame to obtain the initial moving object. The purpose of watershed segmentation is to divide the image into multiple regions according to the spatial information of the image frame and solve the oversegmentation phenomenon by using the region fast merging algorithm based on adjacency graph. Combining with the initial moving object, the image cable ratio method is used to determine the cubic moving object. The main function of geometric curve evolution is to eliminate the noise by level set method in view of the image noise and cavity of the secondary moving object, so as to obtain the final moving object.

According to the demand of video material retrieval, a prototype subsystem of video material retrieval is constructed in this paper. After extracting key frames and moving objects, the video material is stored in the server

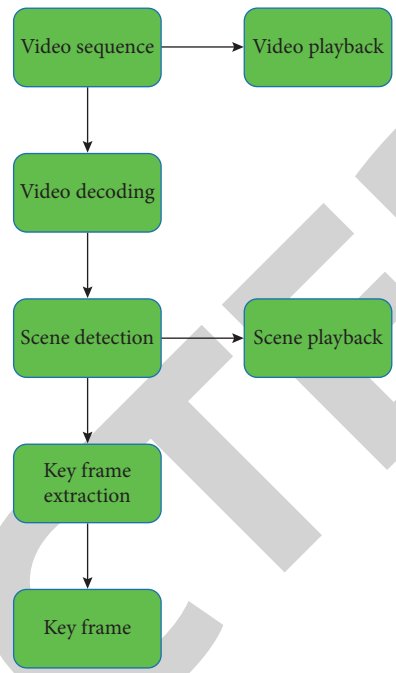

Figure 5: Key frame extraction subsystem structure diagram.

image library in the format of pictures, and the video information description and the color, shape, texture, contour, and other characteristic information of key frames and moving objects are saved in the material database. Its system structure is shown in Figure 7.

Keyword query: semantic automatic extraction has "semantic gap" problem. The solution is to obtain the initial description set of keywords by manual annotation, and then train and modify keywords by using relevant feedback technology so as to achieve the purpose of automatic query of keywords.

Main tone query: color is the most significant feature of color image, and users can easily remember the color features of any object and give one or several main tones of the image. Color is the basic element of an image, such as blue, by describing an image with the sea or sky. In the same way, color is important to describe an animated image. Generally, bright colors are used to match similar things, and the corresponding things will be matched when querying the color.

Sketch query: hand-drawn sketch is an externalization and communication of a common human way of thinking. Sketches express and convey the concept of visual space, and image, intuitive, easy to understand and remember, and more suitable for reasoning and conception. Local objects in a sketch without a background grid tend to be clearer than in an image.

Example query: sample sources include the system to randomly give samples and users to submit samples. In the former, a group of image training samples is randomly given by the system, and users are allowed to evaluate the group of images and select images similar to their retrieval

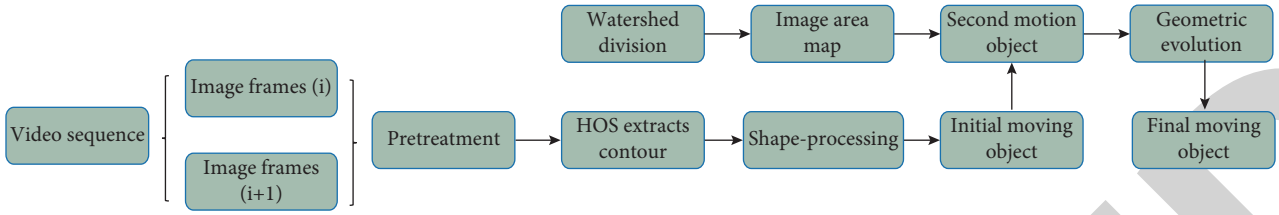

Figure 6: Structure diagram of moving object extraction subsystem.

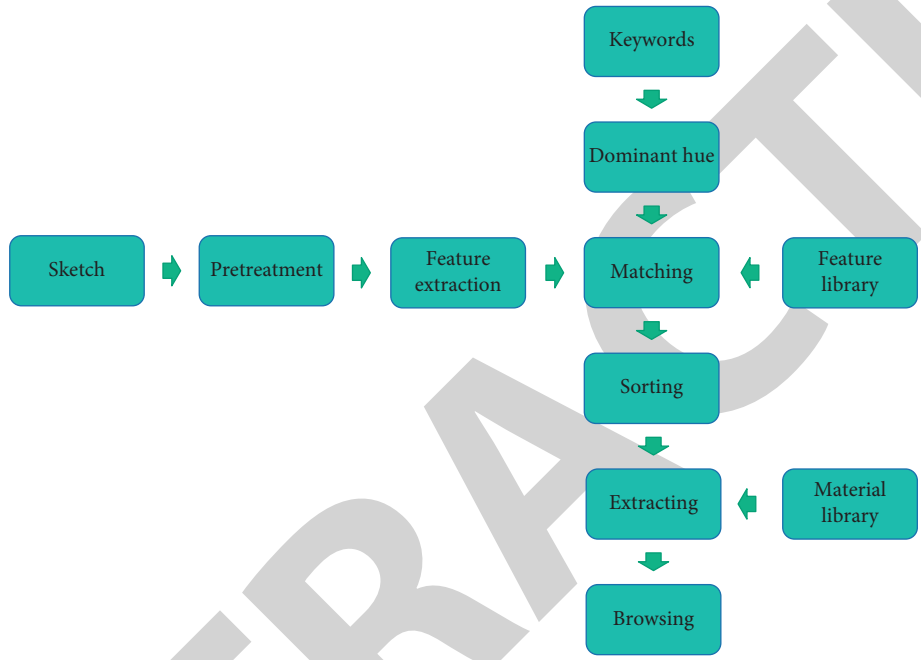

Figure 7: Video material retrieval subsystem structure diagram.

requirements. Then, the images selected by users are analyzed, and other similar images are retrieved through the calculation of information lineal between images. In the latter, users upload a similar image that they are interested in, and the system analyzes and retrieves relevant materials.

5. Conclusion

In this paper, the key frame technology of short video extraction is used to effectively control the behavior of minors participating in online short video. Based on the existing key frame extraction technology, a new key frame extraction technology (IBO technology) is proposed. In the method of key frame extraction, the initial cluster center is determined by the density function method and the number of clusters is determined by average information entropy. This method does not require users to input any parameters related to the clustering pattern, and can automatically complete the clustering process and maintain the stability of the clustering effect. This method can effectively extract key frames of minors' participation in online short video and help the government to effectively monitor online short video platforms.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

This paper is completed by Qiuli Wu, and the contributions of the author are introduced as follows. Conceptualization, data curation, formal analysis, investigation, methodology, project administration, resources, software, supervision, validation, visualization, writing—original draft, and writing—review and editing are completed by Qiuli Wu.

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Hindawi
Discrete Dynamics in Nature and Society
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Retraction

Retracted: Applications of Deep Learning in the Evaluation and Analysis of College Students' Mental Health

Discrete Dynamics in Nature and Society

Received 15 August 2023; Accepted 15 August 2023; Published 16 August 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] L. Zhou, "Applications of Deep Learning in the Evaluation and Analysis of College Students' Mental Health," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7555255, 10 pages, 2022.

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Research Article

Applications of Deep Learning in the Evaluation and Analysis of College Students' Mental Health

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It is an important research direction of mental health discipline in the current era to evaluate and analyze college students' mental health by using deep learning methods and form visual data characteristics and analyzable discipline conclusions. Based on this, this paper carries out the research method of convolutional neural network by using the research concept of deep learning. Firstly, the paper summarizes the fast intelligent analysis model based on the convolutional neural network system algorithm, classifies and summarizes the unique characteristics of college students' mental health, and uses the convolutional neural network processing model to analyze, evaluate, and observe college students' mental health combined with the big data theory. Secondly, through the expansion and utilization of multi-layer neuron self-coding neural network, the psychological health of college students is evaluated and analyzed in the psychological discipline, the discrete data structure is established by using the relevant psychological data, the psychological behavior of college students is analyzed, summarized, and classified, and the data model is filled to judge the mental health status of college students. Finally, through the design of confirmatory experiments, the results show that the college students' mental health evaluation and analysis model based on deep learning is more efficient in individual data analysis. Compared with the mode of analyzing college students' mental health through in-depth learning, the traditional psychological research method has a large workload and is not suitable for the universality and consistency of college students. This paper solves this problem and provides a reference for relevant research.

1. Introduction

In terms of psychology, according to the current situation, China is in the primary stage of development. In the next 15–30 years, psychological research will be an important research direction in China's scientific research field, such as psychological types, influencing factors, the relationship between psychology and behavior, and the relationship between behavior and psychology. These directions are not perfect or specific for our research. Although we have some psychological research theories and methods, they are introduced from abroad from beginning to end. Whether they are suitable for China's national psychology, comprehensive, and perfect needs to be verified [1]. The application of deep learning in college students' mental health is analyzed and summarized through convolutional neural network, multi-layer neuron self-coding neural network, and big data analysis. On this basis, relevant data models are established to evaluate and predict college students' mental health, and predict and intervene their relevant dangerous psychology and behavior [2]. The core content of college students' mental health evaluation and analysis is to find the commonality and correlation of students' psychological characteristics by analyzing a large number of different students' psychological states and psychological thinking, summarize and classify them, modify and improve the accuracy and adaptability of the existing data model according to the data characteristics, and optimize and process the model by taking advantage of the large amount of data [3]. If such a huge amount of data cannot be analyzed and evaluated according to the current psychological analysis concepts and methods, it is difficult to form relevant models and systems, and it is more difficult to evaluate and analyze the huge group of college students [4].

According to the differences of national culture, social customs, family status, and economic development level of various countries in the world, this paper makes a quantitative analysis and judgment on the quality of college students' mental health status. In addition, through the analysis of large amounts of data, the accuracy of individual data can be reduced. The fourth chapter uses the established model and algorithm to judge college students. At the same time, the research model and data algorithm are verified with reference to the nonmechanical human judgment of college students' mental health by mental health tutors and psychology-related researchers. The results show that the research model and data structure of college students' mental health after the combination of convolutional neural network, multi-layer neuron self-coding neural network, and big data analysis algorithm are not much different from the authoritative judgment of psychological tutors and counselors in analyzing the accuracy of college students' mental health.

This paper develops a complete theoretical model and data algorithm to study the mental health status of college students, which is divided into the following four parts. The first part introduces the background, necessity, and research arrangement of college students' mental health; the second part analyzes the research theories, research methods, and research results of college students' mental health in-depth learning at home and abroad, as well as the algorithms and neural networks used, and briefly introduces them. The third part establishes the learning judgment function of college students' mental health by combining convolutional neural network and multi-layer neuron self-coding neural network.

The method of this paper can adapt to the current large group of college students. Combined with relevant psychological theories and research methods, the model has its own unique adaptability and universality. This is a major innovation in psychological research. For individual college students, they can objectively analyze and evaluate their mental health. Compared with the model of analyzing college students' mental health through in-depth learning, the traditional psychological research method has a large workload and is not suitable for the universality and consistency of college students. This paper adopts the research method of combining convolutional neural network, multi-layer neuron self-coding neural network, and big data analysis, which is a great innovation in the field of psychology.

2. The Related Work

At present, in the research process of mental health assessment and analysis of a large number of college students in China, due to the current situation of different regional cultures and different family economic levels, there will be problems of analysis difficulty and inaccurate analysis [5]. It is difficult for scholars at home and abroad to deal with the group of college students in the research of psychology, because this stage of college students is a stage of rapid change in life and prominent life process, so the research situation is more one-sided and concentrated, and there is no general, comprehensive, universal, and all-round research on college students' mental health [6]. Biswas et al. found that the current mental health status of college students is closely related to their environment, their own pressure, man-machine communication relationship, family economic level, and other factors. Therefore, they put forward the psychological concepts and research methods of native family and their own environment, which plays an important role in the formation and improvement of the model [7]. Casciato et al. put forward a concept and method of college students' mental health evaluation and analysis by analyzing the relationship and differences between college students' mental health and the region where college students are located, according to the economic development level of the region where college students are located and the economic situation of their original family, but it is not perfect and systematic [8]. Gruber et al. found that college students in different schools do not pay much attention to their own mental health evaluation and analysis. Students at different levels often pay great attention to mental health evaluation and analysis. Students at higher levels often pay more attention to this matter and have conducted simple psychological evaluation on themselves through some ways and channels. However, students in lower level schools have less awareness of mental health and even do not care about their mental health status [9]. The research results of Vivaldi et al. show that the college students' mental health research model and data structure combined with convolutional neural network, multi-layer neuron self-coding neural network, and big data analysis algorithm have a high level of evaluation and analysis ability for college students' mental health, but they often do not have a high degree of matching and fit for some college students with special thoughts and psychology [10]. Schilaty et al. have conducted research on relevant aspects and fields for the purpose of improving the application scope, value, and accuracy of deep learning in the field of college students' mental health. The main reference contents and aspects are the quantifiable data field and scope of the combination of college students' mental health and deep learning, and the general situation of mental health development and the commonness of psychological process of college students at different levels on the premise of considering the original family and family economic level, so as to find aspects that can be improved by in-depth learning [11]. Algohi et al. have reformed and improved the application of deep learning in the evaluation and analysis of college students' mental health in a wide range by using contemporary convolutional neural network and improved some aspects of deep learning methods through convolutional neural network, so that it can adapt to the particularity of college students' mental health evaluation and analysis and the general adaptability of different students, but did not consider the big data analysis algorithm. The general adaptability of college students is not perfect and accurate [12]. Zenas et al. have made in-depth research on the specificity of college students' psychological activities and ways of thinking, obtained a research theory different from the previous psychological research methods, combined the previous research theories and methods, and made a

theoretical analysis of their research results and non-substantive changes in some aspects, so that their research theory has been applied in the field of psychology and in-depth learning for the first time. This set of theory was used to comprehensively evaluate and analyze the mental health of relevant college students, and considerable analysis data were obtained [13].

To sum up, it can be analyzed and concluded that the current research on in-depth learning in the field of psychology has some shortcomings, such as poor adaptability, difficult to combine the environment, family situation, regional characteristics and folk culture of college students, and the ability to evaluate and analyze special individuals in all college students which needs to be improved [14–16]. At the same time, the existing college students' mental health analysis and evaluation system is difficult to be universal for a large group of college students, and it is difficult to cover all the existing college students. It is difficult to distinguish some students with special situations from ordinary students, and the evaluation and analysis are often inaccurate [17–19]. While analyzing and evaluating the mental health of college students, the ability of self-correction and self-feedback repair of model and data structure needs to be improved [18].

3. Methodology

3.1. An Arithmetic Model for Analyzing and Evaluating College Students' Mental Health Using Deep Learning Methods and Theories. College students' psychological problems can be divided into two categories: one is general growth psychological problems, which tend to have psychological obstacles but are not serious, which is the main problem of college students' psychology. The other is the emergence of psychological barriers of varying degrees. The psychological problems of growth mainly include the problems of environmental change and psychological adaptation, and the psychological problems caused by improper adjustment of learning psychology. There are psychological and behavioral deviations in interpersonal communication, love, and sexual psychology caused by the relatively weak forging ability of emotional control, self-cognition, personality development, and will quality.

Deep learning is a neural algorithm based on convolutional neural network in the field of computing. It completes the understanding and application of psychological data through reading, analyzing, learning, and reinforcement learning of neural data, converts its own psychological data into another form of data, and then makes repeated analysis of psychological data by using the repeated analysis characteristics of algorithm structure. Finally, the characteristics of psychological data they understand are stored in the data structure, and then the data conclusions are transformed by visualization tools [20]. Convolutional neural network algorithm is founded according to the relevant theories of early deep learning. It is based on the analysis and understanding of neural network, combined with the multidimensional and multifaceted operation theory and operation strategy in the fields of mathematics, algorithm, and psychology. It can realize the compound operation in multiple fields and plays a great role in the evaluation and analysis of college students' mental health [21]. The existing analysis mode and evaluation system of college students' mental health are practical operations based on the learning methods and modes of psychological research in previous studies, which often do not have universal authenticity and objectivity. There are also many loopholes and deficiencies in the analysis and evaluation of college students' mental health [22]. After considering the multiple complex analysis algorithms and data structures based on multi-layer neuron self-coding neural network and big data statistical analysis, the accuracy and universal adaptability of the model have made a qualitative leap and improvement. Combined with the self-correction and self-error data correction of deep learning, the test data feedback of college students' mental health analysis and evaluation in the later stage also shows that everything is normal [23].

After considering the above various factors and viewpoints, this paper decides to comprehensively consider various factors and theoretical methods such as convolutional neural network, multi-layer neuron self-coding neural network, and big data statistical analysis when studying the analysis and evaluation of college students' mental health using deep learning. In the process of building the model, psychological theories and viewpoints should be given priority. Taking the above views as auxiliary considerations, this paper makes an in-depth application and in-depth practice of in-depth learning in the analysis and evaluation of college students' mental health, combined with the existing application examples and relevant algorithm models of in-depth learning in the analysis and evaluation of college students' mental health, draws its merits, improves its shortcomings, and corrects many of its disadvantages and wrong directions [24].

3.2. The Construction Process of the Application Model of Deep Learning in the Analysis and Evaluation of College Students' Mental Health. After applying the self-convolutional neural network algorithm to the field of psychology and establishing the relevant algorithm model and data structure, it is necessary to consider the impact and effect of multi-layer neuron self-coding neural network and big data statistical analysis on college students' psychological analysis and evaluation, so as to avoid repetition and the effect in the opposite direction. First, analyze and compare the common points of convolutional neural network algorithm and multi-layer neuron self-coding neural network algorithm, judge whether there will be contradictions and errors [25], analyze the same algorithm structure and effect, make full use of it in the new model, the data structures and algorithms with the same effect are directly presented in the new data model, different data algorithms and data structures need to be analyzed again, judge its effect and conditions of use, and comprehensively consider many aspects [26]. When combining the two fields of in-depth learning and the analysis and evaluation of college students' mental health, we should

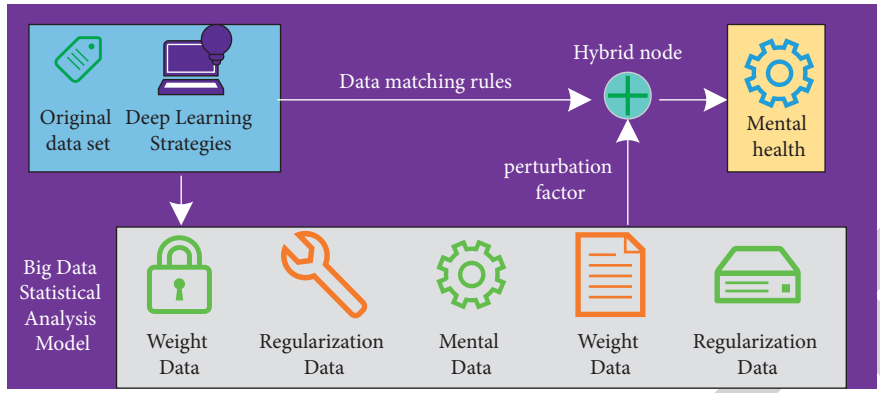

Figure 1: The construction process of the application model of deep learning in the analysis and evaluation of college students' mental health.

first consider the integrity, rationality, applicability, and condition compliance of the data structure, the universality, particularity, and independence of college students, and complete the visual processing and operability of the model. The process is shown in Figure 1.

In the process of analyzing and evaluating college students' mental health by using deep learning, the general process can be understood as three links with different characteristics and different emphasis directions:

The first part is to understand the commonness and difference of the analysis and evaluation of different college students' mental health under the same data structure and algorithm model [27]. In the theoretical model of deep learning, firstly, the operation structure and processing model of convolutional neural network and multi-layer neuron self-coding neural network are used to analyze the mental health of college students, then the data structure obtained from the analysis is arranged, and the big data analysis theory and method are used to conduct secondary analysis, so as to find the commonness of most college students' mental health. Some college students' mental health data that are not common are isolated and specially processed, and the following expression is obtained:

$$R(x) = \frac{\sqrt{P_1 c^{\delta\beta x}/(c-1)^{\alpha x}}}{\sum_{i=0}^{k} P_2 x_i}. \quad (1)$$

Among them, the universal information data of college students' mental health are represented by P_2, the special information data are represented by P_1, the analysis attribution is c, its discrete variable is δ, and the standard quantitative value is 1.

Step 2. in the deep learning analysis method, it is necessary to visually operate and process the special information data and retain the data to obtain the relevant function at this time:

$$R'(x) = \left| \sum_{i=1}^{k} P_i - \frac{\sqrt{P_1 c^{\beta x}/(c\phi-1)^{\alpha x}}}{\sum_{i=0}^{k} P_2 x_i} \right|. \quad (2)$$

The generalized mental health data information of college students is represented by α, and the specialized data information is represented by β. All the data belong to c, its dispersion coefficient is ϕ, and the standard quantitative value is 1. After a different data processing, it is necessary to conduct discrete analysis on relevant data in combination with big data analysis theory to eliminate the influence of some disturbing factors and wrong data. The function expression is

$$R''(x) = \left| \frac{\sum_{i=1}^{k} (P_i - x)^{i\phi}}{\sqrt{\left(c^{11}\phi + c^{22}(1-\phi)\right)}} - \frac{\sqrt{P_1 c^{\beta x}/(c\phi-1)^{\alpha x}}}{\sum_{i=0}^{k} P_2 x_i} \right|. \quad (3)$$

After completing the discrete transformation analysis and processing, it is also necessary to determine the type of data structure. The evaluation and analysis model construction process of deep learning theory on college students' mental health is shown in Figure 2.

3.3. Deviation Analysis and Application of Data Structure and Data Model in College Students' Mental Health Analysis and Evaluation. Although the current data structure and model can analyze and evaluate the mental health of ordinary college students at a shallow level, if it is necessary to conduct in-depth analysis, it needs to be reasonably deepened and processed. It is necessary to limit and distinguish the applicable conditions of the data structure and model in some aspects, and carry out reasonable error analysis and data evaluation on the data structure and model on a certain basis. The corresponding in-depth data analysis and processing correlation analysis model is obtained, and its application level is more in depth [28]. The hierarchical correlation display is shown in Figures 3 and 4.

From the data conclusions in Figures 3 and 4, it can be concluded that under the condition of using the initial model, with the increase of research depth, the degree of deviation of college students' mental health data from the center is higher and higher, while under the corresponding conditions, the degree of deviation of data under the condition of using the deepening model is often much lower than the previous model, which is the relevant role and

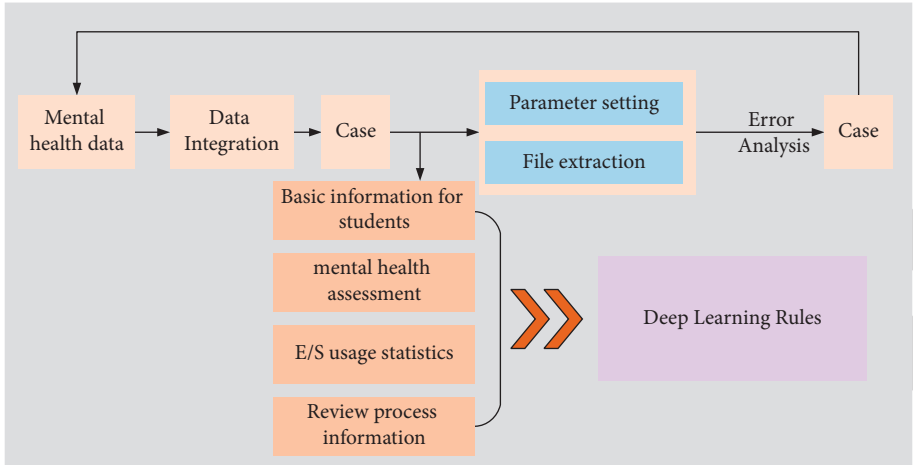

Figure 2: The evaluation and analysis model construction process of deep learning theory on college students' mental health status.

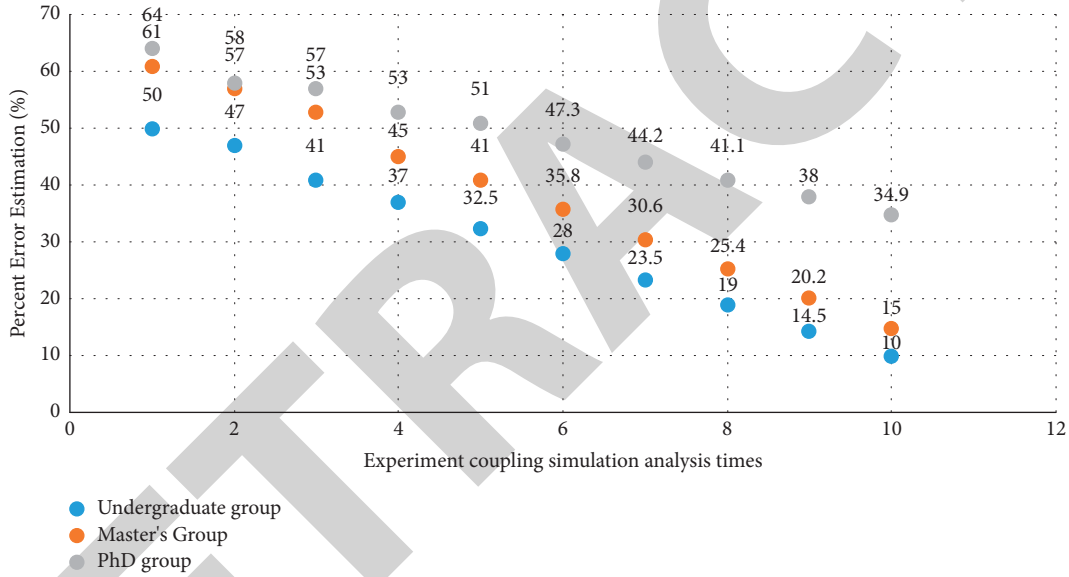

Figure 3: The percentage error obtained under the number of experiments with different degrees of coupling.

influence of model deepening processing. The adaptability of the deepening model and the limitations of the initial model can be obtained. But these are based on a small amount of analysis.

Based on the first mock exam data, the accuracy and accuracy of different data models are different at different levels, and the deviation degree is slightly different. Based on the analysis of the mental health of different university students, the data visualization is shown in Figures 5 and 6.

It can be seen from the data results in Figures 5 and 6 that when using the same data model to analyze different data sources, the analysis results at different levels are very different. In the shallow analysis, the analyzability and visualization of data are higher, the deviation degree of data is lower, and the analysis results are more concentrated. In the high-level analysis, the analyzability of data is reduced, and the visualization degree changes slightly. However, the overall change is small and can be ignored. The deviation degree of the data has a great leap. Therefore, the data separation analysis theory is used to process the relevant deviation data on the other hand. Its expression is

$$\sqrt{B_{le}(x)} = \sqrt{x - \frac{\left(W^{11}B_{le}^{*} - \beta x\right)}{\sqrt{W^{11}} - \sqrt{\alpha W^{22}}} + \frac{W^{11}}{B_{le}^{*}}}. \tag{4}$$

x is the deviation data with high deviation degree, and W is the deviation degree threshold. Relevant data functions are obtained with reference to different specific gravity and control parameters:

$$\sqrt[n]{B_{le}(x)} = \frac{|B_{le}|W^{11} - B_{le}}{B_{le}W^{22} - (1 - B_{le})W^{11}}. \tag{5}$$

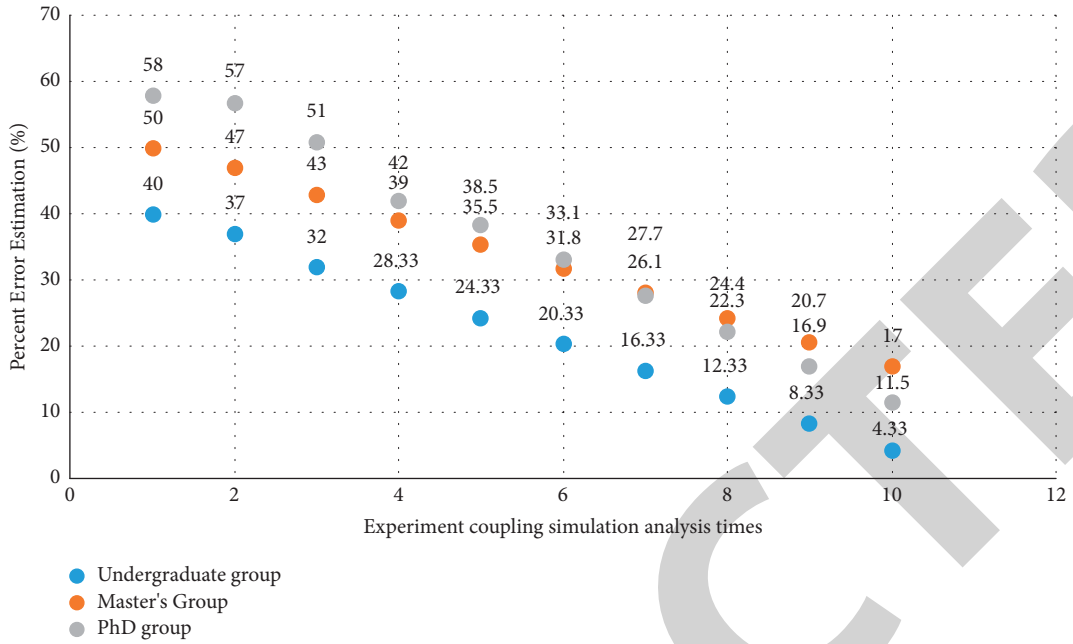

Figure 4: The percentage error obtained under the number of experiments with different degrees of coupling under deep learning.

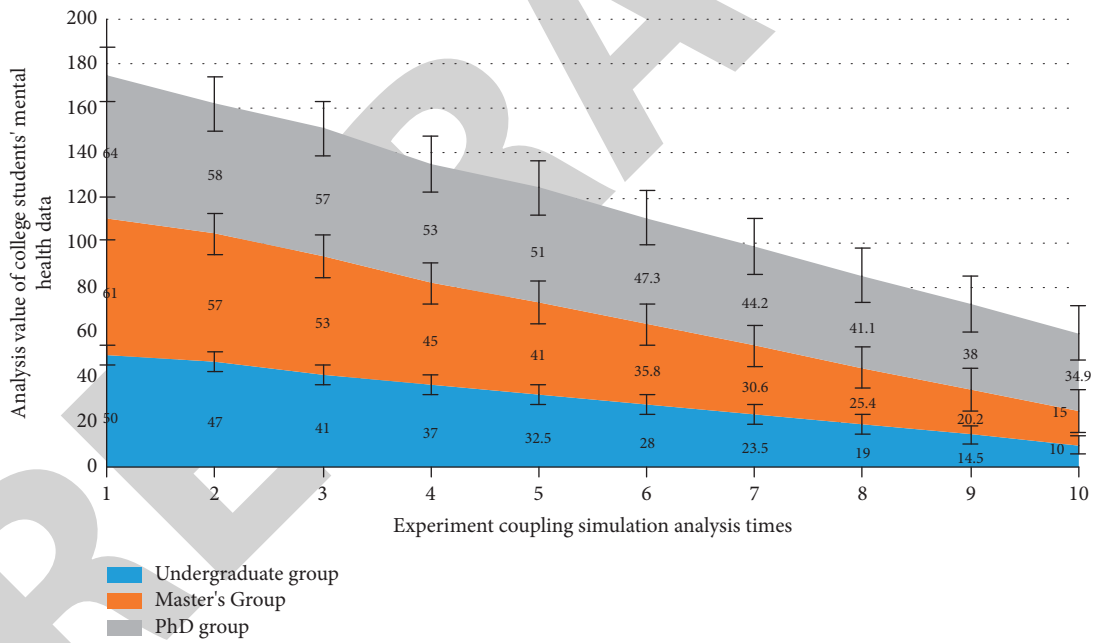

Figure 5: Data analysis results after the same model analyzing the mental health of different college students.

x is the deviation data with high deviation degree, and W is the deviation degree threshold. At this time, the corresponding psychological function of $Q(x)$ is

$$Q(x) = \frac{W^{12}x + \sqrt{x/B_{le}}}{1 - \sum_{i=1}^{k} W^{i} B_{le}}. \tag{6}$$

3.4. The Processing Effect of Variable Analytic Hierarchy Process Model on the Analysis and Evaluation of College Students' Mental Health. The rational application of controllable analytic hierarchy process model in college students' mental health analysis and evaluation can improve the existing data analysis ability of college students' mental health analysis and evaluation in terms of accuracy, hierarchy, and error controllability. In addition, the analysis and operation of convolutional neural network, multi-layer neuron self-coding neural network, and big data statistical analysis are combined into the data processing model. Get the corresponding improved data model and data structure, use it to analyze the

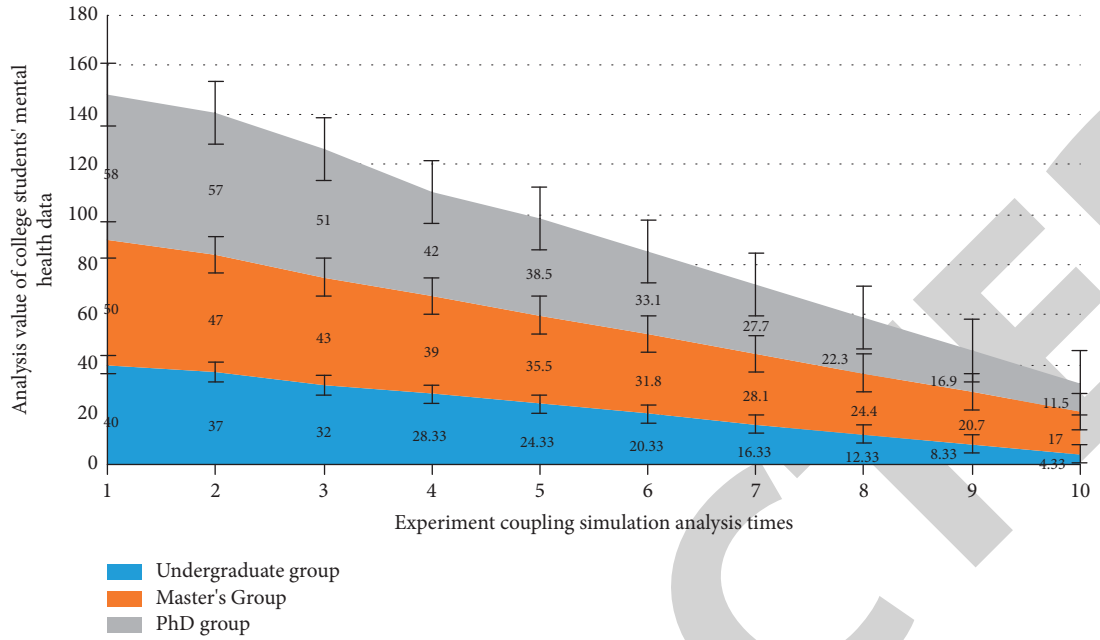

Figure 6: Data analysis results after analyzing the mental health of different college students with the same model under deep learning.

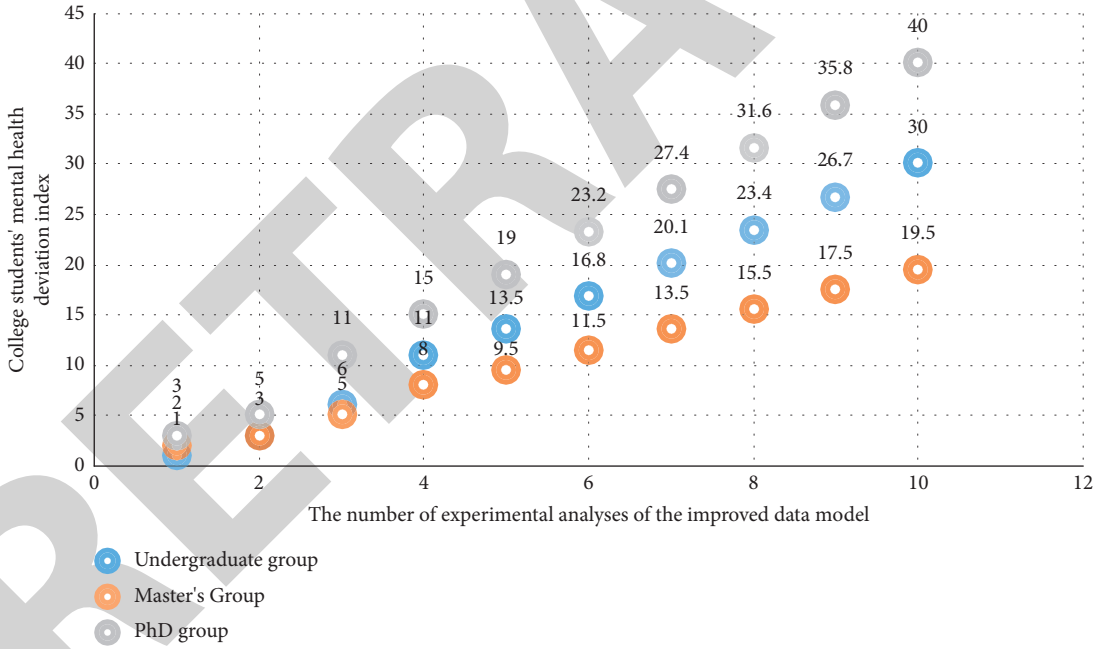

Figure 7: Analysis results of the improved data model and data structure.

characteristics of relevant college students' mental health data, and get the data results with low deviation. The results are shown in Figure 7.

By analyzing the relevant data in Figure 7, it can be concluded that under the same basic data conditions, the characteristics of the analysis results of different models with different data analysis structures and application conditions are different. After the data model completes the analysis and evaluation of the basic data source, when using the data analysis theory and relevant methods for re-analysis, the analysis results of the two often have more similarities and a few differences. This shows that there are often some original correlations between the data. According to its relevant characteristics, the following function analysis formula is analyzed:

$$r(x) = \frac{\sqrt{\alpha + \beta}}{\left(t(x) - y(x)/\alpha^{\beta} + \beta^{\alpha}\right)}. \tag{7}$$

The correlation degree function $D(x)$ and normalization function $F(x)$ of the original data are

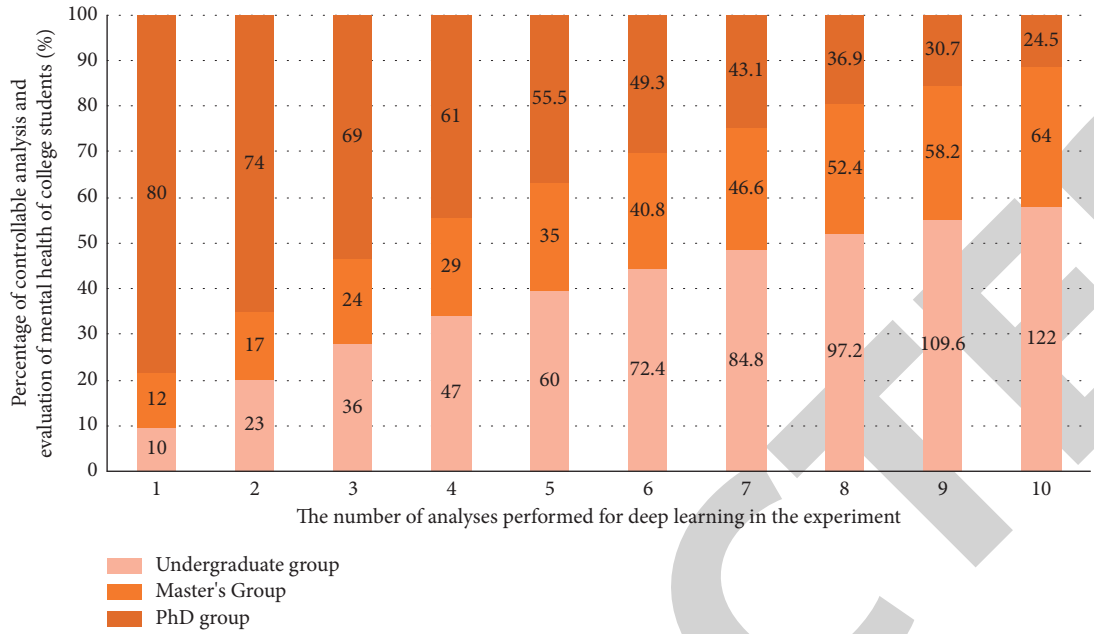

Figure 8: Experimental results of controllable analysis and evaluation of college students' mental health.

$$D(x) = \frac{\sqrt{\alpha Q(x) + \beta t(x) + \alpha\beta y(x)}}{\alpha - \beta}, \tag{8}$$

$$F(x) = \frac{r(x)^{\beta} + \left(Q(x)^{\alpha}/\sqrt{Q(x+1) - 1}\right)}{(\alpha + \beta)D(x)}. \tag{9}$$

Calculate the correlation function $A(x)$ and difference function $E(x)$ of the original data and associated data as follows:

$$A(x) = \frac{\sqrt{Q(x+1)R(x)^{\beta} + Q(x)t(x)^{\alpha}}}{F(x)}, \tag{10}$$

$$E(x) = \alpha\sqrt{nA(x)} + \frac{\beta t(x+1)}{(1-\beta)t(x-1)}. \tag{11}$$

The optimized correlation discrete function $A'(x)$ and the discrete full function $E'(x)$ are

$$\begin{aligned} A'(x) &= \frac{D(\beta x)x^{\alpha} - (D(x)A(x))}{t(x)}, \\ E'(X) &= \sqrt{X^{\alpha\beta} + aR(x) - \frac{\beta t(x)aA(x+1)}{f(x)f(x-1)}}. \end{aligned} \tag{12}$$

The nonoptimized correlation analysis function $G(x)$ and the optimized correlation analysis function $G'(x)$ are

$$\begin{aligned} G(x) &= \frac{\sqrt{3\beta x^2 - 2ax}}{7x^{\beta} + 2x^{\alpha}}, \\ G'(x) &= \frac{\sqrt{6x^{\alpha} - 9x^{\beta}/7a + 8\beta x^{\alpha}/3^{\alpha} - 7x^{\beta}}}{E(\chi)}. \end{aligned} \tag{13}$$

In the above formula, x is the original correlation data information.

4. Result Analysis and Discussion

4.1. Analysis and Evaluation Experiment on Controllability of College Students' Mental Health. Before applying the mental health model, we need to pre-analyze the mental health-related data of college students. After constructing the data model and data structure, the relevant models and data algorithms are modified according to the experimental results. Through the testability experiment, it is found that the correlation and reliability of the relevant experimental data increase linearly with the increase of the amount of data analysis. After further analyzing the data characteristics, it is found that the characteristics of the data also deviate to a certain extent. The relevant results are shown in Figure 8.

It can be concluded from the experimental results in Figure 8 that in the evaluation and analysis of college students' mental health by in-depth learning, the applicability and objectivity of the model are still dominant. The human subjective factors of contemporary psychological research cannot be added to the model analysis. In this way, the analyzed data results show a linear relationship, while the data analysis of the experimental results shows a nonlinear relationship when considering human factors. It is not enough to thoroughly understand the theoretical trend, but it is also not enough for the current case of extreme and relevant data, which is not completely consistent with the theoretical trend.

4.2. Analysis of Experimental Results. In order to enhance the repeated effectiveness of the experimental model again, through the analysis of the data of the application of in-depth analysis to college students' mental health, we draw

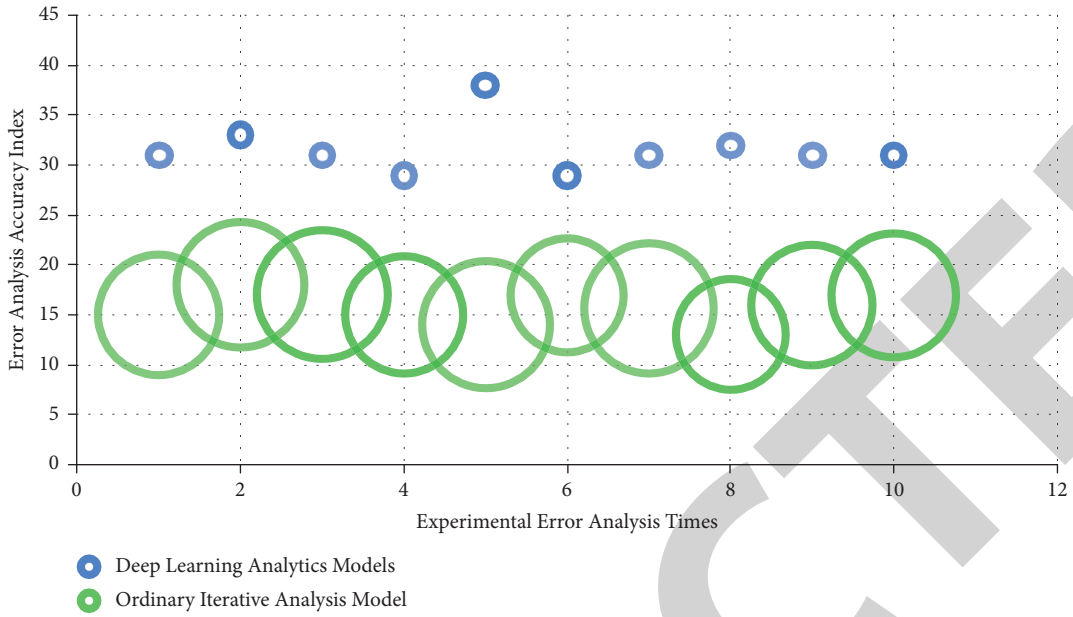

Figure 9: Use the original experimental data to make corrections to the relevant presentation forms within a controllable range.

some conclusions that we need to make variability changes to the analysis model and apply it in a reasonable range. Finally, it is displayed in the form of a quadratic model, and the relevant display forms are corrected within a controllable range by using the original experimental data. The corrected results are shown in Figure 9.

Through the relevant data in Figure 9, we can know that the experimental data results under the application of secondary model correction are controllable and changeable compared with the previous experimental results; that is, the effect of changing the data structure is achieved by changing the original data. At the same time, the relevant data conclusions after the change are reasonable and acceptable in the field of deep learning and psychology. Therefore, the application of quadratic model can be said to be a major innovation of research results. It is a dual innovation in the dual fields of psychology and arithmetic. At the same time, it is also a great achievement in the combination of the two fields.

5. Conclusion

At present, deep learning is not widely used in the field of college students' mental health evaluation and analysis. There are some problems, such as following the trend of research, low universality, shallow depth of algorithm model, and small reform of data structure. On this basis, this paper launches the combined application of convolutional neural network, multi-layer neuron self-coding neural network, big data statistical analysis, and so on. Firstly, it carried out the reform and innovation of algorithm magic. On the basis of some popular algorithm magic, it studied its own unique algorithm structure and combined the research characteristics and research results of arithmetic and psychology, and it created its own unique research direction. Secondly, by using the research method of the quadratic model that is not available in the history research process, we can modify our own use model, improve the quadratic model theory that has not existed in history, and control the error and controllable range of the new model within the known range through testing experiments. Finally, we can summarize the basic theories and research methods of the data model, find and review the omissions, and improve and supplement them. The final quadratic model is obtained. However, the model is not simulated in this paper. Therefore, some data have some problems in the actual evaluation process, which needs to be supplemented and analyzed in future research.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Retraction

Retracted: Enterprise Digital Transformation and Stock Price Crash Risk: Evidences from China

Discrete Dynamics in Nature and Society

Received 19 December 2023; Accepted 19 December 2023; Published 20 December 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] X. Song, "Enterprise Digital Transformation and Stock Price Crash Risk: Evidences from China," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 5389456, 11 pages, 2022.

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Research Article

Enterprise Digital Transformation and Stock Price Crash Risk: Evidences from China

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With unstoppable rise of digital economy globally, digital transformation has become an inevitable choice for enterprises to survive and develop; both the public and the government are paying increasing attention to digital transformation. At the same time, the Chinese government takes more serious attitude towards systemic financial risks, emphasizing the importance of controlling systemic risks such as abnormal stock price in many public occasions. In this context, enterprise digital transformation and stock price crash risk have gained unprecedented attention. It is of great value for both industry and the government to analyze the influence and mechanism of enterprise digital transformation (EDT) on stock price crash risks. This study measures the degree/level of EDT of Chinese A-share publicly owned enterprises through document study and crawler technology, examining the influence and mechanism of digital transformation on companies' stock price crash risk. Conclusions of this paper may provide a theoretical and empirical basis for understanding digital transformation's consequences in capital market and provide a reference for the government and regulatory authorities to formulate support and disclosure policies for digital transformation.

1. Introduction

Digital economy has become an essential growth point of China's economy. Since the G20 Summit listed "digital economy" as an important topic for the first time in 2016, its contribution to China's GDP growth has reached 67.7% in 2019, from which it can be seen that digital economy has become a typical demonstration of the new economy. In such a context, as the core foundation of digital economy development, digital transformation has become inevitable for the survival and continuous development for both traditional enterprises and emerging companies [1, 2].

Essential connotation of enterprise digital transformation (EDT) is transformation from "industrialized management mode" to "digital management mode" [3], which refers to fundamental changes in the business logic, management theory, and organizational form of the enterprise [4, 5], and ultimate changes in economic growth mode, industrial layout, entrepreneurship model, and production and lifestyle [6], through the upgrading and rebuilding of the enterprise organizational structure and business model with the information technology [7]. The current research on EDT mainly pay attention to the relation of digital revolution to enterprise performance. It has been found that the improvement of EDT could encourage the innovation of corporate governance structure and the transformation of internal administration models [8], with the effects of cost reduction, strong innovation, and the improvement of enterprise production efficiency [9]. EDT could also considerably improve the performance of the main businesses [10] through the promotion of the internal information symmetry of enterprises and business model innovation [11].

The development of the capital market is closely related to the national economy. Any changes in the production and management decisions of an enterprise will affect its performance in the capital market to a certain extent. EDT is a systematic and thorough change at an overall level, and the consequences will certainly be reflected in its capital market activities [12]. During the transformation, stock price crash

risk could very likely harm Chinese capital market and its investors [13]. As a result of different foundation and development history from western market, China's securities market remains immature. After decades of development, China's securities market is still incomplete semistrong efficient [14]. Compared with western market, Chinese investors are blinder and more impulsive in judgment and behavior, with limited ability to analyze and interpret information. Nowadays, Chinese government take more serious attitude towards systemic financial risks, emphasizing the importance of controlling systemic risks such as abnormal stock price in many public occasions. In this context, EDT and stock price crash risk have received unprecedented attention, and it is of great value for both industry and the government to explore the impact and mechanism of EDT on stock price crash risks.

After worldwide credit risk since 2008, stock price crashes have aroused extensive attention from regulatory authorities and the industry. Academic researchers are also trying to explore the influencing factors and prevention methods of stock price crash risk from various perspectives [15]. While digital transformation has brought about reforms for enterprises regarding their organizational structure and management theory, what else changes will it bring to the internal management capabilities of enterprises? Are enterprises at different transformation stages receiving the same level of attention from the market, and how does the transformation affect the efficiency of information circulation in the market? Under the background that digital transformation has gained a wide-spread consensus for enterprises, research on the above questions has great practical significance in exploring influencing elements to stock price crash risk, which will help stock market play its role in pricing.

Unfortunately, currently there is no such research on the association of EDT with the stock price fluctuations. People can only speculate the influence direction and possible mechanism of EDT on stock price crash risk from current relevant references. Therefore, this paper intends to introduce the related research of EDT and to explore its influence direction and procedure on stock price crash risks.

The following three perspectives show this paper's possible contributions. Firstly, this paper may provide a new point of view about the business consequences of digital transformation. Unlike existing researches that focus on digital transformation's effect on the business performance, this paper associates enterprises' digital transformation in the new era with its capital market performance and explores the inherent relation between digital transformation and stock price crash risks. Secondly, this study may enrich current research on stock price crash risks. Through verifying two major theories of stock price crash - "Agency Theory" and "Information Theory", this study explores digital transformation's influence path on stock price crash risks. Third, this paper tries to measure the degree of EDT through crawlers' technology and text analysis, which may provide reference and inspiration for the quantitative evaluation of EDT and its economic effects.

This paper may offer benefits and inspiration to global readers in the following respects. China's stock market is the second largest one in the world, while it is also the largest emerging market. Expected to attract more capital, Chinese government is implementing a greater opening-up policy. In this respect, it is very necessary for foreign investors to have an in-depth understanding of the Chinese securities market and its listed companies. This paper can provide experience and advice for researchers and scholars, enabling global investors to gain more information about Chinese market. Thereby, information asymmetry could be reduced, which will facilitate information interpretation and analysis by foreign investors and researchers and strengthen the connection between Chinese market and the world. At the same time, China's cases in this paper can be taken as a reference for countries in digital transformation, leading them to follow closely these topics and consider the economic effects of digital transformation.

Following the introduction are seven parts. The second part is to review the relevant research on EDT and stock price crash risk, putting forward research hypotheses with theoretical analysis. The third part is the research design. The fourth part contains result reports. The fifth part shows the analysis of the influence mechanism. The sixth part shows robustness test. The last comes to research conclusion.

2. Theoretical Mechanism and Hypothesis

2.1. EDT and Stock Price Crash Risk. Stock price crash risk means the chance of a sharp fall to an enterprise's stock price [16]. As a common and bad economic consequence, this risk disturbs financial market and damage individual wealth of investors [13]. There have been extensive discussions on the influencing factors of stock price crash risk. Current researchers commonly attribute causes of this risk to the agency problems in enterprise management [17], the information asymmetry inside and outside enterprises [18] and the policy systems [19, 20].

In addition, the influencing elements of this risk are also investigated from different aspects, including shareholdings [21], institutional investors [15], characteristics of senior executives [13], analysts [22], and margin trading system [23].

The above-mentioned studies up to date provide a wealth of experience and theoretical support for the analysis of the influence of EDT on stock price crash risks. With the current study as starting point, this paper is aimed to explore the impact and possible mechanism of EDT on stock price crash risks through two specific aspects "Agency Theory" and "Information Theory".

Scholars in favor of "Agency Theory" argue that the main explanation for share prices crash risk is that the management level tries to hide the negative news and excessive risks. They choose to hide negative enterprise information depending on various demands including maximizing their own equity value [28], establishing the business kingdom [18], making in-service consumption [29], and promoting their career and salary gap [30]. As the cost of hiding negative information becomes higher and higher, company's management personnel would finally give up hiding information but choose to release the negative information

once for all. The stock price thereof will be greatly impacted in a short time, and then the crash might occur. Similarly, it happens when excessive investment is triggered by regional bribery [27] and decision-making errors due to incomplete information [28]. All will cause enterprise losses, damage enterprise value, and increase risks of future stock price crash.

While scholars like Jin and Myers [16] who are in favor of "Information Theory" believe that the main explanation for stock price crash risk is the information asymmetry, making it hard for people to find the negative information and investment projects in time, which is likely to cause miscalculation of the stock price. Meanwhile, information asymmetry provides the company's management with an opaquer information environment that they would be able to hide more negative information, with an increase of stock price crash risk in the future [29]. Hutton et al. [30] founnd the opaqueness of enterprise's information environment have positive correlation with the executive manipulation of the information disclosure. Enterprise information opacity measured by its earnings can well explain the stock price crash. Short selling [23] and internal governance [31] also provide support for this view by reducing risk through the price discovered function and improving the efficiency of stock price information.

According to above discussion, this paper tries to analyze the possible influence direction and mechanism of EDT on stock price crash risk through the following aspects.

Firstly, EDT can help improve the internal management capacity and alleviate the "principle-agent" problem and thus reduce stock price crash risk. From one point of view, through digital transformation, enterprises can better process massive, nonstructured, and nonstandard information with the help of digital technology, thus improving the information utilization [32]. From another point of view, EDT can also help eliminate the boundaries between departments, making the internal information flow more smoothly and thus significantly improving the internal control of enterprises. It can ultimately urge enterprises to gradually improve its organizational structure, production mode, and decision-making mechanism [33], to achieve the dual goals of "efficiency improvement" and "risk reduction" [13]. Digital transformation can enhance enterprises' insights into all aspects of company operation, helping them make management decisions and improve operation efficiency [4]. To sum up, the improvement of internal management ability and information circulation efficiency is a great help for company to reduce decision-making errors and to improve investment efficiency [8]. Meanwhile, with the quantitative analysis ability of digital transformation, the executive decision-making about cost control and investment decisions becomes more standardized, and the discretionary power is greatly reduced. The above analysis has alleviated the agency problem in some way [34]. With the alleviation of the agency problem and the reduction of the manipulable space for earnings management, the executives will focus more on the main business. The short-sighted behavior such as hiding negative information will be greatly reduced, and ultimately stock price crash risk will be reduced too.

Secondly, EDT helps companies obtain more market attention, reduce information asymmetry, finally reducing stock price crash risks. From one point of view, enterprises have improved their internal data mining and processing capabilities through digital technology. Companies benefit from the standardized data processing results with an easier output and interpretation of information. It helps the company to alleviate information asymmetry inside and outside and meanwhile helps the market understand companies' production and operation status promptly [13]. From another point of view, digital transformation could also help enterprises attract the attention of analysts, improve the information environment, alleviate information asymmetry inside and outside enterprises, and ultimately reduce enterprise stock price crash risks. Analysts and investors' limited attention narrows their capabilities to interpret the market information [35]. Under the background that digital transformation has become a broad consensus, enterprises with a higher digital transformation level are more likely to be reported by media and to arouse analysts' attention [12]. Media reports not only attract analysts' attention, but also improve the quality and reputation of news release for enterprises [36, 42]. It helps to reduce the divergency of analysts, decrease forecast errors, alleviate information asymmetry, and ultimately reduce stock price crash risks. Then this paper proposes relevant hypothesis below.

H1: better EDT could reduce stock price crash risk.

Actually, enterprises sometimes choose to disclose information with strategic purposes, when they intend to exaggerate the degree and effect of transformation [43] and hide corresponding negative consequences and information. For enterprises with more bubbles in their stock price, it may make the market blindly optimistic, overestimate their transformation degree and operation status, and miss the opportunity to find bubbles, thus weakening the suppression effect of digital transformation on stock price crash risk. Then the second hypothesis is proposed below.

H2: effect of EDT on reducing stock price crash risk decreases as the level of stock price bubble rises.

3. Research Design

3.1. Sample and Data. Initial sample of this study is A-share public enterprises in China, between 2013 and 2020. Then the following processing is made: (1) to exclude enterprises with annual stock earnings data of less than 26 weeks; (2) to exclude financial enterprises; (3) to exclude ST and the delisting enterprises during the period; (4) to exclude enterprises whose data are less than five years; (5) and to carry out 1% and 99% winsorization processing regarding continuous variables at the microlevel in order to reduce the impact of outliers on the results. The data of internal control quality in this paper comes from DIB internal control and risk management database. Other data can be found in CSMAR.

3.2. Variables Setting

3.2.1. Stock Price Crash Risk. Based on existing studies [43–58], this paper measures stock price crash risk by

NCSKEW (negative coefficient of skewness) and DUVOL (down-to-up volatility). The specific calculation methods are as follows.

Firstly, using formula (1) to eliminate the influence of annual market elements on the return rate of every firm:

$$R_{i.t} = \alpha_i + \beta_1 R_{m,t-2} + \beta_2 R_{m,t-1} + \beta_3 R_{m,t} + \beta_4 R_{m,t+1} + \beta_5 R_{m,t+2} + \varepsilon_{i,t}. \quad (1)$$

In the formula, $R_{i,t}$ is the weekly return rate of the enterprise i in week t of the current year and $R_{m,t}$ is the average return rate in the market weighted by circulating market capitalization in week t, both of which adopt the value after considering the reinvestment of cash dividends. To control the impact of nonsynchronous stock trading, the lagging and leading term of market returns are added into formula (1). The specific weekly return rate is $W_{i,t} = \ln(1 + \varepsilon_{i,t})$. Residual $\varepsilon_{m,t}$ represents information in the stock return that is not reflected in the market return.

Two variables of stock price crash risk are proposed after the definition of $W_{i,t}$:

(1) Negative Coefficient of Skewness (NCSKEW)

$$NCSKEW_{i,t} = -\frac{\left[n(n-1)^{3/2}\sum W_{i,t}^3\right]}{(n-1)(m-2)\left(\sum W_{i,t}^2\right)^{3/2}}. \quad (2)$$

In the formula, n is the number of trading weeks of enterprise i in that year. Larger *NCSKEW* refers to bigger negative stock return rate's skewness coefficient and greater stock price crash risk.

(2) Down-to-Up Volatility (DUVOL)

$$DUVOL_{i,t} = \log\left\{\frac{\left[(n_u-1)\sum_{\text{DOWN}} W_{i,t}^2\right]}{\left[(n_d-1)\sum_{\text{UP}} W_{i,t}^2\right]}\right\}. \quad (3)$$

In the formula, n_u (n_d) is the number of weeks in which enterprise i's specific return $W_{i,t}$ is bigger than (smaller than) the mean. The higher *DUVOL*, the more leftward the yield's distribution, and the greater the stock price crash risks.

3.2.2. Enterprise Digital Transformation. Most of the existing research on EDT mainly focuses on qualitative analysis from the perspectives of policy suggestions [4] [41] and theoretical analysis [42]. Some scholars began measuring the digital transformation level of enterprises from the microenterprise perspective and considered indicators such as digital intangible assets [43], e-commerce sales revenue [44], and the frequency of words related to digital transformation [12]. According to the research of Lin and Xie [58], word frequency represents the importance level an enterprise has given to the key issues (represented by the word). Based on this, this paper takes the research of Zhao et al. [59] as a reference and establishes a thesaurus containing 99 digital transformation words from four aspects which are digital technology application, Internet business model, intelligent manufacturing, and modern information system (details are omitted in this paper due to limited space). Using the processing functions of Jieba and text analysis in *Python*, this paper tries to analyze all texts of the annual reports of Chinese A-share public enterprises between 2013 and 2020 and to calculate the sum and the logarithm of the frequency of words related to digital transformation. This information after processing will be used as the final index to measure the level of EDT.

3.2.3. Stock Price Bubble. Referring to the researches of Dass et al. [53] and Pan et al. [54], this paper selects the price-to-sales ratio as a measurement of stock price bubble. The higher the price-to-sales ratio, the greater the stock price bubble. Price/sales ratio (*PB*) = closing price of the stock on the last trading day in this year/sales revenue per share in the preceding year.

3.2.4. Control Variables. In regression, this paper controls dumb variables including *RET*, *SIGMA*, *DTURN*, *Tobin_Q*, *BM*, *SIZE*, *ROA*, *LEV*, *AbsACC*, *Ind*, and *Year*. Considering that there may be a time lag in the impact of digital transformation [56] and avoiding potential reverse causality problems, the explained variables are all selected from the data of the preceding period (*t-1*), and all the other variables from the data of the current period (t) in the regression equation. This paper also controls the explained variables of the current period.

3.3. Model Design. H1 is tested by the model of

$$\text{Crash}_{i,t+1} = \beta_0 + \beta_1 DCG_{i,t} + \gamma\text{Controls}_{i,t} + \text{Ind} + \text{Year} + \varepsilon_{i,t+1}. \quad (4)$$

Crash is measured by *NCSKEW* and *DUVOL*. Data of the future period are used in regression. *DCG* represents the degree of EDT, *Controls* represents control variables including current *Crash*, *RET*, *Tobin_Q*, *LEV*, etc., i represents the enterprise, and t represents the time.

H2 is tested by

$$\text{Crash}_{i,t+1} = \beta_0 + \beta_1 DCG_{i.t} + \beta_2 DCG_{i.t} \times PB_{i,t} + \gamma\text{Controls}_{i,t} + \text{Ind} + \text{Year} + \varepsilon_{i,t+1}. \quad (5)$$

In (5), the interactions of stock price bubble (*PB*) and digital transformation (*DCG*) are introduced. By comparing whether the signs of β_1 and β_2 are identical or not, this formula is to investigate the changing trend of EDT reducing stock price crash risk when bubble rises. Please note that i refers to firm and t is the time.

4. Analysis of Results

4.1. Variable Characteristics. Mathematical characteristics of variables are demonstrated in Table 1. The mean values of *NCSKEW* and *FDUVOL* are -0.282 and -0.194, respectively, close to the results in the existing research [15, 29]. According to this event, stock price crash risk could be

Table 1: Variable characteristics.

Variable	Obs	Mean	Standard deviation	Min	Max
NCSKEW	10986	−0.282	0.748	−5.170	4.166
FDUVOL	10986	−0.194	0.501	−3.178	2.287
DCG	10986	0.342	0.579	0	7.160
RET	10986	0.004	0.011	−0.050	0.264
SIGMA	10986	0.064	0.028	0.014	0.326
DTURN	10986	−0.052	0.411	−3.541	3.972
Tobin_Q	10986	0.210	0.169	0.070	8.650
BM	10986	0.611	0.255	0.012	1.430
SIZE	10986	4.065	1.321	0.435	10.10
ROA	10986	0.046	0.061	−0.645	0.675
LEV	10986	0.431	0.199	0.008	1.352
AbsACC	10986	0.058	0.083	0	2.172

believed to have rational indicators. The mean and standard deviation of EDT are 0.342 and 0.579, respectively. The degree of transformation varies significantly among different enterprises, with min and max being 0 and 7.16, respectively.

4.2. Basic Analysis: Enterprise Digital Transformation and Stock Price Crash Risks. This paper uses a time and entity fixed effects regression model, in which the variables of both time and industry dummy are controlled. Table 2 shows a significantly negative correlation between enterprise digital transformation (*DCG*) and stock price crash risks at 1% level. It indicates that enterprises can diminish stock price crash risks through digital transformation, which supports H1. Interactions of EDT and stock price bubbles degree are considerably positive at 1% level. This confirms the following fact: as stock price bubbles keep rising, reducing effect on stock price crash risk through EDT decreases, which is consistent with H2.

Among control variables, regression coefficients of $NCSKEW_t$ and $DUVOL_t$ are considerably negative, which is in line with studies of Quan [50], Sun, and Zheng [20]. The regression coefficients of *RET*, *SIZE*, and stock price crash risks are significantly positive, agreeing with the study by Hutton et al. [30] and Xu et al. [58]. The regression coefficients of *DTURN* and *LEV* are negative, indicating that the higher the *DTURN* and *LEV*, the lower the stock price crash risk. Such consequences are similar to studies carried out by An and Zhang [58]; Callen and Fang [59]; and Wang et al. [21]. On the whole, control variables' empirical results are basically similar to the current research, illustrating this paper's conclusions are trustworthy.

4.3. Analysis of Heterogeneity. The business model, organizational structure, and competitive imitation environment of an enterprise are highly related to the nature of ownership and its main industry. To further analyze the different effectiveness of EDT reducing stock price crash risk, all subsamples are analyzed through categorical regression according to the company's ownership and industry. The outcomes are displayed in Tables 3 and 4 separately.

For different types of ownership, the regression coefficients of non-state-owned companies are quite higher than those of state-owned companies, which means that the digital transformation of non-state-owned companies makes better impact on diminishing stock price crash risks. State-owned enterprises are not entirely for business performance, so the reforms within organizational structure and business models are often subject to stronger administrative constraints. Meanwhile, considering that some key businesses in the state-owned enterprises requires a certain degree of confidentiality, the effect of digital transformation to improve information asymmetry inside and outside enterprises is limited. Non-state-owned enterprises usually face certain resource boundary constraints. Timely disclosure of the progress of digital transformation can help attract the interest of analysts and investors and achieve the purpose of ensuring the liquidity of capital market.

The regression coefficients of manufacturing and non-manufacturing industries are both significant at 1% level. However, absolute values of manufacturing enterprises' coefficients are significantly greater than those of non-manufacturing enterprises, indicating that there exists a better effect of reducing stock price crash risk through digital transformation in manufacturing enterprises. Digitalization is a crucial direction for the upgrading and rebuilding of manufacturing industries in China. Digital transformation can be introduced into all links in the value chain of manufacturing enterprises to improve enterprises' ability of processing data and increasing circulation efficiency of internal information. It also helps to reduce agency problems. Manufacturing enterprises with a certain level of digital transformation are considered to have stronger competitiveness [59] and are more likely to arouse attention of analysts and investors. In this way, they are subject to diminish companies' information asymmetry and ultimately diminish stock price crash risks.

5. Extended Study: Analysis of Influence Mechanism

The fourth part proves that the EDT reduces stock price crash risks, yet the mechanism behind is still unclear. According to the above analysis, EDT, on one hand, may alleviate the "principle-agent" problem by improving the investment efficiency and internal management capabilities

Table 2: EDT and stock price crash risks.

	(1) $NCSKEW_{t+1}$	(2) $NCSKEW_{t+1}$	(3) $NCSKEW_{t+1}$	(4) $DUVOL_{t+1}$	(5) $DUVOL_{t+1}$	(6) $DUVOL_{t+1}$
DCG_t	−0.177***	−0.172***	−0.203***	−0.109***	−0.101***	−0.124***
	(0.031)	(0.031)	(0.034)	(0.021)	(0.021)	(0.023)
$DCG_t \times PB_t$			0.008***			0.006***
			(0.003)			(0.002)
PB_t			0.000			0.000
			(0.001)			(0.001)
$NCSKEW_t/DUVOL_t$	−0.139***	−0.132***	−0.134***	−0.141***	−0.134***	−0.136***
	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
RET_t		6.546***	6.355***		4.589***	4.437***
		(1.353)	(1.312)		(0.992)	(0.955)
$SIGMA_t$		−1.222**	−1.339**		−1.301***	−1.387***
		(0.554)	(0.557)		(0.381)	(0.383)
$DTURN_t$		−0.049**	−0.046**		−0.039**	−0.037**
		(0.023)	(0.023)		(0.016)	(0.016)
$Tobin\_Q_t$		0.078	−0.031		0.015	−0.079
		(0.106)	(0.118)		(0.075)	(0.085)
BM_t		−0.665***	−0.699***		−0.415***	−0.444***
		(0.094)	(0.094)		(0.062)	(0.062)
$SIZE_t$		0.121***	0.126***		0.052**	0.055**
		(0.032)	(0.032)		(0.022)	(0.022)
ROA_t		−0.048	−0.047		−0.050	−0.047
		(0.181)	(0.181)		(0.123)	(0.123)
LEV_t		−0.328***	−0.318***		-0.240***	−0.231***
		(0.108)	(0.109)		(0.074)	(0.074)
$AbsACC_t$		0.176	0.174		0.141**	0.140**
		(0.113)	(0.113)		(0.067)	(0.068)
Constant	−0.271***	−0.134	−0.106	−0.156***	0.063	0.086
	(0.019)	(0.145)	(0.144)	(0.013)	(0.098)	(0.097)
Year, Ind	Yes	Yes	Yes	Yes	Yes	Yes
Obs	10986	10986	10986	10986	10986	10986
Adj-R^2	0.071	0.091	0.092	0.076	0.094	0.095

Note. ***, **, and * represent the significance levels of 1%, 5%, and 10%, respectively. The numbers in parentheses are robust standard errors. Year represents the time dummy variable, and Ind represents the industry dummy variables.

Table 3: Analysis of heterogeneity: based on the nature of business ownership.

	State-owned companies		Non-state-owned companies	
	(1) $NCSKEW_{t+1}$	(2) $DUVOL_{t+1}$	(3) $NCSKEW_{t+1}$	(4) $DUVOL_{t+1}$
DCG_t	−0.175**	−0.083	−0.155***	−0.093***
	(0.083)	(0.054)	(0.034)	(0.023)
$NCSKEW_t/DUVOL_t$	−0.119***	−0.120***	−0.149***	−0.151***
	(0.018)	(0.018)	(0.014)	(0.014)
Controls, Year, Ind	Yes	Yes	Yes	Yes
Obs	4084	4084	6902	6902
Adj-R^2	0.076	0.077	0.105	0.113

Table 4: Analysis of heterogeneity: based on industry categories.

	Manufacturing industries		Nonmanufacturing industries	
	(1) $NCSKEW_{t+1}$	(2) $DUVOL_{t+1}$	(3) $NCSKEW_{t+1}$	(4) $DUVOL_{t+1}$
DCG_t	−0.235***	−0.137***	−0.139***	−0.087***
	(0.052)	(0.036)	(0.038)	(0.025)
$NCSKEW_t/DUVOL_t$	−0.142***	−0.140***	−0.124***	−0.128***
	(0.014)	(0.014)	(0.018)	(0.018)
Controls, Year	Yes	Yes	Yes	Yes
Obs	6834	6834	4152	4152
Adj-R^2	0.108	0.117	0.073	0.067

of the enterprise and finally reduce stock price crash risks. On the other hand, it could reduce such risks by attracting more attention from media, analysts, and investors, decreasing analyst forecast errors and reducing the information asymmetry inside and outside enterprises. Based on this, the paper from the perspective of agency problems and information asymmetry further investigates the mechanism of EDT to reduce stock price crash risk.

5.1. Enterprise Digital Transformation and Agency Problems. The "Agency Theory" holds the opinion that executives hiding negative news and taking excessive risks are essential explanations for stock price crash risks. By improving

management efficiency and internal management capacity, the EDT helps to reduce the manipulable space of earnings management, to alleviate the "principle-agent" problem, as well as to improve both decision-making ability and investment efficiency. Taking the method from Gao and Wang [53] as a reference, the agency costs of enterprises in this paper are measured by the ratio of management expense (*ADE*). The larger *ADE*, the higher agency cost. Dibo Internal Control Index is selected as a proxy variable of internal management capability (*DIB*) [27, 50]. The larger *DIB*, the stronger governance capability. Referring to the existing research [54], the governance effect of management is measured by two indicators, real earnings management (*Earnings*) and investment efficiency (*INV_E*). *Earnings* are calculated by the model from Roychowdhury [55]. The higher *Earnings*, the higher degree of real earnings management. *INV_E* is calculated by the model from Richardson [56]. The higher *INV_E*, the lower investment efficiency of enterprises.

According to Table 5, the EDT significantly reduces *ADE* and improves *DIB*. The EDT reduces accounting manipulation to some extent in the management level, but has no significant impact on *INV_E*. These findings all indicate that through improving executive capacity and reducing accounting manipulation, digital transformation can alleviate agency problems and thus further reduce stock price crash risks. "Agency Theory" about EDT diminishing stock price crash risks is valid.

5.2. Enterprise Digital Transformation and Information Asymmetry. According to the "Information Theory", the main explanation for the risk of specific share price crash in enterprises is the information asymmetry inside and outside enterprises. By improving data mining and processing capabilities of enterprises, the EDT helps the market timely understand the production and operation state of enterprises and attract the attention of analysts, so as to reduce analysts' wrong prediction and to alleviate the information asymmetry inside and outside enterprises. Referring to the method from Huang and Guo [57], media attention (*News*) is measured in this paper by the logarithm of annual media reports of listed enterprises and analysts' attention (*Analyst*) by tracking the number of institutions of a listed enterprise. The further analysis in this paper investigates the change of information transfer efficiency in the capital market by the absolute deviation of analyst forecast (*FERR*) and stock price synchronization (*SYNCH*). According to the analysis of Tan et al. [58], the level of EDT is available information for all analysts, and the relative deviation predicted by the analysts will not change significantly. Therefore, absolute deviation is adopted in this paper to measure the prediction deviation, and the specific calculation methods are shown in (6). This study calculate stock price synchronization from the model in Durnev et al. [59]. To obtain the normal distribution of R^2, logarithmic processing is performed in this paper.

The measuring method of *FERR* is specifically explained here as

Table 5: Analysis of mechanism: agency problems.

	(1) *ADE*	(2) *DIB*	(3) *Earnings*	(4) *INV_E*
DCG_t	−0.013***	0.082**	−0.014*	0.005
	(0.003)	(0.040)	(0.008)	(0.003)
Controls, Year, Ind	Yes	Yes	Yes	Yes
Obs	10986	10986	10628	10176
Adj-R^2	0.193	0.158	0.051	0.040

Table 6: Analysis of mechanism: information asymmetry.

	(1) News	(2) Analyst	(3) FERR	(4) SYNCH
DCG_t	−0.068	0.100***	−0.607***	0.007
	(0.047)	(0.028)	(0.211)	(0.007)
Controls, Year, Ind	Yes	Yes	Yes	Yes
Obs	4563	10986	10953	10765
Adj-R^2	0.572	0.172	0.046	0.332

$$FERR_{i,j,t} = \frac{\left|FEPS_{i,j,t} - EPS_{i,t}\right|}{\left|EPS_{i,t}\right|}. \quad (6)$$

In (6), i represents enterprise, t represents time, and j represents analyst group. *FEPS* represents analysts' expected earnings per share, and *EPS* represents an enterprise's actual earnings per share for the year. The greater the *FERR*, the more significant the absolute deviation of analyst forecasts.

According to Table 6, enterprise digital transformation (EDT) significantly improves *Analyst* and reduces *FERR*. The effect of EDT on *News* and *SYNCH* is not significant. These findings suggest that digital transformation help those enterprises under transformation to arouse more attention from the market, especially the analysts' attention. With the analysts' interpretation of some specific enterprise information, the EDT can reduce the absolute deviation of analysts' forecasts, alleviating companies' information asymmetry, then finally diminishing stock price crash risks. "Information Theory" about EDT diminishing stock price crash risks is valid.

6. Robustness Test

6.1. Endogenous Problems. This paper adopts one-period-ahead dependent variables and uses fixed effect models to control the potential endogenous problems to some extent. However, there may still be reverse causality problems and omitted variables in this study. To make the conclusion more reliable, this paper uses the 2SLS method and DID model to further eliminate the influence of endogenous problems.

In order to solve the potential reverse causality problem, the lag first-order degree of digital transformation (*L.DCG*) and the proxy variable (*DCG_IV*) are adopted as the two instrumental variables for the degree of enterprise digital transformation (*DCG*) to carry out the two-stage least square method. The proxy variable (*DCG_IV*) is constructed as follows. According to studies of Kim et al. [29], Wang et al. [21], and Meng et al. [23], this study adopts the mean value of digital transformation degree of other enterprises in each

Table 7: Endogenous problems: 2SLS.

	First stage	Second stage	
	(1)	(2)	(3)
	DCG_t	$NCSKEW_{t+1}$	$DUVOL_{t+1}$
DCG_t		−0.453***	−0.301***
		(−6.615)	(−6.402)
DCG_IV_t	0.355***		
	(0.052)		
$L.DCG_t$	0.510***		
	(0.039)		
Controls	Yes	Yes	Yes
Obs	7738	7738	7738
Adj-R^2	0.439	0.076	0.080
F-value	172.06		
Underidentification test (Kleibergen-Paap rk LM statistic)		137.542***	137.49***
Weak instrumental variable test (Kleibergen-Paap rk Wald F statistic)		172.06***	171.921***
Overidentification test (Hansen *J* statistic *P*-value)		0.0657	0.0517

Note. Weak instrumental variable test *** indicates that Kleibergen-Paap rk Wald F statistic exceeds all critical values, including 15% and 25%.

Table 8: Endogenous problems: DID.

	(1)	(2)	(3)	(4)
	$NCSKEW_{t+1}$	$DUVOL_{t+1}$	$NCSKEW_{t+1}$	$DUVOL_{t+1}$
$Time_t \times Treat_t$	−0.108***	−0.058**		
	(0.040)	(0.027)		
$Time_t \times Treat_t \times DCG_t$			−0.193***	−0.122***
			(0.022)	(0.015)
Controls, Year, Ind	Yes	Yes	Yes	Yes
Observations	10986	10986	10986	10986
Adj-R^2	0.089	0.092	0.097	0.100

industry except the target enterprise as its proxy variable (*DCG_IV*). Enterprises in the same industry have similar industry characteristics and competitive environment, and the degree of their digital transformation is relatively close. The instrumental variables are correlated with the explanatory variables, meeting the instrument relevance restriction accordingly. However, there is no evidence to prove that other enterprises in the same field are subject to the same effect of digital transformation degree affecting its stock price crash risk. The instrument exogeneity restriction is met accordingly.

According to column (1) of Table 7, the two instrumental variables are not weak (F-value>10), and the two are significantly positively related to the core explanatory variable *DCG* at 1% level. According to columns (2) and (3), the instrumental variables pass the underidentification test and there is no overidentification problem, which proves this study's instrumental variables are reasonable. With endogenous problems controlled, the enterprise digital transformation (*DCG*) and stock price crash risks still meet the significant negative correlation, proving the conclusions of this paper are robust and unlikely to be interfered by reverse causality problems.

Considering that it is an excellent quasinatural experiment for enterprises to promote digital transformation in batches, this paper chooses a multiperiod double-difference model to further solve the potential problem of omitted variables. Based on related research [12], after twice calculus of differences between the Treatment Group and the Control Group before and after the transformation, the DID model can effectively eliminate the biased error caused by internal differences and the time trend irrelevant to the experimental group within enterprises, so that to obtain the "net effect" on stock price crash risks through EDT. This paper constructs the following models to test the effect on stock price crash risks through EDT.

$$\begin{aligned} \text{Crash}_{i,t+1} &= \alpha_0 + \alpha_1 \text{Time}_{i.t} + \alpha_2 \text{Treat}_{i,t} + \alpha_3 \text{Time}_{i,t} \\ &\quad \times \text{Treat}_{i,t} + \gamma \text{Controls} + \varepsilon_{i,t+1}, \\ \text{Crash}_{i,t+1} &= \theta_0 + \theta_1 \text{Time}_{i,t} \times \text{Treat}_{i,t} \times DCG_{i,t} \\ &\quad + \gamma \text{Controls} + \text{Ind} + \text{Year} + \varepsilon_{i,t+1}. \end{aligned} \tag{7}$$

In the above formulas, Treat represents the individual dummy variable. *Treat* = 1 represents the enterprises that have carried out digital transformation from 2013 to 2020, and *Treat* = 0 represents the enterprises that have not carried out digital transformation. *Time* represents the dummy variable of time, which takes 1 as the value from the first year of digital transformation of an enterprise. Otherwise, it takes 0 as the value. Considering that individual enterprise and time dummy variables may ignore the influence brought by the degree of EDT, this paper introduces the DID model (Table 8) with moderating effect to estimate the impact. α_3

Table 9: Robustness test: longer forecast windows.

	(1) $NCSKEW_{t+1}$	(2) $DUVOL_{t+1}$	(3) $NCSKEW_{t+1}$	(4) $DUVOL_{t+1}$	(5) $NCSKEW_{t+1}$	(6) $DUVOL_{t+1}$
$L.DCG_t$	−0.215***	−0.141***				
	(0.040)	(0.027)				
DCG_t			−0.219***	−0.153***	−0.234***	−0.152***
			(0.047)	(0.033)	(0.071)	(0.050)
Controls, Year, Ind	Yes	Yes	Yes	Yes	Yes	Yes
Obs	7985	7985	6283	6283	4698	4698
Adj-R^2	0.11	0.114	0.095	0.098	0.087	0.095

Table 10: Robustness test: change the calculation method of stock price crash risk.

	(1) $NCSKEW\_CAP_{t+1}$	(2) $DUVOL\_CAP_{t+1}$	(3) $NCSKEW\_N_{t+1}$	(4) $DUVOL\_N_{t+1}$
DCG_t	−0.102**	−0.046	−0.141***	−0.083***
	(0.044)	(0.028)	(0.045)	(0.027)
$NCSKEW_t/DUVOL_t$	−0.184***	−0.191***	−0.170***	−0.185***
	(0.014)	(0.013)	(0.014)	(0.014)
Controls, Year, Ind	Yes	Yes	Yes	Yes
Observations	7660	7660	7660	7660
Adj-R^2	0.110	0.118	0.130	0.144

Note. Among control variables, $NCSKEW_t/DUVOL_t$ corresponds to the calculation method of the explained variables.

and θ_1 reflect the change of risk before and after the implementation of digital transformation, which is the core parameter to be estimated in this section.

The main regression results of model (6) and (7) are displayed in columns (1)-(2) and (3)-(4), respectively. Two core coefficients α_3 and θ_1 are both negative at least 5% level, which indicates that after controlling endogenous problems, the degree of enterprise digital transformation (*DCG*) still significantly reduces stock price crash risks. It proves that the problem of omitted variables can unlikely interfere the robust and reliable conclusions of this paper.

6.2. A Longer Forecast Window. The forecast time window for stock price crash risks and EDT is expanded to help enterprises overcome the mutual causal influence between the EDT and stock price crash risks and to further investigate the long-term effect of digital transformation on stock price crash risks. In columns (1)-(2) of Table 9, the consequences of the EDT are treated in a lagging period and in columns (3)-(6) the results of stock price crash risk are dealt for 2–3 periods in advance.

The coefficient of EDT is significantly negative in both advanced and delayed treatment, and the absolute value of coefficient does not decrease with the extension of the forecast window. Enterprise digital transformation has a long-term inhibitory influence to stock price crash risks, which proves that conclusions of this study have relatively higher robustness.

6.3. Different Calculation Methods of Stock Price Crash Risk. Previously, average market return weighted by circulating market value is used to calculate stock price crash risks. In this part, the market average return weighted by total market value and the unweighted market average return rate are adopted to recalculate the risk. Both results are distinguished by subscripts CAP and N, respectively.

According to Table 10, stock price crash risks after EDT and different calculation methods are negatively correlated except *DUVOL_CAP*. The inhibitory effect of EDT on stock price crash risk does not change with the different calculation method, which proves that this paper's conclusions are relatively robust.

7. Conclusion

As the digital economy becomes increasingly important, digital transformation has become an inevitable trend for both survival and sustainable development of corporations. Taking capital market as a study perspective, this paper investigates the impact of digital transformation on stock price crash risks. Based on the data of Chinese A-share public enterprises between 2013 and 2020, the degrees of EDT have been measured by the word segmentation function of Jieba and text analysis of *Python*. Further, empirical tests were carried out to verify the influence direction and possible mechanism of the impact of EDT on stock price crash risks. Major conclusions are summarized in the following section.

EDT can significantly diminish stock price crash risks. As endogenous problems are solved, conclusions remain valid after robustness tests. In particular, the effect of EDT on reducing stock price crash risk declines as the level of the stock price bubble rises, and the effects are different in different ownership systems and industries. Further research in this study finds that EDT can improve internal management capabilities of the enterprise and meanwhile arouse more attention from the external market. Further, it reduces the stock price crash risks by alleviating the "principle-

agent" problem and reducing the information asymmetry inside and outside enterprises.

This paper sheds light on the following policies. China should actively grasp the opportunities of digital economy development and EDT to promote its enterprises in various industries to implement digital transformation at all levels through elaborating supportive policies for different segments and building demonstration enterprises. The purpose is to achieve high-quality development of enterprises. At the same time, regulatory authorities should standardize the disclosure system for EDT, enhance the accuracy and standardization of information disclosure, and improve the information interpretation capabilities of the capital market. For state-owned enterprises, the government should further promote its market-oriented reform and help strengthen its internal management capabilities, and it should empower them to play a more important role in promoting the innovation of Chinese enterprises and leading the digital transformation [53–55].

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

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Hindawi
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Retraction

Retracted: Characteristics Analysis of Mental Health Data of College Students Based on Convolutional Neural Network and TOPSIS Evaluation Model

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

In addition, our investigation has also shown that one or more of the following human-subject reporting requirements has not been met in this article: ethical approval by an Institutional Review Board (IRB) committee or equivalent, patient/participant consent to participate, and/or agreement to publish patient/participant details (where relevant).

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] L. Zhou, "Characteristics Analysis of Mental Health Data of College Students Based on Convolutional Neural Network and TOPSIS Evaluation Model," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 5931991, 9 pages, 2022.

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Research Article

Characteristics Analysis of Mental Health Data of College Students Based on Convolutional Neural Network and TOPSIS Evaluation Model

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With the rapid development of modern society, there are many problems concerning the physical and mental health of students. This paper develops a feature analysis method of the mental health data of students in different colleges and regions and of different ages based on a convolutional neural network and TOPSIS evaluation model and studies the college students' mental health analysis model based on convolutional neural network. First, through the data cluster summary and internal characteristics analysis of college students' psychological questionnaire survey data in different regions and grades, we established a college students' mental health grade system and evaluation index system. Then, the TOPSIS analysis method is used to analyze the characteristics of the data results, and the feasibility of the accuracy of the evaluation index standard is analyzed. Finally, the experimental results show that the college students' mental health analysis model based on convolutional neural network can effectively classify and summarize various mental health data, quickly locate the mental health problems of different students and analyze the optimal solutions, and can effectively promote the process of analysis and research on the mental health problems in modern college students.

1. Introduction

The types of higher education are increasingly diversified. With the enrichment and diversification of social life and the popularization of higher education, the traditional single university with "academic" as the standard has gradually changed. In terms of form, schools with different school systems and different forms of running schools have emerged one after another. In terms of content, the basics, application, and technology are different. General education and vocational education permeate each other. In secondary education, general education takes entering a higher school as the main goal, and vocational education takes employment as the main goal. We will strengthen the popularization of compulsory education and extend the number of years of compulsory education. Compulsory education is stipulated in the form of law, and school education with a fixed number of years will be implemented for a certain age.

In traditional education, teaching only pays attention to the improvement of students' performance and ignores students' mental health. These problems gradually accumulate in the university. Because students cannot get diversified development, many students have some mental health problems in the process of learning. Reference [1]. The convolution of the national data has gradually improved the accuracy of the students. After a series of research on the convolution of the national data, it can gradually improve the students' mental health by using the national mental health system [2]. To sum up, using a convolution neural network algorithm to analyze the mental health data of many students and realize the rapid positioning of the mental health problems in college students has become the development trend of the current education system reform [3]. So far, most of the traditional college students' mental health analysis models do not combine intelligent algorithms or adopt traditional deep learning technology. Although these models can

analyze the mental health problems of some students, most of them have limitations. Some models are established for college students in a certain area, and some models are established for college students in a certain grade [4].

Facing the problems that the traditional model is hard to analyze the data characteristics in the process of data analysis combined with advanced intelligent algorithms such as neural network, the portability of the model is poor, and the scope of application is narrow. This paper studies a variety of mental health analysis models of college students. It is mainly divided into four parts. First, it introduces the modern development background of student health analysis. Section 2 summarizes and analyzes the research status of convolutional neural network application, college students' mental health data analysis, and application methods at home and abroad. In Section 3, we used convolutional neural network to analyze the characteristics of a large amount of data, combined with TOPSIS to evaluate several indicators that have the greatest impact on the mental health of college students and allocated different data weights according to different influences to build a set of portable college students' mental health rating system and scoring index system based on convolutional neural network. In Section 4, the portability and effectiveness of the analysis model of the mental health rating system in college students and the scoring index system constructed in this paper are simulated and compared, and the experimental results are analyzed and demonstrated to draw a conclusion.

Compared with the traditional mental health analysis model, the traditional model is difficult to combine with intelligent algorithm technology such as deep learning, which often makes it difficult to analyze the characteristics of a large amount of data. The new analysis model constructed in this paper applies the fast analysis of data characteristics of big data by convolutional neural network to the mental health analysis model of college students. The model can carry out data engineering planning for a large amount of mental health data of college students, evaluate effective data indicators, realize the high-efficiency and multilevel combined application of mental health data, and use Leibniz theorem to summarize the maximum likelihood data and principal component data. The maximum likelihood data group can evaluate the data trend in the big data cluster and synthesize the principal component data to judge the future psychological trend of each student to realize the judgment of students' mental health.

2. Related Work

At present, most studies on students' mental health problems have not integrated big data for analysis. It is impossible to summarize effective results through data analysis to solve mental health problems. Convolutional neural networks without in-depth analysis of data are analyzed by deep learning technology [5]. To quickly classify and summarize a large amount of survey data and analyze the data, Pablo g and other scholars have established a new set of data processing flow, divided the data into different types according to certain standards, reconstructed the structure of the data, and then facilitated the further analysis of the data. This method can effectively improve the characteristic speed of the data. However, due to the limitation of its classification criteria, the model cannot adapt to most mental health assessments [6]. Serrano J V and other scholars tried to classify college students with different mental health characteristics and conducted long-term tracking experiments to record the changes of students with different mental characteristics in their mental status in the face of the same pressure to realize the characteristic analysis of different data included in different mental characteristics [7]. Chen et al. have demonstrated through experiments that college students in different regions and grades have different psychological needs, and the psychological data characteristics of college students in different regions and grades will be slightly different. Based on this, different data characteristics can be used to locate mental health problems [8]. The research of Felix N and other scholars proved that the data analysis model based on the combination of deep learning and data engineering can greatly reduce the redundant data in big data in the analysis of mental health data of college students. The processed data is processed by Poisson distribution through data engineering, which improves the analysis rate by at least twice compared with the traditional data analysis model [9]. Serrano Ripoll and other scholars analyzed the impact of the environment such as the original family and the living city. From the perspective of students' original family life and urban development, this paper realizes the healthy analysis by comparing the psychological data of different students in the same type of external environment [10]. Maalouf et al. designed a mental health characteristic analysis model of different economic development levels of living cities according to the different psychological basic conditions of students caused by different living cities. The model can analyze the different psychological basic conditions caused by different educational methods caused by different economic development levels. It realizes the division of multivariate data and the efficient utilization of urban data [11]. Through the automatic detection function of artificial intelligence, polanin et al. realized the diversified classification of student data in different colleges and universities and converted the students' data into the sample set data of neural network. The data can be divided into hidden layer test set parameters and function layer test set parameters, which realizes the determination of artificial intelligence neural network architecture parameters and can quickly establish an appropriate analysis model [12]. Scholars from Bowser dm and other universities found that the mental health status of different students will also change continuously during their growth. The transformation of mental health status has obvious internal correlation with external conditions, and the mental health status of college students will change rapidly at a specific time in the growth process [13]. Kresovich A and other scholars have developed a strategy of multiple reorganization and data structure redistribution of mental health data based on multidimensional database FFT analysis algorithm. According to the different psychological states of different types of college students, by analyzing the different data characteristics generated by their different psychological

data, the data structure is redeployed according to different characteristics. It improves the matching rate of neural network for data analysis and redistribution [14]. Choi et al. tracked and recorded the changes of various data indicators and life values of college students from different colleges and universities in different living cities at different stages. Through the regular tracking of two specific data, the characteristic data characteristics can effectively realize the analysis of mental health problems at different stages. This experiment realizes the classification and summary of different types of mental health problems, The corresponding database is established, which greatly improves the efficiency of data analysis [15]. Ren and other scholars found through experiments that different types of college students had different personalities formed in the growth process due to different family conditions, and different personalities will lead to different mental health conditions. They proposed a complementary model of mental health conditions in college students based on adaptive personality strategies formed in different family environments [16]. According to the different teaching concepts caused by the different changes of economy at different times in various regions, Ferguson et al. predicted the development trend of the mental health of college students at different stages based on the data analysis model [17].

To sum up, it can be demonstrated that most of the traditional analysis models of the mental health of college students lack portability, flexibility, and regional assimilation [18, 19]. On the other hand, although diversified data collection and analysis have been carried out for the mental health status of college students in different regions at different times, there are very few results that can be widely used in the research on the mental health status of college students in different regions, and there is no innovative application similar to the method of using multiple neural network algorithm and reliability model of Chebyshev inequality [20, 21].

3. Methodology

3.1. Application of Network Algorithm Combined with TOPSIS Evaluation Model in Mental Health Analysis. Recently, convolutional neural network has been gradually improved and is popular in various data analysis models as a data analysis algorithm. It has been widely used in solving problems in many fields and verified the reliability of convolutional neural network [22]. Convolution neural network adopts multilevel factors. The internal solution goal of this strategy is to find the potential phenomena through complex data tables. To realize the rapid analysis and solution of data structure, the corresponding characterization database is often established.

The typical convolutional neural network structure is a high latitude staggered alternating function grid. The structure has different feature analysis modules and hierarchical transmission strategies. The complexity between each network layer is mainly reflected in a variety of node types and complex startup functions between each network layer [23]. At present, when studying the mental health status of college students, we often need to use various questionnaires and data census filled in by students in colleges and universities, such as academic stress data index, social stress index, love stress index, and other data. To further analyze the potential correlation between various data, we need to use TOPSIS evaluation model to analyze the correlation between various data sets [24]. The processing and analysis are shown in Figure 1.

3.2. The Establishment Process of Enhanced Convolutional Neural Network Model Based on Multidimensional Data Analysis. College students in different regions and grades have different psychological needs, and the psychological data characteristics of college students in different regions and grades will be slightly different. To analyze the changes of students' mental health data in different regions, multidimensional data analysis method can be used to decompose the dimensionality reduction characteristics of big data. For students in different regions, the multidimensional data analysis gradient transformation method based on convolution neural network algorithm is adopted. Integrating the data processing characteristics of neural layer parameter converter and the corresponding data grouping method, the data decoupling and decoupling processing are completed. The decoupling analysis process of enhanced convolution neural network based on multidimensional data analysis method for multidimensional data of mental health is shown in Figure 2.

In the process of multidimensional decoupling and gradient transformation analysis of mental health data of college students in different regions, fitting simulation and data feature analysis need to be carried out for different data groups. If all data groups have no redundant nonprincipal component data features and related branch structures, after data dimension reduction analysis through convolutional neural network and anti-interference deep learning, the dataset with a series of different parameter characteristics and unique changes can be obtained. The fitting process is as follows:

$$P_1 = \sum_{i=0}^{k} \frac{\sqrt{\left(x_1^{\,0}(0), x_1^{\,1}(0), x_1^{\,2}(0), \ldots, x_1^{\,n}(0)\right)}}{x_i^{\,2}(n)}, \tag{1}$$

$$P_2 = \sum_{i=0}^{k} \frac{\sqrt{\left(x_2^{\,0}(0), x_2^{\,1}(0), x_2^{\,2}(0), \ldots, x_2^{\,n}(0)\right) + \sqrt{P_1}}}{x_i^{\,2}(n)}, \tag{2}$$

$$P_3 = \sum_{i=0}^{k} \frac{\sqrt{\sum_{i=0}^{k} \sqrt{\left(x_1^{\,0}(0), x_1^{\,1}(0), x_1^{\,2}(0), \ldots, x_1^{\,n}(0)\right)}/x_i^{\,2}(n)}}{\sqrt{P_2 + P_1}}, \tag{3}$$

$$P_i = \sqrt{\sum_{i=0}^{k} P_i} + \sum_{i=0}^{k} \frac{\sqrt{\left(x_1^{\,0}(0), x_1^{\,1}(0), x_1^{\,2}(0), \ldots, x_1^{\,n}(0)\right)}}{x_i^{\,2}(n)}. \tag{4}$$

$x(n)$ is the mental health data of college students in different universities. By matching the mental data with the analysis of geographical characteristics and restructuring the data structure, combined with the different economic and scientific research development of different universities, the potential correlation coefficient of the mental health data of college students in different universities can be obtained. The calculation formula is as follows:

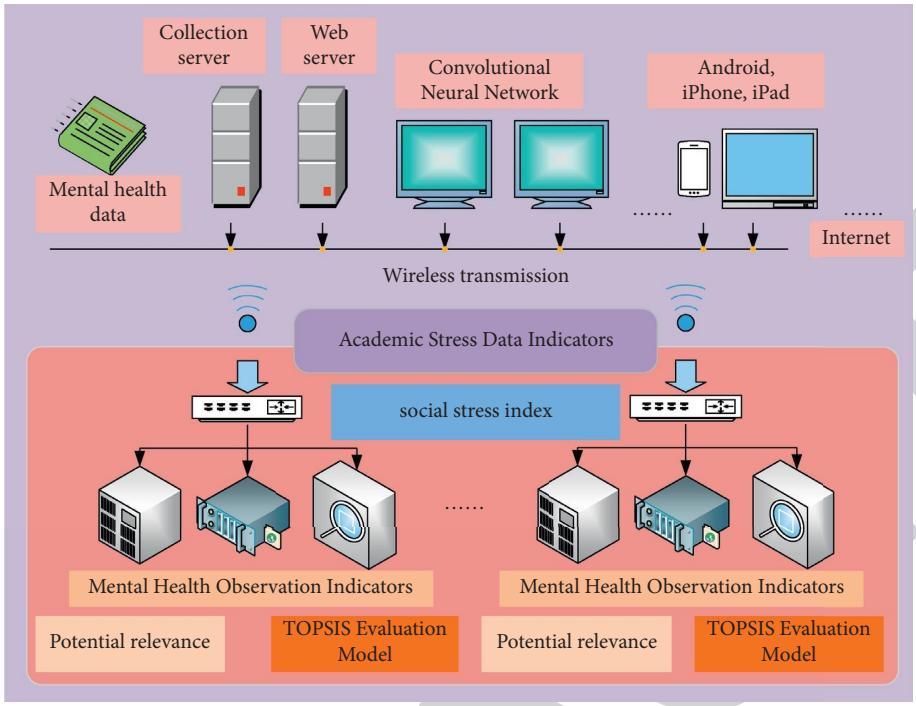

Figure 1: Processing and analysis of the mental health data of college students using convolutional neural networks.

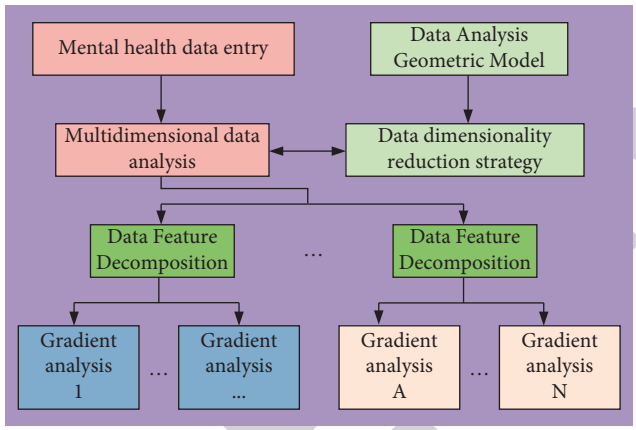

Figure 2: Decoupling and analysis operation process of multidimensional data of mental health by enhanced convolutional neural network based on multidimensional data analysis method.

$$\alpha = \sqrt{\frac{P_1^n}{\sum P_i}} + \sum_{k=0}^{n} \frac{x_1(k) + x_n(k)}{m}. \tag{5}$$

Next, the differential coupling function based on regular gradient change needs to be constructed for the regional economic energy consumption database, and its expression is.

Second, we can conduct decoupling and correlation analysis obtain the correlation strength between each two groups of data. The formula is as follows:

$$D(x) = \frac{{\alpha_i}^2 + \delta_i}{\alpha - 1} + \frac{m+1}{m^i - \alpha}. \tag{6}$$

$\delta_i = \sqrt{i+m}; i = 0, 1, \ldots$. At the same time, when using convolution neural network to analyze the mental health data of different college students, the change trend of the total value of the parameter layer of the convolution network is shown in Figure 3. At this time, the change gradient parameters are Figure 1–3.

For each data unit of data from different colleges and universities, the convolution neural network data feature correlation summary of high-order data parameters (using four data balance factors) is used. The change trend of data miscellaneous parameters is shown in Figure 4.

For each data unit of mental health data from different places, the convolution neural network data feature correlation summary of high-order data parameters (using 8 data balance factors) is used. The change trend of data miscellaneous parameters is shown in Figure 5.

From the result trend of the three groups of data in Figure 3, the data redundancy rate of the mental health data of students in different colleges and universities decreases with the increase of the number of gradient dimensionality reduction factors. With the change of a certain data gradient, the effective value ratio and principal component influence ratio also have a certain degree of fluctuation and step phenomenon. This is because in the process of using multidimensional data analysis to realize data engineering, the Euclidean distance between data groups will change step by step with the change of data dimension, resulting in step interference.

Figures 4 and 5 show that when analyzing and fitting the mental health data of students in different colleges and universities, after establishing the data analysis model with convolution neural network, when the dimension of the model is reduced, the variability and complexity of the data are greatly increased, and there are great differences in different data characteristics. In this process, the starting function of the corresponding convolutional neural network is $F(x)$:

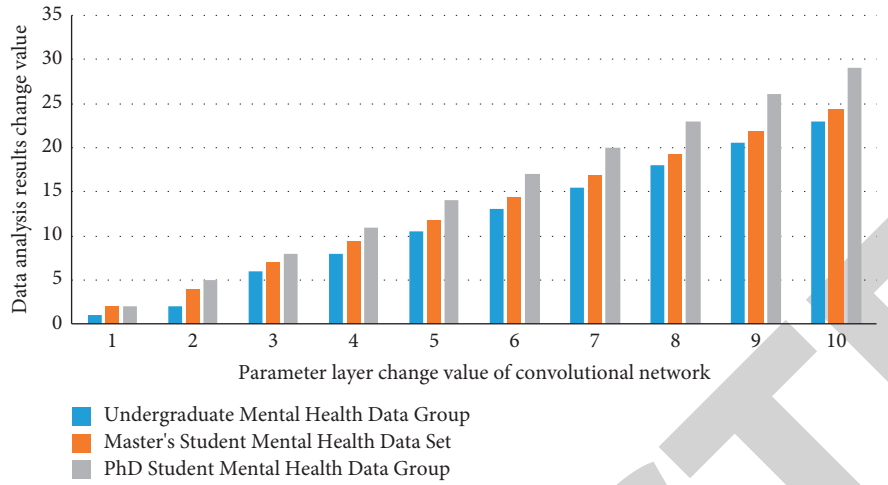

Figure 3: The results of data analysis of the mental health data of different college students using convolutional neural network.

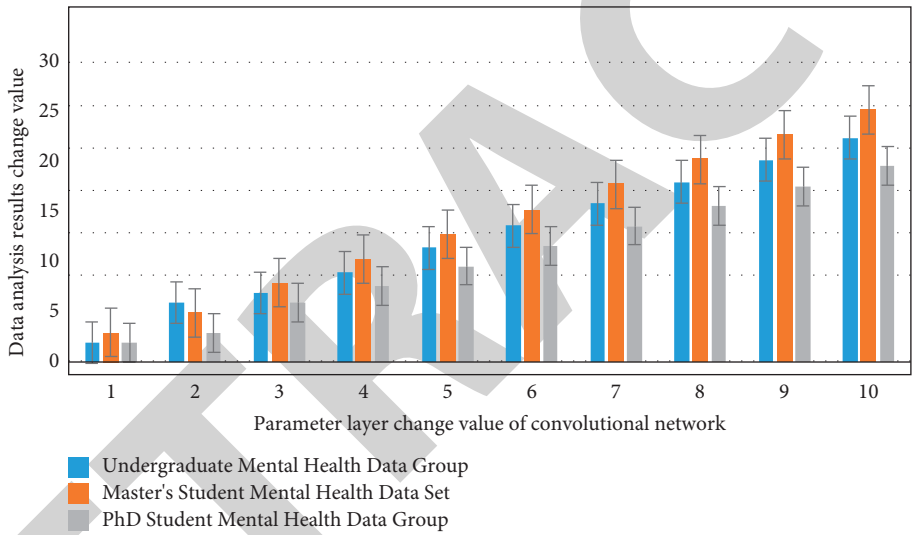

Figure 4: Variation trend of data redundancy of different students (4 data balance factors).

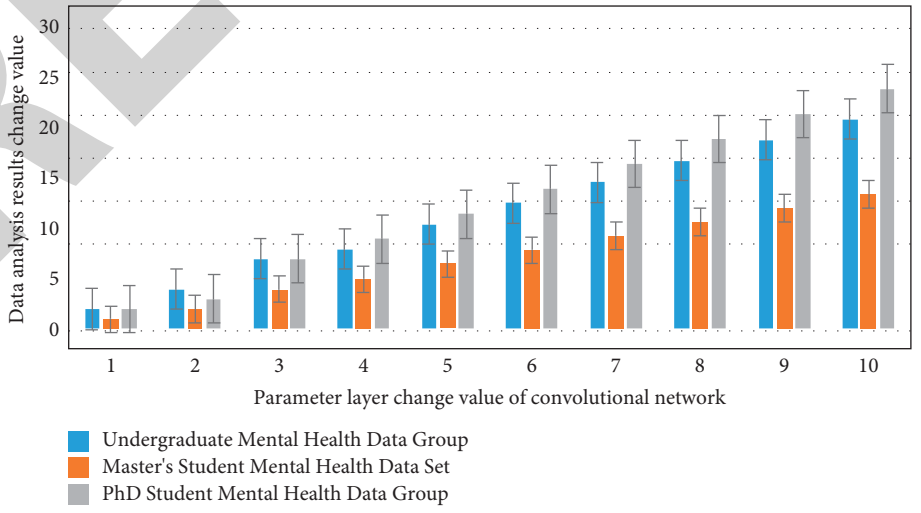

Figure 5: Variation trend of data redundancy percentage of convolutional neural network for the mental health data of students in different colleges and universities (8 data balance factors).

$$F(x) = \frac{x_j(k^*) + x_1(k^*) + {x_2}^2(k^*)}{\sqrt{(\alpha \cdot x_j(k^*) + m}}, \tag{7}$$

where $x_j(k*)$ is the normalization function of the hidden layer of convolution neural network constructed, which is used to continuously normalize the value function without alienation, and its expression is

$$T(x) = \frac{F(x) + \delta}{\sqrt{x_j(k^*) + x_j(k^* - 1)}}. \tag{8}$$

Next, we need to conduct value around combination analysis on the data group. The relative global limiting function is $S(x)$, and the local limiting function is $H(x)$.

$$S(x) = \sum_{j=1}^{k} \frac{F(x) + \sqrt{F(x) + m/F(x) + P_i(x)}}{\delta \cdot F(x) + F(2x)}. \tag{9}$$

$$H(x) = \sum_{j=1}^{k} \left(\frac{\sqrt{\left(x_j^k(k) + x_j^k(k-1)\right)^2 + \beta}}{F(x) + \alpha_j^k + \delta} \right)^k. \tag{10}$$

3.3. Construction Process of Grade Evaluation System Based on Enhanced Convolutional Neural Network. After the dimensionality reduction and decoupling processing of data, it is also necessary to evaluate the effective value and analyze the percentage of redundant value of the processed data. Therefore, a reasonable index evaluation system should be constructed to measure the effectiveness coefficient of the index:

$$\lambda = \frac{\sum \sqrt{\alpha * F(x) - P(k^*)}}{\delta + \alpha_j^k + F(x)} - F^k(x). \tag{11}$$

Normalize it; that is, limit its value to within 1, and then,

$$\lambda' = |P(x) \cdot \lambda| + \frac{\sqrt{\left(F^0(x), F^1(x), \ldots, F^k(x)\right)}}{|\delta \cdot F(x)|}. \tag{12}$$

Combined with the gradient change law of the effect of hidden nodes, genetic factor optimization is used to transform it into an iterative function with nonlinear change. The expression is

$$\sigma(x) = \lambda \cdot \alpha - 1 \sqrt{\frac{\alpha_j^k * P(k) + S(x)}{\lambda \cdot H(x)}}. \tag{13}$$

Through high-order differentiation and effective separation, we can get

$$\sigma\prime(x) = \frac{\sqrt{\lambda + P(k)/\alpha_j^k * H(x)} + \sqrt{\delta + \sigma/\beta + S(x)}}{\lambda P(x) + P(x+1)}. \tag{14}$$

Then, carry out parameter calibration and eigenvalue classification, and you can get

$$\sigma''(x) = S^k(x) * H(x) - \frac{\lambda \cdot P^k(k)}{P(k) + \sigma(x)} \sqrt{\varsigma * x_j^k(n)}. \tag{15}$$

Among them, ς is the characteristic coefficient of each data group of different university data after feature correction. Through the analysis of different dimensions of these different parameters, we can realize the matching and tracking of coupling degree and the separation of value degree of different types of characteristic coefficients of the data group and realize the segmentation of high value degree of different mental health problems, which leads to the emergence of different types of data groups.

4. Result Analysis and Discussion

4.1. The Experimental Process of Positioning the Mental Health Problems in College Students after Dimension Reduction. To effectively verify the feasibility and real efficiency of the college students' mental health analysis model with high portability and rapid data processing, this study uses the mental health data of different colleges. The data neural network structure has high adaptability and rapid transplantation in the process of optimization, some different types of college students' psychological data characteristics and data effective peaks are randomly selected for experiment and optimization verification. The experimental results are shown in Figures 6 and 7.

It can be seen from Figures 6 and7 that, in the process of preliminary experiment and final experiment, the mental health data of college students in different universities correspond to different data characteristics.

According to the multidimensional data analysis and dimension reduction analysis of convolutional neural network, the processed data structure changes alternately. The stability and structural gradient of data hiding layer and functional layer corresponding to the constructed analysis model also show regular changes. This is because, under the analysis of convolution neural network algorithm, when data engineering analysis and data dimensionality reduction are carried out on the mental health data of different colleges and universities, the internal stability and multidimensional of the model will change with the degree of data analysis.

Therefore, we can predict the trend and present the law through the data analysis chart and finally locate the problem through the mental health data of college students and put forward the corresponding solutions. In addition, different types of mental health data have different eigenvalues in different analysis modes. When the vector eigenvalue jumps, its internal information correlation will change irreversibly, but this will not affect the final curve trend. The high value analysis strategies corresponding to different types of data groups with different dimensions also have great volatility and guidance. Therefore, the matching degree of internal related data groups will be different. Therefore, the value degree of different types of data groups in convolutional neural network mode has good matching degree and value analysis degree. Therefore, different data will appear in the final results, resulting in different

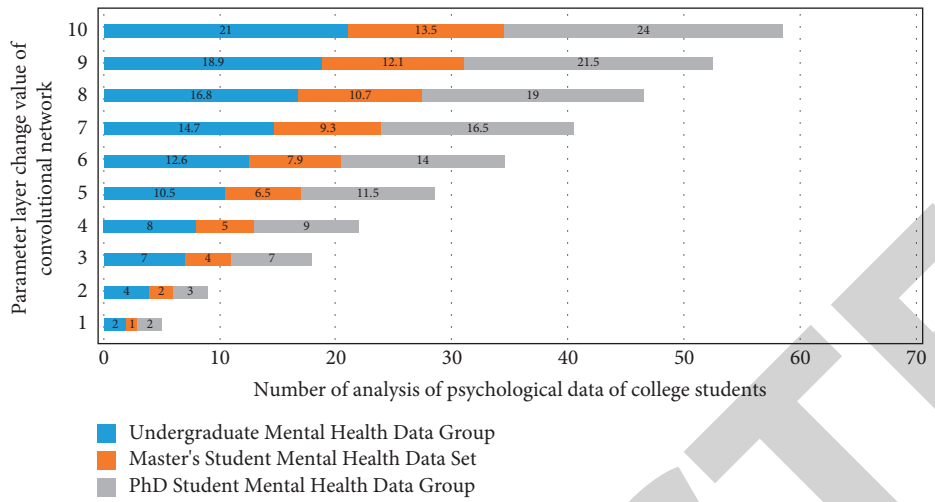

Figure 6: Preliminary experimental analysis results of mental health problems in college students after dimensionality reduction.

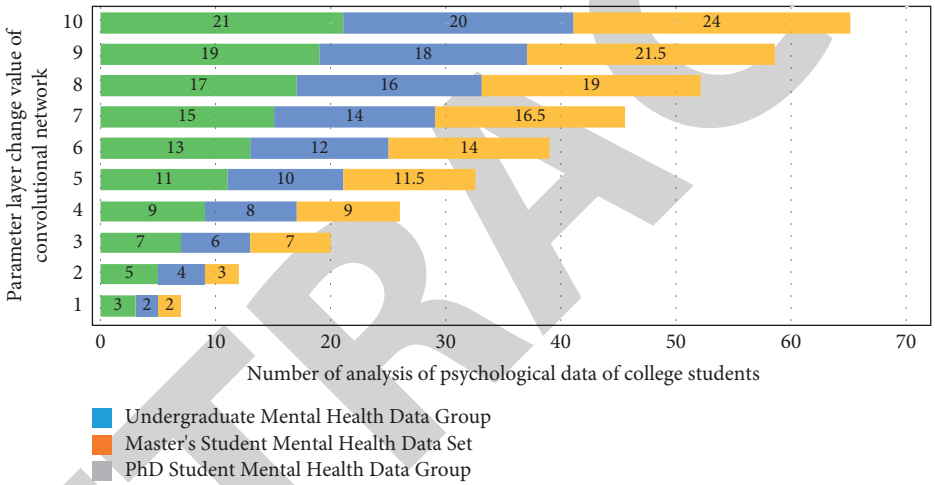

Figure 7: Final experimental analysis results of mental health problems in college students after dimensionality reduction.

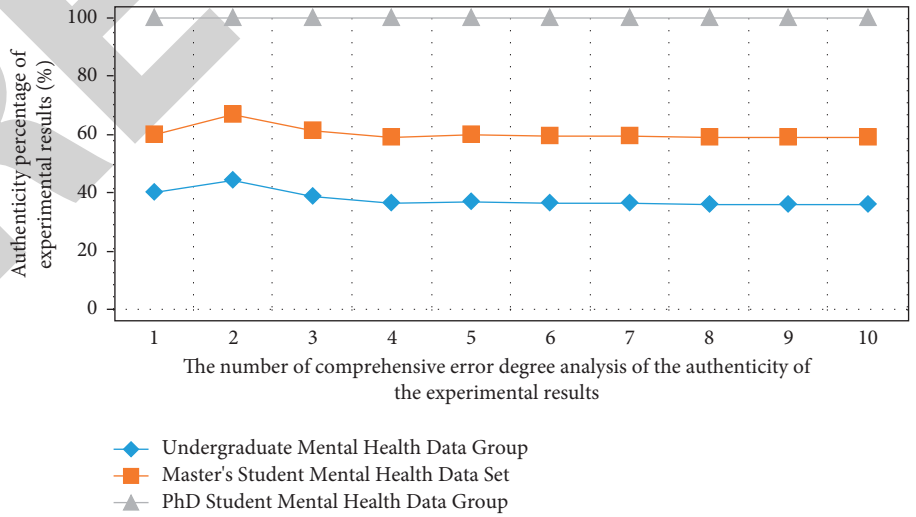

Figure 8: Authenticity analysis results of experimental results.

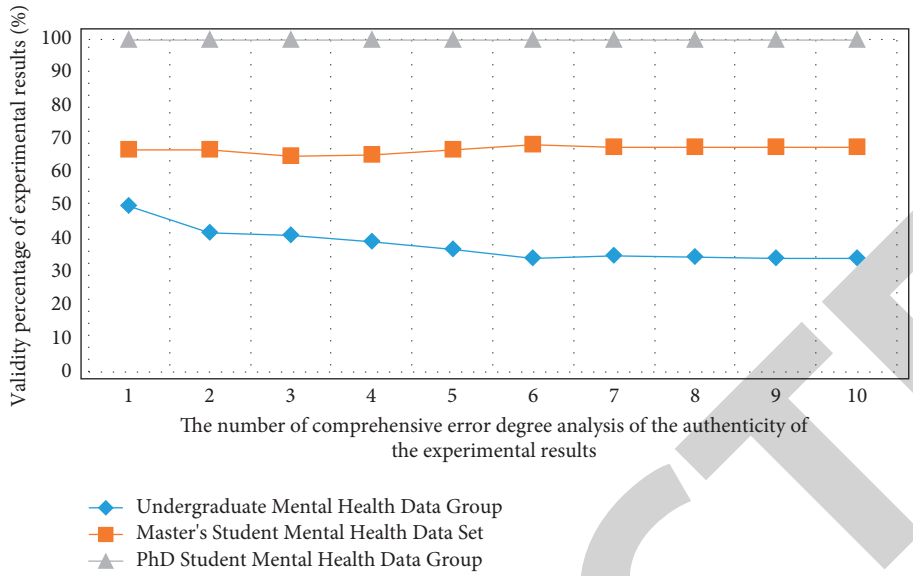

Figure 9: Analysis results.

deviations, and great changes will occur in the direction of the vector.

4.2. Experimental Verification and Analysis of the Accuracy of Students' Mental Health Analysis Model. Through the comprehensive analysis of the experimental results in the direction of authenticity, effectiveness, hierarchy, influence rate, and accuracy, the trend results are shown in Figures 8 and 9.

Through the experimental results in Figure 8 and the dimensionality reduction data processing and data feature analysis results in Figure 9, it can be seen that, in the process of optimization analysis and feature summary of college mental health data in the experimental process, the change of the effective coefficient of the local value of the data presents regular change characteristics. With the increase of the number of optimization factors of model analysis. In the model, the optimization points of the hidden layer and the output layer of the neural network also have different change laws with the matching of the data. This is because the model studied in this paper can reduce the dimension of different types of health data, analyze the parameter adjustment nodes of the data, and set them into the parameter layer of the neural network to ensure that the convolution network model can be flexibly adjustable. The model gradually adjusts the structural parameters of the network in the process of data dimensionality reduction, the model structure is more reasonable, and the analysis results are more reliable.

5. Conclusion

Based on the mental health data of students in different colleges and universities, this paper carries out dimension reduction analysis and processing. Combined with convolution neural network and TOPSIS evaluation method, the collected mental health data of college students is transformed into sample data constructed by the model, and the transfer function of the hidden layer of the model is designed and selected according to the internal relevance of the data. Finally, an analysis model of mental health of college students based on convolutional neural network is designed. Compared with the traditional mental health analysis model, the advantage of the model designed in this study is to use the developed enhanced convolutional neural network for the processing and data feature analysis of large quantities of data. According to the different data features of mental health data of college students in different regions, the potential correlation, and data matching degree between the data, we can locate the impact of the environment on the students' mental health through data analysis. Chebyshev theorem is used to analyze the accuracy of the test results.

The results show that the analysis model based on convolutional neural network can effectively improve the data processing speed and structure portability of the model, realize the rapid processing and analysis of different data, and greatly improve the data processing ability and adaptability of the model. However, the multidimensional data analysis method proposed in this study can only carry out linear analysis and error regression prediction of data information in different regions, without considering the different psychological basic conditions caused by college students' personality in the process of growth. In future research, the comprehensive evaluation index system needs further research. [25].

Data Availability

The data used to support the findings of this study are available from the author upon request.

Conflicts of Interest

The author declares no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

Hindawi
Discrete Dynamics in Nature and Society
Volume 2023, Article ID 9804273, 1 page
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Retraction

Retracted: 3D Simulation Design and Application of Traditional Hanfu Based on Internet of Things

Discrete Dynamics in Nature and Society

Received 19 December 2023; Accepted 19 December 2023; Published 20 December 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

References

[1] L. Lin and W. Gan, "3D Simulation Design and Application of Traditional Hanfu Based on Internet of Things," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 6977485, 8 pages, 2022.

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Discrete Dynamics in Nature and Society
Volume 2022, Article ID 6977485, 8 pages
https://doi.org/10.1155/2022/6977485

Research Article

3D Simulation Design and Application of Traditional Hanfu Based on Internet of Things

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Chinese traditional Hanfu is a kind of clothing that can reflect the changes of Chinese history, culture, and dynasties. With the improvement of people's aesthetic ability and the pursuit of national culture, Hanfu has shown a state of revival. The study of Hanfu has become a research hotspot in today's era. However, there is a big difference between the design of traditional Hanfu and the design of modern clothing. It not only needs to consider people aesthetics and preferences but it also needs to further consider the historical and cultural information represented by traditional Chinese Hanfu. This is a more critical and difficult point for Hanfu designers. If Hanfu cannot be well combined with history and culture, this will easily lead to a misinterpretation of Hanfu. In this study, the feasibility of the 3D simulation design of Hanfu was fully studied by combining the Internet of Things technology and the convolutional neural network method. The research results show that the Internet of Things technology can efficiently and accurately collect the characteristics of patterns, colors, shapes, and historical information of Hanfu. The reliability of IoT technology also improves the accuracy of CNN methods in predicting Hanfu eigenvalues. The largest prediction error is only 2.84%. CNN can also well capture the relationship between historical information features of Hanfu and dynasties, and all predicted feature values are within the 95% confidence interval.

1. Introduction

In the twenty-first century, Chinese Hanfu has been revived again. Hanfu has a history of more than 4,000 years, and it is a symbol of the evolution of Chinese clothing culture [1, 2]. It was destroyed in the Qing Dynasty due to historical reasons and has recently gained a certain rise. The development of Chinese primitive agriculture and textile industry has also promoted the emergence and development of Hanfu, which also reflects the development technology of Chinese early textile industry. With the economic, political, and ideological changes of each dynasty, the characteristics and styles of Hanfu will also undergo great changes. More historical information can also be learned in the form of Hanfu [3, 4]. With the rapid development of Chinese national strength, people began to examine the excellent parts of their traditional culture and try their best to inherit these excellent cultures. More researchers have begun to restore the traditional costumes of the Han nationality by researching Hanfu and taking its essence to get rid of its dross [5, 6]. Hanfu is not only a kind of clothing but also a kind of inheritance of Chinese history and culture. The characteristics of Hanfu are different from those of other countries. It is a representation of Chinese etiquette and the way of daily life [7]. The color, pattern, and shape of Hanfu are closely related to Chinese history and culture and the use of clothing [8]. For designers in today era, the design of Hanfu is also more difficult. It not only needs to combine the characteristics of Hanfu itself but it also needs to be designed with the characteristics of the clothing of the current era. In today era, people aesthetics have undergone great changes. The traditional characteristics of Hanfu can no longer meet the aesthetics of today's people. This requires efficient design based on the historical and cultural characteristics of Hanfu and people aesthetics in today era. For clothing designers, the biggest difference between Hanfu and modern clothing is not the style, pattern, etc. The most important part is the historical information contained in Hanfu. Computer technology can handle the

data of Hanfu design well and it can share information, which is beneficial to the design of Hanfu. Computers can provide Hanfu designers with more historical information about Hanfu. This puts forward more requirements for clothing designers, which also needs to combine computer technology to carry out efficient design.

The Internet of Things technology is a product of the rapid development of science and technology [9, 10]. It combines a technology of information transmission and sharing with hardware devices such as cameras, the Internet, and sensors [11, 12]. The Internet of Things technology has been widely used in many fields, and it can realize tasks such as remote office and resource sharing [13, 14]. For example, the Internet of Things can realize remote teaching through cameras, the Internet, and recording equipment, which improves the utilization of teaching resources [15]. Offsite office is also one of the main applications of IoT technology. Smart home is also a relatively wide application of Internet of Things technology, which can manage and apply the electronic devices of the family in a unified manner [16, 17]. For clothing designers, IoT technology will also facilitate the efficient generation of clothing solutions. For the design of Hanfu, IoT technology can bring together the opinions of experts in multiple fields, which can include researchers in the field of history and researchers in the field of clothing. They can jointly provide relevant opinions for the design of Hanfu. Similarly, IoT technology can collect more information from Internet technology, which can help Hanfu designers come up with more design solutions. Through the Internet of Things technology, the design task of Hanfu can not only achieve remote resource sharing but also it can refer to more Hanfu design schemes from the Internet. This will greatly improve the efficiency of Hanfu design task and which can also take into account the historical elements of Hanfu.

Hanfu designers can not only learn more Hanfu design solutions through the Internet of Things technology but also it can make full use of the Internet technology to refer to the successful Hanfu design cases. The 3D design scheme of Hanfu mainly includes the cultural characteristics, colors, patterns, and shapes of Hanfu. It can fully learn the relationship between the characteristics of Hanfu and the design scheme through intelligent algorithms. Designers can design new Hanfu solutions based on the relationship between the learned Hanfu features and design solutions. This research will also use intelligent algorithms to learn Hanfu clothing patterns, colors, and historical information and other characteristic factors, which will provide more information resources for Hanfu designers. The Internet of Things technology can realize the role of remote office and information sharing for Hanfu 3D simulation, and it can learn more about Hanfu related characteristics through remote resources. The neural network method will be regarded as the intelligent algorithm of this study [18, 19], which uses the characteristic factors of Hanfu as input data. It will map the relationship between Hanfu characteristic factors and Hanfu 3D simulation design scheme. Once the model is trained, the Hanfu designer will match the corresponding solution according to the 3D simulation requirements of Hanfu, and this task will also fully combine the advantages of the Internet of Things technology.

This research will use the Internet of Things technology and neural network technology to realize the 3D simulation design of Hanfu, which will provide more ideas for Hanfu designers. Moreover, this method will save more human and material resources for Hanfu designers. This study will conduct related research from five chapters. The first section mainly introduces the historical background of Hanfu and the application of IoT technology in the 3D simulation design of Hanfu. Section 2 mainly introduces the research status of Hanfu or other types of clothing design, which will also provide more reference value for the 3D simulation of Hanfu. The application scheme of IoT technology and neural network method in Hanfu 3D simulation design is introduced in Section 3. Section 4 introduces the feasibility and accuracy of IoT technology and neural network method in Hanfu 3D simulation design in detail. Statistical parameters such as the prediction error curve of Hanfu characteristics, the thermal distribution map of Hanfu characteristics, and the correlation coefficient map are used to analyze the accuracy of the Internet of Things technology and the application of neural network methods in the design of Hanfu. Section 5 summarizes the research.

2. Related Work

Chinese traditional Hanfu has been revived to a certain extent in recent years, more people have begun to explore the connotation of Hanfu, and many researchers have also conducted related research on Hanfu. Zheng and Lee [20] analyzed the types and characteristics of traditional Chinese women's clothing, which can identify the historical and cultural information of Hanfu through the style of Hanfu. He mainly studied the characteristics of Hanfu in the Han, Tang, and Song dynasties. It mainly studied the forms and characteristics of women's Hanfu based on historical documents and museum information. The characteristics of Hanfu can be studied from the characteristics of shape, pattern, and material. It has also analyzed the style and design of the fusion of Hanfu and contemporary clothing. Zhang and Ma [21] have also noticed that more researchers have begun to focus on the structure and characteristics of Hanfu clothing. The change and development of Hanfu is a process of continuous innovation and progress in a dynasty. He studied the characteristics of traditional Hanfu and improved Hanfu by using the method of cross plane structure. He also used CLO3D software to establish the cross plane structure of Hanfu to study the characteristics of Hanfu and wearing models. He uses this model to explore the fusion of traditional Hanfu and modern clothing, which will be conducive to the effective transmission of traditional Hanfu characteristics in modern society. Taman [22] mainly studied Hanfu from the perspectives of comfort, economy, and artistry. He mainly used the analytic hierarchy process to establish the characteristic model of Hanfu, which will be beneficial to the research of Hanfu. At the same time, he used the AHP grey relational analysis method to fully study the application value and practicability of Hanfu. This research

will be conducive to the efficient integration of Hanfu and current clothing, which has important guiding significance for the design of Hanfu. Chen and Hee [23] have combined the theme of traditional Chinese Hanfu culture with the characteristics of modern men's hip-hop clothing for new clothing design. He designed a clothing scheme based on the fashion-style characteristics of hip-hop clothing and the historical and cultural atmosphere of Hanfu, which will break the characteristics of traditional hip-hop clothing design elements. At the same time, he also applied the concept of SCAMPER to research and design the fusion of hip-hop clothing and Hanfu characteristics. This hip-hop clothing design scheme based on Chinese traditional Hanfu will benefit the development of Chinese clothing fashion. Liu and Shu [24] have conducted analysis and research on Chinese women's cheongsams from six dynasties in China, mainly from the form, pattern, and pattern features of sleeves, collar, waist, and detailed comparative analysis. At the same time, he used 3D Simulation software to compare and analyze the clothing styles of the six dynasties. Through research, it can be concluded that the length of clothes in Qin Dynasty is the longest, and the sleeves in Qing Dynasty are short and wide. This research on the characteristics of Chinese women's Hanfu is conducive to deepening the understanding of the characteristics of Chinese women's Hanfu. Kim and Young [25] have made use of traditional Chinese Hanfu to continuously revive the status quo. He analyzed the characteristics of traditional Chinese Hanfu and the element characteristics of Hanfu, which will help fans to understand the characteristics of traditional Hanfu. At the same time, it will analyze the intersection of Chinese Hanfu elements and Chinese history and national culture. From the above literature review, it can be seen that most of the researchers have mainly conducted relevant research on the characteristics and cultural elements of traditional Chinese Hanfu, which also involves the integration of Hanfu and modern clothing. However, most of them are studied in the manner of historical documents. Wang et al. [26] mainly studied the size measurement scheme of Chinese Hanfu by using the convolutional neural network (CNN) method. He used the technology of multiple transfer learning to obtain the feature points of Hanfu, which will improve the recognition speed of Hanfu features. Then, it will obtain the data of the actual Hanfu size in a proportional way. The results show that the prediction error of this method is only between 0.59% and 4.17%. This research mainly uses the Internet of Things technology and neural network technology to study the 3D simulation design of traditional Chinese Hanfu, which will be different from the above research status. This research utilizes high-performance computer technology rather than just using historical documents to conduct related research.

3. The Introduction of IoT Technology and Neural Network Methods in Hanfu

3.1. The Significance of IoT to 3D Simulation of Hanfu. The design of traditional Chinese Hanfu is different from the design of modern clothing. It not only needs to meet the aesthetic needs of modern people but also it requires designers to understand relevant historical information. The style, pattern, color, and style of traditional Chinese Hanfu will reflect the development history of the dynasty and the economic and ideological state of the dynasty. It cannot be designed without ignoring the historical information of the clothing. Therefore, a new Hanfu design scheme is extremely difficult for a clothing designer. The Internet of Things technology can realize technologies such as remote office and information sharing of Hanfu design, which can allow Hanfu designers to have more design references and help. IoT technology can also help Hanfu designers realize remote Hanfu 3D simulation technology. The emergence of IoT technology provides more historical information for Hanfu designers, which allows them to integrate the characteristics of modern clothing and the characteristics of traditional Hanfu. In short, the application of IoT technology in Hanfu design can help them realize the 3D simulation technology of Hanfu, and it can also provide more information for Hanfu designers.

3.2. The Introduction of 3D Intelligent Simulation System of Hanfu. The goal of this research is to realize the 3D simulation design of traditional Chinese Hanfu by using the Internet of Things technology and neural network method. The 3D simulation of Hanfu is mainly the design of patterns, colors, historical information, and shapes. This performance is mainly designed for simulation of these four characteristics of Hanfu. The hardware devices of IoT technology used in this study are mainly cameras and Internet technology. Figure 1 shows that Hanfu's 3D simulation design system utilizes IoT technology and CNN method. The Internet of Things technology is mainly to realize the sharing of Hanfu information and the acquisition of Hanfu information. CNN technology is mainly to learn the relationship between Hanfu features and Hanfu design. It can realize the design of traditional Chinese Hanfu by this method, which will save a lot of time for Hanfu designers. The Hanfu 3D simulation design system mainly includes two processes: Internet of Things technology data collection and 3D Hanfu simulation design. For the first process, the Internet of Things technology will use cameras and other hardware sensors to collect the characteristic information of Hanfu, and this process will realize remote collection or information sharing. These data will be transmitted through the Internet terminal of the Internet of Things technology. The sensors of the IoT technology will collect the design features of Hanfu, and these features will be transmitted through the Internet technology. This ensures that Hanfu designers receive these Hanfu feature information. For the second process, the CNN method can learn the relationship between Hanfu features and Hanfu design schemes. Once this system is trained, Hanfu designers can achieve efficient simulation design of Hanfu only by relying on the characteristic requirements of Hanfu design.

The Internet of Things technology is a relatively mature technology, which can be easily implemented through sensors and the Internet according to the needs of designers.

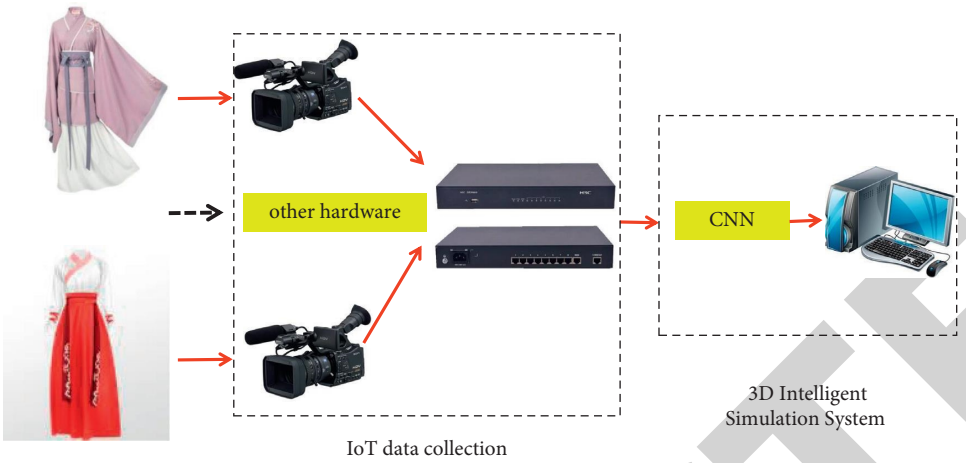

Figure 1: The design of Hanfu 3D simulation system based on IoT technology.

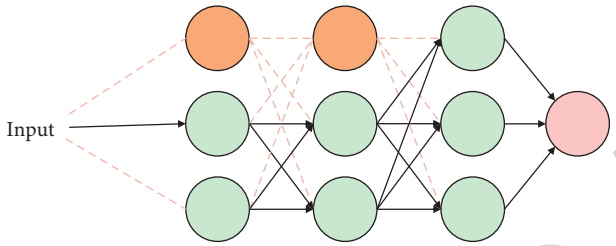

Figure 2: The operational relationship between CNN and perceptron.

The focus of this study is the second process of Hanfu 3D simulation design, which will utilize the CNN neural network approach. Figure 2 shows the operational relationship between CNN and perceptron. Figure 2 shows the structure of the perceptron, which is the basic structure of the neural network approach. CNN is also a kind of neural network method, and its operation will also follow the operation flow of the perceptron. CNN is also a relatively mature algorithm, which has been widely used in people's production and life [27, 28]. CNN is a special form of the perceptron form, which also uses the form of weight and bias distribution to map the nonlinear relationship between input and output [29]. The difference between CNN and perceptron is that it has a weight sharing mechanism [30]. The dashed part of Figure 2 shows the weight sharing method. The weight sharing mechanism can greatly reduce the computational complexity of parameters, and it can also achieve the task of extracting main features. The number of filters chosen in this study is 128. The learning rate 0.001 is chosen, which is to prevent getting stuck in local minima. The stride of the pooling layer is set to 1.

The process of CNN finding the optimal distribution is done through the loss function, which can reflect the difference between the predicted value and the actual value. In the training phase, it needs to provide some label values to complete the operation of the loss function. Equation (1) introduces the calculation process of the loss function of CNN. In this study, a conventional loss function in the form of mean square error is used in this study.

$$E = \frac{1}{2}(d_{out} - O_{real})^2 = \frac{1}{2}\sum_{\kappa=1}^{t}(d_\kappa - O_\kappa)^2. \tag{1}$$

Most CNN will use gradient descent to find optimal weights and biases. Gradient descent methods need to find the partial derivatives of the weights and biases, which will be used to find the minimum. Equations (2) and (3) show the derivation of weights and biases.

$$\Delta\omega_{ji} = -\eta\frac{\partial E}{\partial\omega_{ji}}, \tag{2}$$

$$\Delta u_{ij} = -\eta\frac{\partial E\partial}{\partial u_{ij}}. \tag{3}$$

In the calculation process of CNN, this will involve a large number of derivative operations. If these derivation operations are calculated sequentially, it will not only increase the computational complexity of the computer but it will also occupy a large amount of computer memory. In the actual operation process of CNN, this will use the chain derivation rule, and the propagation process of weights and biases is the application process of the chain derivation rule. Equations (4) and (5) show how the chain rule is applied in CNN.

$$E = \frac{1}{2}\sum_{k=1}^{m}[d_k - f(netw_k)]^2 = \frac{1}{2}\sum_{k=1}^{m}\left[d_k - f\left(\sum_{j=0}^{n}\omega_{jk}y_j\right)\right]^2, \tag{4}$$

$$\begin{aligned} E &= \frac{1}{2}\sum_{k=1}^{m}[d_k - f(netw_k)]^2 = \frac{1}{2}\sum_{k=1}^{m}\left[d_k - f\left(\sum_{j=0}^{n}\omega_{jk}y_j\right)\right]^2 \\ &= \frac{1}{2}\sum_{k=1}^{m}\left[d_k - f\left(\sum_{j=0}^{n}\omega_{j\kappa}f\left(\sum_{j=0}^{q}u_{ij}\chi_i\right)\right)\right]^2. \end{aligned} \tag{5}$$

3.3. The Introduction of Data Evaluation and Data Processing. The pattern, color, historical information, and shape of Hanfu are relatively complex, and it is difficult to directly collect through the Internet of Things technology. Therefore, the data collected through IoT technology need to be evaluated and processed. The evaluation of data needs to use the theory of uncertainty to evaluate, and the place with high uncertainty is the place where the data have larger defects. Once areas of high data uncertainty are detected, researchers need to adjust the data collected by IoT technology. This data evaluation process is carried out after the IoT technology collects the data process. The uncertainty of the data can reflect the data quality of Hanfu, and the place with greater uncertainty is the place with poor data quality. This study evaluates the Hanfu characteristic data collected by the Internet of Things technology through the uncertainty distribution of the data.

Before studying the uncertainty of the data, it needs to determine a distribution that the data needs to satisfy. It can be a Gaussian distribution, a normal distribution, or some other form of distribution. Equation (6) shows the computational form of the Gaussian distribution. Equation (7) shows the distribution form of the weights after using the Gaussian distribution.

$$W_i \approx \mathrm{N}(0, I), \tag{6}$$

$$\omega_q = (W_i)_{i=1}^{L}. \tag{7}$$

It uses the Bernoulli distribution to establish the relationship between weights and probability distributions, as shown in equations (8) and (9). The Gaussian distribution is mainly used for the distribution processing of Hanfu feature data, and the Bernoulli distribution is used for the approximate distribution of the uncertainty integral operation process.

$$W_i = M_i \bullet \mathrm{diag}\left(\left[z_{i,j} \right]_{j=1}^{K^i} \right), \tag{8}$$

$$z_{i,j} \sim \mathrm{Bernoulli}\left(p_i \right). \tag{9}$$

The determination of uncertainty will take the form of a prior distribution and a posterior distribution, and the posterior distribution will be calculated under the condition of prior knowledge. In the process of uncertainty calculation, the posterior distribution is the key to the calculation. Equation (10) shows how the posterior distribution is calculated.

$$\ell_V = \int q(\omega) p(F|X, \omega) \log\, p(Y|F) d^f d\omega - KL(q(\omega) \| \, p(\omega)). \tag{10}$$

In the calculation process of the posterior distribution, the integral is relatively difficult to calculate, and the KL divergence is used here to approximate the posterior distribution. Equation (11) shows the calculation rule for KL divergence.

$$KL(q(\omega) p(\omega)) = \frac{1}{2D} \sum_{i=1}^{D} \left(p_d \| M_d \|_2^2 + \| b \|_2^2 \right). \tag{11}$$

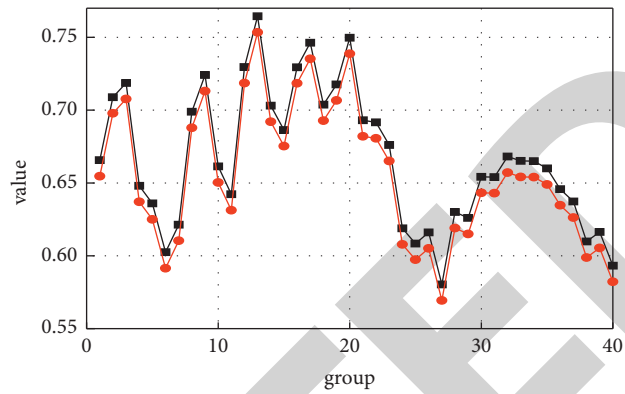

Figure 3: The predicted value of historical information features of Hanfu.

Similarly, data on patterns, colors, shapes, and historical information of Hanfu exist in different forms. For example, the value of color is data between 0 and 255, and the historical information will be converted into data value between 0 and 1. This results in a large difference in the relevant feature data of Hanfu. The preprocessing process of the data will uniformly process the data whether it is the numerical size or the characteristic range of the numerical value. This study uses a standardized preprocessing method, which is different from maximization or minimization.

4. Result Analysis and Discussion

This research will use the Internet of Things technology and CNN method to realize the 3D intelligent simulation design of Chinese traditional Hanfu. The Internet of Things technology will only improve the relevant sensors to collect the characteristic data of Hanfu. The CNN algorithm will predict the characteristic data of these Hanfu, which will provide more reference information for Hanfu designers to realize the 3D intelligent simulation design of traditional Chinese Hanfu. This study selects the Hanfu characteristic data of the four dynasties of Tang, Song, Yuan, and Ming to conduct related research. Figure 3 shows the predicted value of the historical information feature data of Hanfu. In Figure 3, the red line represents the predicted value of the Hanfu historical information feature data, and the black line represents the actual value of the Hanfu historical information. Overall, the CNN method can effectively predict the historical information features of Hanfu. Although the historical information of traditional Chinese Hanfu has relatively large fluctuations for different dynasties, CNN predicts the relevant historical information of Hanfu well. Due to the great differences in the economy and ideology of different dynasties, the characteristics of Hanfu will change greatly. This change can be seen in Figure 3. Although the eigenvalues of the historical information of Hanfu have large fluctuations, and it has many peaks and valleys. However, the predicted value of CNN is still in good agreement with the actual historical information feature value of Hanfu. This accurate mapping relationship will help Hanfu designers to fully grasp the historical information of Hanfu.

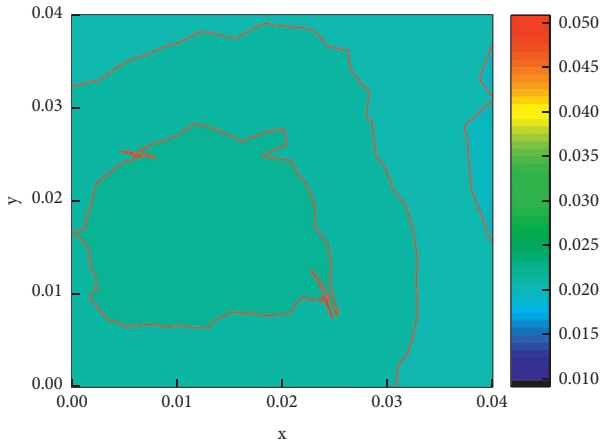

Figure 4: The prediction error distribution of Hanfu pattern features.

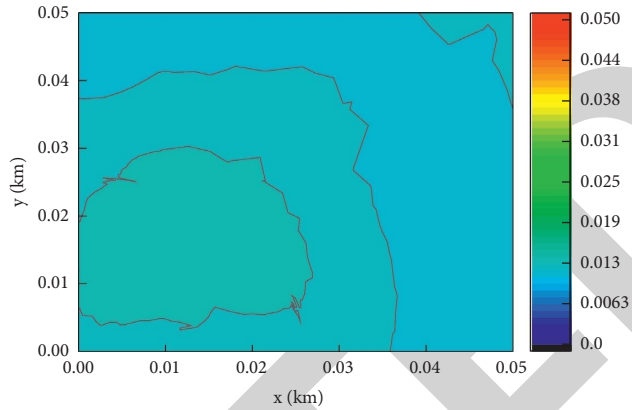

Figure 5: The prediction error distribution of Hanfu color features.

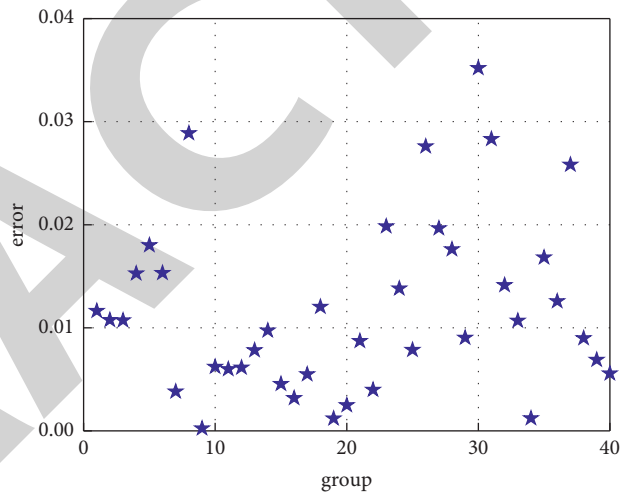

Figure 6: The prediction error distribution of Hanfu shape features.

The pattern feature of Hanfu is also feature that designers pay more attention to it. Pattern information can not only reflect the historical and cultural information conveyed by Hanfu but also it can improve people's preference for Hanfu. Therefore, the pattern feature of Hanfu is also a focus that must be paid attention to in the process of Hanfu 3D simulation design. Figure 4 shows the prediction error distribution of Hanfu pattern features. In general, CNN can better predict the pattern feature values of Hanfu, and most of the error values are distributed within 2%. For the 3D simulation design of Hanfu, this error range is enough to convince the designer. It can also be seen from Figure 4 that the prediction error distribution of Hanfu pattern features is relatively uniform, and there is relatively no large fluctuation. This shows that the CNN algorithm has good stability in the prediction of Hanfu pattern features, which is also a reference for Hanfu 3D simulation designers. It mainly has three error fluctuation intervals, and the larger error interval is also within 3%. In general, the CNN method has better stability and accuracy in predicting Hanfu pattern features.

Color characteristics are also an important feature of Hanfu design. Color characteristics can distinguish the gender of the wearer of Hanfu and the occasion of use of the Hanfu. At the same time, color characteristics can also reflect the preference of Hanfu wearers. The color of Hanfu can also show different forms of cultural elements to a certain extent. In short, the prediction of color features is a key link for the 3D simulation design of Hanfu. Figure 5 shows the prediction error distribution of Hanfu color features. In general, the CNN method can also predict the color characteristics of Hanfu well, and it also has a large color error. Compared with the prediction error of the pattern feature of Hanfu, the error range of the color feature value of Hanfu is smaller. Although it has more error intervals than the pattern prediction error of Hanfu, the values of these intervals are relatively small. This can further illustrate that CNN has better accuracy and credibility in predicting the color features of Hanfu. The distribution of the color prediction error of Hanfu is also relatively uniform, and there is no obvious fluctuation. This can further illustrate the reliability of IoT technology in collecting Hanfu characteristic data.

The shape characteristics of Hanfu can show the historical and cultural characteristics of different dynasties and the changes in thinking. If the designers of Hanfu do not have a good understanding of the relationship between the shape and characteristics of Hanfu and the dynasties or historical culture, it will easily lead to misinterpretation of historical culture. Therefore, the shape features of Hanfu are also a key link in the 3D simulation design process of Hanfu. Figure 6 shows the prediction error distribution of the shape features of Hanfu. Overall, the CNN method can predict the shape eigenvalues of the Hanfu of the four dynasties well. Most of the prediction errors are mainly concentrated within 2%, and only a small part of the error exceeds 3%. This part of the larger error occupies a small proportion, which may be because the shape characteristics of this part of Hanfu are relatively rare, this can improve accuracy by collecting more shape features through IoT technology. Figure 7 shows the feasibility distribution of the prediction error of Hanfu shape features. It can be clearly seen from Figure 7 that all the predicted values are within the 95% confidence interval,

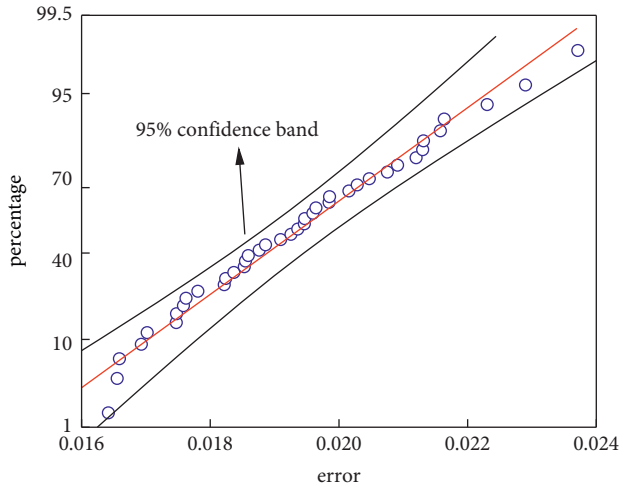

Figure 7: The reliability distribution of predicted value of Hanfu shape feature.

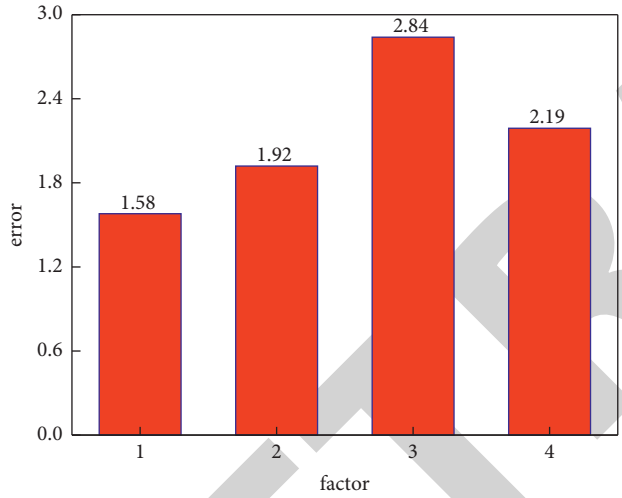

Figure 8: The average prediction error of four features of Hanfu.

which shows that CNN has good feasibility in predicting the shape features of Hanfu, which is conducive to improving the prediction results of Hanfu designers. Reliability: this can also further illustrate the accuracy of the Hanfu shape eigenvalues collected by IoT technology.

The average error value can better reflect the overall performance of CNN and IoT technology in Hanfu 3D simulation design. Figure 8 shows the distribution of the average prediction error of the eigenvalues of Hanfu. Overall, all four mean error values are satisfactory. All prediction errors are within 3%, and the largest prediction error is only 2.84%. This part of the error may be derived from the prediction of historical information of Hanfu, and the reason for the larger error may be that there are certain differences in the collected historical information. This can improve the accuracy of Hanfu historical information data by artificially assisting IoT technology. The smallest average prediction error is only 1.58%, and this part of the error comes from the prediction of the eigenvalues of the Hanfu shape. Figure 8 can further illustrate that the CNN method and the Internet of Things technology have better reliability in predicting the shape features of Hanfu. However, the method proposed in this study has good accuracy for the four eigenvalues of Hanfu.

5. Conclusions

Chinese traditional Hanfu is a symbol of Chinese history and culture. In recent years, Hanfu has begun to gradually revive. The accuracy of the 3D simulation design of Hanfu is a key point for Hanfu designers. However, Hanfu of different dynasties has big differences in pattern, color, shape, and historical information characteristics. This requires Hanfu designers to master more patterns and historical information characteristics, so as to accurately grasp the relationship between traditional Hanfu characteristics and design schemes.

This study combines the Internet of Things technology and CNN technology to study the accuracy and feasibility of the 3D simulation design of Hanfu. For the historical information characteristics of Hanfu, CNN, and Internet of Things technology can well capture the changes of historical information of Hanfu in different dynasties. For the pattern features and color features of Hanfu, CNN, and IoT technology can make good predictions. The prediction error distribution of this feature is relatively uniform, and most of the errors are within 3%. This can further illustrate the accuracy and reliability of the Hanfu eigenvalues collected by IoT technology. When CNN and IoT technology predict the shape features of Hanfu, all feature values are distributed within the 95% confidence interval. For the average forecast error, the largest forecast error is only 2.84%. Overall, the CNN method and IoT technology have good reliability and accuracy in the 3D simulation design of Hanfu.

Data Availability

The data set can be accessed upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: Seismic Performance Analysis of Steel Truss Coal Conveying Trestle Based on Multisensor Data Fusion

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] B.-y. Yao, "Seismic Performance Analysis of Steel Truss Coal Conveying Trestle Based on Multisensor Data Fusion," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 7102779, 10 pages, 2022.

Hindawi
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Research Article

Seismic Performance Analysis of Steel Truss Coal Conveying Trestle Based on Multisensor Data Fusion

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Coal ranks first in the energy demand of our country, and it also plays an unshakable role in promoting national defense and economic development. Coal conveying trestle is the link and lifeline in the process of coal production. Once it is damaged by an earthquake, it will cause great losses in the production of coal enterprises. Therefore, it is of great significance to analyze the seismic performance of long-span coal conveying trestle and apply it to engineering design. To solve this problem, an analysis method based on the combination of field measurement and finite element simulation is proposed. Firstly, multisensor data fusion is introduced, and the finite element model for the dynamic characteristic analysis of long-span coal conveying trestle is constructed. Then, based on multisensor data fusion, the dynamic characteristics of long-span coal conveying trestle are measured. Finally, the model is modified based on the measured results, and the seismic performance of long-span coal conveying trestle under strong earthquake is analyzed. The results show that the model can accurately characterize the seismic performance of long-span coal handling trestle, which provides an effective numerical simulation method for the engineering design of coal handling trestle.

1. Introduction

Coal mining is a development field of great strategic significance. With the progress of industry and the increasing demand for coal energy, the safety and stability of coal mining and transportation engineering have attracted more and more attention [1, 2]. Coal conveying trestle is not only the connecting channel of coal production link but also the link and lifeline of production and transportation process. The coal conveying trestle is strip-shaped, and its structural characteristics are large structural span, high support, heavy bearing equipment, and being greatly affected by working load (motor vibration disturbance, dynamic action of coal conveying belt, etc.). With the continuous development of industry, there are more and more coal conveying trestles used in energy projects such as coal mines, coal preparation plants, and thermal power plants. Ensuring the safety and smoothness of coal conveying trestle is an important link in the whole coal production process. Especially for the long-span coal conveying trestle, its mass and stiffness are unevenly distributed along the vertical direction and there are many weak parts. These characteristics lead to its abnormal sensitivity to vibration load. It should be noted that more than 80% of the mining areas are in strong earthquake areas. Once the coal conveying trestle is damaged by the earthquake, it will cause great losses to the production of coal enterprises. For example, in the "5.12" Wenchuan earthquake, many small- and medium-sized coal mines were completely shut down. According to the survey, some coal conveying trestles that have been designed for earthquake resistance have also been seriously damaged under the earthquake with fortification intensity, which reflects the shortcomings and defects of the seismic design of coal conveying trestles. Therefore, it is of great significance to analyze the seismic characteristics and safety evaluation of long-span coal conveying trestle and apply it to engineering design.

In nearly half a century, the seismic investigation and analysis of long-span trestle have been widely carried out, which provides us with not only valuable experience and

lessons but also the scientific basis for establishing correct seismic design methods and taking effective seismic measures [3, 4]. In the investigation and research of a large number of earthquake disasters, the reasons for the damage of trestle structure mainly include the following: The first reason is the improper connection between trestle spans or between trestle spans and adjacent buildings. When the overall torsion and translational vibration occur in the process of earthquake movement, tensile cracking, falling, and collision damage will occur between spans or ends. The second reason is node failure. The joint connection belongs to the weakness of the structural system. Once the structure is handled improperly or the bearing capacity is insufficient in the design, the whole trestle system will not work normally or even break and collapse. The third reason is damage caused by insufficient seismic capacity of trestle support. Correspondingly, some useful research works on the seismic characteristics of long-span spatial structures have been implemented by scholars. The seismic performance and dynamic response of long-span coal conveying trestle have been studied in [5, 6], providing a reference for the design of trestle engineering. In [7–9], the improvement methods of differential settlement mechanical characteristics and mechanical performance of coal conveying trestle have been studied, providing suggestions for structural reliability appraisal of coal conveying trestle. In [10–12], the seismic performance and damage control of bridges are studied, and their respective solutions are put forward. In [13], the dynamic characteristics of long-span steel structures under strong earthquake are studied, and the anticollapse optimization method of long-span bridges under strong earthquake is proposed. In [14], the seismic performance of long-span cable-stayed bridges is studied, and the main seismic codes are compared to provide a reference for the seismic design of long-span bridges. However, it should be pointed out that most of the above documents are limited to the seismic analysis of bridge structures, but the coal handling trestle structure has its unique characteristics compared with general bridge structures. Therefore, whether the research results of the bridge can be applied to the coal handling trestle is doubtful.

On the whole, at present, the research on long-span coal conveying trestle mostly focuses on the structural optimization of trestle and the development of new system or the dynamic stability of coal conveying trestle under mechanical vibration and wind-induced vibration. The seismic research methods of long-span coal conveying trestle are mostly based on numerical simulation, which is lack of inspection and correction of field measured data. In addition, the established numerical model is relatively simple, which has a certain deviation from the engineering practice. It should be noted that neither numerical simulation nor being relatively close to the actual wind tunnel test can fully simulate the load under the actual situation. Therefore, obtaining field measured data is an indispensable and important link in the research process. In practical application, the environmental factors of coal conveying trestle are very complex. Due to the large number of coal mines in China, there are countless coal conveying trestles of different specifications, which means that there is a large amount of data to be analyzed. The response of coal conveying trestle to vibration load can be extracted by vibration sensor. Sensors are an important part of wireless sensor networks. Sensor nodes can be connected with each other through wireless communication, and the collected information can be transmitted quickly [15–17]. Sensors have the characteristics of sensitivity, miniaturization, and intelligence. A large number of sensor nodes can form wireless sensor networks, and data information collection, transmission, and storage can be carried out in complex environments [18]. With the help of data fusion technology, a large number of sensors can match and correlate multisource information, and systematic, multilevel, and multifaceted processing can be realized. By using appropriate judgment methods, the state of the detection target can be obtained more accurately and reliably. At present, multisensor data fusion technology is widely used. For example, based on multisensor data fusion method, the local state data is estimated in [19], and the global optimal estimation of system state is obtained. In [20], the multisensor data fusion method of Gaussian system is used to fuse the complex data obtained by multiple sensors, the consistency description of the measured object is obtained, and the efficiency of data acquisition and the accuracy of information transmission are also improved. With the development of modern technology, the data fusion technology based on multiple sensors provides an effective solution for the load extraction of coal handling trestle.

At present, sensor based wireless communication technology is widely used in various environmental detection systems. This paper is also proposed under this background. In order to make up for the deficiency of the research status, a method based on the combination of field data extraction and finite element simulation is proposed in this paper. It is used for the seismic design and analysis of coal conveying trestle. The structure of this paper is as follows: In Section 1, the relevant research status is introduced. In Section 2, the principle and classification method based on multisensor data fusion are described. In Section 3, the finite element modeling of long-span coal handling trestle is introduced. In Section 4, the dynamic characteristics of long-span coal conveying trestle are measured. In Section 5, the seismic performance of long-span coal conveying trestle under strong earthquake is analyzed. In Section 6, the work of this paper is summarized and prospected.

2. Data Fusion Based on Multiple Sensors

2.1. Principle of Data Fusion. Data fusion is an information processing method aimed at the specific problem of using multiple sensors in the system. Therefore, data fusion is also called multisensor data fusion. Multisensor system is the hardware basis of data fusion. Multisource information is the processing object of data fusion. Coordination, optimization, and integration are the core of historical data fusion. According to the process of human recognition information, data fusion can be generally defined as follows: through the collection and transmission of effective

information from a variety of information sources, the final cognitive results are generated to assist people in judgment and verification. For different times and places, the acquisition and transmission process of multisensor information is multisensor data fusion, which aims to optimize and simplify the information.

From the perspective of multisensor information processing and synthesis, the internal relations and laws of various information are extracted by multisensor information fusion technology. The useless and wrong information is removed, the correct and useful components are retained, and the optimization of the final information is realized. Using the advantages of multisensor cooperation, the characteristics of the measured object can be accurately reflected, the uncertainty of information can be eliminated, and the reliability of the whole system can be improved. This method can eliminate the limitations of a single sensor or a small number of sensors. Therefore, the fused multisensor data information has the characteristics of redundancy, complementarity, real time, and low cost. The data fusion process mainly includes multisensor signal acquisition, data preprocessing, fusion center (feature extraction and fusion calculation), and result output. The flow chart is shown in Figure 1.

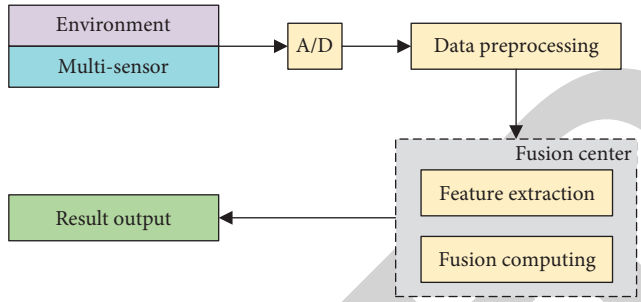


Figure 1: Flow chart of data fusion process.

2.2. Classification of Data Fusion. According to the different types of data processing levels, data fusion can be divided into data level fusion, feature level fusion, and decision level fusion. Among them, data level fusion can directly fuse the information collected by the same kind of sensors, which greatly retains the original characteristics of the data, while other levels of fusion methods cannot retain the original information. It cannot be denied that data level fusion has many limitations, such as more collected data, large amount of data, long processing time, and being easy to delay. Moreover, with the increase of sensor nodes, the amount of information to be processed will also increase, which seriously affects the work efficiency of sensor nodes. However, for the detection of vibration characteristics of coal conveying trestle, the defects of data level fusion can be ignored, and its advantages are particularly obvious, because, compared with other data fusion methods, data level fusion is more suitable for similar sensors. By matching the appropriate data level fusion algorithm, the system can have strong error correction ability and then eliminate the invalid information. The method of data level fusion is shown in Figure 2.

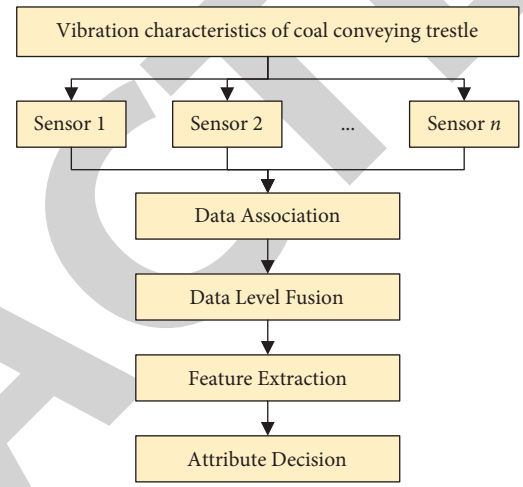


Figure 2: Data level fusion.

It can be seen that the accuracy of data can be guaranteed by detecting the vibration characteristics of coal conveying trestle based on multisensor data fusion. Compared with the uncertainty of the information collected by a single sensor, the data information collected by multiple sensors can make up for each other, reduce the uncertainty of the collected information, and make the obtained data more accurate. In addition, through data fusion technology, the vibration characteristics of coal conveying trestle can be reasonably evaluated.

3. Finite Element Modeling for Long-Span Coal Conveying Trestle

3.1. Basic Theory. The effect of vibration load caused by earthquake on coal conveying trestle and the response of coal conveying trestle are dynamic. In order to analyze the influence of these factors on coal conveying trestle, it is necessary to analyze the dynamic characteristics of coal conveying trestle first. Modal analysis is a typical method, which can effectively avoid the damage caused by resonance of coal handling trestle. At the same time, modal analysis can solve the structural vibration mode and its natural frequency, and it is also an important symbol to measure whether the stiffness and quality of coal conveying trestle match or not. Before the analysis, it is necessary to explain the basic theory of modal analysis.

Under the action of earthquake, the dynamic equation of structural members is as follows:

$$M\ddot{u}_a(t) + C\dot{u}_a(t) + Ku_a(t) = F(t) = \sum_{i=1}^{J} f_j g_j(t), \quad (1)$$

where $g_j(t)$ is the jth time-dependent function and f_j is the time-independent space vector. In modal analysis, the solution of equation (1) is set as

$$u(t) = \phi Y(t), \quad (2)$$

where ϕ is an $N \times N$ matrix and $Y(t)$ is the vector of time function. According to formulas (1) and (2),

$$\begin{cases} \dot{u}(t) = \phi \dot{Y}(t), \\ \ddot{u}(t) = \phi \ddot{Y}(t). \end{cases} \tag{3}$$

The conditions to be satisfied by equation (3) are

$$\begin{cases} \phi^T K \phi = \Omega^2, \\ \phi^T M \phi = I. \end{cases} \tag{4}$$

Equation (4) is the orthogonal condition of the spatial function with respect to the stiffness and mass of the coal handling trestle, Ω^2 is the diagonal matrix of the coal handling trestle, and I is the identity matrix. Substituting equation (4) into equation (1) yields

$$I\ddot{Y}(t) d\dot{Y}(t) + \Omega^2 Y(T) = \sum_{j=1}^{J} P_j g_i(t), \tag{5}$$

where $P_j = \phi^T f$ and d is the damping matrix of the coal handling trestle. The diagonal term is $d_m = 2\xi_n \omega_n$. ξ_n is the ratio of the damping of the coal handling trestle to the critical damping in the nth vibration mode. From the above equation,

$$\ddot{y}(t) + 2\xi_n \omega_n \dot{y}(t) + \omega_n^2 y(t) = \sum_{j=1}^{J} P_{nj} g_j(t). \tag{6}$$

Equation (6) is a typical form of modal equation. Under the action of seismic load, the above equation can be rewritten as

$$\ddot{y}(t) + 2\xi_n \omega_n \dot{y}(t) + \omega_n^2 y(t) = P_{nx} \ddot{u}(t)_{gx} + P_{ny} \ddot{u}(t)_{gy} + P_{nz} \ddot{u}(t)_{gz}, \tag{7}$$

where the seismic excitation generated by the modal coefficient is defined by $P_{ni} = -\phi_v^T M_i$.

ABAQUS is used for the subsequent dynamic characteristic analysis of coal conveying trestle. The solution methods of equation (6) by this software include Lanczos method, automatic multistage substructure (AMS) method, and subspace iteration method (Subspace). In general, the Lanczos method is faster. Subspace is more suitable for solving a small number of modes (less than 20). The solution speed of AMS is faster than that of Lanczos method, especially for systems with multiple degrees of freedom, but AMS method has certain localization. Considering comprehensively, Lanczos method is selected to solve the first 30 natural frequencies and vibration modes of coal conveying trestle.

3.2. Finite Element Modeling. The steel truss coal conveying trestle of a coal mine company is selected as the research object, and its substructure is frame reinforced concrete. The reinforced concrete truss leg and the top of the coal handling trestle frame are connected by anchor bolts and embedded by anchor plates, which can be used as a hinged support. The column bottom of the frame column is rigidly connected with the independent base. The upper end of the truss of the coal conveying trestle is connected with the transfer station through bolts and limit devices, which can be regarded as transverse hinge and longitudinal sliding connection. In order to ensure that the built model can reflect the real structure to the greatest extent, based on the actual design drawings and relevant standards and specifications, the interconnection between structural members in the modeling process is handled as follows:

(1) The connection between the reinforced concrete truss and the top is hinged.

(2) The frame column and the base are completely rigidly connected.

(3) The lowest part of the truss is supported on the rigid column. Because the longitudinal stiffness of the long-span coal handling trestle is smaller than that of the rigid column, the lowest point boundary can be approximated as a hinged support.

(4) The highest point of the truss is connected with the transfer station. The longitudinal displacement of the bridge truss caused by temperature change and the requirements of seismic joint on the structure need to be considered. Therefore, the highest fulcrum is set as the sliding hinge support, which is hinged horizontally and sliding longitudinally along the long-span coal conveying trestle.

(5) As the body of the coal conveying trestle is a prestressed reinforced concrete truss, the two ends of the beam, web member, horizontal support rod, and vertical support rod are rigidly connected. In addition, all nodes in the same span of the coal conveying trestle are regarded as continuous rigid connections.

The relevant material properties in the three-dimensional model of coal handling trestle are shown in Table 1. Besides, the material is considered to be isotropic in all directions. The constitutive model of reinforcement can be regarded as an ideal elastic-plastic model, and the yield strength is 400 MPa. At the same time, in order to improve the computational efficiency, some idealized assumptions are defined. For example, the displacement between the structural members of the model is synchronous, and all connections are regarded as complete rigid connections or hinges. Some components in the structure (e.g., pipeline equipment, belt, etc.) are ignored, because these secondary structural members have little influence on the overall stiffness.

Finally, the C3D10M solid element in ABAQUS is used for discrete operation, and the mesh of the model is divided into triangular elements. The total number of model elements after division is 64852, and the grid density is 0.5 m. The 3D simulation model of the coal conveying trestle structure and the details are shown in Figures 3 and 4.

Table 1: Material properties.

Structure	Young's modulus (N/m^2)	Density (kg/m^2)	Poisson's ratio
Frame concrete	3.25×10^{10}	2.4×10^{3}	0.2
Steel truss concrete	3.35×10^{10}	2.5×10^{3}	0.2
Steel bar	2×10^{10}	7.8×10^{3}	0.2

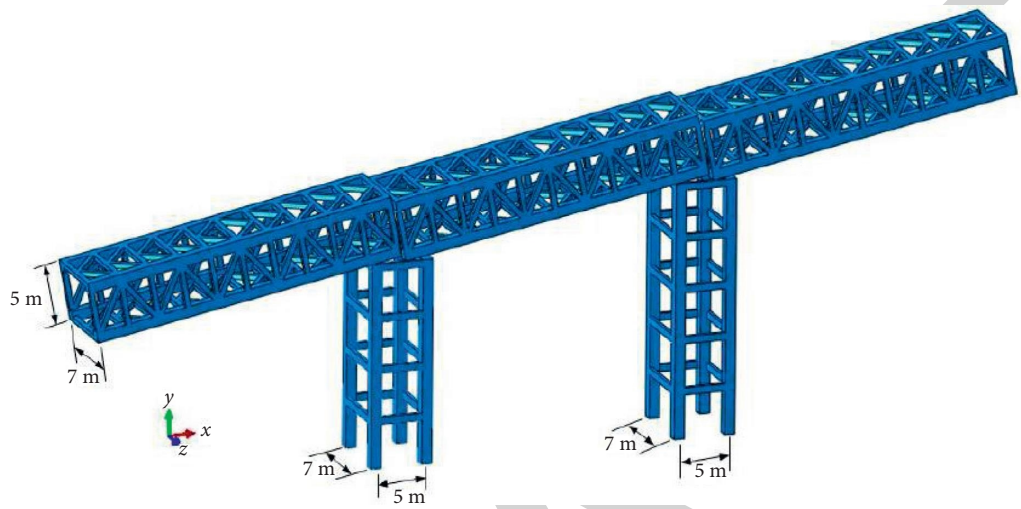


Figure 3: The 3D model of coal conveying trestle.

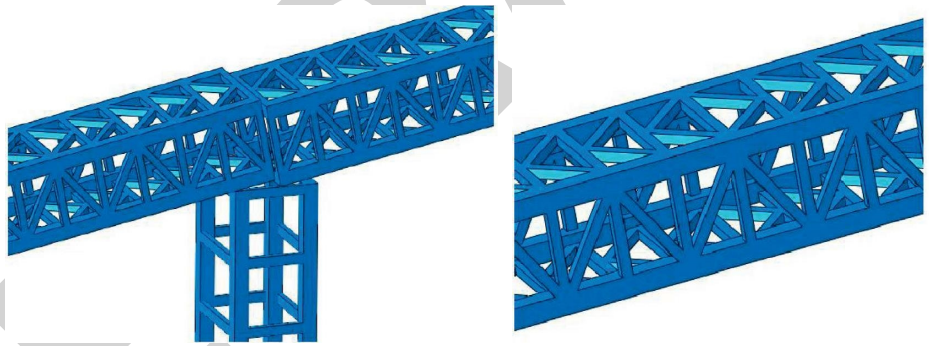


Figure 4: Partial details of the model.

4. Field Measurement of Dynamic Characteristics

Natural vibration frequency is not only an important dynamic characteristic of coal conveying trestle but also an important parameter in the dynamic design of coal conveying trestle. It is only related to the inherent properties of coal conveying trestle but has nothing to do with the dynamic load borne by coal conveying trestle. Therefore, it is persuasive to modify the structural model with the measured natural vibration frequency of coal conveying trestle. It is necessary to obtain the natural frequency of the coal conveying trestle through field measurement and modify the finite element model based on the measurement results, so as to study the seismic performance of the long-span coal conveying trestle.

4.1. Measuring Instrument. In the test, the 991B ultra-low-frequency vibration pickup and corresponding supporting amplifier are adopted. The equipment has the characteristics of large measurement dynamic range, wide frequency band, small volume, and light weight. The main technical indexes of the vibration pickup include the following: input noise $\leq 1\,\mu$V, the output load is 1 K, the input impedance is 300 K, and the magnification is 1~5000. At the same time, the DH3820 high-speed quasi-static strain data acquisition instrument and the corresponding DASP data acquisition software are used for signal processing, and finally the graphics and data can be obtained. The architecture of data acquisition and processing system is shown in Figure 5, and the physical diagram of the data acquisition system is shown in Figure 6.

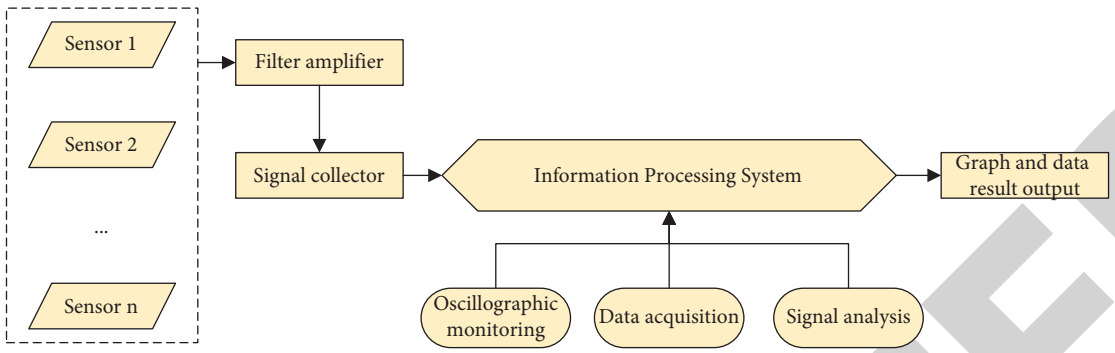


Figure 5: Architecture of data acquisition and processing system.

Figure 6: Physical diagram of data acquisition system.

4.2. Field Measurement Scheme Based on Multiple Sensors. A total of 18 measuring points are arranged at the positions with severe vibration and structural characteristics of the coal conveying trestle. Then, the measuring points with good vibration effect will be selected, and the displacement spectrum can be obtained. The arrangement of measuring points of vibration pickup is shown in Figure 7.

The vibration pickups are installed at each measuring point, and the transverse horizontal vibration displacement of the coal conveying trestle is measured in real time. A cushion block is placed at each measuring point, which is used as the base of the vibration pickup. Finally, the vibration pickup is fixed on the cushion block with glue. A measuring point measured on-site is shown in Figure 8(a). After the vibration signal is measured, it will be processed by the amplifier, as shown in Figure 8(b).

In the process of no-load braking, there is a large variation range in the vibration frequency of the coal conveying trestle. Meanwhile, the natural vibration frequency of the coal conveying trestle is included in this range, so there must be a resonance stage in this process. Therefore, in the no-load state of the coal conveying trestle, when the running speed of the coal conveying belt reaches 4 m/s, the braking deceleration shutdown is implemented. At this time, the vibration displacement data of each measuring point are collected on-site, and the displacement time history curve of each measuring point is drawn, so that the displacement spectrum of each measuring point and the natural vibration frequency of coal conveying trestle can be obtained. Based on this, the measured natural frequency can be used to modify the finite element model.

5. Seismic Performance Analysis

Based on the field measurement of dynamic characteristics in Section 4, the finite element model is modified by using the measured data, and the modal and seismic analysis are carried out through the modified model to study the dynamic characteristics of long-span coal handling trestle under earthquake.

5.1. Modal Analysis. Firstly, the modal solution of the constructed model is carried out to obtain the vibration mode and natural frequency of the long-span coal conveying trestle. The seismic weakness of the coal conveying trestle can be obtained intuitively and qualitatively from the vibration mode diagram, so as to verify whether the ultimate deformation capacity of the weakness can meet the needs of seismic action. The vibration mode diagram of the coal conveying trestle is shown in Figure 9. It can be seen that the deformation of the frame column is large, while the deformation of the trestle body is relatively small, which will lead to greater stress at the connection between the trestle and the frame column. It can be seen that the connection between the support body and the frame column, as well as the frame column are the weak parts of the large-span coal conveying support.

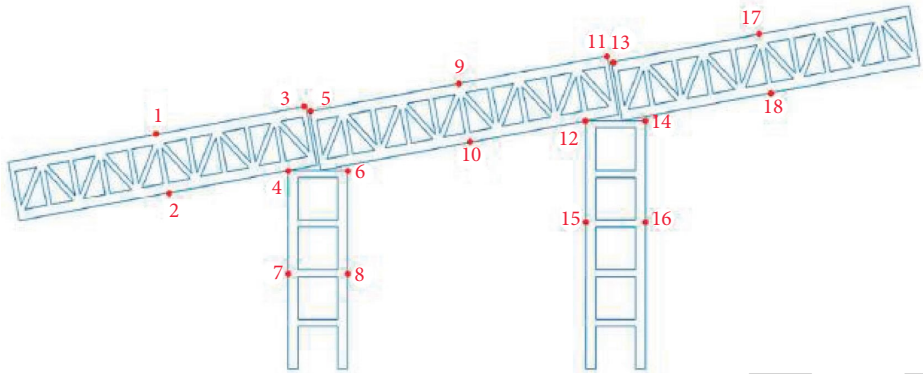
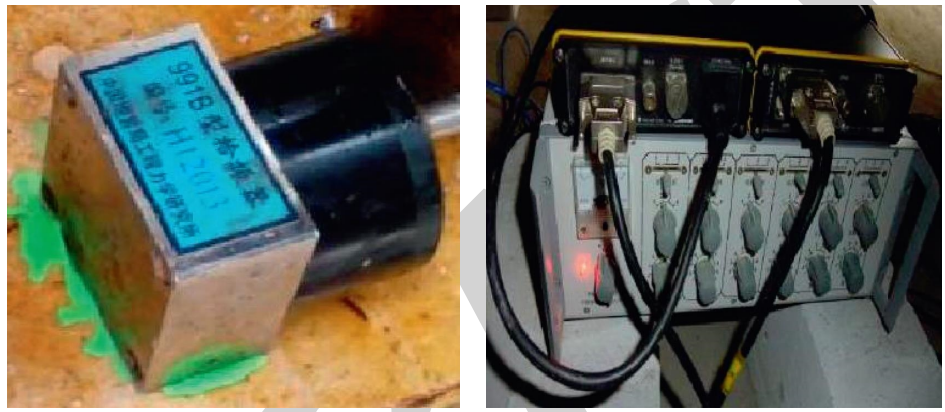


Figure 7: Arrangement of measuring points with vibration pickup.



(a) (b)

Figure 8: Measuring point and the amplifier of vibration pickup. (a) Measuring point 7. (b) Amplifier of vibration pickup.

5.2. Model Correction Based on Measured Data. The displacement data of each measuring point is collected by the device in Section 4, and the measuring point with good vibration effect is selected to draw the displacement spectrum, so as to obtain the natural vibration frequency of the coal conveying trestle. Taking the observed point 8 as an example, its vibration displacement response is shown in Figure 10.

The above test is calculated again by the modified model; the gotten natural vibration frequency of the coal conveying trestle is 1.416 Hz, as shown in Figure 11. The results show that the deviation ratio between numerical simulation and field measurement results is 1.85%, which is acceptable from the perspective of engineering application. Through comparison, it can be seen that the numerical simulation results of the natural vibration frequency of the coal conveying trestle structure are lower than the field measured results. The main reasons for the error include the following: some secondary structures such as the maintenance structure on the side of the coal conveying trestle are ignored in the process of structural model modeling, which makes the overall stiffness of the trestle too small. In addition, there are errors in the field measurement itself. The comparison between field measurement and numerical simulation results shows that the structural modeling method of coal conveying trestle in this paper is feasible.

5.3. Analysis of Dynamic Characteristics under Earthquake Action. The elastic-plastic deformation of coal conveying trestle under strong earthquake is the result of comprehensive deformation of frame column, trestle body truss, and other components. In the following, the maximum interstory displacement angle of frame columns and the maximum deflection of trestle truss under strong earthquake are taken as the basis for investigating the seismic performance of the coal handling trestle structure. Under strong earthquake, the horizontal displacement time curve of observation point 1 on the frame column is shown in Figure 12, and the horizontal displacement time curve of observation point 10 on the trestle truss is shown in Figure 13. It can be found that the shape, amplitude, and frequency of horizontal displacement time curve of frame column and trestle truss are different. It shows that the seismic performance design of frame column and trestle truss is more reasonable, which is also consistent with the actual situation.

The deflection curve of trestle truss under earthquake is given from Figure 14. The results show that the vibration frequency at both ends of the trestle is much higher than that near the frame column in the middle. According to the comparison between Figures 12 and 14, the vibration frequency of frame column is much lower than that of trestle body truss. The main reason is that the frame column is the main structural member against lateral force, and its elastic-

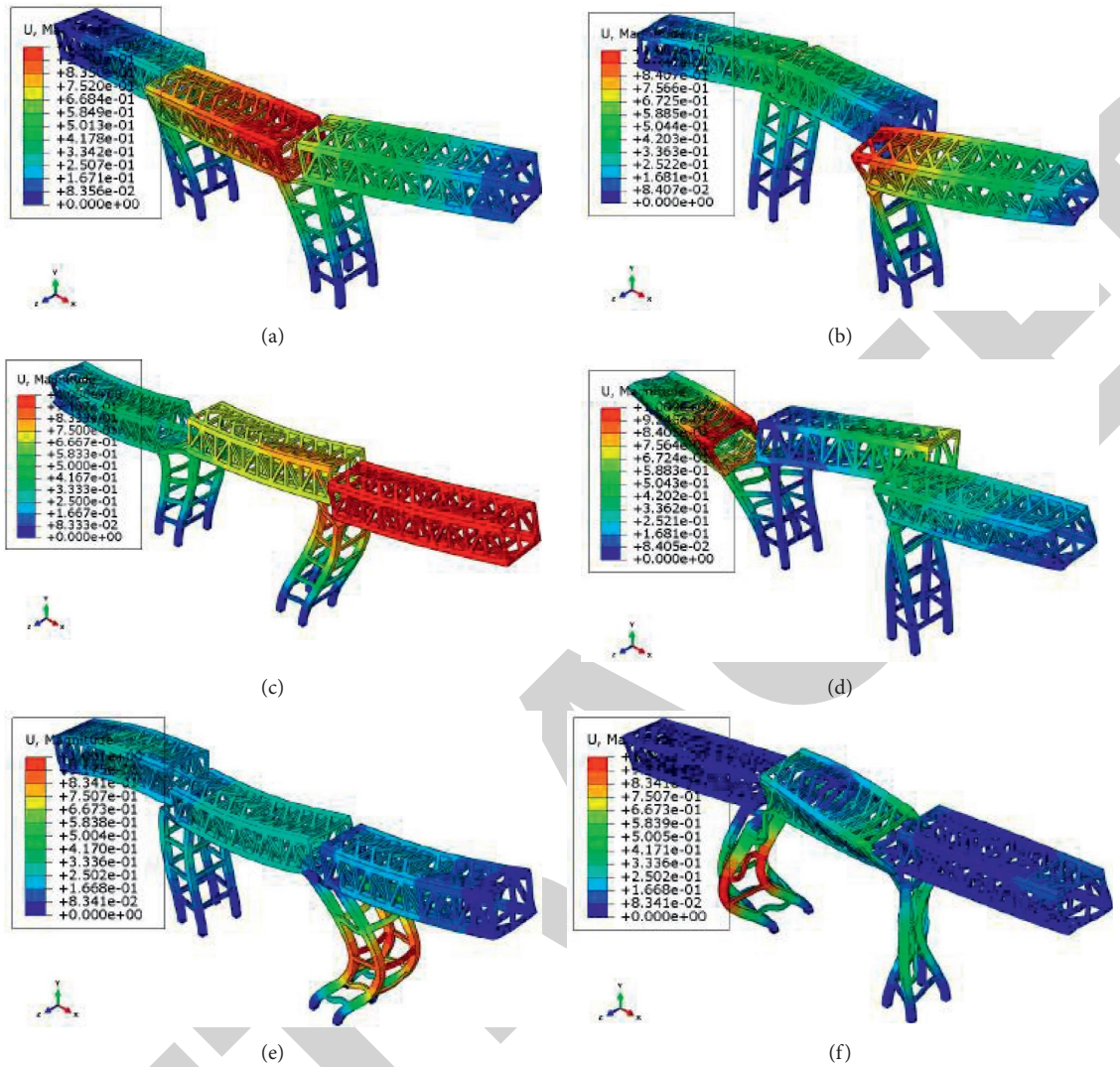


Figure 9: Vibration mode diagram of coal conveying trestle. (a) The first mode. (b) The second mode. (c) The third mode. (d) The fourth mode. (e) The fifth mode. (f) The sixth mode.

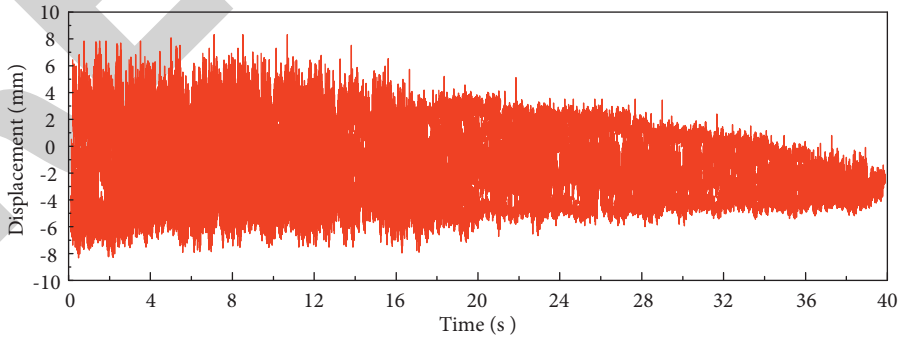


Figure 10: Vibration displacement response diagram of observation point 8.

plastic horizontal displacement is relatively large, which dissipates a large amount of seismic energy of the trestle truss, resulting in a lower vibration frequency of the middle truss near the frame column, but higher than that of the frame column. This also shows that the frame column is the main seismic structure. To sum up, the trestle structure studied has good seismic performance, and the structural deformation is far lower than the provisions of relevant codes. The main truss of trestle is of high seismic bearing capacity, and the deformation under earthquake is acceptable.

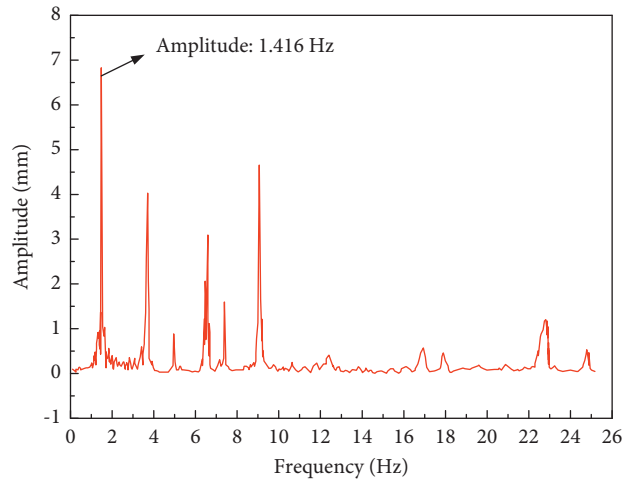


Figure 11: Vibration displacement spectrum of observation point 8.

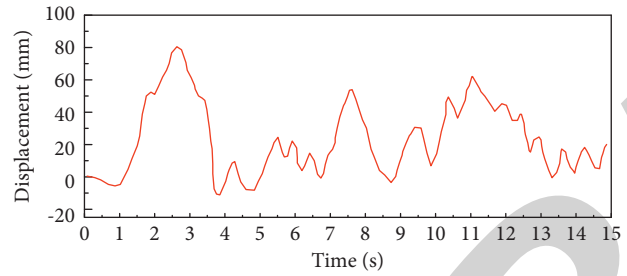


Figure 12: Horizontal displacement time curve of frame column at observation point 1.

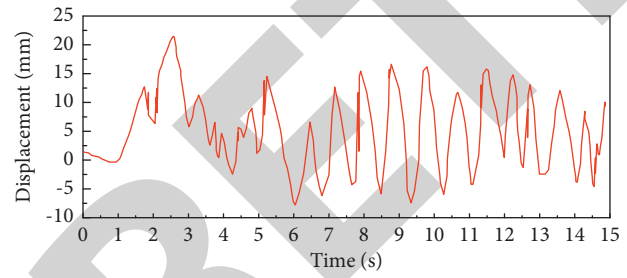


Figure 13: Horizontal displacement time curve of trestle truss at observation point 10.

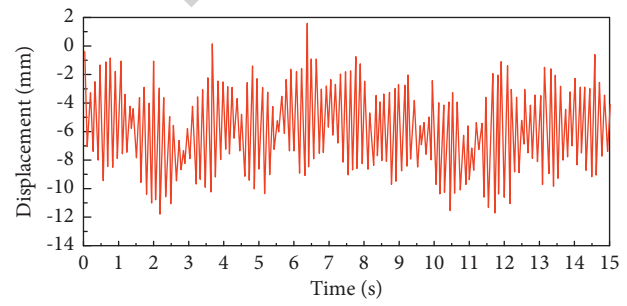


Figure 14: Deflection curve of trestle truss at observation point 1.

6. Conclusion

Aiming at the seismic performance analysis of coal conveying trestle, an analysis method based on the combination of field survey and finite element simulation is proposed. A long-span coal conveying trestle is selected as the research object of this problem. Through the field measurement based on multisensor data fusion, the dynamic characteristics of coal conveying trestle are obtained, and these data are used to modify the finite element model. The seismic performance of long-span coal conveying trestle under strong earthquake is studied. The research results prove the rationality and efficiency of the numerical simulation method and show that the numerical model established in this paper can provide a feasible analysis method for the stress and seismic performance of coal conveying trestle under earthquake and provide a reference for the seismic design of coal conveying trestle structure. Considering the complexity of the environment where the coal conveying trestle is located, the multidimensional seismic input problem can be considered in the future research, which can be expected to obtain a more comprehensive seismic performance of long-span coal conveying trestle.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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Retraction

Retracted: Sentiment Analysis of International and Foreign Chinese-Language Texts with Multilevel Features

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] M. Zhu, "Sentiment Analysis of International and Foreign Chinese-Language Texts with Multilevel Features," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 9879986, 12 pages, 2022.

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Discrete Dynamics in Nature and Society
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Research Article

Sentiment Analysis of International and Foreign Chinese-Language Texts with Multilevel Features

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This paper takes the application of international Chinese to foreigners on the Internet as the research object. A variety of features are constructed according to the characteristics of international and foreign Chinese texts and networks. This paper selects three features: dictionary-based sentiment value feature, expression feature, and improved semantic feature. A text sentiment classification model is formed by fusing multiple features. Compared with the traditional model and other single-feature models on the self-built dataset, the experimental results show that its sentiment classification ability has been effectively improved. The results show that the accuracy, recall, and F_1 value of the fused multilevel feature MFCNN model are much higher than the accuracy, recall, and F_1 value of other models. This also shows that the improved model of this method has a better effect of improving the accuracy.

1. Introduction

With the vigorous development of China's Internet and other tertiary industries, as of March 2022, the number of netizens exceeded 1 billion. The Internet penetration rate is 59.6%. With the promotion of Chinese around the world and its widespread use in the Chinese community, the scale of Chinese-language netizens has exceeded 1.2 billion [1–3]. Therefore, effectively understanding the emotional tendencies of Chinese texts has become a research direction that has received much attention. Chinese text sentiment analysis has become one of the hottest problems in the field of natural language processing [4].

Sentiment analysis is of great significance to applications such as market research, potential user analysis, and online public opinion warning [5]. As an interdisciplinary problem, sentiment analysis research utilizes computer science to analyze textual subjective sentiment information. It has broad theoretical significance and application prospect. First of all, the difficulties faced by Chinese sentiment analysis include the common problems of any kind of natural language sentiment analysis, such as new word recognition and ambiguity resolution. There are also individualized problems, such as Chinese word segmentation and part-of-speech definition specification. Secondly, due to the openness, freedom, and irregularity of online comment text, the semantic expression is more obscure [6]. Understanding emotional expressions requires more context. The network generates a large number of new words, and unregistered words interfere with the judgment of emotional polarity. How to effectively mine emotional information from massive and unstructured Chinese data is challenging [7].

More and more people use Chinese all over the world, and people can express their opinions on news on the Internet at any time. This enables Chinese texts to appear more on various Internet platforms and regions. In this way, the usage rate of Chinese in foreign countries has also been greatly improved. Due to this immediacy and interactivity, information such as attitudes and opinions of users in their daily life experiences in Chinese can map the user's emotional fluctuations into virtual cyberspace through text, video, and other different forms of expression. It is one of the most spoken languages in the world [8]. Chinese texts published on the Internet are the research objects for analyzing textual sentiment analysis. It is necessary to extract as much useful information as possible from the total Chinese

text data, and Chinese text sentiment analysis has also been a very popular research topic in recent years. In terms of public safety, certain trends can be predicted or early warnings can be made based on the public sentiment reflected in the text. In the commercial field, the emotional tendency information in user evaluation texts can help businesses understand the needs of different users. Text sentiment analysis is a method to extract subjective sentiment contained in text. Its main task is to extract users' emotional tendencies from the massive text data brought by the rapid development of the Internet. In this way, the hidden guiding value that can promote the development of all fields of society can be tapped [9, 10]. At present, it has greatly promoted the development of public opinion monitoring and user decision-making. Among the existing text sentiment analysis methods, those relying on sentiment dictionaries rely too much on the quality of the dictionaries, and the computational and maintenance costs are high. When using machine learning algorithms, constructing features is a huge effort and often ignores the semantic sequence associations of text. With the application of deep learning in the field of text sentiment analysis, automatic learning of sentiment features in text sequences is achieved. The generalized capture of the overall semantic information of the text overcomes the shortcomings of traditional sentiment analysis models to a certain extent. However, the current research on deep learning in sentiment analysis tasks is not perfect, and the improvement of sentiment analysis models still has high research value.

This paper mainly constructs multilevel features with emotion value features, expression features, and improved semantic features. The multilevel features include not only text features but also nontext features. On the basis of the above, a sentiment classification model is constructed by proposing a text sentiment analysis method that integrates multiple features. By learning more dimensions of sentiment information in the text, the sentiment classification accuracy is improved.

2. Relevant Theoretical Basis

2.1. Text Mining. As an extension of text data mining, text mining is mainly based on computational linguistics and mathematical statistics. Through the two previously mentioned techniques and theories, some useful information can be obtained from numerous text data, and its main purpose is to explore the relationship between characters, semantics, and syntax [11, 12]. The steps of text mining are shown in Figure 1 and they mainly include four parts: text analysis, feature extraction, core technology, and user interface. After obtaining the text source, the text is preprocessed, including word segmentation and text structure analysis. By calculating the weight of feature words, key summaries, specific information extraction, and text features are extracted [13]. The data is then analyzed and predicted by using five basic techniques such as classification and clustering. Finally, the results are obtained and displayed to the user in a visual interface.

Many core techniques in text mining are inseparable from mathematical statistics, natural language processing, and machine learning. According to the different objects to be mined, the tasks of text mining can also be divided into tasks related to words and tasks related to documents. The task categories for text mining are categorized in Table 1.

2.2. Emotional Mining. Opinions exist in subjective texts. Subjective text is a form of natural language expression relative to objective text. It describes the thoughts or perceptions of an individual, group, or organization about things, people, and events. In addition to this, subjective texts also contain emotions and attitudes [14]. This document contains statements expressing opinions. Such texts are called opinion-based subjectivity texts. Opinion is a quadruple consisting of subject, holder, statement, and emotion. There is an inherent connection between these four elements. That is, the holder of an opinion makes an emotional statement of opinion on a topic. It should be noted that sometimes the subject is also referred to as the focus or object to distinguish possible ambiguities [15].

In general, the point of view in the text is given explicitly and sometimes indirectly, and emotional sentences can be identified using three lexical cues. Examples of declarative verbs that point out the event or thing to be commented on are say, point out, think, and so forth. Sentiment items contain words or phrases of polarity (positive, negative, or neutral), such as good, nice, wrong, and praise. Adverb prompting is the close association of adverbs with ideas, such as possibly, very, and extremely.

In addition to these three clues, there are two more clues that can be added to the analysis of ideas. Negative words reverse the polarity of words, such as no, would not, and never. A transition word reverses the polarity of the sentence preceding the transition word, such as although and but.

2.3. Sentiment Mining and Sentiment Classification. Sentiment mining is also known as opinion mining or sentiment orientation. Sentiment mining is defined as a collection of review texts that contain sentiments (or opinions) about an object. Sentiment mining aims to find the attributes and components of the commented object from each comment text and judge whether the comment is positive, negative, or neutral. Sentiment mining emerges on the basis of text mining to extract subjective expressions in textual information and an emerging discipline that analyzes the emotional tendencies and intensities contained in texts. It involves natural language processing, information retrieval, data mining, machine learning, artificial intelligence, corpus linguistics, and other research fields. Sense mining summarizes comments for users and mines useful patterns for them. According to the definition of opinion in China, the task of sentiment mining is to automatically find the elements and relationships in opinion from comments composed of natural language. It can be divided into four subtasks [16, 17]:

(1) Topic extraction identifies feature words and topic terms in opinions

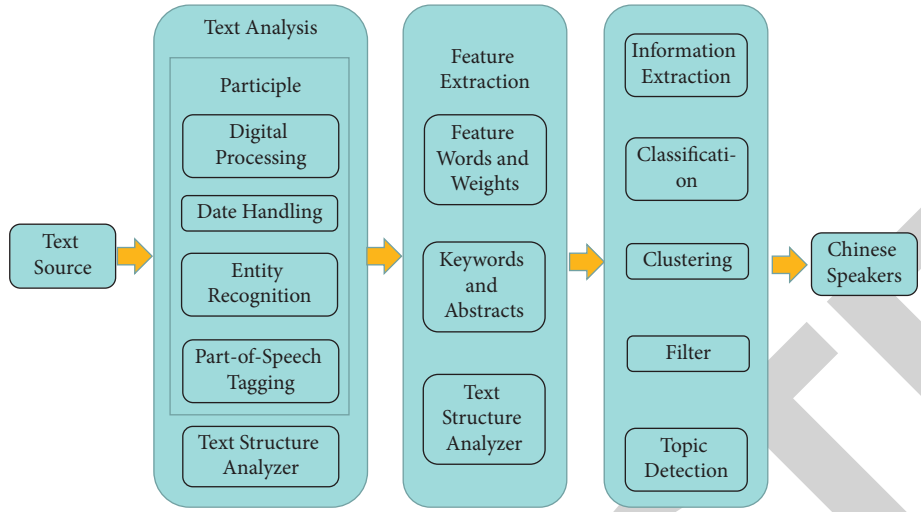

Figure 1: Main steps of text mining.

Table 1: Text mining classification.

	Words	Documentations
Guided learning	Part-of-speech tagging, disambiguation	Classification, information extraction, topic tracking, and detection
Unguided learning	Semantic analysis, keyword extraction, construction of sentiment dictionary	Book clustering, summarization, topic tracking detection

(2) Opinion holders are the authors who identify the statement of the opinion or the publisher of the comment

(3) The choice of statement is to distinguish between subjective and objective descriptions in the text and to extract the part of the statement of opinion

(4) Sentiment analysis is the determination of the semantic tendencies and strengths of opinion statements

The formulation of the statement is the subjectivity classification problem of the text, and the sentiment analysis of the comments is the sentiment classification problem.

(1) Subjective classification

Let $S = \{s_1, s_2, \ldots s_n\}$ be a set of sentences for the document. There are a total of n sentences. Subjectivity classification is a problem of distinguishing opinion-expressing sentences and other subjective sentences from objective sentences describing factual information.

(2) Sentiment classification

For sentiment classification, there are generally two classification methods: two-class sentiment classification and multiclass sentiment classification. Generally, it is necessary to establish a set $D = \{d_1, d_2, \ldots d_n\}$ and a category $C = \{\text{positive, negative}\}$. Sentiment classification is mainly to label elements d_i in set D as factors in category C.

2.4. Text Preprocessing. Before performing sentiment analysis on the text, it is necessary to preprocess the text first. If the text preprocessing cannot be done well in the initial stage, the computational cost of subsequent sentiment classification will increase exponentially. In addition, rough preprocessing will also damage the accuracy of the classification algorithm, so that the ideal classification results cannot be obtained [18]. There are four main ways to preprocess Chinese text: data cleaning, Chinese word segmentation, stop word removal, and simplified and traditional conversion [19].

(1) Data cleaning

In the data cleaning phase, the first thing to do is to unify coding. For the smooth development of subsequent experiments, standardized unified coding is required.

(2) Chinese word segmentation

This paper studies Chinese texts that differ from English texts. English writing uses a space as the separator between each word. In Chinese, there are no separators between words due to the inheritance of ancient traditional writing habits. In ancient Chinese, a single Chinese character often represented the meaning of a word, so people did not need word segmentation to write at that time. With the development of the times, there have been more and more two-character and multicharacter words in modern Chinese. The meaning of a word is no longer the same as a word. Therefore, it is very difficult to understand the meaning of a sentence without precise segmentation.

Different from the mechanical word segmentation method, the statistical word segmentation method focuses more on the adjacent cooccurrence

probability of two words in the string. The algorithm calculates the adjacent cooccurrence probability of each word in the string through point mutual information. When the cooccurrence probability of adjacent words reaches a certain threshold, the algorithm decides that they are likely to form a word. There are many mature Chinese word segmentation systems. There are mainly three popular Chinese word segmentation systems, namely, ICTCLAS word segmentation system, Jieba word segmentation toolkit, and Java word segmentation toolkit. These three systems are sufficient for Chinese text segmentation work.

(3) Remove stop words

The categories of stop words in Chinese text mainly include words that are used too frequently and words that have no actual meaning.

(4) Text structuring

Text structuring is an important step in dealing with text classification problems. The processed text is expressed in human language, and the algorithm cannot directly understand the meaning of the text. Therefore, it is necessary to structure the text first to facilitate the understanding of the algorithm. Methods of comparing mainstream text structuring are bag-of-words model and vector space model.

The BW model is a simplified sentiment analysis model, mainly based on natural language. It is mainly composed of words without order and without grammar. The most important thing in this model is the number of occurrences of the word and its weight among all factors. At the same time, it concatenates the bag-of-words models of all documents in the dataset to form a two-dimensional word-document matrix.

2.5. Feature Selection. Text data is high-dimensional in most cases. The words combined with Chinese characters and English are at least one million or even ten million. Under normal circumstances, after the text is divided into words, it is normal to leave hundreds of thousands of words after removing stop words. If all words are used as features at this time, the dimension of the feature space will be very high. Such high dimensionality is a disaster for most machine learning algorithms, so feature selection is performed on the data [20].

After feature selection, the operation speed of the algorithm can be accelerated. More informative features can be selected to enhance classification accuracy. The current mainstream feature selection methods mainly include mutual information, information gain, and chi-square test.

2.6. Text Vectorization

(1) TF-IDF algorithm

In a piece of text, different words have different importance. The greater the weight of a word is, the better it can represent the theme of the text. TF-IDF (Term Frequency-Inverse Document Frequency) can be regarded as a statistical method to estimate the importance of a word to a given text. It is widely used in text classification and information retrieval. Its main idea is as follows. If a word occurs frequently in certain texts but rarely in other texts, it can be considered that this word is very important for this type of text and can represent the text to a certain extent, so as to achieve a better classification effect. The TF-IDF algorithm is usually used to express the importance of words to different categories of text. Applying the TF-IDF algorithm to text feature representation is beneficial to improve the classification effect to a certain extent.

(2) Word2vec model

Word2vec is a 3-layer shallow neural network model. Text can be converted into vectors after continuous training and optimization using a given corpus and model. The word vectors generated by the Word2vec model can be fed into other neural networks. Word2vec contains two important models. The CBOW model predicts the probability of the occurrence of the current word through the above information and the following information of a word. The Skip-Gram model is just the opposite. The probability of occurrence of the above word and the following word is predicted from the current word.

3. Overview of Text Sentiment Analysis Methods

3.1. Overview of Text Sentiment Analysis. At present, the research work of text sentiment analysis is mostly through some techniques and methods. It enables the computer to automatically analyze, identify, label, extract, and classify the emotional features contained in people's attitudes and evaluations about certain topics and events. The main research contents include four aspects. These four aspects are subjectivity and objectivity, extraction of emotional information, discrimination of emotional tendency, and calculation of emotional intensity [21, 22].

(1) The research on identifying subjectivity and objectivity stems from the fact that objectivity texts have no emotional color but are only objective descriptions of things. Such texts have no value for understanding people's emotions. Sentiment analysis for subjective text will do more with less.

(2) The object of extracting emotional information is mainly the subject, object, emotional vocabulary, and so on expressing opinions. By grasping this information, the collocation relationship between the subject and the object can be obtained. According to the emotional vocabulary, the discrimination accuracy of emotional tendencies can be greatly improved.

(3) Discriminating emotional tendencies is the classification of emotional polarity. The earliest emotion polarity classification tasks are mostly two-dimensional emotion classification. However, with the continuous expansion and refinement of research,

multidimensional sentiment classification has gradually become a hot research topic.

(4) Computing sentiment strength refers to using a real number representation for sentiment strength in the text. The polarity of the text can be judged from these values. Since texts often contain more than one affective disposition, most of the existing research on affective intensity calculation is at the sentence level.

The research method of text sentiment analysis mentioned above is shown in Figure 2.

3.2. Analysis Method Based on Sentiment Dictionary. The sentiment weight of each word is shown in Figure 3.

The weight of a sentiment word indicates the degree of the word on a certain sentiment tendency. Negative words can reverse emotional tendencies. The weights of degree adverbs indicate the degree of intensity, which can enhance or reduce the inclination of emotional words. According to the needs of specific fields and tasks, the vocabulary in the emotional dictionary can be continuously expanded [23].

After the sentiment dictionary is constructed, the words in the text data can be matched according to the rules. The weights of each word are synthesized to capture the sentiment polarity of the entire sentence. The emotional tendencies of paragraphs, chapters, and ultimately the entire document can be obtained step by step. Specific steps are as follows:

(1) After text preprocessing, a sentiment dictionary can be constructed.

(2) According to the given rules, the words need to be matched with the text data to be processed. Whether there is a negative word or an adverb of degree before and after the sentiment word is judged, these negatives and adverbs of degree can be grouped together.

(3) If negative words or degree adverbs are used to modify the sentiment feature, the weight of the sentiment feature can be defined as the product of the number of negative words and the corresponding weight. Finally, the weight value needs to be multiplied by the degree value of the degree adverb.

(4) Finally, the final scores for all groups can be summed as the final value. Anything less than 0 is negative. The magnitude of the score means the degree of positivity or negativity.

3.3. Sentiment-Based Analysis Methods. The sentiment analysis method established by the sentiment dictionary can also be called the sentiment analysis method based on machine learning. Based on the above methods, text sentiment analysis methods can be used as a learning classification problem. The core idea of the above method to deal with the problem is to complete the task through the algorithm. During the learning process, the performance of the built model will gradually improve. In the field of text sentiment analysis, the essence of this learning method is to structure Chinese text and regard it as two sets of training set and test set [24]. The previously mentioned training set and test set are introduced into the classification algorithm and text features to establish a classification model. Finally, it is necessary to compare and analyze the results to verify the sentiment polarity of the text.

3.4. Text Sentiment Analysis Method Based on Deep Learning. The most critical step in text sentiment analysis is to extract sentiment features in Chinese texts. At the same time, the extracted emotional features are also the key to ensure the accuracy of the subsequent model building. In general, algorithms and traditional models of text are ensured mainly through human experience. As for the research focus, the text sentiment analysis method based on deep learning and the text sentiment analysis method based on machine learning are consistent [25]. Only through continuous optimization and screening can the selected emotional features promote the analysis of text sentiment. The process of building a multilayer neural network model is shown in Figure 4. After processing the text data, it is necessary to continuously optimize the parameters and transform the features layer by layer during the training process. It can achieve the purpose of improving the quality of text representation and the final prediction accuracy.

Deep learning-based methods are also essentially based on emotional feature learning. However, in the process of text sentiment analysis and training, a large number of Chinese texts are needed as research objects. Only when the Chinese text cardinality goes far enough can the established model learn more emotional features, processing data at scale faster than machine learning methods [26].

4. Sentiment Analysis of International and Foreign Chinese Texts with Multifeature Fusion

Due to the rich content and various forms of Chinese texts, the semantic features only composed of text word vectors cannot fully express the emotional information of Chinese texts. Therefore, this paper proposes a text sentiment analysis method based on multifeature fusion. Fusion of multiple features forms a text sentiment classification model MFCNN. The model can learn more dimensional sentiment information of text from the multieigenvector matrix. Compared with the traditional CNN model and other single-feature models on the self-built dataset, the experimental results show that its sentiment classification ability has been effectively improved.

4.1. Dictionary-Based Sentiment Value Features

4.1.1. Build a Dictionary. The dictionary constructed in this paper includes basic sentiment dictionary, negative word dictionary, and degree adverb dictionary. The Boson NLP sentiment dictionary launched by Boson natural language processing company is used as the basic sentiment dictionary. The dictionary is constructed from text annotated by a large number of social networking sites. Compared with the traditional sentiment dictionary, the Boson NLP sentiment dictionary contains many popular Internet terms. It is more

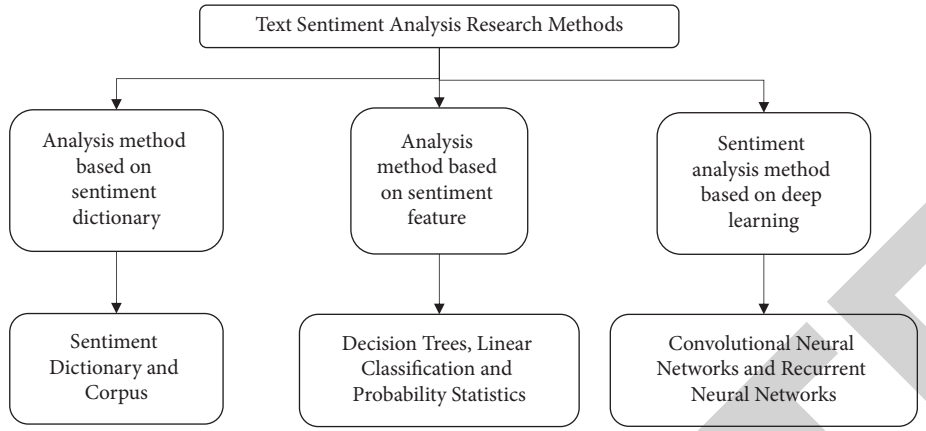

Figure 2: Research method of text sentiment analysis.

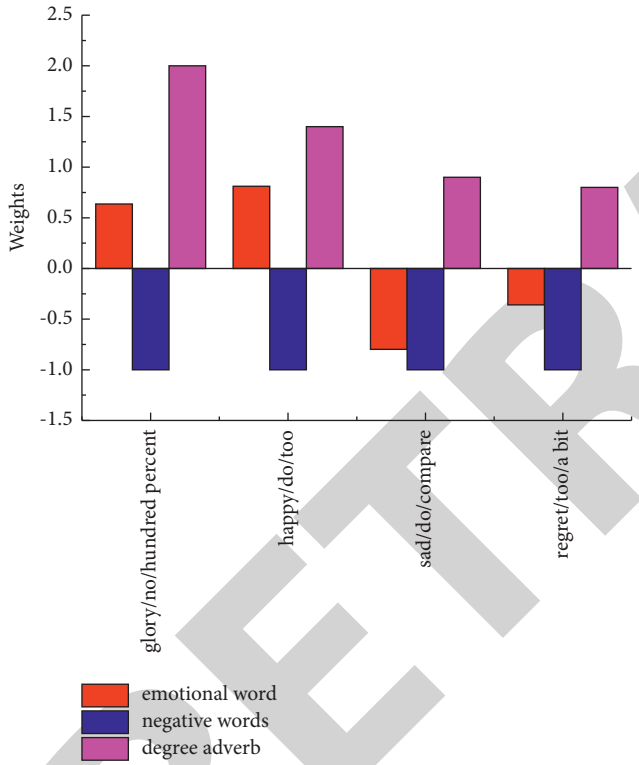

Figure 3: The sentiment weight of each word.

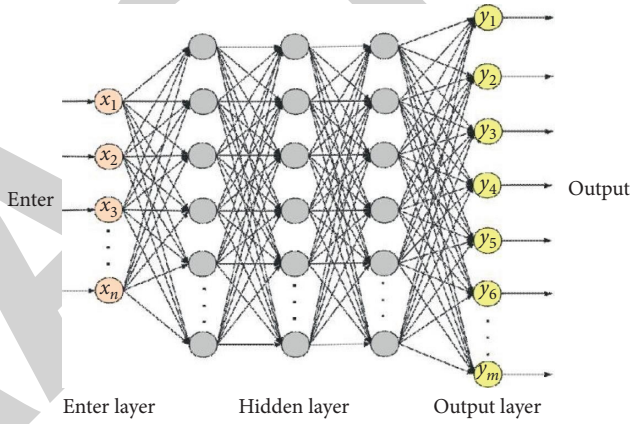

Figure 4: Multilayer neural network model.

suitable for sentiment analysis of international and foreign Chinese texts under the conditions of the new era [27, 28].

There are two kinds of modifier dictionaries in this paper, namely, the dictionary of negative words and the dictionary of degree adverbs. If a negative word appears before the sentiment word, its sentiment tendency is likely to be opposite. This article is based on negative words in Chinese dictionaries. Combining with the common negative words in the text and further expansion, 71 negative words are sorted to form a negative word dictionary, and the weight of negative words is set to −1.The degree adverbs dictionary refers to the dictionary provided by HowNet and some degree adverbs in international Chinese texts are supplements. The adverbs of degree dictionary have a total of 219 words. A weight needs to be assigned to each degree adverb.

4.1.2. Sentiment Value Feature. Based on the emotional words and modifiers contained in the matching text and the subsequent weighted calculation, the emotional value feature can be obtained as the representation of text emotion.

It needs to input international and foreign Chinese text and output text based on the sentiment value features of the dictionary. Text can be read and preprocessed. A sentiment dictionary is matched with words in the text. If the word is positive, the score is 1 point. If the word is negative, the score is −1. In neither case, the score is 0. If there is a modifier before the sentiment word, its quantity and weight need to be recorded. The sentiment value of the text can be calculated by

$$\text{score} = \sum_{j=1}^{m} \text{base} \times \prod_{i=1}^{n} \text{weight}_i, \tag{1}$$

where m is the number of bases, N is the number of weights, base is the base score, and weight is the degree adverb or negative weight.

4.2. Facial Features. Emotional words and emoticons are both common carriers of emotional cues. Although sentiment words also have sentiment information, it is not enough just to formulate rules to calculate sentiment scores

for a few words. In contrast to emotion words, emojis use graphical representations [29]. They have richer and more intuitive emotional information, and the emotions they express tend to be stronger. When emojis appear in text, they are more likely to dominate the sentiment of the text message. Statistical analysis of emojis is performed on the self-built dataset, and the results are shown in Figure 5.

As can be seen from Figure 5, 47% of the texts in the dataset contain emojis. It shows that nearly half of the microblogs in the dataset contain subjective emotional expressions displayed. 50% of the positive emotion text contained emojis. 42% of negative emotional text contains emojis. Expression features can be constructed based on the multidimensional information of emojis. This includes factors such as extreme emotions, occurrences, and semantic information of emojis. According to the emoticons in the self-built database, 85 emoticons need to be selected for the next step. Expressions can be divided into three different forms: positive, neutral, and negative. There are 37 positive emotion emojis and 43 negative emotion emojis. For emojis that are ambiguous or have no obvious emotional expression, they can be defined as neutral emotions. There are 5 of these emojis in total. Different emojis express different emotions. A score of −2 to 2 is given according to the positive or negative emotion and the strength of the emotion expressed. Expressions expressing positive emotions range from 0 to 2 from weak to strong. Expressions expressing negative emotions range from 0 to −2 from weak to strong. Emoticons that express neutral emotions are assigned a value of 0.

The extreme value of text emotion is

$$\text{score} = \frac{\sum_{i=1}^{M} F(e_i, \text{pos})}{M} + \frac{\sum_{j=1}^{N} F(e_j, \text{neg})}{N}, \quad (2)$$

where M and N are the numbers of positive and negative emojis in the text, respectively. e is an emoji. *Pos* and *neg* are the extreme value tables of positive and negative emoji, respectively. The function of function F is to take out the score of the corresponding emoticon in the extreme value table.

The cumulative distribution function (CDF) is

$$F_X(x) = P(X \le x). \quad (3)$$

Figure 6 shows the relationship between the number of emojis and emotion polarity obtained from the statistical dataset.

It can be seen from Figure 6 that when there are three or more emojis in the text, the probabilities of expressing positive emotions and expressing negative emotions in this type of text are similar. When there are two or less emojis in the text, the tendency to express negative emotions is slightly higher.

When constructing the dataset, the expression words are vectorized through the Word2vec model. The word vector is used as the semantic information for the emoticon and is included in the expression feature.

4.3. Improved Semantic Features. In some cases, the semantic features of text can also be text word vectors. This is mainly due to the fact that word vectors themselves have

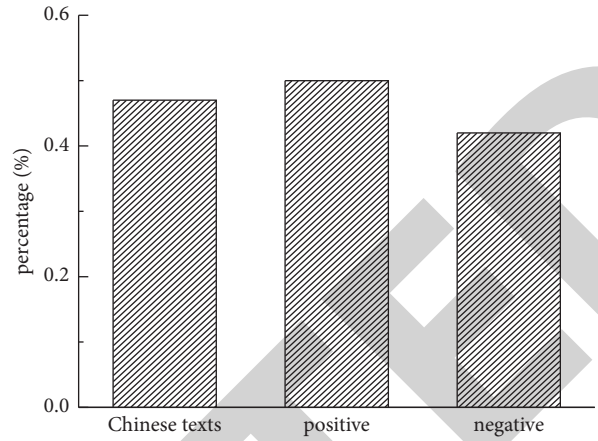

Figure 5: Statistical results of text with emojis.

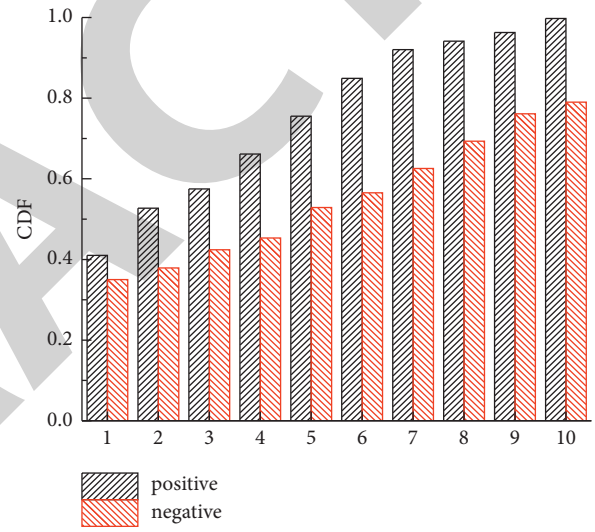

Figure 6: The relationship between the number of emojis and emotional polarity.

semantic information [30]. Therefore, this paper adopts the model Word2vec to convert all texts into text word vectors. In this way, there is no need to think too much about multidimensional issues, and the sequence information of words in the text is preserved as much as possible. In order to make the sequence information of the words in the text more perfect, the TF-IDF algorithm needs to be used to solve it. The text word vectors obtained based on the two above methods not only retain sequence information but also have corresponding weights. A text d_i can be assumed. The number of words after participle is Q. The word vector dimension is L. The text of the article is expressed as

$$d_i = \langle w_1, w_2, \ldots w_n \rangle. \quad (4)$$

The text contains multiple words, and each word has its corresponding word vector. By splicing them together, a vector matrix $G(d_i)$ of $Q \times L$ dimension of the text can be obtained. By multiplying with its weight matrix, the vector matrix $W\_G(d_i)$ can be obtained.

$$G(d_i) = \{W(w_1), W(w_2), \ldots W(w_Q)\},$$
$$W\_G(d_i) = \{\text{weight}(w_1)W(w_1), \text{weight}(w_2)W(w_2), \ldots \text{weight}(w_Q)W(w_Q)\}, \quad (5)$$

where $W(w_i)$ is the word vector of word w_i in the text. Weight(w_i) is the weight value of word w_i calculated by the TF-TDF algorithm.

4.4. Text Sentiment Analysis Method with Multifeature Fusion. This paper takes the sentiment feature as one of the multilevel features. A text sentiment analysis method integrating multilevel features is established. The steps of establishing a text sentiment analysis method with fused multilevel features are obtained as shown in Figure 7.

The text part is stored in D_t, and the expression part is stored in D_e. The text preprocessing is performed on D_t, and the sentiment value feature of the text is calculated by combining the sentiment dictionary and the modifier dictionary. D_t is trained by the improved Word2vec model to obtain the text word vector, which constitutes an improved semantic feature. The emotion extrema of the expression are calculated by combining the emoji emotion extrema table. Together with the number of expressions and the semantic information, the expression features are formed together. The three features are fused to perform text sentiment analysis. As the most popular method for text sentiment analysis and building deep learning models, Text CNN is widely used in various sentiment analysis research works. Therefore, this paper takes it as the core of the research. Based on this method and theory, a novel sentiment analysis model (MFCNN) with multifeature fusion is established. The process of building a model is mainly to transform vectors through features and then construct a multifeature vector matrix through feature fusion. Finally, the model is obtained by inputting the textual convolutional neural network.

In summary, the fusion of multiple features is used to solve the problem of sentiment analysis of international and foreign Chinese texts. A new research scheme is provided for improving the performance of microblog text sentiment analysis.

5. Analysis of Results

5.1. Text Vectorization. Text vectorization is to convert the text that has been preprocessed into words and convert each word into a vector. Then, each word vector is formed into a vector matrix according to the order of the words in the text. This way the mapping of words to a vector space preserves their semantic information. Text vectorization is the cornerstone of text research. Whether the word vector can be correctly expressed will affect the judgment of text orientation. In this paper, the Word2vec model before and after the improvement is used to vectorize the text, and the final sentiment classification results are compared. The specific parameters of the Word2vec model are shown in Table 2.

5.2. Experimental Environment. The experimental environment of this paper is shown in Table 3.

5.3. Evaluation Standard. The main evaluation indicators of text sentiment analysis are accuracy, precision, recall, and F_1 value. The accuracy (Y_1) is expressed as

$$Y_1 = \frac{A_1 + A_2}{A_1 + A_2 + A_3 + A_4}, \quad (6)$$

where A_1 represents predicted positive affect and actual positive affect. A_4 represents predicted positive affect and actual negative affect. A_3 represents predicted negative affect and actual positive affect. A_2 represents predicted negative affect and actual negative affect. Y_1 is the accuracy rate.

The accuracy (Y_2) is expressed as

$$Y_2 = \frac{A_1}{A_1 + A_4}. \quad (7)$$

The recall rate (Y_3) is expressed as

$$Y_3 = \frac{A_1}{A_1 + A_2}. \quad (8)$$

The F_1 value is a comprehensive consideration of precision and recall:

$$F_1 = \frac{2Y_2Y_3}{Y_2 + Y_3}. \quad (9)$$

The macro precision (P), macro recall (R), and macro F_1 value (F_{11}) can be

$$P = \frac{1}{k}\sum_{i=1}^{k} Y_2(i),$$
$$R = \frac{1}{k}\sum_{i=1}^{k} Y_3(i), \quad (10)$$
$$F_{11} = \frac{1}{k}\sum_{i=1}^{k} F_1(i).$$

5.4. Analysis of Results. In order to make the fusion multifeature text sentiment analysis method better compare with the traditional high-level method, seven groups of fusion different multilevel feature analysis methods can be designed

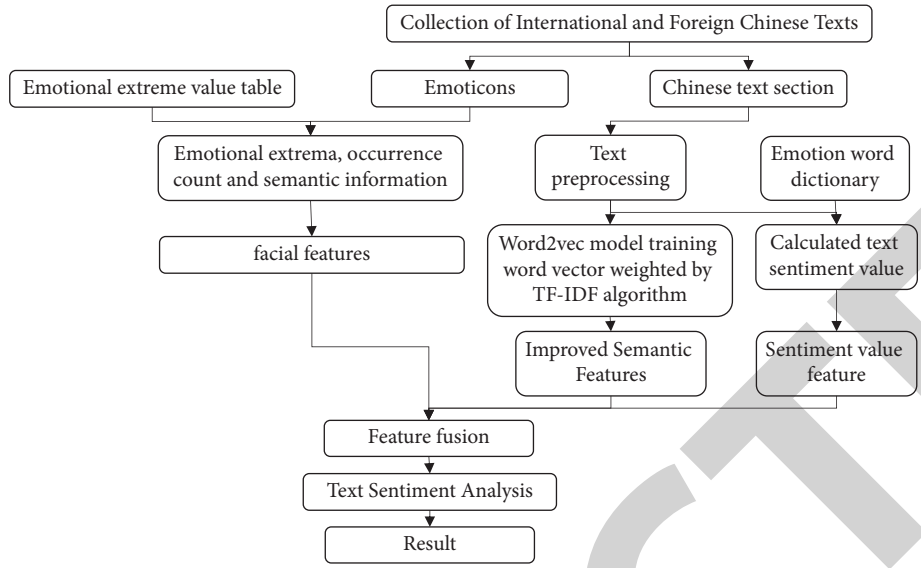

Figure 7: Flow chart of text sentiment analysis with multifeature fusion.

Table 2: Word2vec model parameter values.

Parameter	Values
Sentences	Data
Sg	0
Size	150
Window	5
min_count	5
hs	0
Iter	5

Table 3: Experimental environment.

Experimental environment	Specific configuration
Operating system	Windows 10
CPU	Intel (R) Core (TM) i7-10710U CPU
RAM	32 GB
Programming language	*Python* 3.6
Development tools	JetBrains PyCharm
Deep learning framework	Keras
Word vector training tool	Word2vec

as comparative experiments. These seven analysis methods must adopt the fusion method of different characteristics.

CNN model: The word vectors trained by the Word2vec model are input to Text CNN for text sentiment classification.

TCNN model: Word vectors are trained by Word2vec model weighted based on TF-IDF algorithm. Text sentiment classification is by input to Text CNN.

SCNN model: On the basis of the CNN model, the dictionary-based sentiment value features are fused.

ECNN model: On the basis of the CNN model, the expression features are fused.

TSCNN model: On the basis of the TCNN model, the dictionary-based sentiment value features are fused.

TECNN model: On the basis of the TCNN model, the expression features are fused.

MFCNN model: The dictionary-based sentiment value features, expression features, and improved semantic features are fused to form a multifeature vector matrix.

The text sentiment analysis method used in this paper is mainly based on the Text CNN model. The parameter values of this method are obtained as shown in Figure 8.

The maximum length of text reserved is 120. The part of the text whose length exceeds 120 will be discarded, and the part whose length is less than 120 will be filled with 0. Other parameters not in the above table use default values.

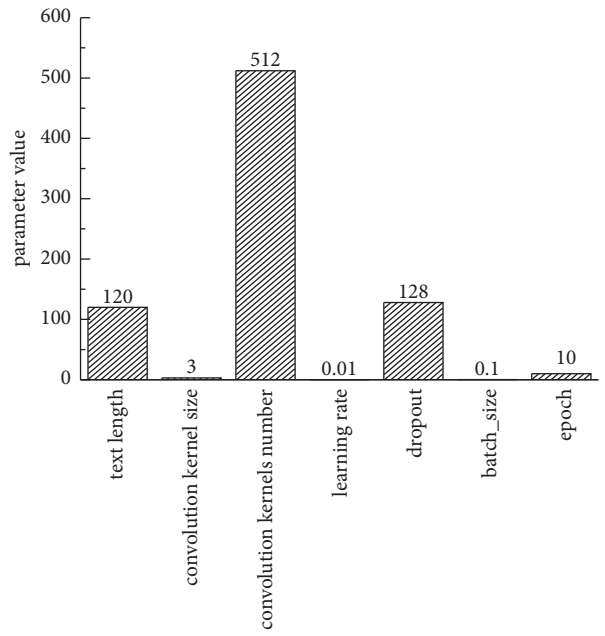

Figure 8: Model parameter values.

The comparison results of the 7 groups of models on the binary dataset are shown in Figure 9.

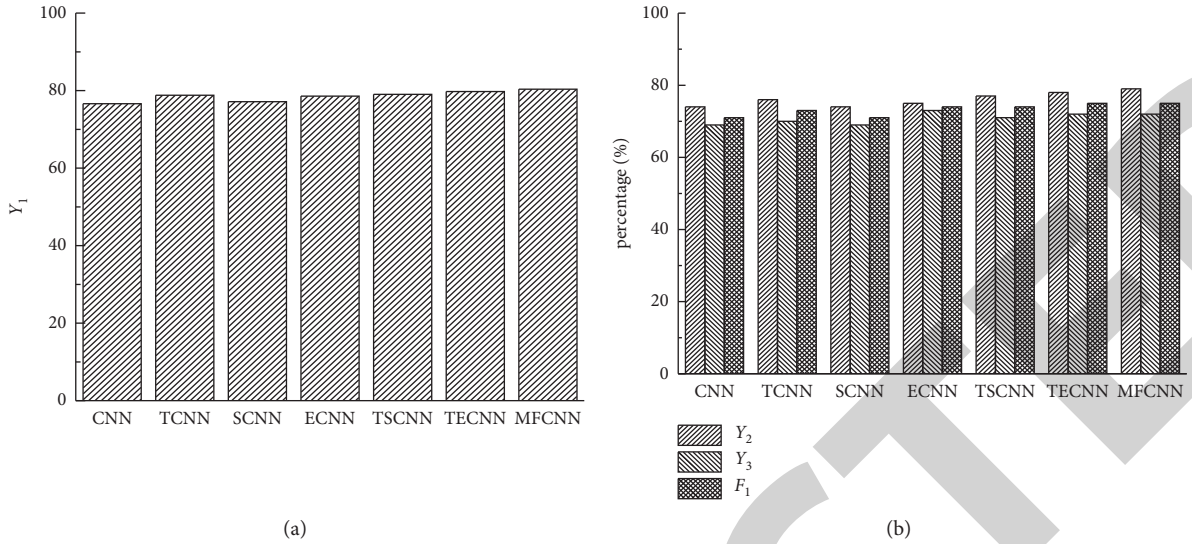

Figure 9: Comparison of experimental results. (a) Model accuracy. (b) The other three indicators.

It can be seen from the change rule of the histogram in Figure 9 that the accuracy of the improved model is much higher than that of the traditional model. This shows that the multilevel feature fusion model has greatly improved the effect of international and foreign Chinese text sentiment classification. This is mainly because the improved model can obtain more dimensional emotional information, which in turn improves the accuracy of the model.

Compared with the accuracy of the traditional model, the accuracy of the TCNN model fused with multilevel features can be greatly improved. This accuracy improves by about 22.1%. This shows that the model after the improvement of the TF-IDF algorithm has a positive effect on improving the weight of keywords in the text. The model incorporating multilevel features, after being improved by the TF-IDF algorithm, can help improve the performance of sentiment classification.

Compared with the CNN model, the accuracy of the TSCNN model, which combines the improved semantic features and sentiment value features, is improved by 24.2%. Compared with the CNN model, the accuracy of the TECNN model, which integrates the improved semantic features and expression features, is increased by 31.7%. The model accuracy improved by 31.7%. The MFCNN model that finally fuses the three features is 5.9% to 37.6% more accurate than other comparison models. It shows that the MFCNN model can learn more dimensional emotional information of text from the multifeatured vector matrix. The feasibility and effectiveness of the method are proved.

Compared with the accuracy of the traditional model, the improvement of the accuracy of the model after the model fusion of a single feature is not obvious. Therefore, when a single feature is fused to build a model, it does not help to improve the accuracy.

This paper proposes a weighted Word2vec model to train word vectors based on the TF-IDF algorithm. To demonstrate its effectiveness, it is compared with the traditional Word2vec model in three sets of experiments. The experimental results are shown in Figure 10.

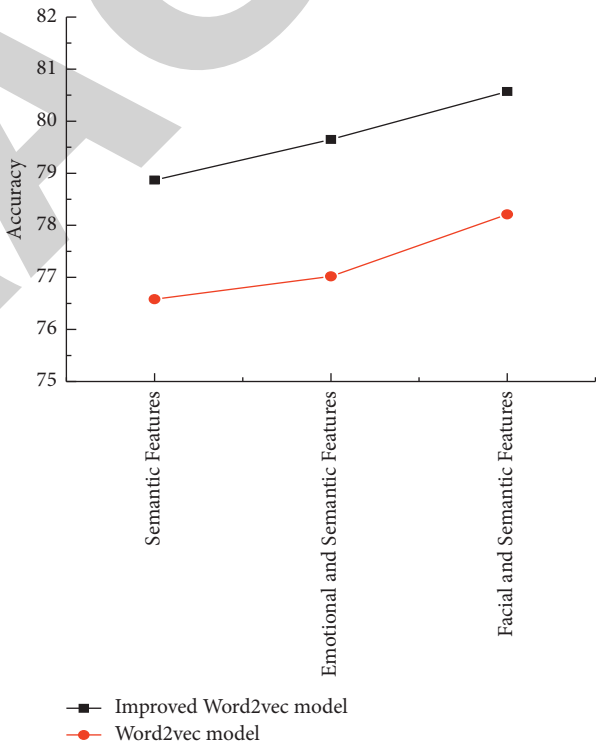

Figure 10: Comparison of the accuracies of the improved Word2vec model and the traditional model.

It can be seen from Figure 10 that the improved Word2vec model achieves better results in sentiment analysis.

6. Conclusions

Based on the multilevel feature fusion theory, a novel text sentiment analysis method is proposed. By analyzing the

feature information related to sentiment polarity in microblog texts, dictionary-based sentiment value features, expression features, and improved semantic features are constructed, respectively. In the designed text sentiment classification model fused with multiple features, the features are combined in various ways through different feature construction methods, which can reflect the classification effect after fusing each feature. The experimental results show that the fusion of expression features or improved semantic features has a great improvement. The improvement effect of fusion emotional value features is small. The text sentiment classification model MFCNN that fuses multiple features achieves the best performance. It shows that the multifeature fusion gives full play to the complementary role of expression information, text information, and other information and further improves the sentiment classification effect of Weibo text.

A dictionary-based sentiment value feature, facial expression feature, and improved semantic feature are constructed. In the designed text sentiment classification model fused with multiple features, the features are combined in various ways through different feature construction methods. It can reflect the classification effect after fusing each feature. The experimental results show that the fusion facial features or the improved semantic features have a great improvement. The improvement effect of fusion emotional value features is small. The text sentiment classification model MFCNN that fuses multiple features achieves the best performance. It shows that the multifeature fusion gives full play to the complementary role of expression information, text information, and other information and further improves the effect of sentiment classification of international and foreign Chinese texts.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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Research Article

Intelligent Malfunction Identification Method in Mechanical Manufacturing Process Based on Multisensor Data

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Current technology trends have been gradually integrated into the production of all walks of life, which play an indispensable part in promoting the intelligent development of enterprises, and have brought a greater impact on production and reformation. With the rapid development of the economy and technology, the manufacturing industry has played a very important role. For this reason, the introduction of artificial intelligence into machinery manufacturing can not only improve production efficiency but also save labor and reduce labor costs. The application of artificial intelligence in machinery manufacturing has a critical good role in promoting industrial upgrading and transformation. This time, through the application of smart algorithms in machinery manufacturing and its automation, we expect that such a technological revolution can provide a new development prospect for the development of manufacturing intelligence and automation. Taking the malfunction identification of string striking machinery as an example, this paper studies the smart identification method of mechanical malfunction based on multisensor. In the process of malfunction identification of keyboard stroke machinery, the accuracy of malfunction identification results is low due to the influence of the identification model. Moreover, a malfunction identification and analysis method for keyboard stroke machinery based on BP optimized by GA is proposed. The mechanical data of keyboard chords are acquired by sound-sensitive sensors, and the data features are extracted by wavelet packet decomposition. Based on the optimized BP, a mechanical malfunction judgment model is constructed, and various parameters in the model are calculated. The results show that the intelligent identification method proposed has exhibited strong adaptability and superiority compared with the traditional method.

1. Introduction

The manufacturing industry has played a very important role in pushing for technological innovation. It can be said that the level of manufacturing development will have an important impact on technological innovation. Intelligence and automation have become very lively topics in today's society. Researchers [1–3] will integrate artificial intelligence into machine manufacturing to drive the development of the entire industry. This promotes the continuous upgrading and transformation of machinery manufacturing. In addition, this can also highlight its own competitive advantages in optimization and enhance core competitiveness [4–6]. At present, artificial intelligence has covered all walks of life, and its application scope is becoming wider and wider, but the links involved in machinery manufacturing are very complex and changeable. The integration of new technologies still requires constant running-in. How to make full use of artificial intelligence to upgrade the improvement of manufacturing level and quality has become the focus of the current industry. By analyzing the application advantages of artificial intelligence in machinery manufacturing and its automation, the application situation at different levels is expounded, and then, the positive impact of artificial intelligence on the development of the manufacturing industry is revealed.

To meet the spiritual needs of people and the needs of the country, the application of musical instruments, such as the piano, is more extensive. Among them, due to the complex structure of the piano, there are many failures. The most common one is the mechanical failure of the keyboard [7–9]. Due to the prolonged use of the keyboard mechanism, the mechanism may be deformed or damaged, thus affecting the

normal operation of the piano. Therefore, it must be implemented immediately to conduct regular inspections of the keyboard action mechanism. In the research process of conventional mechanical malfunction identification method, there are always shortcomings. At present, the traditional feature extraction method mainly includes wavelet analysis [10–12], Empirical Mode Decomposition [13, 14], Ensemble Empirical Mode Decomposition [15, 16], wavelet packet analysis [17, 18], and Complete Ensemble Empirical Mode Decomposition with Adaptive Noise decomposition [19, 20]. Traditional feature extraction and malfunction classification method rely heavily on manual engineering and expert knowledge. In particular, with the advent of the era of industrial big data and the development of sensor technology, traditional feature extraction and malfunction classification method have been unable to meet the diagnostic needs under massive data. In this context, the development and promotion of intelligent malfunction identification have begun. Intelligent malfunction identification refers to the application of machine learning theories such as artificial neural networks, support vector machines, and deep neural networks to machine malfunction identification. However, the traditional recognition method is given to the traditional algorithm such as artificial neural network or support vector machine to realize the calculation process. Due to the shallow network structure, their ability to extract complex malfunction features is limited. In recent years, deep neural networks such as deep autoencoders and deep convolutional neural networks have been widely used to build end-to-end intelligent identification models, reducing the dependence on manual labor and expert knowledge, and greatly promoting the development of intelligent malfunction identification. Based on a convolutional neural network, Zhao et al. [21] extracted features from mechanical vibration data and used long-term and short-term memory networks to judge malfunction conditions. The diagnostic accuracy of this method has been improved, but the scope of application is small. Senger and Karim [22] used the improved random forest method to obtain useable mechanical malfunction feature vectors through the mechanical principal features, thereby constructing a malfunction identification model. Through research, it can be seen that this method has a strong anti-interference ability, but the calculation process is complicated and takes more time.

Aiming at the shortcomings of the above identification method, the mechanical malfunction identification method is designed based on the BP optimized by GA and based on the principle of wavelet packet analysis through the extraction of mechanical features, the construction of network models, and the design of model parameters. In addition, high-precision identification and identificationing results of mechanical malfunctions in piano keyboard strokes are obtained. Before elaborating on the main text, for the convenience of readers, we intend to use the following abbreviations to replace the cumbersome words in the text. The main contents include replacing BP neural network with BP and replacing the genetic algorithm with GA. This substitution is only for the convenience of reading the article and does not involve grammatical issues of the overall terminology.

2. Design of Mechanical Malfunction Identification and Analyze Method

In the process of mechanical malfunction identification, all diagnostic analysis behaviors need to be based on mechanical characteristic signals. Through the extraction of feature vectors, basic data are provided for subsequent malfunction identification. Firstly, the acoustic wave sensor is used to collect the corresponding keyboard vibration signal, and the interference information in the signal is removed by soft threshold denoising, including high-frequency noise signal and ultra-low-frequency signal trend item. Then, the preprocessed signal is decomposed by multilayer wavelet packet analysis, which is an upgraded algorithm of the wavelet transform. The influence of the number of decomposed layers and the selected wavelet basis function on the decomposition result is obvious. In the process of mechanical signal analysis, the wavelet basis function needs to meet the requirements of orthogonality, regularity, and compactness. According to the previous research [23–25], this paper selects "db10" to decompose the collected acoustic signal with 5 layers of wavelet packets, which is used to explore the distribution of mechanical signals in the frequency domain. Next, the decomposed results are processed by the normalization method, and the eigenvectors of the frequency channel and the overall eigenvectors are obtained, respectively. The detailed process of wavelet packet decomposition is shown in Figure 1.

In the figure, $D_{j,k}$ represents the original signal and f represents the signal frequency. It can be seen that the original signal is decomposed into 3 layers.

According to the feature extraction results, to ensure that the processing speed of the neural network is improved, the network input nodes are minimized so that the network speed can be improved. In this way, the purpose of selecting the feature quantity in the mechanical data can be achieved.

2.1. BP Optimized Based on GA. As one of the data-driven method, BP does not require complex mathematical calculations but only relies on the computing power of computers. By correcting the weights and thresholds of the learning samples in BP, we can improve the nonlinear fitting effect. Because the information synthesis ability of BP is extremely powerful, this intelligent prediction method can be applied to other scientific research fields and has wide adaptability. However, the recognition system also has certain problems. It mainly includes the selection of the initial threshold and weight of the neural network, the construction of the overall framework of the neural network, and the problem of how to correctly and reasonably select the prediction output function.

GA is a parallel random search optimization method that simulates the natural genetic mechanism and biological evolution theory. Based on the biological evolution principle of nature, it is introduced into the coding tandem group formed by the optimized parameters. Individuals are screened according to a chosen fitness function and by the selection, crossover, and mutation in genetics. Individuals with good fitness values are retained, and individuals with

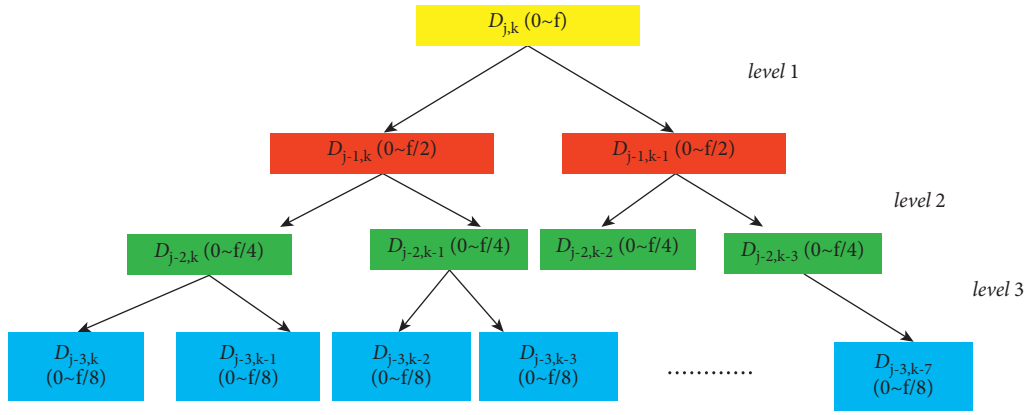

Figure 1: Schematic diagram of wavelet packet decomposition.

poor fitness values are eliminated. The advantages of genetic algorithms are mainly manifested in three main aspects. Moreover, its applicability has been recognized by domestic and foreign scholars and institutions.

GA optimization-based BP includes three parts: neural network structure determination, GA optimization, and BP prediction. Among them, GA is used to optimize the initial weights and thresholds of BP so that the optimized BP can better predict the output. GA finds the optimal initial weights and thresholds for BP neural network through selection, crossover, and mutation operations.

Aiming at the analysis of the malfunction identification, the problem of the hammering machinery belongs to the field of nonlinear pattern recognition and is suitable for the recognition problem of BP. Therefore, in the process of malfunction identification, it is necessary to optimize the overall identification system by setting the relevant GA factors based on the BP, building a network model, and expressing the output part of the model to the malfunction identification result file. The input part of the network model is the malfunction identification of the hammering machinery, and the BP model optimized by the GA is used to complete the real-time judgment of the mechanical malfunctions of the keyboard hammering. The application of the BP recognition system based on GA optimization is shown in Figure 2.

Typically, the operation of a BP model consists of two parts. On the one hand, there is the working link, in which the connection weights of different nodes need to be fixed. The calculation of the network model starts from the input layer, and through various levels of calculation, the output value of each node is obtained. On the other hand, there is the learning link, in which the output is guaranteed to be a fixed value, and each connection weight is calculated in reverse from the output layer, to modify each connection weight in the reverse calculation process of the neural network model. Figure 3 exhibits the operation procedure of the simplest neural network.

In the figure, X_1 and X_2 represent neurons corresponding to the input layer. h represents the computational error of the hidden layer and the output layer. w is the calculation weight. A_1 and A_2 represent the correlation coefficients of the output layer.

The BP network belongs to a multilayer feedforward neural network, which transmits the signal forward and transmits the error backward. The results of each training prediction are different, which is due to the randomness of the parameter selection of the BP network, and the initial value of each time is different. And the BP network is easy to fall into the local optimum in the process of evolutionary learning, the proficiency speed is slow, and the global optimum cannot be found. GA includes population initialization, fitness function, selection operation, crossover operation, and mutation operation. It is a global search algorithm. Combining the local search ability of the BP with the global search ability of the GA makes up for the random defect in the parameter selection of the BP, and the prediction results are more accurate.

In the actual operation process, the initial weights and thresholds of the BP can be obtained according to the individual, and the BP is trained with the training data to predict the system output, and the absolute value of the error between the predicted output and the expected output and E is used as the individual fitness. The formula for calculating the value F is as follows:

$$F = k\left(\sum_{i=1}^{N} \operatorname{asb}\left(y_i - o_i\right)\right), \tag{1}$$

where N is the number of network output nodes, y_i is the expected export of the ith node of the BP, o_i is the actual output of the ith node, and k is the coefficient related to the built-in laws of the algorithm.

GA selection operation has many methods such as the roulette method and the tournament method. When we choose the roulette method, that is, the selection strategy based on the fitness ratio, the selection probability p_i of the individual can be expressed as follows:

$$\begin{cases} f_i = \dfrac{j}{\overline{F}_i}, \\ \\ p_i = \dfrac{J_i}{\sum_{j=1}^{m} f_j}, \end{cases} \tag{2}$$

where F_i is the value of the fitness function of the individual, j is the relevance reduction factor, and m is all databases involved in overall intelligent computing.

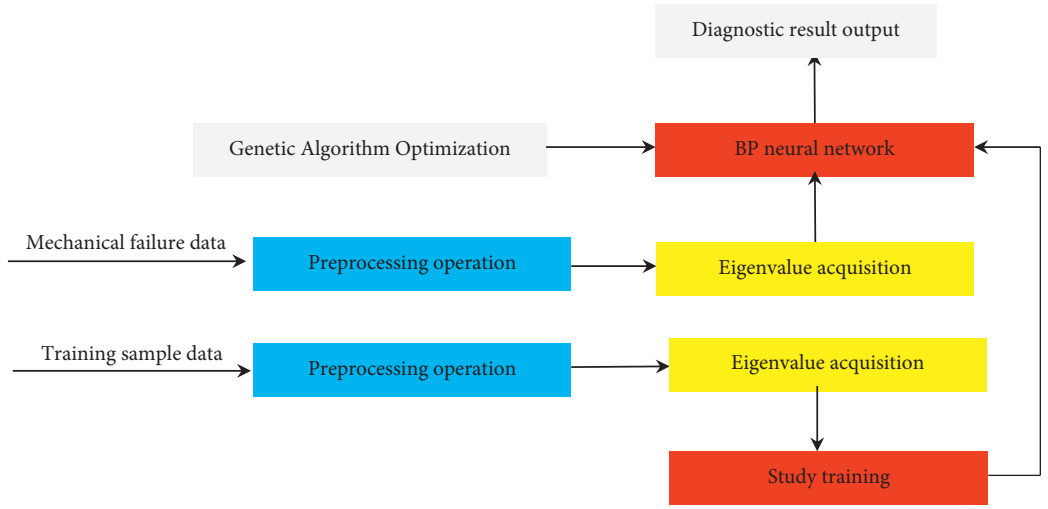

Figure 2: Design of identify structure based on GA-optimized neural network pattern recognition function.

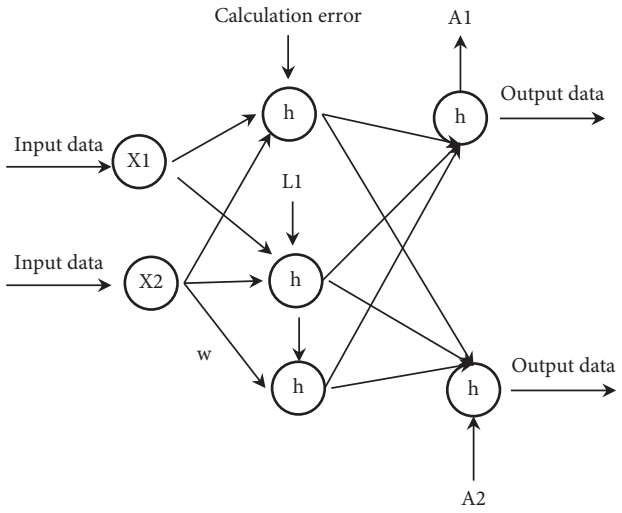

Figure 3: The operation flow of BP.

The crossover operation method of the kth chromosome and the lth chromosome at j is as follows:

$$\begin{cases} a_{kj} = a_{kj}(1-b) + a_{lj}b, \\ a_{lj} = a_{lj}(1-b) + a_{kj}b, \end{cases} \quad (3)$$

where b is an artificially set Gaussian random number. Its value range can be preprocessed by normalization.

We can select the jth gene of the ith individual to perform the mutation operation to complete the overall process of the GA.

Based on the idea of biological evolution, the GA performs genetic operations on the solution domain to find the optimal value and the corresponding optimal fitness value. GA optimization BP is divided into three parts, namely, BP structure determination, GA optimization, and BP prediction. The main content of the first part is to determine the BP structure according to the number of input and output parameters and then determine the individual length of the GA. The main content of the second part is to use the GA to optimize the parameter value. Each individual in the population contains a network ownership value and threshold value, and the minimum value of the fitness function is found through selection, crossover, and mutation operations. Finally, the BP prediction uses the network initial weights and thresholds corresponding to the optimal individual to assign values, and the function output is predicted after training. The basic process of genetic algorithm optimization of the neural network is shown in Figure 4.

2.2. Calculation Parameters of Malfunction Identification Model. In the model calculation process, to ensure good communication between the input layer and the output layer, it is necessary to enable the concealed layer to receive and extract the output layer information and transmit the processed information to the output layer. The research on the number of concealed layers shows that it has a non-negligible impact on the computing power of the prediction system. As the number of layers increases, the computing power will increase accordingly. However, it also increases the computation time of the prediction system. Neural network structures all contain a concealed layer. Taking into account the computational accuracy of the network, the appropriate number of neurons is determined by increasing the quantity value of concealed layer nodes. In the process of determining the number of neurons in the concealed layer, it is indispensable to analyze the input and output of the prediction system.

$$m = \sqrt{n+l} + a, \quad (4)$$

where n, l, and m represent the number of nodes in the input layer, the concealed layer, and the output layer, respectively. a represents the linear coefficient in the calculation process.

Simultaneously, two transfer functions are needed in the BP structure to safeguard the accuracy and real-time performance of data transmission. The sigmoid activation function is used to complete the information transfer at different levels. Because the range of output values involved

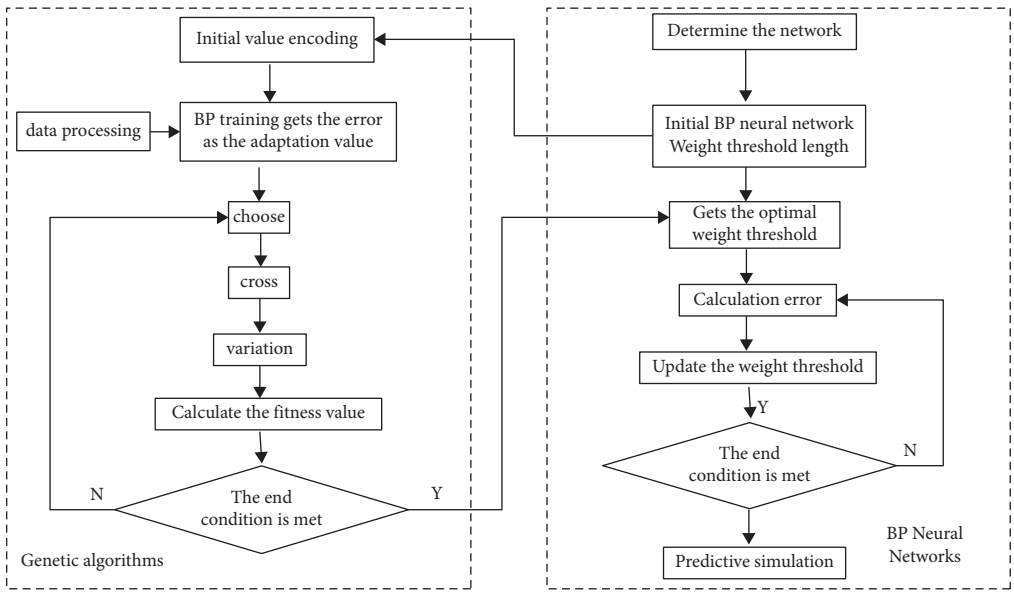

Figure 4: GA optimization-based BP.

in malfunction identification is small, the sigmoid function can be selected for both transfer functions.

$$f(n) = \frac{1}{1 + \exp(-n)}, \tag{5}$$

where n represents the number of layers of decomposition.

In the process of model application, it is also necessary to determine the learning efficiency. On the one hand, based on the experience, the learning rate of network training is selected, and then, the value of numerical experimental error is used to analyze whether the network learning rate meets the requirements. On the other hand, when the network is trained for a long time and cannot produce a large degree of error reduction, it proves that the selected learning efficiency cannot meet the requirements. Through the continuous trial calculation and back-calculation process, we can obtain the computational network model required for error prediction. Figure 5 exhibits the variation law of numerical experimental error with respect to training time.

As shown in Figure 5, when the number of training times reaches the optimal value, the experimental error of the network will reach the minimum value. Beyond this range, there will be a state of overtraining, increasing the range of training errors. For each network trial calculation, the optimal training times of the model can be determined through a mapping relationship curve similar to that shown in Figure 6.

To sum up, the operation of the mechanical malfunction identification system based on the GA optimization neural network proposed in this paper can be completed in Figure 6.

3. Brief Description of Experimental Monitoring and Experimental Results

3.1. Case Verification and Analysis. To ensure that the designed malfunction identification method can exert good performance in practical application, an experimental test is

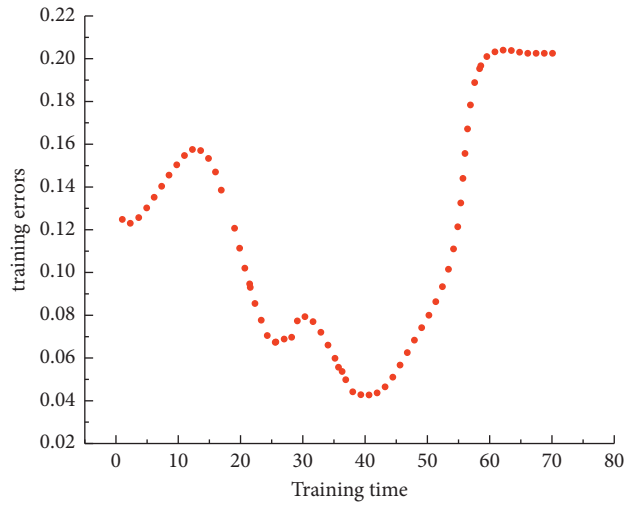

Figure 5: Training times and training errors of BP.

carried out. The mechanical transition data set of keyboard stringing is used, which contains 300 fundamental wave data, including multiple sets of single-string and multistring malfunction data. Since the ratio between the two is set to 10 : 2, the purified signal data extracted from multiple sets of experiments are used to verify the correctness, rationality, and adaptability of the proposed method. Due to the designed diagnostic method, it is based on the BP optimized by GA.

Among them, the typical signal collected is shown in Figure 7.

According to the calculation principle of GA and BP, the GA optimization BP algorithm is realized in MALTAB. The graph of adaptation degree with increasing computation time is shown in Figure 8.

According to the above calculation results, the optimal parameter values, namely, weights and thresholds, are obtained. Then, we can assign optimal initial weights and

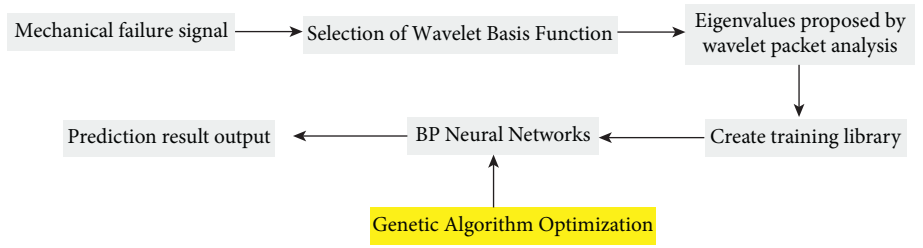

Figure 6: Mechanical malfunction identification system based on GA optimized neural network.

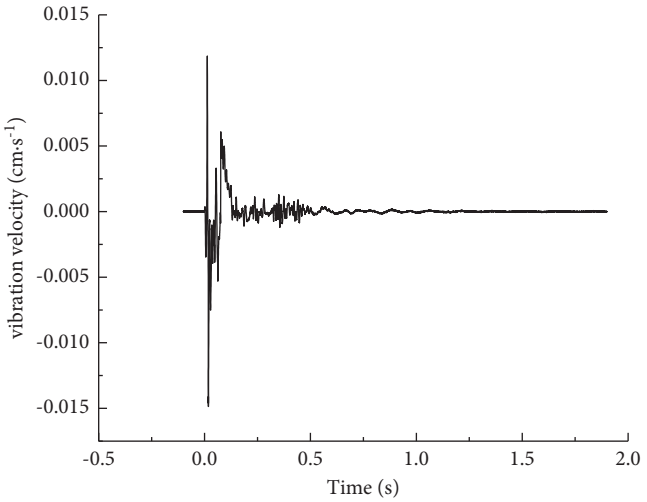

Figure 7: Typical time history curve of signal.

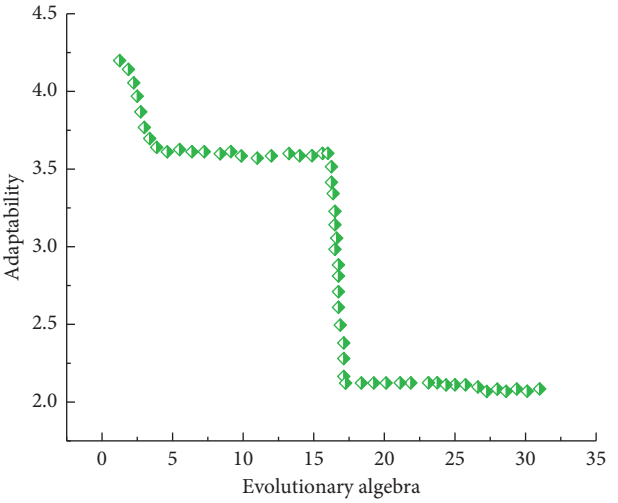

Figure 8: The change of the fitness function with the number of calculation steps.

thresholds to the neural network. Finally, it is output after training 1000 times with the training data.

At the beginning of the experiment, the number of neurons must be decided, and the number of input neurons for the identification subnet is set to $n = 10$. The number of output neurons is represented by L, and here, we set $L = 7$. The value range of the number of hidden layer nodes is set between 6 and 16. Table 1 summarizes the analysis data of the preprocessing results of the numerical experiments.

According to Table 1, when the number of concealed nodes is 9, 10, 11, and 12, the training error will change. It can be clearly found that when the numerical value of the total number of nodes is 12, the number of training steps of the neural network is the smallest, only 168 steps. Figure 9 is the training error curve of the overall system. Figure 10 shows the relationship between the training error and the number of concealed nodes.

Since the network converges in step 168, the number of nodes in the concealed layer of the BP network is set to 11. The above parameters are used for mechanical malfunction Identity, and two conventional malfunction identification methods are selected for testing under the same conditions. Through the comparison of experimental results, the performance of different malfunction identification methods is analyzed.

To show the accuracy of the prediction method, the optimized BP is compared with the traditional neural network. The comparison errors of the 100 groups of training

Table 1: Relevant training results of BP.

The number of concealed layer nodes	Training error	Training step
6	$4.37e-4$	532
7	$1.64e-4$	346
8	$1.22e-4$	235
9	$1.02e-4$	219
10	$9.87e-5$	200
11	$9.62e-5$	168
12	$1.01e-4$	212
13	$1.35e-4$	378
14	$1.38e-4$	352
15	$1.25e-4$	333
16	$1.23e-4$	311

data obtained in the experiment are shown in Figure 11. It can be seen from Figure 10 that the prediction error of the BP is relatively large compared with the measured relative variables of mechanical failure, and the maximum has reached −0.4. The error of the network optimized by the GA is basically kept up and down the horizontal axis, the error is small, and the maximum error is less than 0.1. The above analysis results show that it can basically reflect the changing trend of mechanical failure variables in the spatial dimension.

In order to further verify the reliability of the experimental results, as shown in Figure 12, the root mean square

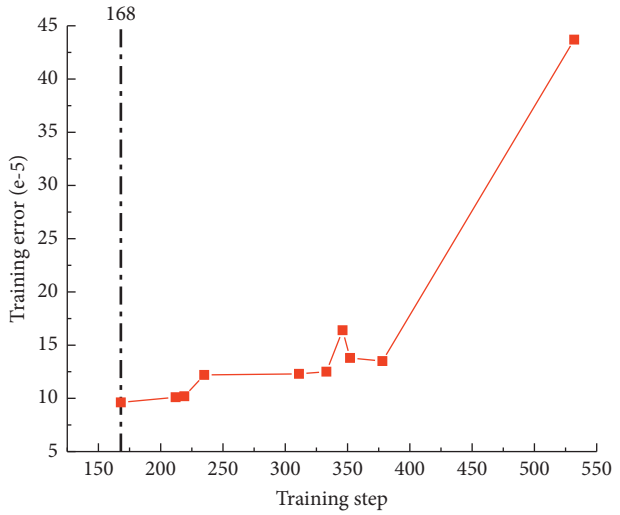

Figure 9: Mathematical relationship curve of two key variables of neural network steps.

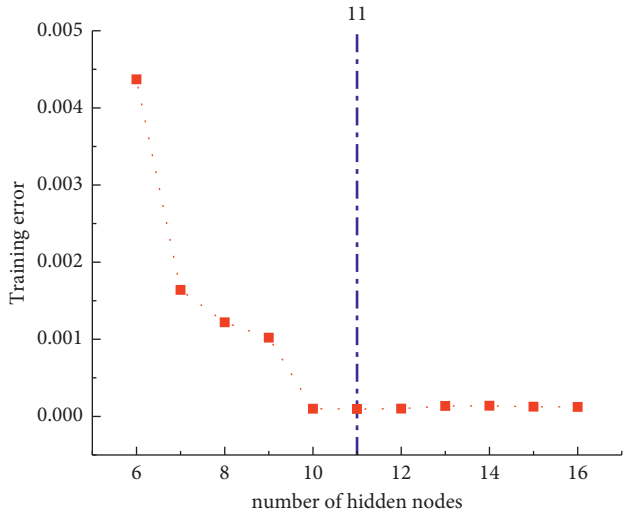

Figure 10: Correlation mathematical fitting curve between the number of nodes and the experimental normalization error nodes.

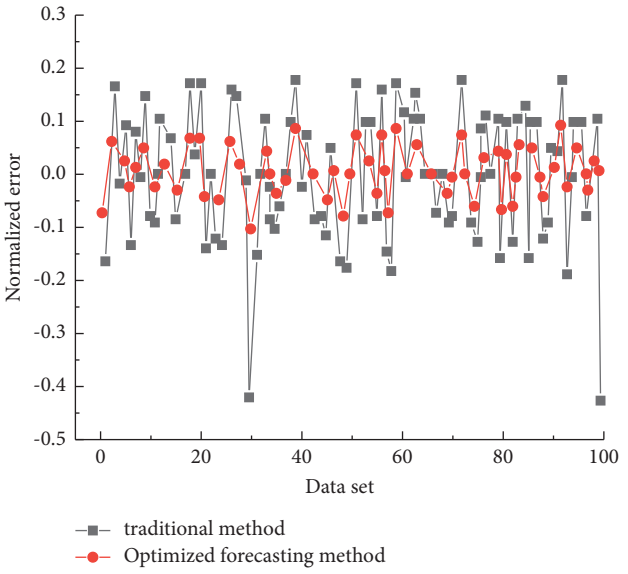

Figure 11: Comparison of training errors of the two methods.

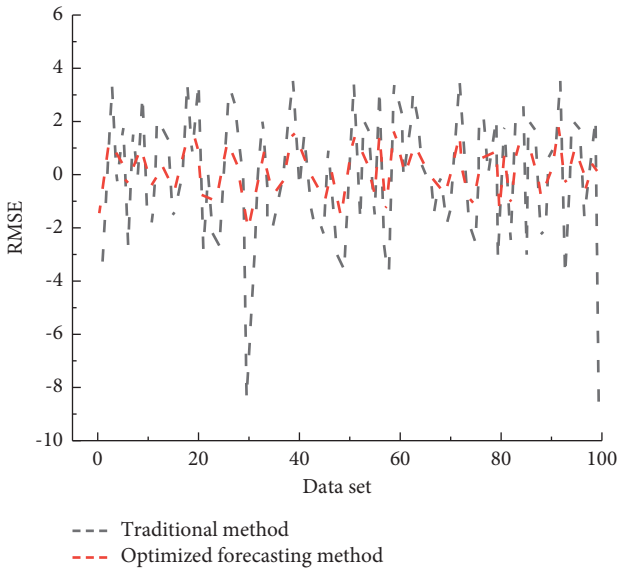

Figure 12: Comparison of root mean squared difference of the two methods.

difference of the two methods is compared. The comparison results are consistent with the results obtained by experimental error.

Figure 13 is an overall model data display effect diagram. We can clearly draw the following viewpoints that when training rounds reach 225, the training losses of the three methods gradually stabilize. However, the analysis shows that the stability of the designed diagnostic method is better, and the overall loss is significantly reduced compared with the other two conventional traditional prediction methods. This also proves the advanced nature and adaptability of the aforementioned method.

3.2. Comparison of Experimental Results of Single-String Malfunction Identification. For single-string mechanical malfunctions, it is divided into 3 test sets for malfunction identification testing, and the single-string malfunction identification results are recorded. In addition, we calculated the diagnostic accuracy of different malfunction identification methods through the previously formulated calculation program. The specific experimental results are shown in Table 2.

From the accuracy comparison relationship in Table 2, it can be found that the identification result of the aforementioned method optimized by GA is obviously better than the two conventional methods. The diagnostic accuracy of the method in this paper is higher than 90%, and the average accuracy is 92.51%. The average diagnostic accuracy of the two conventional methods was 86.94% and 87.85%, respectively. Through multiple network model training, the number of

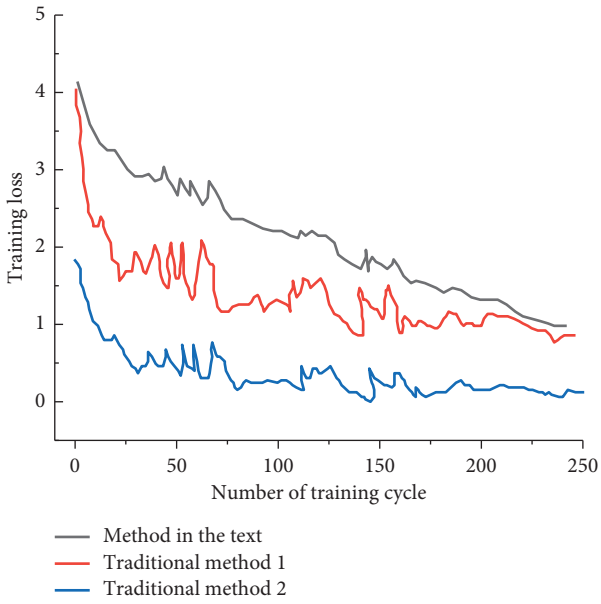

Figure 13: Comparison of training losses for the three methods.

Table 2: Comparison of single-string malfunction identification accuracy.

Method	Accuracy of test identification			Average accuracy
	U1 (%)	U2 (%)	U3 (%)	
Proposed method	90.53	93.27	93.75	92.51
Traditional method 1	84.34	88.79	90.68	86.94
Traditional method 2	87.16	88.79	87.51	87.85

Table 3: Comparison of multistring malfunction identification accuracy.

Method	Accuracy of test identification			Average accuracy
	U1 (%)	U2 (%)	U3 (%)	
Proposed method	91.27	90.18	89.68	90.38
Traditional method 1	85.71	83.57	84.54	86.41
Traditional method 2	83.93	84.03	81.46	83.32

layers of the BP is increased, various intelligent parameters in the BP network are optimized, and the malfunction identification accuracy is effectively optimized. Compared with the two conventional traditional methods, the diagnostic accuracy was increased by 2.57% and 5.66%, respectively.

3.3. Comparison of Experimental Results of Multistring Malfunction Identification. Similarly, for multistring mechanical malfunctions, it is divided into 3 test sets for malfunction identification testing, and the single-string malfunction identification results are recorded. We can calculate the diagnostic accuracy of different malfunction identification methods through a preset program. The specific experimental results are shown in Table 3.

From the accuracy comparison relationship in Table 3, it can be found that the identification result of t the aforementioned method optimized by GA is obviously better than the two conventional methods. The diagnostic accuracy of the method in this paper is higher than 89%, and the average accuracy is 90.38%. The average diagnostic accuracy of the two conventional methods was 86.41% and 83.32%, respectively. Through multiple network model training, the number of layers of the network is increased, the various intelligent parameters in the BP network are optimized, and the malfunction identification accuracy is effectively improved. Compared with the traditional method, the diagnostic accuracy is increased by 5.76% and 7.15%, respectively.

To sum up, the identification design method of the aforementioned method optimized by GA has better malfunction identification performance for mechanical malfunctions. The introduction of this method based on coding calculation provides a new innovative idea for solving similar engineering cases.

4. Conclusion

(1) From a global and local perspective, the experimental operator can optimize the parameters of BP through GA and organically combine the global search ability of GA with the local search ability of BP. In this way, the defects caused by the randomness of weights and thresholds in the actual algorithm can be compensated to the greatest extent. The identification method proposed here has more accurate prediction results and better innovation than traditional prediction ideas.

(2) In view of the shortcomings of the traditional malfunction identification method, a learning model is constructed through BP, and reasonable malfunction identification model parameters are set by using its learning mechanism and nonlinear mapping level. The results show that the designed malfunction method improves the performance of mechanical malfunction identification, which makes the field of mechanical malfunction detection have a better development prospect. The research results have achieved the expected goal, and more in-depth research will be conducted on mechanical malfunction identified in the future.

(3) It has certain engineering significance in the processing of mechanical construction. According to the current practical application situation, the practical direction of artificial intelligence in mechanical design and manufacturing and its automation mainly includes mechanical design, information processing, and malfunction identification which brought an important impetus that cannot be ignored.

Data Availability

The data set can be accessed upon request.

Conflicts of Interest

The author declares no conflicts of interest.

Acknowledgments

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Retraction

Retracted: Low Carbon Economy Assessment in China Using the Super-SBM Model

Discrete Dynamics in Nature and Society

Received 15 August 2023; Accepted 15 August 2023; Published 16 August 2023

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Peer-review manipulation

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] Y. Ding and Y. Han, "Low Carbon Economy Assessment in China Using the Super-SBM Model," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 4690140, 9 pages, 2022.

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Research Article

Low Carbon Economy Assessment in China Using the Super-SBM Model

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This review proposes a performance evaluation system of low-carbon economic development based on multiobjective analysis in low-carbon environment. This is a modeling method combining super efficiency and relaxation-based measurement model (super-SBM model), which can effectively measure green innovation efficiency with unexpected outputs and traditional innovation efficiency without unexpected outputs. Using the Malmquist–Luenberger index method to dynamically analyze the efficiency of green innovation, a multiobjective model is obtained, including economic scheduling target considering wind power cost and low-carbon scheduling target considering carbon trading. The efficiency of green innovation considering unexpected output is obviously lower than that of traditional innovation without considering unexpected output. This phenomenon is more pronounced in some areas of central and western China. Technical efficiency improves the innovation level of environmental protection economy in China and the impact of technological progress is greater than that of technical efficiency. In this review, the output super SBM model is used to study the development of China's low-carbon industry, and the correlation between the prediction model and the performance change of low-carbon economic development is analyzed. The Malmquist–Luenberger (ML) index of environmental protection product development efficiency in China is not less than 1. Due to the improvement of the efficiency of scientific and technological development, the combination of the two will eventually lead to the improvement of the development of green products and environmental economic products in China. Combining with the empirical analysis, this paper puts forward some methods to promote the low-carbon economy in the economic zone.

1. Introduction

For the past few years, China has paid more attention to the adverse effects of industrial development on the ecological environment. The government reduces resource consumption and environmental pollution by developing renewable energy and establishing various emission reduction mechanisms [1]. At present, resources and environment problems associated with China's rapid economic development need to be solved urgently. In 2020, China's Global Environmental Performance Index (EPI) ranked 120th out of 180 countries and regions [2]. Therefore, the Chinese government plans to improve the overall coordination mechanism in the ecological field to achieve a comprehensive green transformation [3, 4]. Low-carbon products can bring benefits in different regions according to local conditions [5, 6]. This will help China achieve high-quality development and green transformation.

At present, we mainly discuss and distinguish the evaluation model of low-carbon economy from two aspects: (1) from the qualitative perspective, the evaluation model is discussed from different perspectives by establishing various theoretical models, among which the most important three perspectives are linear analysis, nonlinear analysis, and system construction [7, 8]. (2) From a quantitative perspective, specific evaluation numbers are obtained through empirical research on relevant theoretical frameworks [9, 10]. Beise [11] proposed that enterprises should adopt cleaner production methods, such as process and technology, to reduce environmental problems. Ghisetti and

Rennings [12]divided green innovation into energy resource efficiency type and external reduction type. Zhang et al. [13] divide green innovation into three types: resource-saving, environment-friendly, and hybrid green innovation based on the framework of "motivation-process-result." The evaluation methods of green innovation efficiency into two different types: the first type is data envelopment analysis (DEA). For example, Sueyoshi et al. first proposed the DEA-RAM model and through this model, the data of economic benefits are calculated [14]. The second type is random forward edge analysis (SFA). For example, Aigner et al. proposed the stochastic frontier model for the first time and analyzed the factors affecting the efficiency of technological innovation [15].

The data size of output indicators of environmental protection and economic development speed includes two categories: the first is a phase of input and output evaluation index system and does not include intermediate output. Yan et al. selected the human resources, capital, infrastructure investment, and scientific and technological achievements, such as economic, social, and environmental performance of nine indicators to measure regional innovation efficiency in China [16]. Guo et al. constructed an evaluation index system of total factor productivity of low-carbon economy consisting of three first-level indicators of input, expected and unexpected output, and five second-level indicators of labor, capital, energy, regional GDP, and "three wastes" emissions [17]. The second type is two-stage input–output index system, including intermediate output. Jiang et al. constructed an evaluation index system consisting of 5 first-level indicators of innovation input intermediate output, non-R&D input, expected, and nonexpected output and 15 second-level indicators to measure green technology [18]. Through the summary of existing literature, many scholars have conducted a lot of studies on the efficiency of low-carbon economic development, but there are some shortcomings in evaluation methods and index selection [19]. DEA is the main evaluation method, but the traditional DEA model seldom considers the "slack" variable and the unexpected output at the same time, which may cause the efficiency value to be overestimated [20].

In 1978, Charness, Cooper, and Rhodes initiated DEA model to measure the degree to which the inputs (outputs) of decision-making units need equal proportion improvement when they reach the production frontier. The DEA model is a new advanced learning method, as one of the main research methods of efficiency evaluation [21]. The super-SBM model makes up for the weakness that the SBM model cannot distinguish effective decision units. First, the effective units are deleted from the production possible set and the distance from them to the production front is measured [22]. The super-SBM model is very efficient in evaluating the cross-sectional data of the development efficiency of the low-carbon economy. However, what we usually refer to as industrial development is often a dynamic process involving the improvement of production technology and the proficiency of worker skills [23]. Obviously, from the viewpoints of Dell, McDuffie, and Becker, it can be found that they are all in favor of a causal relationship model, and they propose a simple and intuitive model of the impact of organizational effectiveness, which effectively solves the process of human resource management practice. The problem is that the variable in this model is benefit, and the only influencing factor of this variable is the original variable. However, the specific situation is often more complex, and the general situation is much more complicated than the theoretical idea. In practice, the model needs to set more variables, and in these models, it is only an ideal situation, and there are a very few variables to consider. Therefore, these theoretical assumptions also lead to certain defects in the linear mode, which needs to be improved in practice [24]. The Malmquist index contains two methods, a component of the catch-up effect and a component of the frontier movement. The catch-up effect reflects the change effect of technical efficiency, while the frontier movement reflects the movement of all referenced production fronts in two periods [25]. The theory has carried out a detailed discussion on the antecedent part, and also added a lot of process influencing factors, so that the theory can more truly reflect and approach the actual situation. The paper considers that the SBM model with undesired output may have multiple decision units that are effective at the same time, so it is not convenient to distinguish and sort these decision units. The super-SBM model with unexpected output effectively solves the discrimination and ranking problems when multiple decision units are effective at the same time. It can reflect the essence of efficiency evaluation of regional low-carbon economy [26]. Based on some research background, this paper uses the super-SBM model and ML indicators to measure and analyze the different levels of low-carbon economy operating efficiency in most provinces and cities in China. Incorporate resource and environmental factors into the input and output indicators of innovation process. The low-carbon economic operation efficiency including undesired output is calculated and compared with the traditional innovation efficiency without undesired output. The static and dynamic levels of low-carbon economic operation efficiency in China are analyzed comprehensively [27]. Traditionally, we believe that due to pollution emissions, environmental quality in nonmodern urban areas may be better than in areas with a high level of modernization. This paper mainly studies and evaluates the development of low-carbon economy by using the super-SBM model. At the same time, it also conducts effective forecasting of production frontiers and dynamic monitoring and practical demonstration of changes in low-carbon economic development performance.

2. Advantages of Super-SBM Model and SOM Neural Networks

The method of super-SBM model belongs to packet envelope analysis model. This model measures efficiency from radial and angle, without considering the problem of input–output relaxation. Super-SBM model analyzes and calculates the growth efficiency of low-carbon economy. When input and output are nonzero slack, calculated efficiency value is not accurate. See the result in Figure 1, the spatial structure of the SOM neural network outputs the results of running the SOM neural network model.

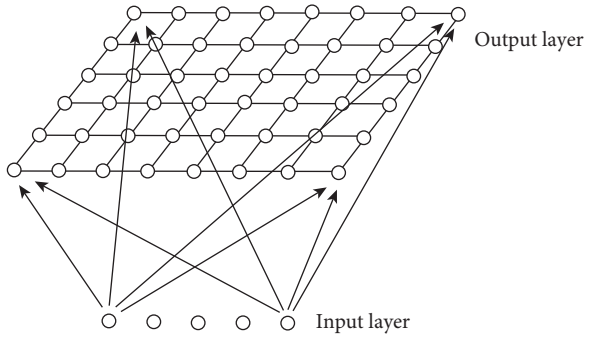

Figure 1: The spatial structure of neural networks.

Main steps of establishing a neural network management efficiency evaluation model are as follows:

(1) In order to determine the risk factors, find out the appropriate evaluation criteria by analyzing the data.

The appropriate low-carbon economic index benefit factor can be selected as the evaluation standard, as shown in equation (1) [28].

$$N_{mn} = e^{-(m-n)^2/2\delta^2}, \quad (1)$$

where N_{mn} is standard evaluation function, and δ is the training speed of model, which is a constant.

(2) Input information points to the SOM neural network model.

The model is still in its infancy, it is especially important to choose the coefficients, which are related to the validity and accuracy of the model predictions. When using the low-carbon economic indicator benefit as the description object and through the set of elements determined during data processing, the selection range can be fixed between the closed interval of 0 and 1. At the same time, the use of the normalized calculation method can solve the problem of inaccurate settlement results. The normalized function is shown in equation (2):

$$q_{mn} = \frac{w_{mn} - w_m}{w_{mn} - w_n}, \quad (2)$$

where q_{mn} is the calculated weight $Wm = \mathrm{mix}\ (Wmn)$, $Wn = \max\ (Wmn)$, $Pmn \in [0, 1]$.

(3) Advantages of the SOM model. The correct selection of information points is related to the prediction results of the model, and there is a strong correlation between information points and prediction results. If the number of selected information points is small, the prediction accuracy of the output of the SOM model will be reduced. Equation (3) represents the appropriate information points selected in the model:

$$r_{mn} = \frac{\sqrt{\sum_{n=1}^{m} (w_m - w_n)}}{P - 1}, \quad (3)$$

where r_{mn} is the optimal number of data points to hide.

(4) Select the output information points of SOM model

As mentioned above, the number of information points is related to the prediction result, and the model output value can directly reflect the quality of the evaluation result on this basis. The evaluation model results can be divided into five levels. From level one to level five. The lower the maximum safety factor of the number of levels, the level one is the safest level. It can be shown by formula (4) [29]:

$$H = \sum_{I=1} (J_I - J_P) \times \eta(J_I, J_P), \quad (4)$$

where H refers to the number of selected information points.

In addition, super-SBM model has three advantages: (1) effectively improve the inconsistency of input-output variables; (2) fully consider and solve the problem of poor output data; (3) propose solutions for the problem of different simultaneous ordering of multiple decision-making units. Compared to other data envelopment analysis (DEA) methods, the super-SBM model can more truly reflect the nature of the evaluation of low-carbon economic efficiency in different regions.

3. Construction of Low-Carbon Economic Operation Efficiency Evaluation Model

3.1. Traditional Evaluation Model. After determining the evaluation index set in traditional economic operation efficiency evaluation model, the dimensionless characteristic value and weight of each index can be determined by comprehensive fuzzy evaluation method. The model is used to determine the proportion of eigenvalues after considering the neutralization evaluation index. The weighted average method is generally used, and the next step is selected according to the evaluation indicators, then, the final evaluation result of super-SBM model was obtained [30].

Nevertheless, this method cannot be used for the efficiency evaluation of green economy. As the efficiency of green economy management is affected by various results, and there is a mutual relationship between various influencing factors. If only under a single functional condition, the relationship between each influencing factor and the result is not certain, so there is a typical nonlinear system. It truly reflects the efficiency of the evaluation model of human resources. In this process, the dynamic changes and nonlinear problems can be mainly checked and solved in the model shown in Figure 2.

If expert scoring method is used, the weights determined by this method are flawed to a certain extent. First, there is a large human factor, and there are great differences in the personal preferences of experts, which may cause the authenticity of the measurement to be disturbed. The second is poor flexibility [31]. The determined weight is difficult to be changed, which is inconsistent with the existence of uncertain factors in the actual situation.

3.2. Evaluation Method Based on SOM Neural Network. If only the original evaluation data are used as the output object, the intermediate parameters are not considered, the

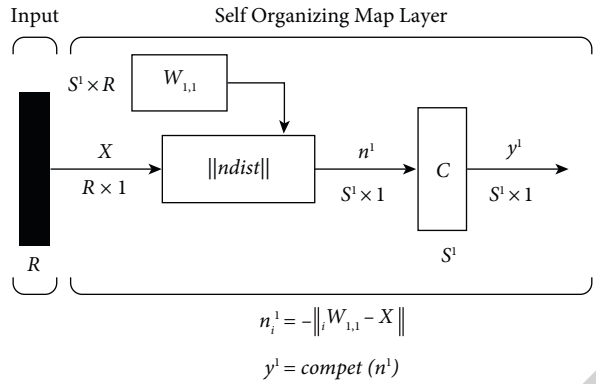

Figure 2: The low-carbon economic evaluation model based on SOM neural network.

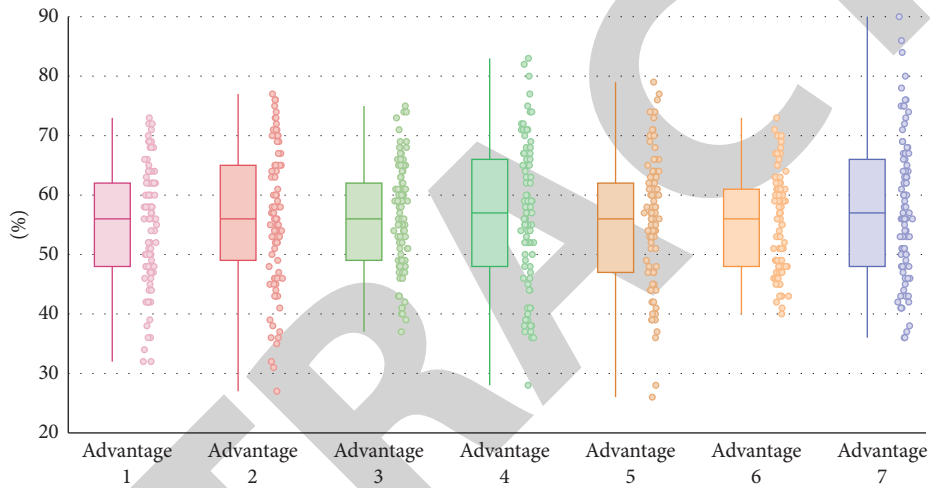

Figure 3: Clustering of input vector neurons with different benefits.

entire SOM model is equivalent to a closed interval, and only one benefit degree can be the output. If the whole evaluation system is regarded as a nonlinear function, the effectiveness of the evaluation index system can be realized, and the complex mechanism of the large system of human resource management can also be satisfied. Figure 3 shows a variety of input vector neurons that have different strengths and can exploit the strengths of the model from different angles. SOM model can well identify the elements, complex, high dimension, nonlinear relationship between its essence and is a kind of input and output layer of neural network, and they are all connected on the basis of the neurons (parameters) between the organization model for different types of intrinsic characteristics, thus mapping distribution and classification. It can effectively solve the problem of sample type recognition in which the parameters of each index are intermingled with each other and the category characteristics are not obvious.

There are various forms of neural network computing models, including SOM model. It consists of two layers: input and output, and there is a strong correlation between them. The only flaw is that cells at the same level are not linked. There are two forms of operation of the SOM network: forward propagation and backward propagation. When forward propagation does not meet the output requirements, it will turn to back propagation. At the same time, the input layer receives error information from the results fed back by the output layer. During this process, the connectivity of each cell in each layer of neurons and the error offset of each layer of neurons change, thereby continuously reducing the error.

3.3. Super-SBM Evaluation Model. At present, the research on low-carbon economy in China has made some advancements. In different research fields, the research design has a wider level, and scholars conduct research from the national to the city. From the perspective of research methods, data envelopment model (DEA) is commonly used to evaluate low-carbon economy, and different models will be selected according to the index system and research perspective of scholars. Some scholars use the traditional CCR model or BCC model for measurement. However, the traditional DEA model has certain limitations, so the improved super-efficiency DEA model (super-SBM) is more used at present. On this basis, we introduce nonexpected

output, namely low-carbon cost input, as a variable, and use the nonexpected output super-efficiency SBM model to evaluate the efficiency of economic growth so that the measurement data can be more objective and guide the sustainable development level of low-carbon economy to a certain extent.

From the perspective of low-carbon economy, the primary issue in studying the efficiency of capital allocation is to measure the degree of low-carbon economics. According to the data, in the pursuit of low-energy consumption, low emissions, low pollution, and advocacy of green technological progress, we employ DEA-based green TFP indicators, including energy transition and accelerated CO_2 emissions, which measure the degree of change in low-carbon economic development.

Different from ordinary DEA, the green TFP index takes energy and carbon emission into account. Due to the lack of carbon emission price information and cost variables, environmental factors are often ignored by researchers in the analysis of their impact on economic growth. This is because the distance function obtained through linear programming is calculated based on seeking output maximization in the case of input or pursuing input minimization in the case of output input. Taking carbon dioxide emission as an input factor can make input-based distance function reflect the connotation of low-carbon economic better.

The super-SBM model considering the relaxation variable can be expressed as follows:

$$\rho = \min \frac{1/m \sum_{i=1}^{m} x_i / x_0}{1/s_1 + s_2 \left(\sum_{r=1}^{s_1} y_r^g / y_{r0}^g + \sum_{r=1}^{s_2} y_r^g / y_{r0}^g \right)}, \quad (5)$$

$$\text{s, t, } x_0 = X\lambda + S^-, \; y_0^g = Y^g \lambda - S^g.$$

where ρ is the target low carbon efficiency value.

In addition to measuring the technical efficiency level of green economy development performance, we also investigate the intertemporal dynamic changes of green economy development performance. The dynamic change of green economy development performance is not only related to technical efficiency but also closely related to technological progress. Therefore, based on the reference output-oriented Malmquist productivity index, on the basis of combining direction distance function, put forward considering the expected output of total factor productivity index, index and total factor productivity change further and are decomposed into two parts, namely, the change of the technical efficiency and technical progress, as shown in type (7):

$$\text{TFP} = \left[\frac{D^t (x_{t+1}, y_{t+1})}{D^t (x_t, y_t)} \times \frac{D^{t+1} (x_{t+1}, y_{t+1})}{D^{t+1} (x_t, y_t)} \right]^{0.5}. \quad (6)$$

Equation (6) can also be decomposed into the product of three parts:

$$\text{TFP} = \text{PE} \times \text{SE} \times \text{TC}, \quad (7)$$

where TFP stands for low-carbon economic efficiency; TC stands for technological progress and change; PE represents pure technical efficiency change; and SE represents the change in scale efficiency.

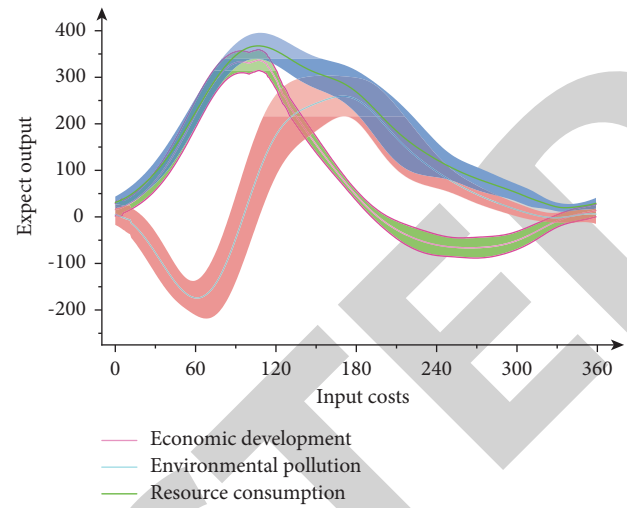

Figure 4: Eco-efficiency evaluation index system.

Using this model to evaluate the ecological efficiency index, the results are shown in Figure 4. The development trend of low-carbon economy and environmental pollution is opposite.

4. Index Selection and Data Processing

Energy input is beneficial to the economic progress of a region, while scientific research input is essential to the development and progress of technology. In addition, the characteristics of industrial structure and urbanization level affect carbon emission level and energy consumption structure from different aspects. Therefore, on the basis of the previous studies, this paper selects corresponding indicators from the perspectives of energy, industrial structure, and urbanization level to measure the input of low-carbon economic development. In terms of the selection of output indicators for low-carbon economic development, these two indicators are favored by the majority of researchers due to the comprehensive and authoritative GDP indicators and the unique advantages of carbon productivity in measuring economic development. In Figure 5, we can see that with the increase of economic input, the comprehensive index of low carbon economy is significantly higher than that of medium carbon and high carbon. However, carbon productivity index has some defects because it cannot reflect the environmental cost in the process of economic development. In view of this, in this paper, GDP and unit carbon dioxide emissions of each region are selected to measure the expected output and unexpected output of low-carbon economic development. As can be seen from Figure 5, there are mainly three different forecast results of low-carbon economic development in China under low-carbon economy. The chart reflects the general development trend of low-carbon economy.

Figure 6 shows the DEA calculation method. This method can be used to evaluate the input and output prediction of multiple indexes. Its principle is to calculate and evaluate the computational efficiency of DMU by using

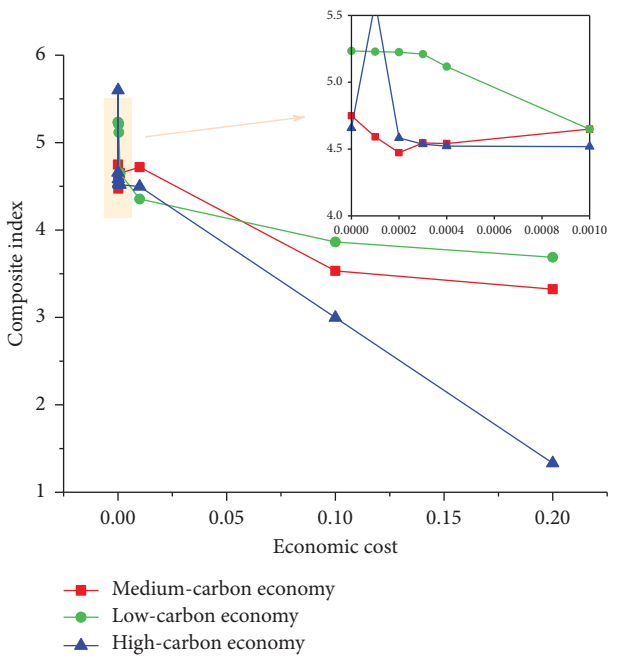

Figure 5: Various economic index models.

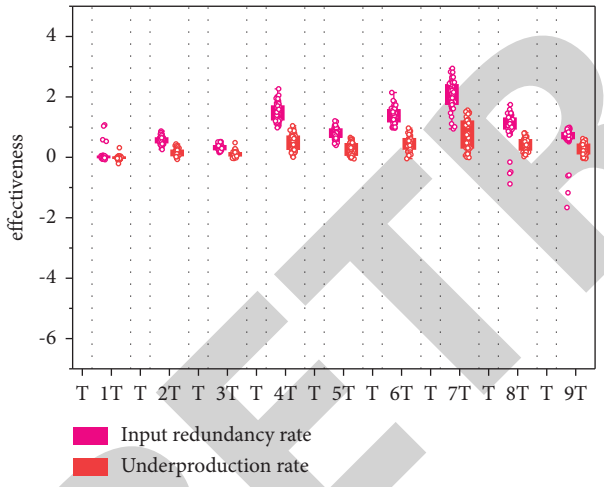

Figure 6: Input redundancy and output insufficient efficiency diagram.

mathematical programming model. From Figure 6, it can be seen that the ratio of research and development investment is higher than that of output, which also increases the difficulty of implementing. In the evaluation index model, the amount of research and development expenditure cannot be truly measured due to the flow index characteristic of "research and development expenditure of medium-sized and above industrial enterprises." At the same time, GDP is calculated according to current price without excluding price factors, so the data of these two indicators are processed accordingly, while the data of other indicators are based on original data.

$$K_{it} = (1 - \delta_{it})K_i + I_{it}, \tag{8}$$

where K_{it} is the *R&D* capital stock of region I in phase T; I_{it} is the actual *R&D* expenditure of Region I in Phase T.

5. Model Results Analysis

This part first evaluates the relative efficiency of China's economic zone development in order to understand the realistic level of different economies. Then, based on the relative efficiency evaluation, the paper makes a projection analysis on the production front of the ineffective cities to determine the degree of improvement of the ineffective cities' attribute value and the ideal value of input–output. Finally, the evolution of economic development performance from a dynamic perspective is investigated to reveal the deep-seated reasons for low-carbon economic. Based on the above analysis, this model is used to measure the speed of economic zone development in China.

From the input-oriented perspective, in terms of pure technical efficiency, DEA is effective when the efficiency values are all greater than 1, indicating that technological innovation, especially energy technology and emission reduction technology innovation, has been fully utilized in the low-carbon economic development of these cities. When the efficiency values are all 1, the weak DEA is effective, indicating that technological innovation effects such as energy technology and emission reduction technology are more effectively played in these cities. When the efficiency values are all less than 1, DEA is invalid, indicating that technological innovations such as energy technology and emission reduction technology have not played their due role in these cities. For cities with ineffective DEA, by projecting the production front of ineffective cities, we can not only understand the use status of their factor inputs but also analyze the reasons for their ineffectiveness and determine the extent to which their attribute values should be improved and the ideal value of input–output.

The total factor productivity (TFP) change index (Malmquist) and technological progress change (TC) index were introduced to evaluate the relationship between low-carbon technologies and the performance of low-carbon economic development more directly. The dynamic evolution of the performance of low-carbon economic development in China's economic zones presents the following states:

(1) Technical changes and TFP changes are stable

(2) Technological changes and TFP changes show an increasing trend year by year

(3) Technological change and TFP change showed a decreasing trend year by year

(4) Technological changes and TFP changes present a state of fluctuation

(5) Technological change and TFP change direction are inconsistent

The predicted results of these five models are all possible. In the super-SBM model, we can better judge the implementation of low-carbon economy and YI by simulating these change curves.

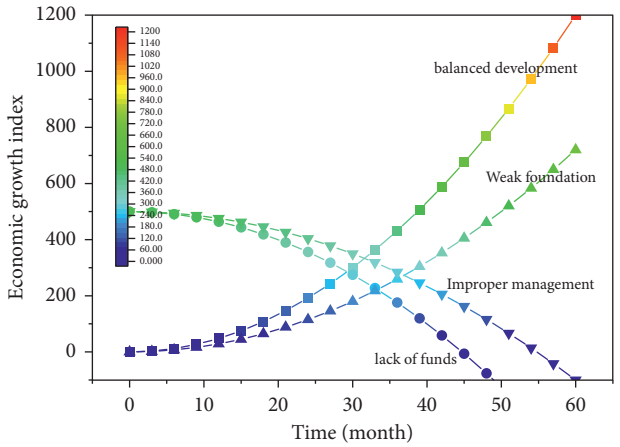

Figure 7: The development rate of low-carbon economy of four types of enterprises.

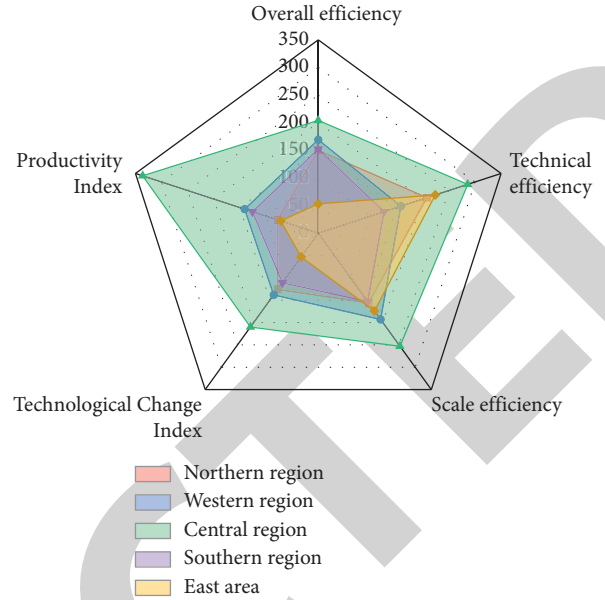

Figure 8: Distribution map of low carbon index in various regions.

6. Regional Difference Analysis of Low-Carbon Economic Level

The ML index under technical conditions in period t can be expressed as follows:

$$\theta = \frac{1 + D\left(x^t, y^t, b^t, y^t, +b^t\right)}{1 + D\left(x^{t+1}, y^{t+1}, b^{t+1}, y^{t+1}, +b^{t+1}\right)} = \alpha \times \beta. \quad (9)$$

Where $\theta > 1$ indicates that the total increases, and vice versa represents a decrease, that is, the frontier shift effect. If $\alpha > 1$, it proves that the frontier of efficiency has expanded, and economic progress or technological innovation has occurred, and vice versa. Economic decline hinders efficiency improvements. The economic efficiency index reflects the change degree of the distance between the decision-making unit and the efficiency frontier between the t period and the $t+1$ period, that is, the catch-up effect. $\beta > 1$ proves that the relative efficiency of the decision-making unit is improved compared with the previous period, and the green resources are well utilized. If it is close to the frontier, on the contrary, the relative efficiency will regress, and the resource utilization will be poor, which is gradually far away from the efficiency frontier. Use this formula to analyze the development rate of low-carbon economy through enterprises. From Figure 7, we can see that balanced growth enterprises develop the fastest low-carbon economy and enterprises that are short of funds and improperly managed all show negative growth.

The super-SBM model is used to analyze and calculate the efficiency of China's low-carbon economic development. In order to compare the regional differences of the impact of low-carbon environment on economic efficiency in different regions of China. The ML index can evaluate the factor input according to the results of the frontier function and can also effectively deal with the data fluctuation of economic output and environmental output. The model budget of eastern China remains at an efficient level of 0.8, while that of Central China is only around 0.5 and that of western China is only around 0.35. Traditionally, we believe that less-developed regions are likely to have better pollution emissions, environmental quality, and low-carbon approaches than economically developed provinces due to industrial underdevelopment. The results contradict the judgment that developed eastern China is economically superior to central and western China, but central China is the best in terms of controlling environmental pollution and maintaining less pollution. This can also be confirmed by Figure 8, which shows that the index is more comprehensive in the central region, followed by the western and eastern regions.

7. Conclusion

The super-SBM model is used to analyze relative evaluation efficiency of low-carbon economic, projection performance of production frontier, and the dynamic evolution characteristics of the relative evaluation efficiency of low-carbon economic development in China. From the perspective of the dynamic evolution of low-carbon economic performance, technological change and TFP change have strong similarities. Different from other research methods, the SOM model can effectively deal with the analysis of China's economic situation because of its applicability, accuracy, and validity. This study establishes a research model of economic development efficiency from the perspective of low-carbon development. The following conclusions can be drawn: (1) the efficiency of green innovation considering undesired output is lower than that of traditional innovation without considering undesired output. (2) China's overall low-carbon economy development level is low, but the overall efficiency of green innovation in China is increasing, but the average efficiency is relatively low, showing inefficiency, and there is a large room for progress. (3) The average ML index of China's green innovation efficiency is greater than 1, in which technical efficiency and technological progress jointly lead to the improvement of China's green innovation level.

The impact of technological progress is greater than that of technical efficiency, and its convergence with the ML index is higher. (4) There is a big difference in the development level of low-carbon economy among the three major regions of China, east, middle, and west. The eastern region is characterized by relatively low-carbon development, and the western region is the most backward, with the highest carbon emissions, but the weakest development capacity, with obvious high-carbon characteristics; the central region is located between the two. (5) The super-SBM model can be effectively used to analyze the evaluation of low-carbon economy.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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Retraction

Retracted: 3D Video Analysis and Its Application in Developmental and Educational Psychology Teaching

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

In addition, our investigation has also shown that one or more of the following human-subject reporting requirements has not been met in this article: ethical approval by an Institutional Review Board (IRB) committee or equivalent, patient/participant consent to participate, and/or agreement to publish patient/participant details (where relevant).

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] Z. Chen and L. Ding, "3D Video Analysis and Its Application in Developmental and Educational Psychology Teaching," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 2551272, 9 pages, 2022.

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Research Article

3D Video Analysis and Its Application in Developmental and Educational Psychology Teaching

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With the rapid development of information technology and network technology and the new requirements of education and teaching in the new era, 3D video technology has been more and more widely used in the field of education and teaching. Educational psychology plays a positive role in the field of education. Applying its relevant theories to classroom teaching is not only conducive to the establishment of a good teacher-student relationship but also helps teachers to understand the psychological characteristics and learning process of students, so as to greatly improve the quality of teaching. Therefore, this article is based on 3D video analysis technology, through the observation of the teaching video and coding, the verbal interaction between teachers and students' lines of code and data analysis, mainly to its frequency, specific length and single length data used for analysis, explores the lesson for the current situation of the teaching video case teacher's teaching behavior, commonness, and difference. From the perspective of learner psychology, the model of teacher's teaching behavior in MOOCs teaching video is constructed. On the other hand, from the perspective of coding system and learner psychology, this paper proposes the improvement strategies of teachers' teaching behavior in MOOCs teaching videos in China. The results show that the application of 3D video analysis method and educational psychology in student education can improve student work efficiency.

1. Introduction

In the 21st century, the rapid development of information technology is affecting every aspect of human activity, powered by technology, driven by information, driven by knowledge of the global new economy has been formed, these technologies changed the way people live, work, entertainment, at the same time in agriculture, medicine, engineering, education and other fields has a very important change [1, 2]. Students are always the main body of teaching; teachers should make clear this premise.

MOOCs have become a new way to meet the diverse needs of higher education because they can solve the problems of cross-space and sharing of educational information [3, 4]. At present, the improvement of the teaching effect of MOOCs has attracted extensive attention from the educational circles at home and abroad. Relevant researches mainly put forward suggestions and strategies to improve the teaching effect of MOOCs from the construction of MOOCs platform, MOOCs teaching videos, and learners themselves. As the most important part of MOOCs, 3D teaching videos can directly determine the teaching quality of MOOCs. And the key of MOOC teaching lies in the teacher, who can impose teaching intervention on learners through specific teaching behavior [5, 6]. In other words, teachers' teaching behavior largely determines the quality of MOOCs teaching videos. As an important way to improve the quality of MOOCs teaching, it plays a very important role and value in meeting the emotional needs of learners and improving the quality of MOOCs teaching.

Classroom 3D video (see Figure 1) analysis method is a research method that researchers use video analysis software to analyze teachers' real classroom scenes based on recorded classroom videos and according to certain coding rules, so as to obtain classroom information such as teachers' classroom teaching behaviors. In the research, 3D video analysis method can facilitate researchers to repeatedly watch the content of teaching videos and encode and record [7, 8]. We

Figure 1: Classroom 3D video analysis.

can refer to the "class behavior and teaching media classification coding" proposed by scholars, combine with the precise definition of teaching, formulate the mathematics course teaching coding table, design the class video recording table, and use video analysis software to encode the selected class videos, and then analyze the data results. Therefore, from the perspective of 3D video analysis, this paper analyzes teachers' teaching behaviors in MOOCs teaching videos, providing experience and reference for the design of teachers' teaching behaviors in MOOCs teaching videos, and thus making certain contributions to the improvement of MOOCs teaching effects. Therefore, in general, the research objectives of this paper are: choosing high quality 3 D video of classroom teaching, using the method of 3D video for selected cases evaluated with quantitative and qualitative analysis, from the research starting point, the framework structure, to explore the classroom teaching of junior middle school mathematics teachers' behavior in the act of teaching of teaching structure and the correlation between them, and analyze the teacher's teaching behavior sequence of hysteresis characteristics [7, 9]. Based on the analysis of the characteristics of teachers' teaching behavior in high quality classrooms and the actual situation of Chinese education and the characteristics of subject teachers, this paper puts forward development strategies for teachers' teaching development.

On the other hand, the teaching process is an activity completed by the interaction of teachers and students, with students as the main body and teachers as the leading part. The study of educational psychology not only contributes to the establishment of a good teacher-student relationship but also helps teachers to understand the psychological characteristics and learning process of students and adopt effective teaching methods, so as to better play a leading role and improve the learning efficiency of students [10, 11]. In the actual teaching process, teachers are required not only to combine the characteristics of the course but also according to the physiological and psychological characteristics of students of different ages, and adopt appropriate teaching methods under the guidance of the theory of educational psychology, so as to produce good teacher-student interaction and achieve ideal teaching effects [12, 13]. When carrying out 3D video teaching, teachers should focus on students to determine the teaching content and teaching design.

Living in the rapid development of the 21st century, to a variety of new things to accept the speed of the relatively advanced thinking, new ideas, dare to say no to the old ideas, the courage to innovate, good at questioning, not satisfied with their current situation, but they also have the comparison, advocating famous brand of these relatively public problems [14, 15]. As the "post-90s" and "post-00s" grow up, education, especially student education, becomes more complicated and changeable. Current education to adapt to the new environment and change, mastering and application of a good education psychology theory and knowledge, a comprehensive understanding of students' learning psychology, meet the students in the learning life concrete actual needs, to help students overcome all kinds of psychological barriers, so as to achieve the purpose of effectively improving the learning efficiency, it also proposed many challenges to our education workers [16, 17].

According to the principle of educational psychology, teacher-student relationship is the most basic and important interpersonal relationship in the educational process. The equal teacher-student relationship has a positive impact on the development of students' cognition, emotion, and mental health [18, 19]. Because our teachers are in the leading position in teaching activities, this requires us to first change the traditional concept, put down the shelf of teachers, take the initiative to approach students, and form a new democratic, equal, and cooperative relationship between teachers and students. For example, secondary school students, first of all to understand the physiological and psychological characteristics of secondary school students. Secondary school students are in the period of adolescence between the age of 14 and 18 when they study in school, and this stage is their rapid physical and mental development, rich and intense emotions, and emotional fluctuations. This period is also the most prone to psychological problems, so teachers need to pay more attention to them. According to the psychological survey, students like the most is amiable, with a democratic style of teachers; what students hate most and even hate in their hearts are those authoritarian teachers [20, 21]. Therefore, teachers should respect students, get along with them on an equal footing, carry forward

democratic style in teaching, promote mutual trust between teachers and students, establish a friendship relationship, and then educate students, so that this friendship relationship can be transformed into a good teacher-student relationship. In this way, students can establish correct value orientation through psychological learning, and guide their own behavior, and lay a solid foundation for long-term development in the future.

In addition, establish positive teacher expectations. According to the Rosenthal effect, teachers' different expectations have a huge impact on students. In terms of the relationship between teachers and students, students who are highly expected by teachers show better adaptability, more vitality, and stronger thirst for knowledge. On the contrary, students with low expectations from teachers are not able to give full play to their potential [22, 23]. In the teaching of various subjects, students of different levels can participate in the activities according to the difficulty of tasks, so that they can feel the attention and expectation of teachers, and get a sense of achievement in the activities. Make students feel that teachers can treat every student equally, but also let students feel that they are an indispensable part of the collective, so that every student has a sense of belonging. This will naturally make the relationship between teachers and students closer, harmonious, and tacit understanding [24, 25].

All in all, by combining 3D video analysis method with educational psychology, the application of 3D video analysis method in practical teaching activities will not only help to establish a good teacher-student relationship but also help teachers to understand the psychological characteristics and learning process of students, thus greatly improving the quality of teaching.

2. Teacher Teaching Behavior Research Based on 3D Video Analysis

In this paper, in the verbal interaction between teachers and students, the system is divided into teachers' speech, students' speech and silence with three parts such as chaos, subdividing each part, teachers' words can be divided into indirect influence and direct impact, speech act is divided into students active, passive and discussing with fellow students, quiet and chaos into meaningful silence and quiet and confusion. In order to unify the coding standards and ensure the consistency of coding, this study conducted an in-depth analysis of the meaning and characteristics of each sub-code before formal coding, and explained each coding type according to the actual situation in class.

Teacher's acceptance of emotion: teacher's speech is to accept and understand students' emotion, attitude, and point of view. For example, the teacher said in class, "These two students simulated this process very accurately, with very accurate language and words," "I think your idea is novel," and "very good, scientist's idea" .

Teacher praise or encourage: teachers praise and affirm students' words and deeds in class, or inspire students when they encounter problems. This code is subjective to the teacher. For example, a student has been speaking actively in class, other students should learn from him.

The teacher adopts, corrects, or supplements the student's point of view: after asking questions, the teacher adopts the student's statement or supplements or corrects the student's point of view. For example, the teacher repeats the student's answer to the class, or the teacher supplements the student's answer and passes it on to the class.

Teachers' questions can be divided into two situations. One is open questions raised by teachers, that is, there is no standard answer to the questions raised by teachers, and students can express their opinions freely without limitation of scope. This kind of questions can train students' divergent thinking.

The non-verbal behavior coding system of teachers and students designed in this study is composed of two categories: teachers' classroom non-verbal behavior and students' classroom non-verbal behavior. The forms of teachers' nonverbal behavior in class can be divided into symbolic action, illustrative action, demonstrative action, instrumental action, adaptive action, accommodative action, and distance action. However, this study only counted nonverbal behaviors with positive significance in classroom teaching, so adaptive actions and regulatory actions were eliminated. For example, teachers can carry out situational teaching mode. After watching the video, teachers can guide students to combine their own experience.

On the basis of the coding system of MOOCs teaching video analysis, a preliminary analysis is made based on the questionnaire survey results. The following studies teachers' teaching behaviors in MOOCs teaching videos from the aspects of reliability and validity analysis, descriptive and difference analysis, attribute classification analysis, and Better-Worse coefficient analysis.

Reliability analysis is used to study the reliability and accuracy of the answers to quantitative data. If the coefficient k satisfies formula (1)–(3), respectively, it indicates that the questionnaire has a high reliability level, which is acceptable and untrustworthy.

$$k > 0.8, \quad \text{Highly reliable}, \tag{1}$$

$$0.6 < k < 0.8, \quad \text{Reliable}, \tag{2}$$

$$k \leq 0.6, \quad \text{Not reliable}. \tag{3}$$

Berg proposed that when the frequency difference between the highest and second-highest attributes in a behavior I is less than or equal to 5%, it can be classified by the value of user recognition coefficient. In other words, when Si meets the following equations, the behavior is, respectively, attributed to the charm attribute (A), the expectation attribute (O), and the necessary attribute (M).

$$\begin{aligned} S_i &> 1.1, \quad (\text{A}), \\ 0.9 < S_i &< 1.1, \quad (\text{O}), \\ S_i &< 0.9, \quad (\text{M}). \end{aligned} \tag{4}$$

The calculation formula of the relative recognition coefficient of users is

$$S_i = \frac{A_i + O_i}{O_i + M_i}. \quad (5)$$

After classifying the attributes of the functions, we use the Better-Worse coefficient to analyze the influence of teachers' teaching behaviors on learners' perception in MOOC teaching videos. Better is the satisfaction coefficient after the increase, and its value is usually positive. The higher the value, the faster the learners' recognition will improve. Worse is the dissatisfaction coefficient after the elimination, and its value is usually negative. The lower the value, the faster the learners' recognition will decline.

$$Better = \frac{A + O}{A + O + M + I},$$
$$Worse = -1 * \frac{O + M}{A + O + M + I}. \quad (6)$$

Correlation analysis was used to study the correlation among the six dimensions of teacher teaching, classroom content, teacher-student interaction, vitality, dedication, and concentration in learner emotion. Pearson's correlation coefficient can represent the strength of the correlation relationship. When Pearson's correlation coefficient R, respectively, meets the following formula, the corresponding correlation is low correlation, medium correlation, and high correlation, respectively.

$$\begin{aligned} r &< 0.4, \quad \text{Low correlation,} \\ 0.4 \le r &\le 0.7, \quad \text{Medium correlation,} \\ r &> 0.7, \quad \text{High correlation.} \end{aligned} \quad (7)$$

3. Educational Psychology Teaching Based on 3D Video Analysis

3 D video analysis is the most important step in encoding, how the objective and accurate video coding is the most crucial step in this study, after the video quality of longed for class teaching lesson video coding repeatedly, summed up the following need to be aware of specific issues: first, the coding of the smallest unit is a word or an action, such as a problem or a nod. If a sentence or an action contains the corresponding meanings of multiple codes, these multiple meanings should be coded separately. For example, when students answer questions, the teacher continues to ask questions, both of them should be coded. Second, be familiar with the code and the corresponding meaning of the code, so that you can code the fragment in your mind without looking at the code table. Third, be familiar with the "excellent lesson" video of selection coding, watch these six teaching videos repeatedly, and memorize the interactive content between teachers and students in the teaching videos. Fourth, in order to avoid mistakes in the coding process, the researcher asked his friends to help encode the video of "Youke" for two times, respectively. When it was not easy to determine the attribution of the video, the two of them discussed before coding. Fifth, this study only codes the video clips with clear representation and meaning, mainly reflected in the process of encoding the nonverbal behaviors of teachers and students, and only codes the nonverbal behaviors that can be clearly observed in the video. Teachers deduce it in the form of groups in class, from different role playing and character perspective, to deeply understand the content of psychological teaching, and clear the importance of mental health.

In order to transmit teaching information more effectively, no matter there are learners or not in MOOCs teaching videos, teachers must simulate the teaching state of traditional classroom, whose teaching essence and core remain unchanged. Therefore, this study believes that teachers' teaching behaviors in MOOCs teaching videos can be quantified through coding.

Modern semiotics has broken the shackles of semiotic language range in the old times and divided signs into verbal signs and non-verbal signs according to the way of communication. In the sense of semiotics, teachers' teaching behavior refers to the process of information exchange and sharing by using symbols. Based on the above analysis, this study preliminarily classifies observable behavior into two dimensions: "teacher's speech behavior and teacher's non-speech behavior."

Teacher's speech act is the main dissemination type of teaching information in teaching process. Based on the analysis of existing literature and typical interactive analysis coding system, some codes and expressions suitable for MOOCs teachers' speech acts are selected and collected, and the codes and expressions are adjusted and modified in combination with the characteristics of MOOCs teaching videos. Teacher's non-verbal behavior refers to the media behavior and facial expression behavior aimed at communication or information transmission in the teaching process. At present, there is no coding system for teachers' non-verbal behaviors, and the classification of teachers' non-verbal behaviors is also unified. From the perspective of functions, Cooper divides non-verbal functions into six categories: self-display, rules and regulations implementation, response and emphasis, indicating attitude to school rules and regulations and curriculum and influencing learners, controlling and guiding classroom dialogue, and controlling the classroom. Chen minghua divides teachers' non-verbal behaviors into three types: easy, intuitive, and suggestive. From the form of expression, Yang Ping classifies it succinctly into: close body language, body language, and paralanguage; Boyd believes that teachers' non-verbal behaviors are manifested in seven forms: kinesiology, nearness, haptics, ophthalmology, linguistics, environmental factors, and facial expressions.

From the perspective of learner emotion as model construction, this paper designs teacher's speech act and teacher's non-speech act, respectively, and constructs teacher's teaching behavior model in MOOCs teaching video according to the priority of learner perception on teacher's teaching behavior. And teachers on the premise of their own attention, invest more time and energy, and finally realize their own comprehensive development.

In the MOOCs video analysis and coding system constructed in this paper, teachers' teaching behavior is divided

into two dimensions: teacher's speech behavior and teacher's non-speech behavior. Through the research, it is found that Chinese MOOCs teachers do not have strong awareness of the use of non-speech behavior, and it is relatively random. The non-standard use and abuse of non-verbal behaviors will lead to bad teaching effects such as learners' inability to understand teachers' ideas or distraction of attention. Teachers should reflect on this and improve it in time, strengthen the awareness of active learning of non-verbal behavior, and find a more appropriate form of expression of non-verbal behavior. In view of this, the author puts forward the following two improvement strategies.

3.1. Improve the Awareness of Non-Verbal Behavior Use. MOOC teachers in China attach great importance to their speech acts. They will carefully design each teaching link and main speech acts before class, but often ignore the design and use of non-verbal acts. Obviously, when teachers' verbal and non-verbal behaviors complement each other, good teaching effects will be achieved. Therefore, it is very necessary to pay attention to the use of non-verbal behavior, which should become an important part of the improvement of teachers' teaching behavior ability. In order to improve the teaching effect of MOOCs, teachers should fundamentally change their ideas and improve their awareness of the use of non-verbal behaviors.

3.2. Regulate Non-Verbal Behavior. At the national level, a set of standard guidelines for the use of teachers' nonverbal behaviors can be put forward to regulate the performance of teachers' nonverbal behaviors in MOOCs teaching videos. From the government level, systematic training can be conducted on the use of nonverbal behaviors of teachers in MOOCs teaching videos. From the personal level of teachers, the first way is to learn the experience of using nonverbal behaviors from teachers with rich teaching experience. Excellent teachers with rich teaching experience are more natural and appropriate in the expression of nonverbal behaviors.

The second way is to communicate with learners, understand their opinions, and combine the use of nonverbal behaviors with learners' perception. The third way is to watch excellent MOOCs cases, especially popular MOOCs, in which teachers' non-verbal behaviors are relatively mature and standardized.

According to the classification and priority order of teachers' teaching behaviors in MOOC teaching videos perceived by learners, the author proposes improvement strategies from three aspects: essential attribute, expectation attribute, and charm attribute.

3.2.1. Essential Attributes. First, the comprehensive use of a variety of teaching methods. Non-national quality MOOC teachers are mainly lecturing, and ask fewer questions in the whole teaching process. In the long run, learners' abilities of active exploration and independent thinking will be weakened. However, high-quality MOOCs teachers at home and abroad or from other countries focus on heuristic teaching, helping learners to create "zone of recent development" and guiding learners to think through progressive and in-depth questioning. Combined with the basic situation of education in China, MOOC education in China should be an organic combination of "teaching" and "inspiration." The two are indispensable, which should not only impart knowledge but also guide digestion and absorption. Only when the two promote each other can the teaching quality be effectively improved.

Second, use the way of "teacher-medium combination" to assist teaching. MOOCs teachers can intentionally combine themselves with simplified teaching media to form a unified whole of "teacher-media combination," so as to cause learners' behavior of changing viewpoints between teachers and media, avoid visual fatigue, and enhance learners' "stickiness" in using MOOCs.

Third, comprehensive use of a variety of teaching media. It is particularly common for teachers to use single teaching media in MOOCs teaching videos, which is not easy to attract learners' attention for a long time, and learners' enthusiasm in learning involvement or participation will gradually decline. In essence, no single media can perfectly support all the teaching content. According to different teaching strategies and teaching objectives, teaching content also has different needs for teaching media. In MOOCs teaching videos, teachers should enrich the use of other media so as to increase the teaching vitality. However, it should be noted that the diversified use of teaching media in MOOCs teaching videos does not mean that the more media types, the better. The purpose of the course, the ability of teachers to manipulate, and the ability of learners to accept should be considered comprehensively, and all kinds of teaching media should be properly used.

3.2.2. Expectation Attribute. Different body movements have different functions, and Mark believes that placing hands near the navel better expresses the true feeling of the intention, while placing hands near the chest better expresses the excitement of the intention. On the one hand, teachers should deliberately learn the meaning and role of different sign language or body language, and correctly use body movement to assist teaching. On the other hand, teachers can improve the effectiveness of body movements through training. Online reflection, summary, and redesign of body movements are performed through video analysis. Offline through repeated training, the muscles form a mechanized memory and the brain's subconscious response. Of course, teachers should also follow a number of principles to ensure the correct use of video, so as to maximize its role and contribute to the improvement of teaching quality.

3.2.3. Charm Attribute. In the process of communication between teachers and students, teachers' charismatic behavior can alleviate the problems of online learners' burnout and bad learning emotions, and promote learners' deep learning. In order to strengthen teachers' emotional support, improve teachers' teaching affinity and enhance learners'

involvement, MOOC teachers in China should improve their emotional expression ability from the following two aspects.

First of all, it is necessary to sublimate teachers' professional emotion and maintain positive emotional state. After teachers touch the true meaning of education and their own responsibility and mission, they will unconsciously have a favorable impression on education, gather more sense of responsibility and value, and form a positive teacher professional emotion. In the recording process of MOOCs teaching videos, teachers should always maintain their own positive emotional state and create a positive and happy emotional state. At this time, teachers' emotional support, as a kind of implicit teaching behavior, is kept in the teachers themselves. However, in the application of actual teaching, teachers should combine with the actual situation of students, and deeply analyze the reasons that hinder the efficient development of psychology, in order to be able to use videos pertinently, strengthen the psychological construction of students, and promote the healthy development of students.

Second, reasonable expression of their emotional support. On the one hand, the teacher's emotional expression should accord with the teacher's role identity and the identity of the teacher's expression object; on the other hand, it should be combined with the teaching content for rational expression, so as to be touching and decent. In MOOCs teaching videos, teachers should express them through charming behaviors according to the educational objectives, educational situations, and educational needs, so as to create a warmer teaching environment, make learners feel positive, have a happy learning experience, and meet their emotional needs.

In order to conduct data analysis on the whole course, data selection and analysis were conducted for basic problems and teaching activities before the course. Fifteen students, 15 students, and 20 students from three classes were selected as the research objects. The results are shown in Figure 2. 48% of them reported frequent use of video teaching resources in their daily courses. Besides, the percentage preference for different educational tools is shown in Figure 3.

The number of lines of code of a course is shown in Figure 4. The "lines of code" chart of the whole level-1 code mainly presents the distribution information of "teacher's speech," "student's speech," and "silence and chaos" in the class example visually.

From the horizontal perspective of "teacher's speech," the green coded bar in the first line represents the verbal interaction between teachers and students as "teacher's speech." As can be seen from the figure, teacher's speech runs through the whole class with a relatively large frequency and takes a long time, reflecting the leading role of teachers in the class.

From the horizontal perspective of "students' speech," the yellow code bar in the second line represents the verbal interaction between teachers and students as "students' speech." As can be seen from the figure, "students' speech" is widely distributed, which reflects that teachers pay attention

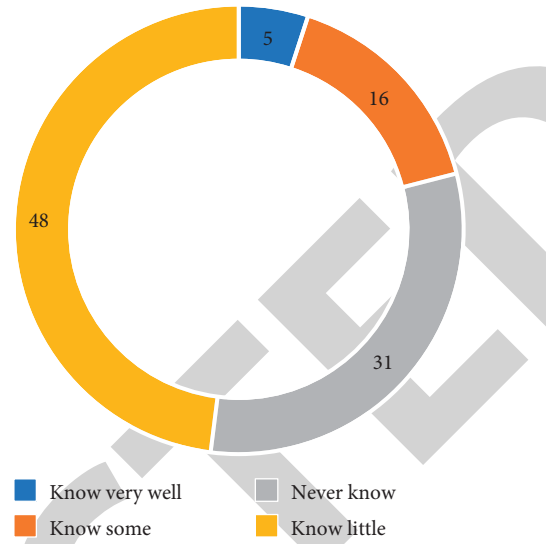

Figure 2: The cognition of video teaching resources.

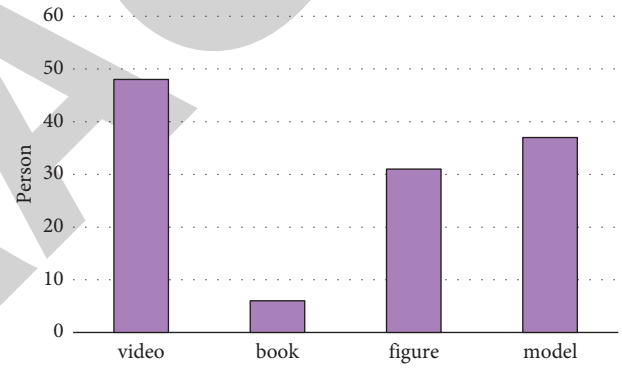

Figure 3: Percentage preferences for different educational tools.

to students' subjectivity and give students sufficient time and opportunities to express themselves.

From crosswise "quiet and chaos" in the classroom, the third line of blue article code on behalf of the verbal interaction between teachers and students is a "quiet and chaos," "quiet and chaos" of this study mainly refers to students' thinking time, doing homework or watching video, meaningless pause, etc., can be seen from the figure in the "quiet and chaos" of the frequency and time is more, it shows that students have more time to think. The normalized frequency is shown in Figure 5.

Figure 6 shows the frequency of classroom teaching behaviors. It can be seen that in the classroom, the largest proportion of classroom teaching behaviors is giving guidance or instruction (Code 6), followed by teachers asking questions (Code 4) and students actively responding (Code 11). Praise and encouragement (Code 2), acceptance or use of students' opinions (Code 3), teacher's explanation (Code 5), and students' passive response (Code 10) also account for a certain proportion. Accept and positive emotions (code 1), with the help of the media, or AIDS (8) code of practice, interaction, promote or emphasized

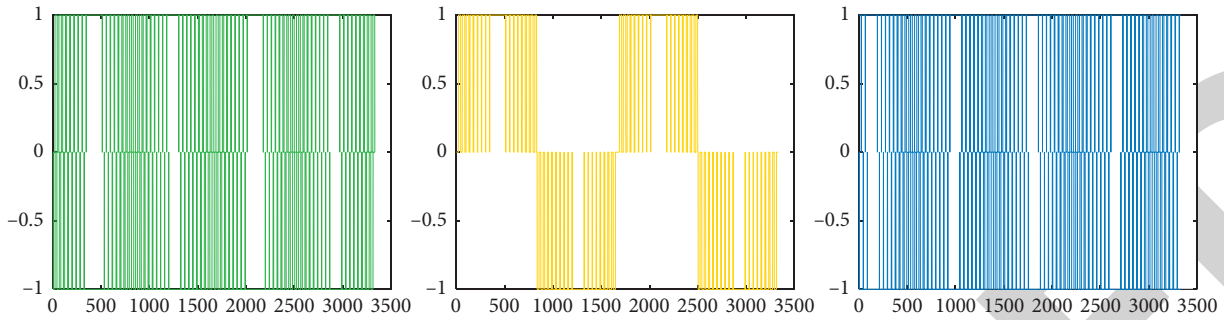

Figure 4: The number of lines of code of a course.

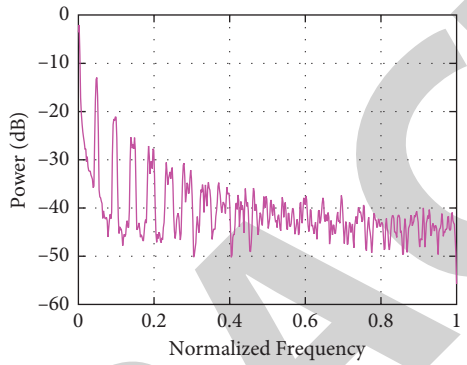

Figure 5: The normalized frequency.

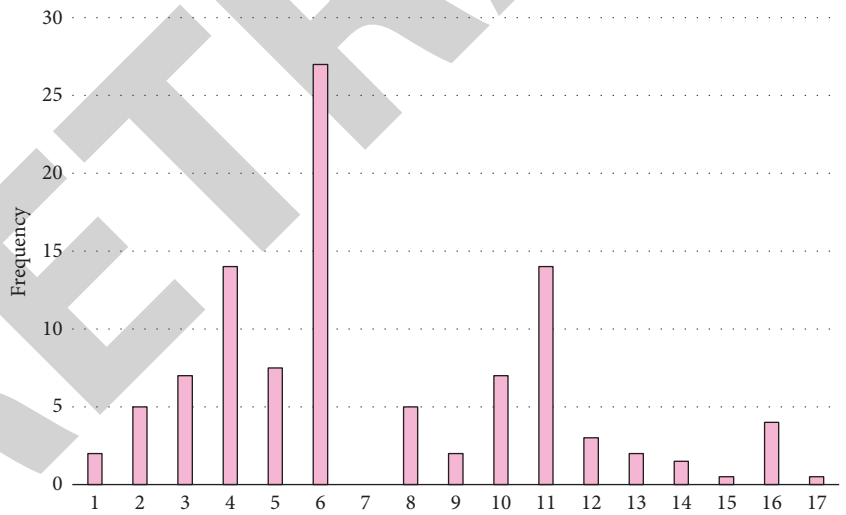

Figure 6: Proportion of classroom teaching behavior frequency.

students (9) coding, speech or presentation (12) coding, student collaboration (13) coding, students' use of education resources (14) coding, students practice or create works (15) coding, students thinking (encoding 16). These kinds of teaching behaviors appear less frequently in this lesson; criticism or maintenance of authority (Code 7) and confusion or unhelpful silence (Code 17) are almost absent in this lesson. According to data analysis and coding information analysis, teachers in this class mainly issue instructions and guidance to students, teach knowledge by asking questions and answering students, and help students better understand knowledge and form knowledge framework by combining teachers' explanation and summarization of knowledge points. The prediction is also shown in Figure 7. The application of 3D video is an important breakthrough in secondary vocational psychology teaching, which breaks the rigid dogma of traditional teaching and injects new vitality into the classroom.

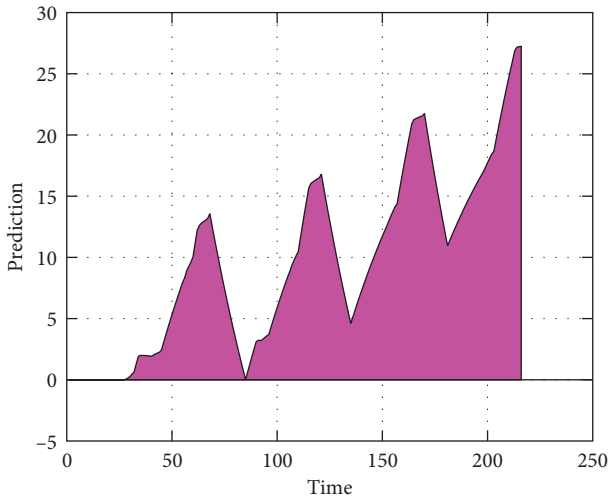

Figure 7: The prediction.

4. Conclusion

In this paper, 3D video analysis method is taken as the basic research method. Compared with other classroom research methods, video analysis method has more comprehensive research data, and video analysis method can record the classroom teacher-student interaction process more completely through sound and images. In the process of data statistics, video analysis software can be used, or classroom teaching videos can be repeatedly played, so that the data obtained is more objective and comprehensive, and the influence of human subjective factors can be avoided to the greatest extent. In addition, the research efficiency of video analysis method is high, which breaks through the limitation of research time and place. Video analysis software is used to process and analyze classroom videos, which reduces the time and energy consumption of researchers and improves the research efficiency.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Research Article

Examining and Expanding the Expectancy Disconfirmation Model: Evidence from Rural China

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In public management research, the Expectancy Disconfirmation Model (EDM) is increasingly used to measure citizen satisfaction. However, current EDM research in the public sector has been applied primarily in the United States and sets of the city, state, federal, or local government services. It leaves the validity of EDM for other levels and countries of government services to be verified. This study tests and extends the EDM by comparing it with previous studies and adding additional expectation priors to the model. Analysis of survey data from 313 citizens in 6 rural communities in China indicates that the basic model functions well in rural public services. In addition, the study of the extended EDM shows significant relationships between trust, service awareness, bureaucratic responsiveness, and expectations, which suggests new directions for future research using the model.

1. Introduction

With the emphasis on government performance in public management research, measuring citizens' satisfaction with public services has become crucial. The Expectancy Disconfirmation Model (EDM), initially used in business to measure customer satisfaction, is increasingly applied to government service research [1–4]. The theory suggests that citizens' satisfaction with public services depends on an implicit comparison between perceived service quality and pre-expectations (disconfirmation). Van Ryzin (2004) first applied the model to the field of public administration [1], and numerous studies have found that the model functions well when applied to public administration [5–7].

However, current EDM research in the public sector has been primarily applied in the United States and focused on urban, state, federal, or local government services. It leaves open the question of the effectiveness of EDM for other levels and nations of government services, especially for rural government services, which have not been tested for EDM. So, we conduct a study on rural public services in China. First, the model's applicability in a differential setting is worth verifying. Second, China has a large rural population, with important practical implications for future applications. Last, rural public services in China are mainly supplied by the government, consistent with the scope of EDM applications in the public sector.

Nevertheless, urban and rural citizens may have diverse concerns about public services in China due to disparities in the type and quality of public services provided in rural and urban areas. Combined with variances in the political environment and government responses, this may lead to significant differences in rural and urban citizens' expectations of government services and the processes that generate those expectations. In addition, difficulties exist in improving the quality of public services in rural China due to input constraints, and expectations become a crucial factor influencing rural citizens' satisfaction with public services. How to influence citizens' expectations becomes a critical clue to improving satisfaction with public services in rural China, and again this is a limitation of current EDM. Therefore, we expanded the model's expectation antecedents to understand better the factors that influence rural residents' expectations.

This study first validates the model using survey data of public services in rural China and compares it with previous

studies. Our findings indicate that EDM has good applicability in China's rural public services, which aligns with theoretical expectations. Comparisons with previous research findings suggest that the model's parameters can maintain some consistency with US city and local government services, even if there are differences in the testing environment, sampling, and survey methodology. Second, we expand the EDM and find significant relationships between trust, service awareness, bureaucratic responsiveness, and expectations, providing new perspectives for the model's future expansion and application.

In the following article, we provide an overview of EDM and discuss the literature on its application in public administration. We then explain the rationale for testing the model in rural China and the reasons for including the antecedent variables of expectations. Next, we describe the methods used to collect data in rural China and the measures used to process the variables. Then, we discuss statistical techniques and comparative results with previous studies and antecedents of expectations. Finally, we discuss future research, theoretical and practical implications, implications for public administrators and researchers, and how to improve perceived performance.

2. Theory and Hypotheses

Expectation disconfirmation theory originated from social psychology and organizational behavior and is widely used to study marketing consumer satisfaction and consumer behavior. The theory suggests that consumers form initial expectations about product performance before buying or using a product. The actual product performance they receive afterward is inconsistent with their initial expectations, which, together with initial expectations, affects consumer satisfaction [8]. The difference between expectations and perceived (goods or services) actual performance is disconfirmation. Disconfirmation can be positive (when performance exceeds expectations) or negative (when performance does not meet expectations). Oliver argues that disconfirmation is crucial because expectations may change over time. Theoretical construction and model testing have been refined in different consumer behavior studies [8–10] and are supported by empirical studies [8, 11].

According to the assumptions of the expectation disconfirmation model (Figure 1), prior expectations are critical variables in the model that directly and indirectly affect subsequent perceptions. Path A suggests a negative correlation between expectations and disconfirmation. As expectations increase (decrease), disconfirmation decreases (increases), or high expectations lead to negative disconfirmation. Path B indicates a positive correlation between perceived performance and disconfirmation, that is, high perceived performance will lead to positive disconfirmation and vice versa. Path C represents the direct and positive relationship between disconfirmation and satisfaction. Positive disconfirmation (higher performance than expected) leads to higher satisfaction, and negative disconfirmation (lower performance than expected) leads to lower performance satisfaction. Path D indicates a direct

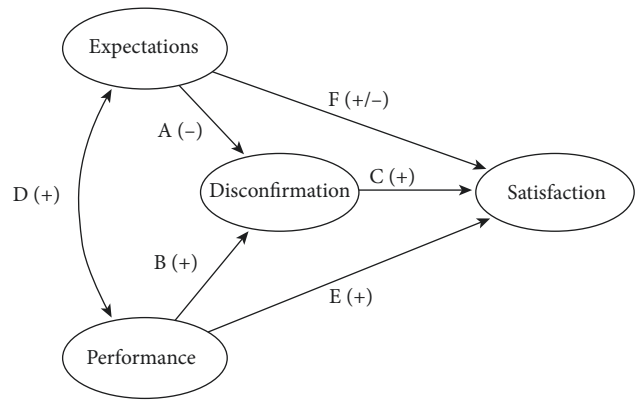

Figure 1: Expectancy disconfirmation model [12].

positive relationship between expectations and performance, with higher expectations leading to higher perceptions of performance, although the causal direction of this relationship is not explicitly stated [12]. Path E is the direct relationship between performance and satisfaction, where higher performance should logically lead to higher satisfaction, implying a direct effect of performance on satisfaction. Path F indicates the effect of expectations on satisfaction, which can be either positive or negative. When forming satisfaction, people may use previous expectations as a benchmark or starting point, primarily when the evaluated service is ambiguous [12]. Differences in empirical and normative expectations may be related to satisfaction in different directions due to empirical expectations (what you think will happen) may cause positive correlations, and normative expectations (what you think should happen) may cause negative correlations [2, 5]. Citizen expectations in this study are empirical expectations, so we assume that expectations positively affect satisfaction. When examining the direct effect on satisfaction, expectations and performance are assumed to exist prior to disconfirmation and are therefore conceptualized as exogenous variables.

EDM has been adopted and applied by a large number of academic studies [8, 11, 13]. However, public administration has been relatively late in using it to explain citizen satisfaction with government services, with Van Ryzin first applying EDM to public administration in 2004. Over the past few years, research on EDM satisfaction with government services has begun to increase [3, 5, 14, 15]. There are direct studies on model applicability and hypothesis relationship validation [1, 14, 16]. More other studies, while not testing the EDM directly and instead exploring the role of the model in the formation of citizen satisfaction, still found the EDM to be applicable in explaining government services [2, 3, 6]. In addition, some studies use EDM to examine specific local government services such as police services, residential garbage collection, public schools [5], and street cleaning [17]. Studies have also applied EDM in discussions of state government services [3, 5] and federal government services [16]. Moreover, some of these studies have tested EDM in institutional settings with limited accountability and widespread citizen distrust [18] and the impact of partial matching between voters and elected municipal leaders on

citizen satisfaction with municipal services [7]. Finally, there are studies on the impact of macroenvironmental variables on service quality in a cross-country context [19].

The development of EDM research in the public service context is an ongoing and continuous refinement process, and the application of the model in different areas of public service is yet to be further explored. The application of the government service model is mainly in urban, state, and federal areas and has not been tested in rural areas (Van Ryzin study in 2006 [14] for local government, although it included rural government, only involved 11% of rural citizens). In addition, current research primarily focuses on the United States, with scattered studies in Denmark and the United Kingdom, and the model's applicability to rural areas and across nations remains to be tested. We, therefore, conduct the study on rural public services in China, where the applicability of the model in different political and economic contexts is worth exploring on the one hand, and where China, with a rural population of over 500 million (36.11% of the total) [20], has important practical implications for future application. In addition, rural public services in China are mainly provided by the government, which is also in line with the application of EDM to government services.

Unlike conventional countries, scholars often view Chinese society as a dualistic structure of rural-urban divide [21, 22], that is, there is a relative pattern of rural versus urban areas, with significant differences in political, economic, and social environments. Therefore, rural areas are an essential field to test the model. There is a lack of empirical testing support to predict the applicability and effectiveness of the model in rural public services, and empirical findings in rural areas may be contrary to expectations. Indeed, there is good reason to suspect that the expectations of rural Chinese citizens for public services may differ significantly from those of citizens served by urban or local governments in other countries, leading to notable differences in the functioning of the EDM.

Possible differences in rural and urban citizens' expectations of rural and urban public services can lead to different relationships in EDM. First, there are specific differences in the types and quality of services in China between rural and urban public services, and citizens may have different experiences and expectations. For instance, there is considerable inequality in the distribution of resources between rural and urban public health care services [23], with cities often having large well-equipped hospitals and rural areas having only small clinics. There are inevitably differences in citizens' expectations of the health care services available to them, that is, citizens with major illnesses often have no expectations of rural health care services and have to resort to urban health care services. The same differences exist for services such as security, education, and employment, which vary so much in nature that it is reasonable to infer the relationship between rural citizens' expectations, perceived performance, and degree of disconfirmation in public services be different.

Another noteworthy fact is that due to China's fiscal decentralization system, governments are given the primary responsibility for the provision and financing of public services [24]. However, the poor economic conditions in rural areas and the excessive decentralization of spending responsibilities have led to inadequate funding and public services, thus making it difficult to improve the quality of rural public services. Expectations have become a key factor affecting rural citizens' satisfaction with public services. Although we do not advocate manipulating expectations to come to public satisfaction, a better understanding of expectations still can enable public managers, under limited conditions, to improve rural citizens' satisfaction as much as possible. Thus, we expanded the model's expectation priors to understand better the factors that influence rural citizens' expectations.

Regarding factors influencing expectations, it is essential to note that citizens' trust in rural government may influence their expectations of the services provided by this rural government. Political trust has been suggested as being positively associated with public service satisfaction. Citizens' political trust is relevant for citizens' subjective well-being [25]. Regarding the effect of citizens' trust before accessing a public service on their satisfaction after accessing it, we can expect that no transaction, let alone citizens' satisfaction, will likely occur without a minimum level of trust accessing a public service. If rural citizens do not consider their local hospital worth going to, they will not choose it. Thus, the relationship between trust and satisfaction is circular. Current levels of trust in government may impact perceptions of government performance [26]. For a first-time public service recipient, initial trust is formed by indirect experiences, such as reputation, others' evaluations, and ethos, even though he or she has no previous direct experience of receiving public services. When a citizen trusts the government, he or she feels secure through an implicit belief that the government's actions will lead to positive rather than negative outcomes [27]. Therefore, a citizen who trusts the government more has more positive expectations than one who trusts it less.

In the case of China, there are considerable differences between rural and urban citizens' trust in government, and a Spanish study found that people in rural areas have lower political trust than in urban [28]. Also, in China, Chinese citizens "disaggregate" the state with high levels of trust for the central government, which falls dramatically as trust levels are noticeably lower for those in rural China [29]. The much lower trust in the rural government than in the central government may be a deeper reason for the difference in satisfaction between urban and rural citizens. Citizens' low trust in rural government leads them to hold low expectations when experiencing public services, which results in low satisfaction. Therefore, changes in the trust may lead to expected changes to alter the relationship between variables in the EDM. Thus, this article proposes the following hypothesis:

H1. Citizens' trust in rural government is positively related to their expectations of public services.

In addition, citizens' awareness of public service may also be an essential factor influencing expectations. Service awareness is usually based on previous interactions, direct or

indirect experiences, and learning about what, who, and how services are provided [30]. It is usually measured by whether the respondent is aware of the particular institution and its services [31]. Generally, citizens are not well aware of all the government policies and performance [32]. Policies information may originate from media, personal experiences, informal communications, and service providers [33, 34]. Citizens are prone to bias in receiving information, especially in insurance policy changes, such as the scope of diseases covered by health insurance, employment assistance policies, and low-income subsidy rates. In China, the education level of rural citizens is generally lower than that of urban citizens to the extent that rural citizens may have even lower awareness of public services. As the types of public services have increased in recent years, the relevant policies have changed rapidly, so there may be a situation where citizens are not familiar with the content of public services and have insufficient knowledge. When citizens are unclear or unfamiliar with the content of certain public services, they cannot know whether or how much they can access the services, and then they may not have clear expectations of the services. Thus, the extent to which citizens are aware of public services is likely to influence citizens' expectations of public services. Based on this, this research puts forward the following hypothesis:

H2. Citizens' awareness of public service policies is positively related to their expectations of public services.

An equally important variable that may shape citizens' public service expectations is bureaucratic responsiveness. Bureaucratic responsiveness is how administrators can quickly identify and track fluctuations in citizens' desires and provide the appropriate services needed [35]. In marketing, responsiveness is considered as a critical factor in shaping customer expectations and is widely used in the SERVQUAL model [36–38]. Research on the impact of bureaucratic responsiveness on citizens' expectations, especially in EDM's framework, still needs to be further explored in public management research. In rural China, the closer social distance between citizens also manifests between rural citizens and village committees (rural governments), with village chiefs' mailboxes and village assemblies as channels for rural citizens to express their needs. Thanks to the size of rural areas, population, flat hierarchical structure, and deliberative system, rural citizens have more convenient channels to communicate with the government than urban citizens, and the rural government's responsiveness can be direct. Typically, when rural citizens receive positive feedback on their needs, the expected needs are likely to be met, thus raising expectations for public services. Therefore, it is reasonable to suspect that the responsiveness of rural bureaucracies may also drive citizens' expectations of rural government services to influence EDM outcomes. Therefore, we propose the following hypothesis:

H3. Bureaucratic responsiveness to public needs is positively related to citizens' expectations of public services.

In summary, the above facts suggest a strong need for EDM testing of rural public services, which is currently lacking. Furthermore, we have extended the original model, which may be effective when applied to rural public services. Therefore, we propose to study the extended model of EDM rural public services. The diagram of this model is shown in Figure 2.

In this extended version, the relationships of the variables in the original EDM model remain the same, but we hypothesize that certain preexisting perceptions of rural government will significantly affect citizens' expectations of rural public services. First, we hypothesize that trust in rural government may affect citizens' expectations of the services they receive, with those who express greater overall trust in rural government also holding higher expectations of the services they will receive, and vice versa. In addition, we hypothesized that citizens' awareness of public services would influence citizens' expectations of rural public services, with higher awareness of public services associated with higher expectations. Finally, we also hypothesized that bureaucratic responsiveness to citizens' needs has a positive and significant effect on expectations of rural public services, with higher levels of responsiveness associated with higher citizen expectations.

Five measures were used to control for the effects of external environments that may affect citizens' perceptions of service performance, expectations, and satisfaction. First, a previous study shows that gender and age significantly affect public service satisfaction. Male and older individuals tend to evaluate differences and rate higher the level of experienced satisfaction than female and younger citizens [39]. Second, household income, research shows that poverty levels are negatively related to the service performance of local governments [40], and household income has been suggested as positively related to normative expectations [41]. Third, education level was included because increased education was considered positively associated with normative expectations and negatively associated with positive expectations [42]. Last, the length of residence has also been positively correlated with citizens' satisfaction [43].

3. Data and Methods

Considering the possible influence of regional economic development status on services and citizens' perceptions, we stratified a sample of 21 regions in Sichuan province by GDP, divided these regions into 3 classes, randomly selected 1 region from them, and then randomly selected 2 rural communities from these regions to obtain 6 rural communities. We also conducted a stratified sampling of residents through the demographics of the community obtained from the village center. The questionnaire was administered to citizens of the rural communities in the sample through visits from March 2 to April 27, 2021. As some citizens cannot be reached, a total of 420 questionnaires were distributed, and 337 were returned, excluding invalid questionnaires, resulting in 313 valid questionnaires.

The questionnaires measured basic information, public service expectations, perceived service performance, degree of disconfirmation, satisfaction, trust in government, perceptions of public services, and bureaucratic responsiveness among citizens in rural communities. Van Ryzin's study in 2004 treats perceived service performance as a potential

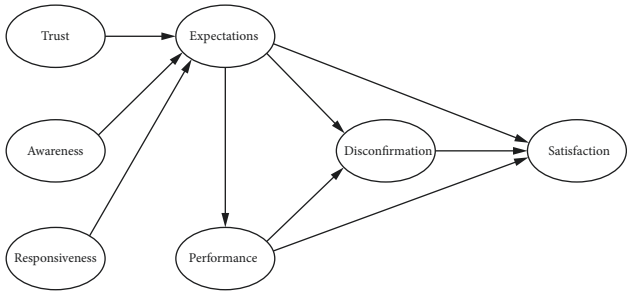

Figure 2: Expectancy disconfirmation model with antecedents of expectations.

variable measured by multiple indicators [1]. The same treatment was done to measure expectations since people may have different expectations for different public services. Measures of government responsiveness and service awareness also use multiple indicators. We classified the rural public services according to China's Urban and Rural Public Service Plan [44] in terms of service types. For the remaining variables in the basic model, disconfirmation, satisfaction, and trust, we followed the strategy used in previous EDM studies and measured them using a single observed variable.

Regarding the disconfirmation measure, we compare the subtractive measure used by Van Ryzin [1] with the ratings of perceived disconfirmation recommended by Oliver [9]. Subtractive measures may lead to a significant increase in the correlation between expectations, performance, and disconfirmation. Thus, we use Oliver's rating scale [9] for perceived disconfirmation. The measure of trust used the scale from previous EDM outreach studies [15, 16] from the American Customer Satisfaction Index (ACSI). To measure service awareness, we adopt the dimension of service awareness from Crist et al. [45], adapted from previous service awareness studies [46–48]. Responsiveness was measured using the SERVQUAL measure of responsiveness, but with the deletion of "tells citizens exactly when services will be performed" because this situation is hardly addressed in China's rural public services. To avoid a possible confusion of evaluation criteria due to different scales (a mixture of 1–4, 1–7, 1–10, and 1–100 scales were used in previous studies), we standardized the measurement of the model variables using a 7-point Likert scale, and the question wording and descriptive statistics of the model variables shown in Table 1.

4. Results

We used the structural equation model and the full information maximum likelihood estimation method (FIML) to analyze the primary and extended models of the EDM. FIML is a fully systematic approach that considers all the information provided by the structural equations, that is, all the equations applied in the structural model, and then estimates all the structural parameters simultaneously using the maximum likelihood method. FIML is widely used in the solution of SEM, outperforming lea squares regression in various cases [49, 50], and it has been used in previous EDM studies for analysis [1, 14, 16]. All facts recommend we use this method in our study. The correlation matrix of variables in our structural model is shown in Table 2. The test results of the basic EDM model (Model 1) are shown in Figure 3. Table 3 compares the path coefficients of Model 1 with earlier studies. A discussion of these results is presented as follows.

Overall, Model 1 shows results that largely support EDM use in rural public services, and the model performs well as expected. The observed results also confirm the previous judgment that EDM application in their rural public services is effective. Looking specifically at the parameter estimates, the relationship between expectations and perceived performance ($ß = 0.32$, $p < 0.001$) is significant and consistent with the expected positive correlation, suggesting that for citizens experiencing rural public services, higher citizen expectations have a positive effect on perceived public service quality is guided. The coefficient is also almost identical to the findings of Van Ryzin [1, 14] in Table 3 ($ß = 0.32$ vs. $ß = 0.34$, $ß = 0.35$).

The relationship between expectations and perceived disconfirmation ($ß = -0.36$, $p < 0.001$), similar to the results of Van Ryzin's 2004 study [1], is also inverse and significant, in line with the theory but with a lower degree of influence. On the other hand, the relationship between performance and perceived disconfirmation is confirmed, with a positive and significant relationship between performance and disconfirmation ($ß = 0.45$, $p < 0.001$) and also very close to Van Ryzin study in 2004 ($ß = 0.40$). Finally, the three variables in the EDM directly affect citizen satisfaction. Although the effect is relatively small, expectations are positively and significantly related to satisfaction ($ß = 0.14$, $p < 0.05$). It is still higher than Van Ryzin's [14] model ($ß = 0.14$ vs. $ß = 0.10$). Although the effect was relatively small, the study found a significant positive correlation between expectancy and satisfaction ($ß = 0.14$, $p < 0.05$). It is still higher than Van Ryzin model in 2006 ($ß = 0.14$ vs. $ß = 0.10$).

Perceived disconfirmation also had a positive and significant effect on satisfaction ($ß = 0.40$, $p < 0.001$), suggesting that, as hypothesized in the model, those citizens who felt that rural public services exceeded expectations had higher public service satisfaction. In this model of rural public services, perceived disconfirmation is not as strong a determinant of satisfaction as in Van Ryzin's [1, 14] model ($ß = 0.40$ vs. $ß = 0.67$, $ß = 0.49$), but it is also the strongest of the factors that influence satisfaction. Finally, the relationship between performance and satisfaction was positive and significant ($ß = 0.22$, $p < 0.001$), as hypothesized in the EDM, suggesting that more robust performance (or better-perceived service quality) would lead to greater satisfaction. The performance-satisfaction relationship in the model test for rural public services was not as strong as in the test for Van Ryzin's model in 2006 ($ß = 0.22$ vs. $ß = 0.41$) but close to the results of Van Ryzin study in 2004 ($ß = 0.20$).

In summary, the EDM tests in Chinese rural public services remain broadly consistent with past research, with little difference in model results between Chinese rural public services and US urban and local government services,

Table 1: Question wording and descriptive statistics for the model variables.

	Variables in order asked during interview	N	Min	Max	Mean	SD
Expectations	First—thinking back a few years—how would you rate your expectations back then of the quality of the flowing services? 1 = very low quality, to 7 = very high quality					
Police	Police protection	313	2	7	5.92	1.32
School	Public education	313	2	7	5.94	1.30
Health care	Community clinics	313	3	7	5.97	1.26
Hardship assistance	Poverty assistance	313	2	7	5.96	1.30
Labor and employment	Career guidance	313	2	7	6.02	1.32
Agricultural support	Agricultural assistance	313	1	7	5.81	1.45
Legal services	Legal consultation	313	2	7	5.92	1.38
Family planning services	Birth control guidance and consultation	313	1	7	5.95	1.32
Recreation and sports	Recreational and sports facilities	313	2	7	5.68	1.54
Quality	Considering all of your recent experiences, how would you rate the quality of the following services where you live? 1 = very low quality, to 7 = very high quality					
Police	Police protection	313	1	7	5.69	1.42
School	Public education	313	1	7	5.29	1.47
Health care	Community clinics	313	1	7	5.23	1.61
Hardship assistance	Poverty assistance	313	1	7	5.45	1.42
Labor and employment	Career guidance	313	1	7	4.89	1.78
Agricultural support	Agricultural assistance	313	1	7	5.34	1.73
Legal services	Legal consultation	313	1	7	5.27	1.71
Family planning services	Birth control guidance and consultation	313	1	7	5.473	1.65
Recreation and sports	Recreational and sports facilities	313	1	7	5.35	1.75
Satisfaction	Satisfaction means many things. Overall, how satisfied are you with the services provided by the local government where you live? 1 = very dissatisfied, to 7 = very satisfied	313	1	7	3.81	1.91
Perceived disconfirmation	Considering all of your expectations, to what extent have the services provided by your local government fallen short of your expectations or exceeded your expectations? 1 = fallen short of my expectations, to 7 = exceeded my expectations	313	1	7	3.99	1.35
Trust	How much of the time do you think you can trust the government in where you live? 1 = only some of the time, to 7 = always	313	1	7	4.96	1.76
Awareness						
	Before the survey, to what extent were you aware that all of the above services existed in this community? 1 = not at all aware, to 7 = very aware	313	1	7	5.14	1.63
	To what extent do you know about the public services you need? 1 = not at all, to 7 = very much	313	1	7	5.14	1.69
	To what extent do you know how to contact the service? 1 = not at all, to 7 = very much	313	1	7	5.12	1.60
Responsiveness						
	Do government officers give prompt service to citizens? 1 = not timely at all, to 7 = very timely	313	1	7	4.88	1.64
	Are government officers always willing to help citizens? 1 = not at all, to 7 = very willing	313	1	7	5.11	1.59
	Are government officers never too busy to respond to citizens' requests? 1 = completely disagree, to 7 = strongly agree	313	1	7	5.04	1.63

and are more supportive of the theory than Van Ryzin study in 2006 [14] tests at the local government level. It suggests that EDM theory is broadly applicable.

We see two sets of relationships that stand out the most in terms of differences. First, the negative effect of expectations on disconfirmation is weaker for rural than for urban public services, suggesting that expectations of rural public services have a relatively small effect on disconfirmation. Thus, there is less concern that overly high expectations will diminish the degree of disconfirmation and reduce satisfaction. However, it may also be due to the different measurement methods. Unlike the univariate measurement in previous studies, the measurement of expectations in this study used multiple indicators, and the perceived measure of disconfirmation may also be another reason. As Van Ryzin explains, the model remains quite sensitive to the question of how to measure disconfirmation [14], and in addition, different political, economic, and cultural environments may also play a role in a transnational context. Further validation is pending for later studies.

Table 2: Correlation matrix of variables.

	1	2	3	4	5	6
1. Trust	—	—	—	—	—	—
2. Responsiveness	0.258	—	—	—	—	—
3. Awareness	0.341	0.494	—	—	—	—
4. Expectations	0.338**	0.402**	0.46**	—	—	—
5. Performance	0.125	0.149	0.170	0.371**	—	—
6. Disconfirmation	−0.062	−0.074	−0.085	−0.184	0.339	—
7. Satisfaction	0.052	0.062	0.071	0.154*	0.406**	0.449**

*Significant at $p < .05$; **Significant at $p < 0.01$.

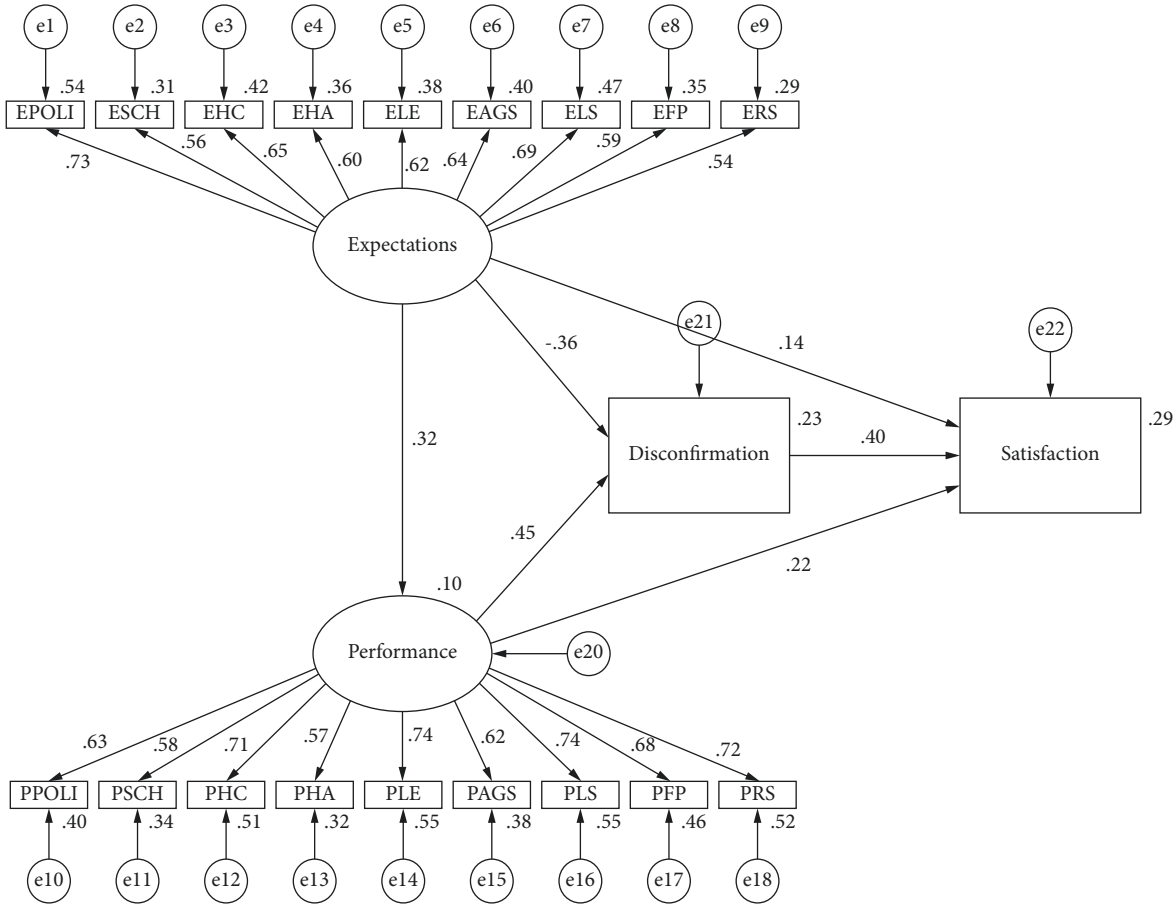

Figure 3: Model 1: the basic Expectancy Disconfirmation Model.

Another difference is that the direct effect of public service expectations on satisfaction is weaker in rural China than in urban government services but stronger than in the United States for local government services. Therefore, when the quality of public services is difficult to improve, increasing satisfaction with rural government by raising expectations of rural public services is still a better way to go. The theoretical and practical implications of these findings will be discussed in more detail in the article's final section.

After testing the basic EDM model, we also tested an extended version of the model with the addition of expectation priors (Model 2). The results of the tests are shown in Figure 4.

The results of Model 2 are consistent with the theoretical expectations. For the added expectations antecedents, the three hypotheses are fully supported. We find, first, that rural citizens' trust in government has a positive and significant effect on public service pre-expectations ($\beta = 0.18$, $p < 0.001$), supporting H1, which indicates that citizens' trust in rural government moderately influences their expectations of what public services they will receive from the rural government. Second, a positive and significant effect of the degree of knowledge about rural public services on public service expectations ($\beta = 0.29$, $p < 0.001$), supporting H2, means that more knowledge and familiarity with rural public services is associated with higher public service expectations. Finally, the degree of bureaucratic responsiveness also has a positive and significant effect on public service expectations ($\beta = 0.21$, $p < 0.001$), supporting H3, indicating that the more

Table 3: Comparisons of path coefficients with earlier studies.

	This study Rural	Van Ryzin (2004) Urban	Van Ryzin (2006) Local government
Expectations —> performance	0.32	0.34	0.35
Expectations —> disconfirmation	−0.36	−0.68	0.03
Performance —> disconfirmation	0.45	0.40	0.68
Expectations —> satisfaction	0.14	0.69	0.10
Performance —> satisfaction	0.22	0.20	0.41
Disconfirmation —> satisfaction	0.40	0.67	0.49

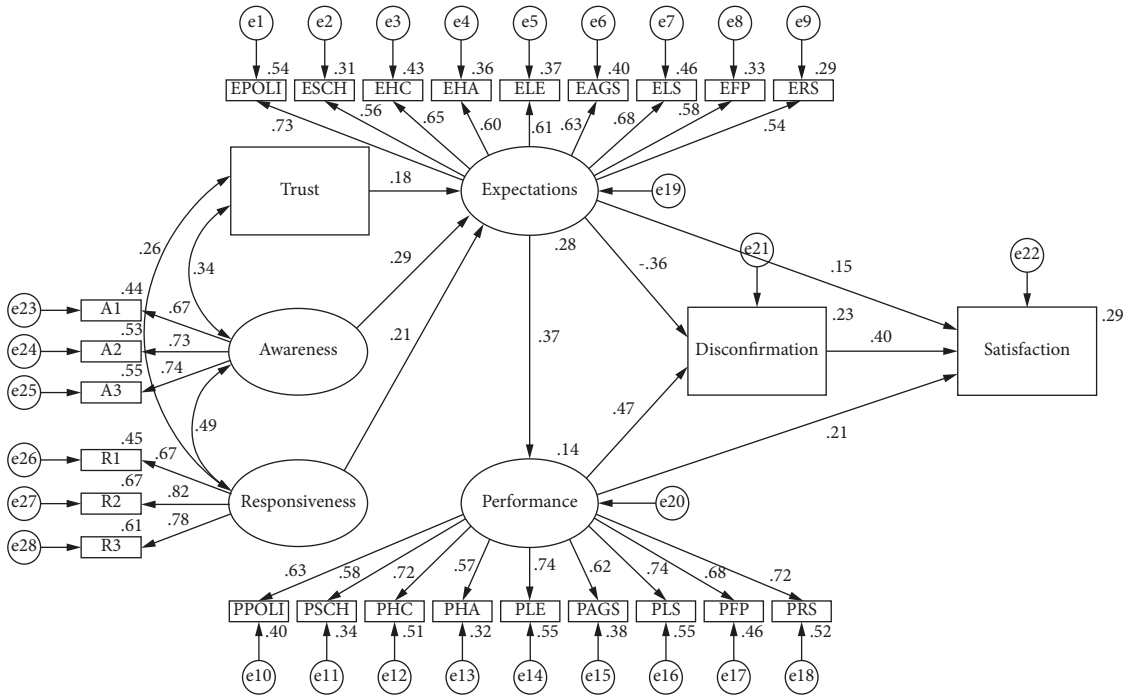

Figure 4: Model 2: the expanded expectancy disconfirmation model.

responsive the government is, the higher the citizens' expectations of public services.

5. Discussion

This study applies the EDM to rural public services in China, thus filling a gap in the existing literature where EDM testing has focused only on the state, city, or local government level, and primarily in the United States. In addition, we complement the theoretical support of strategies to influence expectations when the service quality in EDM is challenging to improve. We have tested an extended version of this model that includes trust, service awareness, and bureaucratic responsiveness as influences on expectations of rural public services. The results show that research data on rural public services in China support the EDM model well, and the model results are similar to previous research on services at other levels of government. The extended EDM is also confirmed for rural public services, providing a good perspective for studying expectation influences. In sum, these findings suggest that EDM can help present the cognitive process by which citizens judge their satisfaction with rural public services, thereby helping researchers and public managers better to understand citizen satisfaction with this rural public service.

Before discussing the implications of the findings, it is appropriate to mention the limitations of this study and suggestions on how to overcome these limitations in future studies. In terms of sampling, although the sampling was based on local demographics, the overall sample size is small. It may hardly reflect the complete picture of rural services in Sichuan province and China, especially since Sichuan is a vast province and there are significant differences between China's eastern and western parts. In addition, the relevance and accuracy may be lacking due to the different political environments from previous EDM studies, considering different political ideologies but using the same scale and question-wording for measuring trust. Therefore, in future studies, expanding the research sample and designing a scale more in line with localization will help identify EDM and expand the stability of EDM in a changing political environment.

In terms of the theoretical implications of this study, first, this study provides new dimensions for future research on EDM and public services, that is, the applicability of the model to different levels and cross-national government

services and how the model can be further expanded and refined in the future. Our study confirms that the EDM is valid at the level of rural government and rural public services and that the model shows relatively consistent results in a cross-country context and across different levels of government. Besides, our study provides new perspectives on extending EDM's refinement to understand further the antecedents and their role in influencing citizen satisfaction through expectations.

Regarding the practical implications of our study, the selection and extension of the rural public service domain are critical when considering the application of the model to different levels of government services. Because at the same level of regional development, the quality of rural public services is lower than in urban areas, and it is more challenging to promote rural citizens' expectations and satisfaction with limited improvements in rural public services. These findings can undoubtedly help public managers at the rural level better understand how their institutions, products, or services affect citizen satisfaction and the role of citizen expectations within them. Even in cases where it is hard to change citizen expectations (given the limited power and financial resources of rural Chinese governments), these results can still provide managers with an understanding of the disadvantages they may face in achieving their citizen satisfaction goals. For example, understanding that a decline in trust lowers expectations and adversely affects citizen satisfaction can certainly lead public managers to deepen their understanding of the importance of citizen trust and create an environment of positive expectations. Besides, understanding the extent to which a region's public services are categorized, how universal the content is, and how responsive agencies are to citizens can help managers understand the reasons for the higher (or lower) expectations that citizens bring to their interactions with agencies. Public managers should make more efforts to raise the expectations and satisfaction of citizens in terms of universal access to public service content and strengthen the sector's responsiveness under financial constraints.

Moreover, the results we found in our study may themselves have significant practical implications for urban and rural public administrators, among others. For example, we can draw some insights from the finding that expectations have a more significant impact on satisfaction at the level of rural public services in China than local government services in the United States. A possible reason for this is that because Chinese rural public services have made great strides relative to the local government services experienced by US citizens, rural citizens, particularly, enjoy more minimum living security, hardship assistance, and poverty alleviation services. These services have direct economic benefits for rural citizens and are more highly valued, leading them to fully consider their experiences and hold more realistic and rational expectations.

Finally, the positive role of citizens' perceptions of performance in increasing satisfaction with rural public services cannot be ignored. Although rural citizens' satisfaction can be influenced by changing expectations, for rural governments, the focus of rural public services should be more on tangible improvements in service quality to increase rural citizens' positive disconfirmation and satisfaction. Despite the limited financial power of rural governments, they can at least contribute to citizen satisfaction through internal performance and service quality improvement measures.

Data Availability

All data and models used during the study are available from the corresponding author by request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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Retraction

Retracted: Relationship between Capital Allocation Efficiency and Diversification Strategy from the Perspective of Internal Control

Discrete Dynamics in Nature and Society

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This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] J. Wang and W. Xia, "Relationship between Capital Allocation Efficiency and Diversification Strategy from the Perspective of Internal Control," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 5081126, 14 pages, 2022.

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Research Article

Relationship between Capital Allocation Efficiency and Diversification Strategy from the Perspective of Internal Control

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Based on the quality of internal control, this study discusses the impact of internal control quality on resource allocation in the internal capital market and how capital allocation efficiency affects strategic decision-making. If the quality of internal control can be correctly evaluated and included into the management's strategic decisions, the enterprise can improve the efficiency of capital allocation and formulate an appropriate development strategy. Using panel data from the Shanghai and Shenzhen stock markets from 2013 to 2017, we investigate the relationship among overall internal control information quality, capital allocation efficiency, and enterprise strategic decision-making. The results show that when the level of free cash flow is high, the incentive mechanism of corporate governance increases the possibility of diversification; the lower the quality of internal control information is, the more likely it is for enterprises to pursue diversification; improving the quality of internal control helps management to allocate internal resources reasonably. When the efficiency of capital allocation is high, it can effectively prevent diversification. This study contributes by revealing the mechanism of the impact of internal control quality on strategic decision-making and expands the relationship between internal control and corporate strategic management.

1. Introduction

With the rapid changes in the economic and political environment, there are increasingly greater requirements for enterprise specialization and globalization. Traditional enterprises started with profit maximization as the economic goal and gradually moved towards a sustainable development goal. Many Chinese companies have accelerated the process of transformation and enterprise reengineering to promote the sustainable development of listed companies. Diversification is one way to realize this transformation. Many studies in the field of corporate strategy and behavioral finance have pointed out that the motivation for diversification stems from the internal and external environments faced by enterprises. To create a regional economy, enterprises try to enter related industries, which is a low-cost attempt. The motivation for these stems from trying to find a simple retreat for enterprises [1]. According to the theory of diversification motivation, there are three main reasons for diversifying: individual, organizational, and economic rational motivation. Among them, rational organizational motivation seeks to reduce the overall risk of the enterprise, while individual rational motivation mostly pursues personal interests of managers. In recent years, studies have found that diversification strategy is mainly the result of the pursuit of value maximization by organizations and personal interests by managers [2, 3]. From the perspective of principal-agent theory, large shareholders or managers often consider diversification strategy to appropriate the interests of small and medium-sized shareholders [4]. The traditional bureaucratic management mode separates cash flow rights and enterprise control rights [1]. Diversification does not reduce the risk of enterprises. On the contrary, agency problems such as on-the-job consumption are more likely to occur, and accounting performance reduces [1]. Hence, a diversified development is not applicable to all enterprises.

The release of "basic norms of internal control" and "supporting guidelines" provides an institutional guarantee for the standardization and legalization of internal control information for Chinese enterprises and demands higher requirements for internal control and management of enterprises. The standards clearly state that improvement of internal control system should serve the goal of enterprise development and effective utilization of internal capital. Whether a diversification strategy is suitable for Chinese enterprises and whether it can provide a path for their transformation and sustainable development is an urgent question to be answered. However, there are only a few studies on internal control behavior and internal capital allocation, and there is not much information on the impact of their relationship on enterprise strategic decision-making. There is also very little research on whether improvements in internal control quality provide a good basis and guarantee for business decision-making and development planning. Hence, this study explores the relationship between enterprise internal control and resource allocation efficiency and its impact on enterprise strategic decision-making, which has practical significance for enterprise management.

2. Review of Related Research

The literature on the impact of internal control in western countries mainly focuses on the quality of accounting information, agency cost, and enterprise value, and many scholars have discussed the relationship between corporate governance and capital allocation efficiency. There are only a few studies on the relationship between information quality of internal control, efficiency of capital allocation, and strategic decision-making. Fang and Jin [5] pointed out that the role of corporate governance and internal control is different, and the focus of the company's business decision-making and internal management is also different. Corporate governance is only one aspect of the internal environment in internal control (as shown in Figure 1), while internal control is a part of all activities of internal governance, operation, execution, and supervision. Internal control is a comprehensive management system. In empirical studies, the representative variables of corporate governance and internal control are easily confused with each other, which leads to deviations in the design and measurement of internal control [6]. Skaife et al. [7] used the internal control deficiency disclosure under the Sarbanes-Oxley Act (SOX 302) to study the failure of disclosure control and discussed the problems and causes of internal control. They found that the business of companies with internal control disclosure deficiency is more complex than that of undisclosed enterprises and that there are many organizational structure adjustments, lower capital allocation efficiency, higher accounting risks, and auditors before disclosure deficiency. Employee turnover is also high. Deumes and Knechel [8] found that the degree of disclosure of internal control is negatively correlated with the shareholding ratio of management and major shareholders because the management weighs the possible economic cost of disclosing the deficiencies in internal control. Li [9] believed that the quality of internal control information should play a role in value creation, and not just in issuing reports. Internal control information quality should be considered from multiple levels of corporate governance, company operation, and execution. In addition to functioning as an internal auditor, internal control should also have the functional attributes of corporate management [10]. Therefore, it is important to explore whether the level of internal control has an impact on the efficiency of enterprise capital allocation.

The existing research on internal control can be roughly divided into the following two different viewpoints: Scholars in the theory of internal control inhibition believe that internal control will destroy the innovation environment of enterprises to a certain extent [11, 12], inhibits employees' enthusiasm and innovative spirit [13], and dampens the enthusiasm of management to increase investment in innovation [14]. Therefore, internal control will adversely affect the efficiency of capital allocation. Li et al. [15] hold that the higher the quality of internal control, the less the capital investment of enterprises. Ni and Wang [16] found that high-quality internal control inhibited the ability of enterprise management, led to the reduction of R&D investment, and finally reduced the R&D performance of enterprises, so they believed that strict internal control limited the resource allocation of enterprises. Bargeron et al. [17] found that the institutionalization of internal control reduced the ability of enterprises to take risks, which was not conducive to the development of innovative strategies. At the same time, scholars of "internal control promotion theory" think that internal control can help improve the management level of enterprises and provide goals, guidelines, and structured support for enterprise development [18–21]. Some scholars have found that the higher the quality of internal control is, the stronger the binding force on the management's on-the-job consumption is, and the better it can promote the fulfillment of corporate social responsibility and attract R&D talents, which in turn helps to improve the level of corporate capital allocation; papers [22–24] empirically found that the implementation of internal control norms promoted the disclosure and repair of internal control defects, reduced the risk level of enterprises, and enabled companies to establish and improve internal control systems.

From the perspective of maximizing enterprise value, management usually considers only those investment projects with an expected net present value greater than zero. Investment risk is seldom considered in achieving optimal allocation of capital [25]. Due to agency problems and the pursuit of private interests, management often chooses projects with low investment risk, which leads to underinvestment. Faccio's study shows that enterprises with female CEOs are more obviously underinvested, and their capital allocation efficiency is lower than that of enterprises with male CEOs. High returns are accompanied by high risks, and a high capital allocation efficiency means that companies choose projects with higher returns and abandon those with lower returns [26]. Other studies have shown that improving the quality of accounting information disclosure

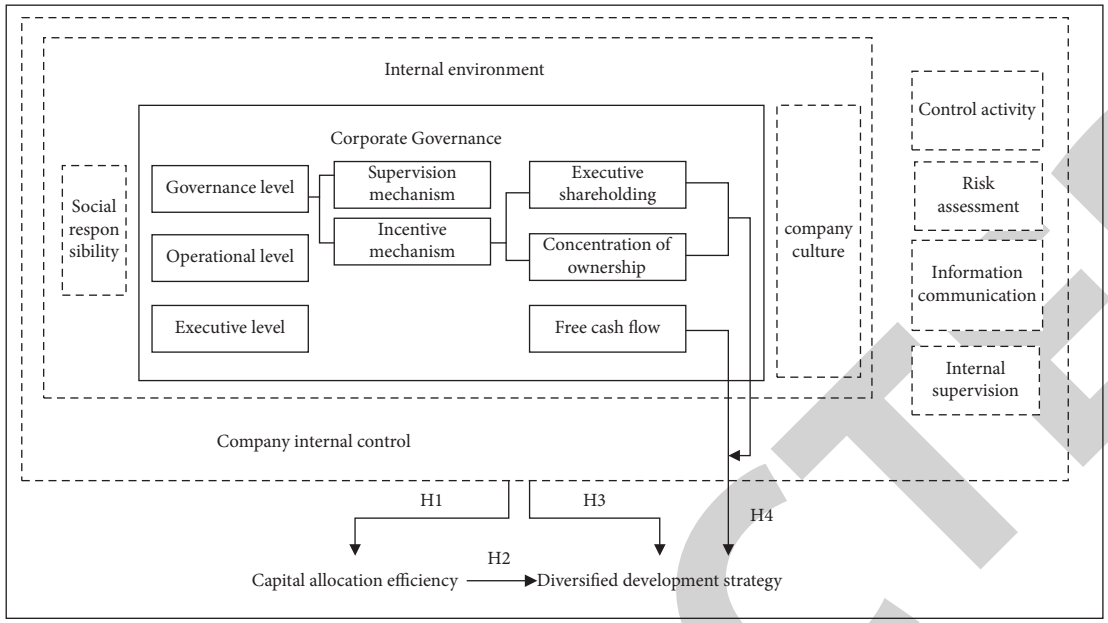

Figure 1: Relationship between internal control, internal capital allocation efficiency, and diversification.

and internal control can avoid information asymmetry, thus, reducing the cost of capital financing and agency costs and achieving an effective allocation of capital. Therefore, the level of accounting information disclosure is inseparable from the level of internal control quality [7]. The present study investigates whether enterprises with high levels of internal control can reasonably avoid risks and achieve effective utilization of resources.

How management allocates internal resources is closely related to the enterprise development strategy. Initially, diversification strategy was mostly considered to maximize enterprise value [27] and reduce enterprise risk [28]. The research on the determinants of diversified operation of listed companies mainly focuses on corporate governance characteristics, such as company value, company growth [29], operational risk, consistent design of management interests, company size, listing years, and industry category [30]. Jensen's principal-agent theory has provided the theoretical support for the explanation of enterprise management behavior. Amihud and Dennis and other studies on the diversification of companies before the 1990s showed that the reasons for diversification are on-the-job consumption, empire building, diversified M&As, and cross-subsidization of interdepartmental performance. Diversification was used as a business model by the company's management to seek nonmonetary private interests, which damages the interests of shareholders and incurs agency costs [31]. Chintrakarn et al. showed that when the controlling power of shareholders is weak, management is more likely to carry out diversification [32]. Goranova et al. showed that the incentive mechanism of corporate governance induces enterprises to implement diversification [33]. Chen and Yu conducted an empirical analysis of Taiwanese enterprises to test the relationship between management control mechanisms, diversification, and accounting performance. Their findings show that the relationship between management equity incentives and diversification is U-shaped and that diversification improves the short-term performance of enterprises but has little impact on medium- and long-term performance [34]. Combining the concepts of resource relevance and economic cost, Lieberman et al. evaluated the impact of resource reallocation potential on the entry and exit of diversified businesses [35] and concluded that correlated operations reduce the sunk cost of new businesses and help in exiting poorly performing new businesses. Due to the difficulty in redeploying resources, diversification can reduce entry "error." Their findings show that there is a negative correlation between efficiency of capital allocation and the degree of diversification. Jin Xiaobin found that diversification strategy in China is not vicious but neutral. It is a rational organizational behavior to maximize company value in a market economy. Diversified companies in China generally command a premium with a high market value and book value, high investment level, and excess value [36]. The above study analyzes the reasons and consequences of a diversification strategy from different angles but does not analyze the impact of internal control on the efficiency of capital allocation or the possible degree of diversification. The present study attempts to explore the influence and role of internal control level on the strategic decision-making of management and examines whether capital allocation efficiency can be improved by improving the level of internal control, to guide enterprises in making correct strategic decisions.

3. Theoretical Analysis and Research Hypotheses

To expedite the transformation and upgrading of enterprises, while preventing improper management behavior and low capital allocation efficiency, enterprises usually formulate a series of systems and policies to supervise and

restrict internal management activities and the business activities handed over to the outside world. As a long-term qualitative internal control management, enterprises form an invisible "ecosystem" influence. The development and growth of enterprises form the corporate culture. Therefore, internal control is a kind of institutional arrangement to monitor the various operations and activities within the company. It provides a good "ecological environment" not only for the better realization of financial transparency, but also for efficient management operation. Li Wanfu, Lin bin, and Song Lu emphasized the role and status of internal control in the company's investment decision-making and found that low-quality internal control exacerbates inefficient investment, both overinvestment and underinvestment [37]. At the same time, the level of internal control also affects the quality of company's financial reports. The financial report information is the main reference material for the enterprise's shareholders and stakeholders. Low information quality of financial reports leads to information asymmetry and affects the decision-making of the company and other stakeholders [38]. Anna Costello et al. showed that if there are deficiencies in the internal control disclosures of the company, banks and financial institutions might require the company to pay a higher loan interest rate. When the company corrects the disclosure deficiencies in its internal control, lending institutions reduce the loan interest rate [39]. It can be seen that the quality of internal control reduces the degree of information asymmetry of the management, plays an important role in rational allocation of capital, and is conducive for avoiding enterprise risks. According to the signal transmission theory, when there is asymmetric information, the management, which has the advantage of information resources, transmits internal information to potential external investors through the capital structure or dividend policy [40]. External investors then participate in and influence the decision-making of internal resource allocation and future strategies. If corporate governance fails in its regulatory role, it becomes necessary for enterprises to compensate for its deficiencies by improving internal control. When the shareholding ratio of the management is high, the signal is stronger, indicating that management would not encroach on the company's resources and shareholders' rights and interests and strive for more resources [41, 42]. As a reliable signal, the quality of internal control is conducive for improving capital allocation efficiency and plays the role of an internal auditor [43]. The internal control system provides internal control and supervision not only for financial and accounting behavior but also at all levels of the whole enterprise [6]. The information parameters of internal control quality can directly quantify this governance role. With continuous improvements in an enterprise's risk-taking ability, improving internal control provides guarantees for enterprises to control risks and optimize resource allocation. Therefore, this study proposes the following hypothesis.

H1: The higher the quality of internal control, the higher the efficiency of capital allocation.

Li and Zhu found that the wealth loss of shareholders of M&A companies was significant in 1–3 years after the M&A, with a loss rate of 6–9% [44]. Zhang and Gao suggest that diversification without a synergistic effect reduces the efficiency of capital allocation in the internal capital market of the enterprise, and the transfer of capital from departments with strong profitability to those with poor profitability damages enterprise value [45]. The diversification is likely to result from a decrease in capital allocation efficiency. Lamont and Polk examined the diversification of a company's discount situation and found that, with an increase in investment opportunities, the discount phenomenon is more significant, and improper investment behavior directly affects the efficiency of capital allocation. More opportunities for enterprise transformation are likely to induce the management to choose diversification. Yang [46] believes that low efficiency of capital allocation increases the possibility of value loss in corporatized companies. Inefficient or ineffective capital allocation strategies usually advocate "equalitarianism." Due to the presence of more businesses, inefficient departments are likely to allocate more capital, while efficient departments get less capital. When enterprises are in nonrelated fields, the investment prospect gap between departments is large, which leads to cross-subsidization among departments. Wang [47] believes that the efficiency of capital allocation tends to increase when enterprises move from specialization to diversification. However, any further increase in diversification after attaining a certain degree reduces allocation efficiency in the internal capital market. The effective allocation of internal capital can drive enterprises to improve their accounting performance, while diversification has a negative correlation with accounting performance. For example, Lu [48] showed that the stronger the business relevance of subdepartments, the lower the efficiency of capital allocation, and the higher the degree of diversification, the lower the efficiency of resource allocation in the internal capital market. In their study, enterprises developed diversification strategies. The index is not accurate enough for measuring diversification degree. It can be measured more accurately from the composition of the operating environment. Therefore, this study proposes the following hypothesis.

H2: The higher the efficiency of capital allocation is, the less likely it is for enterprises to implement diversification.

Internal control is an important mechanism to ensure the effective implementation of the internal contract, and in modern enterprise system, it is particularly important to act according to contract rules. Rajesh et al. found that if there is an efficient incentive contract within the enterprise, the low capital efficiency of the enterprise would be controlled and the possibility of diversification would be reduced [49]. We believe that the effect of capital allocation efficiency on diversification is regulated and influenced by the quality of internal control. Theoretically speaking, when there is no investment opportunity, management cannot obtain direct benefits from a reasonable distribution of capital or obtain the corresponding returns, or the returns are indirect or invisible. If the internal control is deficient, it would directly affect the strategic decision-making of the management and make them more motivated to carry out diversification to

achieve on-the-job consumption or empire building. Therefore, we propose the following hypotheses.

H3: The lower the quality of internal control is, the more likely the enterprise will implement diversification.

In the literature on enterprise development strategies, the level of free cash flow is an important factor in strategic decision-making. The failure of internal control provides managers with the opportunity to invest the internal free cash flow in projects that are beneficial to some managers but are expensive for shareholders. When a company has more free cash flow, managers or CEOs are more likely to engage in self-interested pursuits [32], such as empire building, on-the-job consumption, diversified M&As [50], and cross-subsidization between departments. The possibility of implementing diversification is related to the level of free cash flow held by the enterprise during the current period or the previous period. If the proportion of management shareholding is high, it may lead to the possibility of an interest convergence effect to stimulate the development of a diversification strategy for the enterprise, thus, damaging the interests of creditors or other stakeholders [51]. When ownership concentration is high and there are few active parties to collect information and monitor management, the management is more likely to implement diversification to disperse the supervision of large shareholders. Therefore, the following hypothesis is put forward:

H4: When the level of free cash flow is high, the convergence effect of management interests increases the possibility of implementing diversification.

4. Research Design

4.1. Research Samples and Data Sources. This study selected A-listed companies on the Shanghai and Shenzhen stock exchanges from 2013 to 2017 and sorted the sample data according to the following criteria: ① exclude financial and insurance listed companies; ② exclude ST and ST* companies; and ③ eliminate missing data and abnormal samples. After the above screening, 9012 valid samples were obtained. The financial data are taken from the China Stock Market and Accounting Research database, Wind-Economic database, and DIB internal control and risk management database of the Chinese stock market. We used Stata 11.0 software for the statistical analysis.

4.2. Design of Main Variables

4.2.1. Diversification. From the relevant literature, we compared and analyzed business counting, HHI, HDI, and entropy methods and finally decided to use the HDI method. Refer to Herfindahl index,

$$\mathrm{HHI} = \sum_{i=1}^{n} Pi^2. \tag{1}$$

Pi is the proportion of the income of each industry in the total income. Referring to the Herfindahl method of calculating income, for example, enterprises A and B operate in two industries, in which the composition of main business income of enterprise A is 80 : 20 and that of enterprise B is 50 : 50. Then, the HHI index of enterprise A is 0.68 and that of enterprise B is 0.5.

Referring to C.H. Berry's findings, this study uses the weighted average HDI index to measure diversification. It is calculated as

$$\mathrm{HDI} = 1 - \mathrm{HHI} = 1 - \sum_{i=1}^{n} Pi^2. \tag{2}$$

When HDI is high, it indicates a more diversified enterprise; when HDI is 0, it indicates a specialized enterprise. In the above example, enterprise B is more diversified than enterprise A.

4.2.2. Free Cash Flow Level. According to Richardson [52], free cash flow is the cash flow of an enterprise that is in excess of the funds required to maintain the existing assets and optimal new investment. The cash asset ratio of the previous accounting year is expressed using T-1 period. The calculation formula is

$$\mathrm{FCFF}_{i,t-1} = \frac{(CFO - I1 - I2)_{t-1}}{\mathrm{TotalAsset}}. \tag{3}$$

CFO is the net cash flow of operating activities, $I1$ is the cash expenditure required to maintain production and operation and asset scale, and $I2$ is the new investment in the current year cash paid for in the net cash flow.

4.2.3. Efficiency of Capital Allocation. Referring to McLean's method [53], the efficiency of capital allocation is measured by the sensitivity of the company's investment to marginal Q, mainly involving the company's investment level (investment) and investment opportunity (Tobin's Q). In the regression of investment level to investment opportunity, the regression coefficient of investment opportunity in the previous period represents the sensitivity to the efficiency of capital allocation. In the model, the interaction between the internal control index and the last investment opportunity represents the influence of the quality of internal control on the efficiency of capital allocation. A positive coefficient indicates that the quality of internal control can promote the sensitivity of the company; that is, improving the level of internal control is conducive to the management's control of investment opportunities and efficiency of capital allocation. The investment level of the company is measured by the ratio of current net cash flow to total assets, and Tobin's Q is used to measure investment opportunities.

4.2.4. Internal Control Index. Following Yang Deming [54] and other studies, this study uses the "internal control index" of DIB Risk Management Technology Co., Ltd., to measure the internal control quality of listed companies. The lowest score on the original index is 0, while the highest is 1000. In this study, the internal control level of a company is calculated by adding 1 logarithm after converting the index into a percentage. In addition, internal control dummy variables were used for the robustness test.

4.2.5. Corporate Governance Indicators. Referring to Beatty and Zajac [55], we use the ratio of the number of shares held by the company's senior managers to the total number of shares of the company and use the ratio of the number of shares held by the largest shareholder to the total number of shares of the company to measure the degree of ownership concentration.

4.2.6. Control Variables. Referring to Goranova [33], the following nine control variables were selected. Accounting performance is expressed as the rate of return on assets; enterprise scale is expressed as the natural logarithm of total assets; financial leverage is expressed as the year-end total asset liability ratio; enterprise growth is measured by the increment rate of the main business income of the accounting year; the period of listing is measured by the listing period; company risk is expressed as the top three of net profit rate of total assets; and ownership nature is divided according to the type of the ultimate controller in the annual report of listed companies, in which 1 is state-owned holding, while 0 is other. In addition, there are industry dummy and annual dummy variables. A summary of each variable is shown in Table 1.

4.3. Research Model

4.3.1. Internal Control and Capital Allocation Efficiency. This study uses feasibility generalized least squares regression analysis to test the relationship between internal control quality and capital allocation efficiency.

$$\begin{aligned}\text{Investi}_{i,t}\alpha_0 + \alpha_1\text{Tobin'sQ}_{i,t-1} + \alpha_2\text{ICI}_{i,t} + \alpha_3\\ \text{Tobin'sQ}_{i,t-1}\bullet\text{ICI}_{i,t} + \alpha_4\text{Control}_{i,t} + \varepsilon_{i,t}.\end{aligned} \tag{4}$$

Invest represents the investment level of the company, ICI is the allocation efficiency of the internal capital market, ICI is the internal control index of the company, Tobin's Q represents the investment opportunities of the company, Control includes all the control variables, α 0 is the intercept term, α 1 ~ α 4 is the regression coefficient, and ε is the residual term. In formula (4), if the coefficient of α 2 is significantly positive, it signifies that the improvement of the company's internal control can promote the resource allocation of the enterprise's internal capital market; thus, H 1 will be proven. Referring to Mclean and Pontiff [56], a company's capital allocation efficiency is measured by the sensitivity of the company's investment to marginal Q. Tobin's *Q* takes the observation value of one lag period. In formula (4), the coefficient of interaction α 3 is significantly positive, indicating that an improvement in internal control has a positive regulatory effect on the resource allocation of the internal capital market.

4.3.2. Diversification and Capital Allocation Efficiency. This study uses the following model to test hypotheses H2 ~ H4:

$$\begin{aligned}\text{HDI}_{i,t} = \beta_0 + \beta_1\text{Invest}_{i,t} + \beta_2\text{Deficiency}_{i,t} + \beta_3\text{Tobin'sQ}i_{,t-1}\\ + \beta_4\text{FCFF}_{i,t-1} + \beta_5\text{Internalgovernance} \times \text{FCFF}_{i,t-1}\\ + \beta_6\text{Control} + \varepsilon_{i.t},\end{aligned} \tag{5}$$

where HDI represents the degree of diversification of the enterprise, Invest represents the level of internal capital allocation of the company in the current period, and Deficiency indicates whether there are deficiencies in internal control. Internal governance indicates the ownership concentration of internal governance mechanism and the proportion of senior executives' shareholding; FCFF is the level of free cash flow; Control are all the control variables, and ε is the residual item. Formula (5) examines the impact of deficiencies in internal governance mechanism and internal control on corporate diversification and verifies H 2 ~ H 4. To eliminate outliers and extreme outliers, 1% tailing was applied to all the continuous variables.

5. Empirical Analysis

5.1. Descriptive Statistical Analyses. Table 2 gives the descriptive statistics of the entire sample. The average diversification index is 0.204. From the standard deviation, minimum value, and maximum value, we see that the degree of diversification of the whole sample is quite different. Average investment level is 0.049, and the overall investment level is not high. Among these, the minimum value is −0.002, while the maximum value is 0.642, which indicates that there are significant differences among enterprises. Average return on assets is 0.044, and the profitability of the entire sample is not high. The minimum value is −1.05, while the maximum value is 7.11, which indicates that there are significant differences among enterprises. The growth index shows that the overall growth of China's listed companies is not strong, and there are large differences among the companies. The average value of free cash flow is only −0.035, the overall level is low, and other data show that the proportion of state-owned holding companies is not high.

5.2. Correlation Tests. Table 3 shows the correlation coefficient matrix of the study variables. The indicators reflecting capital allocation efficiency are significantly positively correlated with the quality of internal control and investment opportunities at the 1% level, indicating that an improvement in internal control quality is conducive to improving capital allocation efficiency. Thus, Hypothesis 1 is preliminarily verified. The diversification development index is negatively correlated with investment level, internal control quality, ownership concentration, and management shareholding at the 1% level. This shows that improving the efficiency of capital allocation and level of internal control can prevent enterprises from diversifying. Thus, H2 ~ H4 are preliminarily verified.

Another table shows that there is no significant collinearity between variables.

Table 1: Variable definitions.

Variable name	Variable meaning	Calculation method
HDI	Degree of diversification	1-HHI, HHI = $\sum_{i=1}^{n} Pi^2$ Pi is the proportion of industry income to total income
Invest	Investment level	Purchase and construction of fixed assets and intangible assets cash paid for other long-term assets Cash received from disposal of the above assets Total assets
ICI	Internal control index	Natural logarithm of DIB internal control index percentage
Deficiency	Internal control defects	When there are deficiencies in internal control, the value is 1; otherwise, the value is 0
Tobin's Q	Investment opportunity	Ln [(Total liabilities + current stock market value + net assets per share × number of nontradable shares)/Total assets
CR1	Ownership concentration	Ratio of the number of shares held by the largest shareholder to the total number of shares of the company
MStock	Shareholding ratio of senior executives	Ratio of the number of shares held by senior managers to the total number of shares in the company
FCFF	Free cash flow level	Proportion of free cash flow to total assets in T-1 period
Size	Company size	Natural logarithm of total assets
Lev	Financial leverage	T-1 liabilities/Total assets
ROA	Accounting performance	Net profit/Average annual total assets
Tenure	CEO tenure	Ln (Tenure of general manager)
Firmrisk	Enterprise risk	Standard deviation of ROA from T-3 years to T-1 years
CEOsuc	CEO succession	1 = General manager changed in the current year, 0 = other
List	Enterprise age	Year of IPO date
State	Nature of ownership	1 = state-owned enterprise, 0 = non-state-owned enterprise
Growth	Growth	(Main business income of period T-1 - Main business income of phase t) Main business income in T-1
Indus	Industry dummy variable	If the company is in industry I, the value is 1; otherwise, it is 0
Year	Annual dummy variable	If the company data is for year n, the value is 1; otherwise, it is 0

Table 2: Descriptive statistics.

Variable	Observation value	Average value	Standard deviation	Minimum value	Maximum
HDI	9012	0.204	0.239	0	0.965
Invest	9012	0.049	0.049	−0.002	0.642
ICI	9012	−0.418	0.113	−0.852	−0.192
Deficiency	9012	0.356	0.479	0	1
Tobin's Qt −1	9012	0.332	0.861	−2.493	5.449
CR1	9012	0.155	0.130	0	2.210
Mstock	9012	0.045	0.115	0	0.810
FCFFt −1	9012	−0.035	0.933	−87.79	1.027
Size	9012	22.28	1.300	15.58	28.51
Lev	9012	0.464	0.290	−0.195	11.51
ROA	9012	0.044	0.099	−1.052	7.109
Lntenure	9012	1.443	0.561	−2.996	3.081
Firmrisk	9012	0.025	0.085	0	5.880
CEOsuc	9012	0.170	0.376	0	1
List	9012	11.23	6.482	1	26
State	9012	0.462	0.499	0	1
Growth	9012	0.168	0.557	−0.546	4.070

5.3. Regression Analysis Results of Internal Control Quality and Capital Allocation Efficiency. From column (1) of Table 4, the regression coefficients of investment opportunity and internal control on capital allocation efficiency of lag one period are 0.002 and 0.03, respectively. Without controlling for other influencing factors, the regression coefficient of investment opportunity is not significant, but investment opportunity and internal control in the previous accounting year are not significant. The interactive items of internal control level in this period are significantly positively correlated at the 1% level. It can be seen from column (2) that, after adding control variables, the regression coefficient of investment opportunity in the last accounting year is significant at the 1% level, which indicates that when a company has more investment opportunities, the greater is the company's investment expenditure. The regression coefficient of the interaction between investment opportunity and internal control quality in the previous accounting year

Table 3: Pearson's correlation coefficient analysis of main variables.

Variable	HDI	Invest	ICI	Deficiency	Tobin's Qt-1	CR1	Mstock
HDI	1						
Invest	−0.071***	1					
ICI	−0.034***	0.080***	1				
Deficiency	0.113***	−0.078***	−0.047***	1			
Tobin's Qt −1	−0.018*	0.072***	−0.054***	−0.066***	1		
CR1	−0.031***	0	0.133***	0.00500	−0.135***	1	
Mstock	−0.091***	0.129***	0.027**	−0.157***	0.210***	−0.053***	1
FCFFt −1	−0.0110	−0.055***	0.00200	0.0120	−0.063***	0.0170	−0.00800
Size	0.085***	−0.024**	0.236***	0.107***	−0.595***	0.276***	−0.181***
Lev	0.074***	−0.093***	−0.025**	0.132***	−0.369***	0.028***	−0.196***
ROA	−0.039***	0.102***	0.125***	−0.062***	0.214***	0.037***	0.074***
Tenure	−0.00300	0.052***	0.048***	−0.026**	−0.058***	−0.025**	0.028***
Firmrisk	0.00100	0.021**	−0.086***	0.0150	0.155***	−0.032***	−0.00300
CEOsuc	0.028***	−0.038***	−0.048***	0.046***	0.00300	0.0130	−0.056***
List	0.225***	−0.240***	−0.070***	0.241***	−0.191***	−0.076***	−0.410***
State	0.095***	−0.098***	0.037***	0.164***	−0.321***	0.175***	−0.345***
Growth	0.018*	0	0.00600	0.0140	0.048***	0.00900	−0.00400
	FCFFt −1	Size	Lev	ROA	Tenure	Firmrisk	
*FC*FFt − 1	1						
Size	0.0160	1					
Lev	0.023**	0.305***	1				
ROA	−0.741***	−0.00200	−0.290***	1			
Tenure	0.0120	0.00900	−0.0100	0.0110			
Lntenure	0.0100	0.00300	−0.050***	0.030***	1		
Firmrisk	−0.500***	−0.117***	0.366***	0.313***	−0.042***	1	
CEOsuc	−0.022**	0.023**	0.065***	−0.035***	−0.207***	0.052***	
List	0.00300	0.198***	0.286***	−0.098***	−0.023**	0.034***	
State	0.022**	0.310***	0.201***	−0.084***	0.046***	−0.040***	
Growth	−0.00400	−0.00800	0.214***	−0.097***	−0.0110	0.062***	
	CEOsuc	List	State	Growth			
CEOsuc	1						
List	0.081***	1					
State	0.043***	0.412***	1				
Growth	0.024**	0.00800	0.0110	1			

Note. ** and ***are significant at the 1% and 5% levels, respectively.

is significantly positive at the 1% level, which indicates that the sensitivity of capital allocation efficiency to investment opportunities is enhanced. Improving internal control is conducive to improving the internal resource allocation of enterprises. Thus, H1 has been verified.

5.4. Regression Analysis Results of Capital Allocation Efficiency and Diversification Degree. Using formula (5), we conducted multiple regression analysis on the sample data and the regression results are shown in Table 5. Column (2) gives the regression result of the control variable and main independent variable, and column (3) is the regression result after adding the interaction item. The results show that there is a significant negative correlation between the efficiency of capital allocation and the diversification strategy of enterprises (all significant at the 5% level). There are deficiencies in the internal control of enterprises, and enterprises are more likely to implement diversification. Thus, H2-H3 have been verified. According to the principal-agent theory, an increase in the proportion of managerial ownership improves the level of diversification of enterprises, and our results show that an increase in the proportion of senior management shares reduces the level of diversification of enterprises, which may be caused by the overall low proportion of senior executives' shareholding in listed companies in China.

The regression results show that the level of free cash flow is positively correlated with the degree of diversification, and it is significant at the 1% level, which is consistent with the theoretical expectation. When the interaction item is added, the influence of free cash flow level on the degree of diversification weakens. In addition, the interaction between the level of free cash flow and the shareholding ratio of the largest shareholder is positively correlated with the degree of diversification of the enterprise, and it is significant at the 1% level, which indicates that when management holds more cash, it increases the possibility of inefficient internal capital allocation. The convergence effect of management and the positive regulation of free cash flow are likely to lead to the implementation of diversification in the future. Thus, H4 has been verified.

In the research on the relationship between capital allocation efficiency and diversified development strategy, the existing research found that the information asymmetry of

Table 4: Regression analysis of internal control quality and capital allocation efficiency.

Variables	Model 1	Model 2
Tobin's Qt − 1	0.002	0.015***
	(1.330)	(6.312)
ICI	0.030***	0.007*
	(6.782)	(1.675)
Tobin's Qi, *t* − 1 •ICIi, *t*	0.007***	0.007***
	(2.781)	(2.807)
*FCF*Ft − 1		0.002
		(1.475)
Size		0.004*
		(1.905)
Lev		−0.007*
		(−1.649)
ROA		0.035*
		(1.853)
Growth		0.001
		(0.609)
List		−0.008***
		(−16.345)
State		−0.004
		(−0.774)
Cons	0.062***	0.0470
	(33.09)	(1.038)
Year	No	Yes
Industry	No	Yes
N	9012	9012
r_2	0.008	0.094

Note. (1) ***, **, and * are significant at the 1%, 5%, and 10% levels, respectively. (2) Data in brackets are *t* values, adjusted by white heteroscedasticity and processed by cluster at the company level.

diversified operation would lead to agency conflict, resulting in low capital allocation efficiency, thus damaging the enterprise value, that is, the phenomenon of diversified discount existed. A large number of empirical studies found that the reason for discount came from the low capital allocation efficiency. Shin [57] thinks that there is asymmetric information cost between the general manager of the company and the managers of each business unit, which leads to the lower benefit of diversified enterprises than independent single enterprises. Lamont and Polk [58] found that inefficient capital allocation is the main reason for diversification discount, while inefficient internal resource allocation is caused by information asymmetry. Because of information asymmetry, the branch managers of diversified enterprises are endowed with rent-seeking characteristics, and they try to get more remuneration or resource allocation by lobbying the headquarters, which eventually leads to the discount phenomenon of diversified enterprises [59]. Shin and Stulz [57] found that the headquarters of diversified enterprises are similar to each department in general, and the efficiency of capital allocation did not play the role of effective allocation of funds, and the development of middle departments of diversified enterprises depended more on their own funds. Mansi and Reeb [60] found that diversification reduces shareholder value and increases creditor value and comprehensively found that there was no significant correlation between diversification and excess enterprise value.

5.5. Regression Analysis of Capital Allocation Efficiency and Diversification Degree under Different Levels of Internal Control. To further test the influence and difference of capital allocation efficiency on diversification under different levels of internal control, we use model 2 to carry out regression analysis on different internal control effect groups. The results are listed in Table 6. We divided the sample companies into three groups according to the quality of internal control: (1) group with low quality of internal control, (2) group with medium quality of internal control, and (3) group with high quality of internal control. The results show that, in the group with higher quality of internal control, the efficiency of capital allocation has a negative correlation with the degree of diversification, which is significant at the 5% level, while the influence of other groups is no longer significant. This shows that a high quality of internal control positively regulates the relationship between the efficiency of capital allocation and the degree of diversification of enterprises. Therefore, improving internal control is helpful for making strategic decisions. Different from previous studies, we found that the quality of internal control played a restraining role in the relationship between the efficiency of capital allocation and diversified development, indicating that internal control affected the capital allocation and strategic choice within enterprises to a certain extent, but previous studies did not find the regulating role of internal control.

Table 5: Regression analysis results of internal capital allocation efficiency and diversification degree.

	Model 1	Model 2	Model 3
Invest	−0.353***	−0.119**	−0.118**
	(−5.606)	(−2.131)	(−2.094)
Deficiency	0.034***	0.018***	0.018***
	(6.072)	(3.655)	(3.608)
Mstock	−0.123**	−0.086*	−0.093*
	(−2.271)	(−1.683)	(−1.831)
Tobin's Qt −1	0.073***	0.012*	0.011*
	(12.792)	(1.828)	(1.792)
CR1	−0.149***	−0.024	−0.019
	(−2.626)	(−0.561)	(−0.463)
FCFFt −1	0.003***	0.005*	−0.008
	(6.747)	(1.946)	(−1.502)
Size		0.03***	0.036***
		(4.066)	(4.087)
Lev		0.021**	0.022**
		(2.038)	(2.221)
ROA		−0.065**	−0.064**
		(−2.494)	(−2.433)
Tenure		0.003	0.004
		(0.425)	(0.500)
Firmrisk		0.110*	0.101*
		(1.887)	(1.724)
CEOsuc		0.003	0.003
		(0.532)	(0.586)
List		0.004*	0.003*
		(1.942)	(1.735)
State		0.019	0.019
		(0.833)	(0.832)
FCFFt −1 • CR1			0.288***
			(2.696)
FCFFt −1 • Mstock			−0.131
			(−1.217)
Cons	0.214***	−0.619***	−0.620***
	(21.657)	(−3.377)	(−3.386)
Year	No	Yes	Yes
Industry	No	Yes	Yes
N	9012	9012	9012
r_2	0.05	0.277	0.277

Note. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

Table 6: Regression analysis of capital allocation efficiency and diversification degree under different levels of internal control.

Variable	Low	In	High
	−0.04	0.022	−0.013
	(−1.041)	(0.266)	(−1.636)
	0.650**	0.08	0.234*
	(2.445)	(0.208)	(1.687)
	0.027	0.066	−0.194
	(0.086)	(0.217)	(−1.581)
Invest	−0.117	0.085	−0.177**
	(−1.059)	(0.560)	(−2.431)
	−0.003	0.026*	0.014
	(−0.196)	(1.837)	(1.625)
Mstock	−0.208*	−0.225	−0.037
	(−1.906)	(−1.249)	(−0.625)
CR1	0.082	0.200*	−0.139**
	(1.602)	(1.721)	(−2.358)
	0.005	0.023**	0.022***
	(0.439)	(2.145)	(3.496)

Table 6: Continued.

Variable	Low	In	High
Size	0.016	0.024	0.048***
	(0.767)	(1.236)	(4.392)
Lev	0.063	0.023	0.023**
	(1.119)	(0.447)	(2.542)
ROA	−0.099**	−0.098	−0.059
	(−2.126)	(−0.527)	(−1.578)
Tenure	0.025*	−0.017	−0.003
	(1.762)	(−0.855)	(−0.264)
Firmrisk	0.129	−0.0200	−0.061
	(1.324)	(−0.069)	(−0.594)
CEOsuc	0.001	0.003	0.004
	(−0.031)	(0.347)	(0.684)
List	0.006	0.004	0.001
	(1.264)	(0.973)	(0.526)
State	−0.025	0.061	0.032
	(−0.655)	(1.417)	(0.872)
Cons	−0.212	−0.447	−0.837***
	(−0.507)	(−1.032)	(−3.698)
Year	No	Yes	Yes
Industry	No	Yes	Yes
N	1803	1803	5406
	0.273	0.288	0.281

Note. ***, **, and * denote significance at the 1%, 5%, and 10% levels, respectively.

6. Conclusion

This study selects 9012 nonfinancial companies' samples from the Shanghai and Shenzhen stock markets from 2013 to 2017 to explore the impact of internal control quality on capital allocation efficiency and diversification. The results show that improving internal control enables enterprises to seize investment opportunities and implement effective capital allocation. This study also examines the impact of capital allocation efficiency and free cash flow on the diversification level and the differences among the internal control groups. The results show that, first, the internal control is an important guarantee for the daily operation and management of enterprises. Attaching greater importance to internal control promotes efficient resource utilization in the internal capital market. In the long run, the development of internal control is conducive for reducing the short-term behavior of management and eliminating the agency problem, which enables management to make strategic decisions. Second, improving capital allocation efficiency will lead to an improvement in the control of investment opportunities, restrain the company from overdiversifying, and ensure the rights and interests of stakeholders. Third, when the level of free cash flow is relatively high, the convergence effect of management interests will enhance the degree of diversification of enterprises, and a higher quality of internal control environment can restrain this influence. Fourth, in companies with low internal control, the sensitivity of capital allocation efficiency to the degree of diversification is not as significant as that of companies with high internal control. The company's internal control system is a series of activities carried out by managers to better fulfill the entrusted economic responsibility and realize the company's strategy and objectives. The design of the company's internal control system needs cost, and the implementation of internal control needs to follow the principle of cost-effectiveness. In the weak corporate governance environment, the internal controller, in order to safeguard his own interests or self-interest behavior, causes the implementation cost of internal control to be higher. Therefore, internal control, as a mechanism embedded in the company, should establish a self-reinforcing mechanism. The formulation of the company's internal control system is a common rule endogenous through the interaction of the company's participants, and the implementation of internal control is the principle of "spontaneous order" and "self-implementation." The company's internal control constantly adapts to the environmental changes it faces. This study provides pointers for an in-depth analysis of the relationship among capital allocation efficiency, free cash flow level, internal control governance, and diversification strategy in China's transitional economy.

As Chinese listed companies do not pay enough attention to internal control, this study analyzes the relationship between capital allocation efficiency and diversification from the perspective of internal control, revealing the positive role of internal control on investment decision-making, and points out that there is a difference between the efficiency of capital allocation and the degree of diversification among different internal control quality groups. The same can be said for the impact. The results of the regression analysis show that strengthening internal control management is effective for investment decision-making and capital allocation of the company. It can not only reduce the long-standing agency problem but also help the management in reducing the sunk cost caused by poor

allocation of resources. The results of this study have a practical significance for China's listed companies in standardizing their internal control. It also contributes towards standardizing the evaluation system of internal control, unifying the basic standards of internal control for the whole industry, and attaching importance to the quality of internal control. In this study, internal governance and internal control are introduced into the same empirical research framework, and their impact on strategic decision-making is investigated. The influence of corporate governance and internal control on corporate strategy implementation is clarified. It is found that there is a complementary relationship between them, which has a positive role in promoting research on the quality of internal control and strategic decision-making and points out the potential relationship between capital allocation efficiency and strategic decision-making.

6.1. Research Limitations. This study considers only the long-term incentive mechanism effect in the empirical analysis of corporate internal governance factors, and other factors such as supervision mechanism have not been fully considered. In the future, scholars can add external environmental factors and enterprise risk control. Diversification is a long-term development strategy of enterprises. The five-year sample data span considered is too short. Future studies could investigate whether diversification can achieve improvements in resource allocation efficiency and profitability by considering a longer sample period.

6.2. Future Research Direction. With the continuous rise of enterprise diversification strategy and the development of M&A business, the efficiency of capital allocation and strategic development have become hot issues in academic circles. In order to cultivate collectivized enterprises, our government advocates improving the efficiency of capital allocation, constantly supports enterprises to set up enterprise groups, takes the road of collectivized development, and encourages groups to be listed on the stock market as a whole. Therefore, the capital allocation efficiency of listed companies, especially conglomerates, has a broad research space. In the future, we can make further research from the following aspects: what kind of internal institutional environment is needed for the capital allocation efficiency of listed company groups, how to better play the allocation role of internal capital market, and how corporate governance factors affect the capital allocation efficiency and strategic decision-making [53, 61].

Data Availability

Panel data from the Shanghai and Shenzhen stock markets from 2013 to 2017 were used.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Retraction

Retracted: Can Swimming Teaching Prevent Drowning? An Experimental Study of Children in China

Discrete Dynamics in Nature and Society

Received 23 January 2024; Accepted 23 January 2024; Published 24 January 2024

This article has been retracted by Hindawi following an investigation undertaken by the publisher [1]. This investigation has uncovered evidence of one or more of the following indicators of systematic manipulation of the publication process:

(1) Discrepancies in scope

(2) Discrepancies in the description of the research reported

(3) Discrepancies between the availability of data and the research described

(4) Inappropriate citations

(5) Incoherent, meaningless and/or irrelevant content included in the article

(6) Manipulated or compromised peer review

The presence of these indicators undermines our confidence in the integrity of the article's content and we cannot, therefore, vouch for its reliability. Please note that this notice is intended solely to alert readers that the content of this article is unreliable. We have not investigated whether authors were aware of or involved in the systematic manipulation of the publication process.

Wiley and Hindawi regrets that the usual quality checks did not identify these issues before publication and have since put additional measures in place to safeguard research integrity.

We wish to credit our own Research Integrity and Research Publishing teams and anonymous and named external researchers and research integrity experts for contributing to this investigation.

The corresponding author, as the representative of all authors, has been given the opportunity to register their agreement or disagreement to this retraction. We have kept a record of any response received.

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[1] S. Zhang, J. Dai, and Z. Nie, "Can Swimming Teaching Prevent Drowning? An Experimental Study of Children in China," *Discrete Dynamics in Nature and Society*, vol. 2022, Article ID 6141342, 8 pages, 2022.

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Research Article

Can Swimming Teaching Prevent Drowning? An Experimental Study of Children in China

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Background. The drowning death rate of Chinese students ranks among the top three in the world, and drowning has become an urgent problem for the country and society to solve. *Objective*. To test whether traditional swimming teaching can improve students' knowledge and skills of water safety and reduce the probability of drowning in China. *Methods*. A total of 82 second-grade students in elementary school were selected as experimental subjects, and the repeated measures analysis of variance experiment design was used to carry out the research. *Results*. After the experiment, the swimming safety education model significantly increased the scores of swimming safety knowledge and skills and the difference was statistically significant ($t = 4.060$, 5.325, $P < 0.05$); the attitude and behavior scores decreased, and the difference was statistically significant ($t = -4.392$, -2.201, $P < 0.05$). After the experiment, the swimming safety education model is more effective in teaching swimming safety knowledge, attitude, and behavior than the traditional swimming teaching, and the difference is statistically significant ($t = 2.699$, 3.852, 4.308, $P < 0.05$). After the experiment, when the traditional swimming teaching model is compared with the control group, the difference in swimming safety skills was statistically significant ($t = 4.704$, $P < 0.05$) and other dimensions were homogeneous. In conclusion, the traditional swimming teaching can only improve student's swimming safety skills but cannot reduce student's drowning injuries. The swimming safety education model is superior to the traditional swimming teaching in terms of swimming safety knowledge, attitudes, and behaviors. *Recommendations*. For beginners in swimming, the teaching content of swimming self-rescue skills and swimming safety knowledge should be added.

1. Introduction

Drowning is a public problem that affects the health of children around the world [1], and it is also the second leading cause of death for primary school students after traffic accidents [2, 3]. According to the results of the Global Burden of Disease (GBD) in 2016, the number of drowning deaths in China in 2016 was about 63,724, accounting for 21% of the global drowning deaths [4] and the drowning death rate ranked second in the world [5], while the actual number of drowning deaths may be far more than statistical data [6]. In the prevention of student drowning, some scholars believe that education is one of the most effective means with the least investment [7]. In order to prevent student drowning, the State Council Education Supervision Office issued the first warning in 2019 "Tighten the safety string and resolutely prevent student drowning"; the following year, it issued the first warning of 2020 "Strengthen the work of preventing drowning to ensure safety of students' lives." Child drowning has become a very serious problem in China.

On August 10, 2021, the Ministry of Education, the Ministry of Development and Reform Commission, the Ministry of Finance, the Health Commission, and the State Administration of Market Supervision jointly issued the "Opinions on Comprehensively Strengthening and Improving School Hygiene and Health Education in the New Era" (hereinafter referred to as "Opinions") requirements, the "Opinions" pointed out "Advocate science, respect life, guide students to actively learn and master daily exercise... cardiopulmonary resuscitation, safe avoidance and emergency care and other knowledge and skills; "At the same

time, the "Opinions" also pointed out "Encourage the development and application of high-quality first aid skills education and training curriculum resources, build a team of high-level first aid training lecturers, strengthen first aid training for school-age students, and gradually popularize first aid knowledge and skills among teachers and students." [8] Swimming as a "survival skill" [9], under the development strategy of a healthy China and a strong education country, is one of the effective means to prevent student drowning. However, the current academic research on the field of antidrowning education has the following shortcomings.

On the one hand, although the school organizes antidrowning education activities every year, it is subject to the lack of mandatory requirements and guarantees in terms of class hours, teachers, venues, and equipment [10, 11]. The antidrowning safety courses are usually conducted in the classroom, which emphasizes theory rather than practice [12]. On the other hand, some scholars believe that the best way to prevent drowning is to let students learn to swim [13]. However, in the popularization of swimming teaching in China, swimming ability (competitive ability, completion distance, and completion time) is used as the main teaching content and assessment standard, and the teaching content of water safety knowledge or water safety skills is not involved [14], and swimming distance of 25 meters does not seem to improve students' ability to prevent drowning. Therefore, Petrass, Mccool, and others believe that learning to swim cannot be equated to mastering drowning prevention skills. It is also necessary to educate students on swimming knowledge, attitudes, and behaviors [15, 16]. In view of this, this study adopted two types of swimming training content: one is the traditional swimming training content for children's beginners, and the other is based on the traditional swimming training content, adding water safety knowledge content, drowning self-rescue and rescue skills, drowning self-rescue and rescue scenario simulation and drills, etc. This research aims to achieve three goals through water safety education and teaching practice:

(1) Understand the effects of the traditional swimming teaching on improving students' knowledge and skills of water safety and reducing water safety attitudes and high-risk behaviors

(2) Exploring water safety and the impact of educational intervention on the knowledge, skills, attitudes, and behaviors of water safety in elementary school students

(3) Comparing the differences in water safety knowledge, skills, attitudes, and behaviors between the two teaching methods

Our research hopes to master the actual level of Chinese children's primary swimming teaching and build a set of swimming teaching that can improve children's water safety knowledge and skills, change water safety attitudes, and reduce high-risk behaviors of drowning. This study can not only provide theoretical basis for drowning prevention work but also provide practical support for the formulation of children's swimming training plan. This research can not only provide theoretical basis for drowning prevention work but also provide practical support for the formulation of children's swimming training plans.

2. Method

2.1. Concept Definition. In this study, based on the theory of "health, knowledge, trust, and action," education of water safety is defined as: a purposeful educational activity that helps individuals predict, analyze, control, and eliminate hazards in a wading environment. It not only includes self-rescue and life-saving water area safety knowledge and water area safety skills to control and eliminate dangers when accidents occur on the water but also covers swimming safety awareness when predicting and preventing water accidents. Water area safety education mainly includes four dimensions of water area safety knowledge, water area safety skills, water area safety attitudes, and water area high-risk behaviors [17]. The higher the water area safety knowledge and water area safety skills, the better the water area safety attitude. The better the water security attitude, the fewer the high-risk behaviors in the water [18].

2.2. Subjects. Taking a total of 82 students in the second grade of a primary school as the subjects, one group is randomly selected as the control group of 30 (15 males and 15 females); the other is the experimental group A with 27 people (13 males and 14 females), referred to as "swimming group"; a group of 25 people (13 males and 12 females) in experimental group B, referred to as "teaching group."

2.3. Experimental Hypothesis. In previous studies, scholars have found that China's swimming teaching lacks the training or drills of drowning self-rescue and rescue skills [19]. In dealing with accidental drowning emergency response capabilities, most students do not lack the ability to swim, but they lack swimming self-rescue ability [20]. Students' swimming safety awareness is weak [21], and the traditional swimming teaching emphasizes competition and neglects practicality [22]. The increase in swimming distance may not reduce the risk of drowning but will increase the probability of drowning [23], because simple swimming teaching does not include prevention [24] Only by teaching the "prevention of drowning" skills during swimming can students truly "prevent drowning" [25]. In addition, the Australian Life Rescue Association believes that every child should have a high-quality "water safety education program," which includes swimming survival and rescue skills and water safety knowledge [26]. Later, Xia Wen built a KSAP water area safety education model based on the theory of health, knowledge, belief, and behavior and believed that the improvement of water area safety knowledge and water area safety skills will change students' attitudes towards swimming safety, thereby reducing students' high-risk behaviors in water areas [27].

Based on the above research results, this research proposes two hypotheses:

(1) The teaching group can improve students' knowledge and skills of water area safety, change students' attitudes towards water area safety, and reduce high-risk behaviors in water areas

(2) Compared with the swimming group, there is a significant difference in the children's effect on reducing high-risk behavior in the water.

2.4. Experimental Design. This experiment uses a repeated measurement mixed experimental design of 3 (control group, swimming group, teaching group) × 2 (male, female) × 2 (pretest, posttest) method. Domestic and foreign research results show that the probability of drowning in men is higher than that in women [28, 29]. In order to obtain better internal validity and avoid the interaction between gender and experimental treatment affect the experimental results, this experiment controls gender as an intervention variable. At the same time, in order to examine the effectiveness of the experimental treatment, the comparison between the control group, the swimming group, and the teaching group was carried out before and after the "KSAP Scale for Primary School Water Safety" experiment using repeated measures analysis of variance.

2.5. Experimental Materials. In this study, based on the MORAN "KAB Mode" and TEVFIK "KSAB Mode" [30], Xia Wen compiled a localized "KSAP Scale of Water Safety for Primary School Students" [18], which included 10 questions about water safety knowledge, for example, do you know common swimming safety signs? (1: very clear; 5: very unclear); 9 questions on water safety skills, for example, can you tread water in the water? (1: very familiar; 5: very unfamiliar); 10 questions about swimming safety awareness, for example, go swimming with classmates, it doesn't matter if there are no adults nearby (1: strongly agree; 5: strongly disagree); 10 questions about high-risk behaviors in the water, for example, ran to the pool alone to play (1: always do this; 5: never been). This question and answer survey uses a 5-point Likert scale to score points. Among them, the higher the scores of water safety knowledge and skills, the higher the degree of mastery; the water safety attitude and high-risk behaviors adopt the rhetorical method. The higher the score, the worse the water safety attitude and the higher the incidence of high-risk behaviors in the water. This scale is an advanced scale. Cronbach's α coefficient of the total scale reaches 0.934, and it has been used by many people [31, 32]. The reliability coefficient of Cronbach's α in this study is 0.827.

2.6. Experimental Procedure

2.6.1. Pretest. Both the control group and the experimental group participated in the pretest, and the content of the test was the KSAP Scale for Water Safety in Primary Schools.

2.6.2. Experimental Intervention. The experiment was conducted by a head coach and two assistant coaches (1 male and 1 female). The head coach was responsible for the formulation and implementation of the swimming teaching plan, and the assistant coach followed the arrangements of the head coach to ensure the safety of the students. To prevent the Hawthorne effect, this experiment uses a single-blind design. In order to prevent teachers from mutating the results of the experiment, the experiment is guaranteed to be carried out by the same group of coaches. "Swimming Group" class time is Monday, Wednesday, and Friday (15:30–17:30), "Teaching Group" class time is Tuesday, Thursday, and Saturday. The class time on Tuesday and Thursday is 15:30–17:30 and on Saturday, the class time is 09:00–11:00. The experimental group has 12 classes, which are the same as the traditional children's swimming training class. Each class is 90 minutes, and students have 30 minutes to take a bath and change clothes. The swimming pool is indoor with a constant temperature of 28 degrees. The students are sent to the swimming pool by the school teachers. The specific experiment content and format are as follows: (1) The "control group" normally attends classes without any intervention. (2) The training content of the "swimming group" is the summer traditional breaststroke teaching content. 1–3 lessons are carried out in shallow water areas with breathing, body position, and breaststroke leg training; 4–6 lessons are carried out with buoyancy sticks and back floats in deep water areas in Breaststroke Legs, Breaststroke Hands, and Breaststroke Exercises; after 7 classes, according to the students' mastery, back-off float or buoyancy bar training is carried out. There is no swimming ring during the training process, which is the same as the children's summer swimming teaching content. (3) The "teaching group" will learn about water safety knowledge for 15–25 minutes in each of the first six classes. In addition to the traditional breaststroke hands and legs exercises and cooperation with teaching, they will also perform self-rescue skills such as treading water and prone floating.

The swimming teaching experiment is done for nearly a month; the researchers will arrive at the scene every day to observe the subjects and communicate closely with the coaches during and after class to ensure that the activities are carried out in an orderly manner under safe conditions. In addition, this study distributed a copy of the "Informed Consent" to all parents of the subjects.

2.6.3. Posttest. At an average interval of 15 days, both the control group and the experimental group participated in the posttest and the test content was consistent with the pretest.

2.7. Statistical Methods. According to the pretest and posttest scores of each student in the "KSAP Water Safety Scale for Primary School Students," Excel 2018 version for data statistics, SPSS 23.0 version for repeated measures analysis of variance, independent sample t-test, paired sample t-test are used and the differences between before and after intervention are compared.

3. Research Results

3.1. Before and After Score Comparison. In order to test the effect of the water area safety education teaching model on students, descriptive statistics and repeated measures analysis of variance were performed on the preteaching and postteaching test scores of the control group and the experimental group. See Table 1 for details.

The data in Table 1 show that the main effect of time is statistically significant in the dimensions of safety knowledge and safety skills ($P < 0.05$); the main effect of gender is statistically significant in the dimensions of safety knowledge, safety attitudes, and dangerous behaviors ($P < 0.05$). The main effect of group and the interaction effect of time × group are statistically significant in the dimensions of safety knowledge, safety skills, safety attitudes, and dangerous behaviors ($P < 0.05$).

3.2. Simple Effect Test of the Interaction between Time and Group. In order to further explore the interaction between time and group and clarify the experimental treatment effect, a simple effect test was carried out on the interaction effect between time and group in each dimension. The results are shown in Table 2.

The results of the data in Table 2 show that at the first level test (pretest), the differences in the simple effects of each dimension are not statistically significant ($P > 0.05$), indicating that the control group and the experimental group are basically homogeneous; at the second level test (posttest), comparing the control group and the swimming group, the differences in safety knowledge and safety skills were statistically significant ($P < 0.05$) and the differences in safety attitudes and dangerous behaviors were not statistically significant ($P > 0.05$), indicating that the swimming group can improve swimming safety skills. The skill dimension is better than of the control group, and the other dimensions are homogeneous with the control group; the comparison between the control group and the teaching group shows that the differences in each dimension are statistically significant ($P < 0.05$), indicating that each dimension of the teaching group is better than of the control group and swimming group. Compared with the teaching group, differences in safety knowledge, safety attitudes, and dangerous behaviors were statistically significant ($P < 0.05$), indicating that the teaching group is better than the swimming group in the three dimensions of safety knowledge, safety attitudes, and dangerous behaviors.

3.3. Time Simple Effect Test. The data results in Table 3 show that the control group has no statistically significant difference in each dimension in the simple effect test of the pretest and posttest time ($P > 0.05$); the swimming group has statistically significant differences in safety skills in the simple effect test of the pretest and posttest time ($P < 0.05$), and the differences in the other three dimensions were not statistically significant ($P > 0.05$); the difference in each dimension of the teaching group was statistically significant in the simple effect test of the pretest and posttest time ($P < 0.05$). This result shows that the teaching group is better than the swimming group and the control group in the dimensions of safety knowledge, attitude towards group safety, and dangerous behaviors.

4. Analysis and Discussion

4.1. Reasons for the Insignificant Difference between Gender before and after Test. Due to the active nature of boys and their preference for stimulating games, boys are more likely to rate themselves as "excellent" or "very excellent" swimmers than women. Boys will overestimate their swimming ability and are more likely to engage in high-risk behaviors in waters [33]. Generally, the drowning death rate of men is greater than that of women and even three times that of women [34]. In this study, the gender main effect has significant differences in water safety knowledge, water safety attitudes, and high-risk behaviors between men and women. This shows that girls have a higher level of knowledge about water safety than boys and have a stronger attitude towards swimming safety than boys. The risk behavior of engaging in swimming activities is also lower than that of boys. However, in terms of water safety skills, no significant differences between boys and girls were found and boys were even better than girls in terms of water safety skills [35]. In the comparison of the interaction effect of gender and time, it is found that there is no significant difference in the learning ability of male and female students, which is consistent with the research results of Petrass [15], but this contrasts with the research results of Zhang et al. [29]. The reason is that it is related to the biological differences between men and women and changes with age, leading to more and more significant gender differences. For example, in infancy, boys' arousal levels are higher than girls [36]; in childhood, boys' language and body control abilities are lower than girls [37]. During adolescence, boys have higher levels of physical fitness, such as strength, speed, and endurance, than girls. The older you get, the more obvious the difference between boys and girls [38], and their swimming ability will be overestimated. This may be the reason why the gender difference in childhood is not significant, but the gender difference in adolescence is significant.

4.2. Limitations of the Traditional Swimming Teaching. Water safety education is considered to impart knowledge and skills of water safety in foreign countries and can form positive attitudes, concepts, and behaviors of water safety in the water environment [39]. In addition, some scholars believe that water safety education should be carried out when children are 6 years old, so that they can engage in activities related to water under the premise of ensuring safety, and we must provide rescue techniques needed to assist others in water emergencies as much as possible and cardiopulmonary resuscitation skills [5]. However, at present, whether it is swimming training in winter or summer or swimming teaching organized by schools, China is less involved in the learning of water safety knowledge and ability and less concerned about students' water safety

Table 1: The test results of descriptive statistics and repeated measures analysis of variance before and after the integration of water safety education for primary school students with swimming teaching.

Before and after	Group	Gender	Knowledge	Skill	Attitude	Behavior
Before the experiment	Control group	Male	3.10 ± 0.76	2.65 ± 0.72	3.62 ± 0.85	3.47 ± 1.39
		Female	3.36 ± 0.39	2.61 ± 1.11	2.90 ± 1.12	2.90 ± 1.56
		Overall	3.23 ± 0.60	2.63 ± 0.92	3.15 ± 1.28	3.17 ± 1.48
	Swimming group	Male	3.16 ± 0.90	2.76 ± 0.71	3.53 ± 1.27	3.33 ± 1.49
		Female	3.40 ± 0.93	2.55 ± 0.75	3.25 ± 1.71	2.90 ± 1.64
		Overall	3.27 ± 0.90	2.67 ± 0.72	3.55 ± 1.49	3.14 ± 1.54
	Teaching group	Male	3.05 ± 1.02	2.54 ± 0.82	3.69 ± 1.14	3.34 ± 1.33
		Female	3.36 ± 0.85	2.70 ± 1.06	3.11 ± 1.23	2.96 ± 1.64
		Overall	3.20 ± 0.93	2.61 ± 0.92	3.41 ± 1.49	3.16 ± 1.46
After the experiment	Control group	Male	3.15 ± 1.03	2.53 ± 0.88	3.43 ± 1.44	3.40 ± 1.36
		Female	3.39 ± 1.17	2.75 ± 1.27	2.90 ± 1.12	2.98 ± 1.40
		Overall	3.27 ± 1.09	2.65 ± 1.08	3.15 ± 1.28	3.18 ± 1.36
	Swimming group	Male	3.30 ± 0.93	3.75 ± 0.23	3.81 ± 1.28	4.02 ± 0.70
		Female	3.92 ± 1.10	3.66 ± 0.88	3.25 ± 1.71	3.22 ± 1.35
		Overall	3.59 ± 1.04	3.71 ± 0.61	3.55 ± 1.49	3.65 ± 1.10
	Teaching group	Male	4.20 ± 0.79	3.87 ± 0.52	2.47 ± 0.73	2.30 ± 1.25
		Female	4.46 ± 0.64	3.86 ± 0.49	1.96 ± 0.68	1.96 ± 1.28
		Overall	4.32 ± 0.72	3.87 ± 0.49	2.22 ± 0.74	2.14 ± 1.25
Main effect of time (F)			10.953*	35.349*	2.641	0.512
Gender main effect (F)			3.965*	0.01	7.327*	4.009*
Group main effect (F)			3.151*	5.701*	3.334*	3.195*
Time × gender interaction effect (F)			0.113	0.84	0.001	0.016
Time × group interaction effect (F)			4.470*	8.565*	3.431*	3.559*
Gender × group interaction effect (F)			0.118	0.246	0.001	0.085
Time × group × gender interaction effect			0.212	0.232	0.009	0.113

Table 2: Time and group interaction simple effect test results (t-value).

Group interaction	Knowledge		Skill		Attitude		Behavior	
	Before	After	Before	After	Before	After	Before	After
Comparison between control group and swimming group	−0.163	−0.987	−0.147	−3.397*	0.068	−0.970	0.066	−1.293
Comparison between control group and teaching group	0.157	−3.671*	0.055	−4.704*	−0.213	2.852*	0.021	2.565*
Comparison between swimming group and teaching group	0.272	−2.699*	0.212	−0.954	−0.294	3.852*	−0.045	4.308*

*The difference is statistically significant ($P < 0.05$).

Table 3: Time simple effect test.

Group	Knowledge		Skill		Attitude		Behavior	
	t	P	t	P	t	P	t	P
Control group before and after	−0.174	0.864	−0.064	0.949	0.452	0.656	−0.025	0.980
Before and after swimming group	−1.217	0.236	−5.862	0.001	−0.562	0.579	−1.435	0.165
Before and after the teaching group	−4.060	0.001	−5.325	0.001	4.392	0.001	2.201	0.040

attitudes and high-risk behaviors in waters. Through the investigation of this research, it is found that the children's traditional swimming teaching cannot improve students' knowledge of water safety nor can it reduce students' water safety attitudes nor can it reduce students' high-risk behaviors in waters. Although the "swimming group" water area high-risk behavior dimension was not statistically different before and after the measurement, the "swimming group" dangerous behavior dimension had a higher score than the previous measurement, which was consistent with the data collected by Kjendlie and the Canadian Red Cross. Generally, people with higher swimming levels are more likely to engage in water-related hazardous activities, which may increase the risk of drowning [40, 41], which is why 69% of drowning people in Canada is due to swimming [42]. There are two main reasons why "swimmers are prone to drowning": First, the improvement of swimming skills will affect the psychological feelings of experienced swimmers. Faced with the temptation of various water activities, they will overestimate their swimming skills. The ability to control the environment [43] is similar to the effect of overconfidence in driving skills on high-risk behaviors. Individuals with high driving skills and overconfidence are more likely to have high-risk behaviors such as overtaking,

speeding, and even drifting [44]. Swimming ability is the same as driving skills. The higher the swimming ability, the easier it is to make dangerous behaviors in the water. The second is related to the coach's teaching methods and the evaluation standards of swimming teaching. Swimming teaching in our country emphasizes competition and neglects practicality, lacks the theoretical study of water safety knowledge, lacks the evaluation standard of water safety skills, lacks the teaching goal of reducing high-risk behaviors in the waters of students, and even lacks the improvement of water safety knowledge and skills and the reduction of students' attitudes towards water safety.

4.3. The Effectiveness and Shortcomings of the Water Safety Education Model in China. Statistics show that the "teaching group" has the best effect on changing students' water safety attitudes and reducing students' high-risk behaviors in waters. The ability to achieve such a teaching effect mainly depends on the effective reference of "healthy knowledge, belief and deeds." In this study, in order to be able to better improve students' knowledge and skills of water safety, one must improve students' attitudes towards water safety and reduce students' high-risk behaviors in waters. Based on the KSAP model [45], the following contents should be included in swimming teaching: ability to launch safely, correct breathing, ability to recognize direction in water, normal swimming ability, ability to safely lift out of water, use of flotation device, ability to adjust direction in water, water area mastery of safety knowledge, and ability to deal with dangers in water [46, 47]. In actual drowning cases, it is not that children's drowning incidents are frequently caused by insufficient swimming skills. More factors are students' lack of knowledge of water area safety, lack of "practical" water area safety skills, improper entry methods, or lack of protection against danger. In addition, water area safety knowledge is considered to be one of the factors that can affect safety attitudes in this model [48], so in the water area safety education model, in addition to adding "practical" water area safety knowledge, theory learning of one hour of water area safety knowledge is also added.

However, this model also has its shortcomings: except for a few outstanding students, most students fail to complete the 25-meter breaststroke without any buoyancy equipment. Although the improvement of swimming ability may increase students' "overconfidence," the 25-meter swimming ability is undoubtedly essential. It is also not good to only teach 25-meter swimming, and it is not good to pay too much attention to swimming self-rescue skills and ignore swimming distance. A more functional explanation is that the ability to swim 25 meters should be regarded as an important content of water safety education [49]. Therefore, in the subsequent swimming training, the teaching time should be increased from the current 8 lessons and 12 lessons to 20 lessons and 25 lessons; in terms of teaching content, the quality of swimming training should be improved and the water area should be increased. Practice and theoretical study of safety knowledge increase swimming self-rescue skills, shore rescue techniques, and cardiopulmonary resuscitation skills; in terms of teaching evaluation, we must build water safety skills evaluation standards, increase government and swimming associations' supervision of swimming training institutions, and ensure that "learn to swim" is equivalent to mastering a survival skill."

5. Conclusion

Through the investigation of this study, it is found that traditional Chinese swimming teaching cannot improve students' knowledge of water safety, nor can it change students' attitude towards water safety and reduce students' high-risk behaviors in water. This shows that traditional swimming teaching cannot reduce the risk of drowning but can only increase the students' mastery of swimming distance. The new swimming safety teaching mode combines theory with practice. In terms of teaching content, the theoretical study of water safety knowledge has been added. In terms of teaching methods, the "encouraging" teaching method of coaches is reduced and more emphasis is placed on students' attitudes towards water safety, thereby reducing students' high-risk behaviors in water.

In addition, Shichao Zhang was a professional swimmer. Through the observation of this study, it is found that swimming coaches often use words of encouragement such as "don't be afraid of water" and "you have to overcome it" to help students overcome the fear of bowing their heads and exhaling in the water. But will this language teaching method make it easier for students to make dangerous actions in the water?

This study hopes that follow-up researchers can use the teaching methods of coaches to try whether the coaches can change the language in the teaching process to reduce the risk of drowning of students.

However, there are still shortcomings: the sample size of the study is small, and only students from Yunnan Province, in China, are selected as the survey objects. Follow-up research can try the influence of children's swimming beginner methods in different regions on improving students' water safety knowledge and skills.

Data Availability

All data, models, and codes generated or used during the study are included within the article.

Disclosure

This research is continuously improved on the basis of the 2021 International Conference on Health Big Data and Smart Sports (HBDSS) in 2021 based on the following link: https://ieeexplore.ieee.org/document/9681109.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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