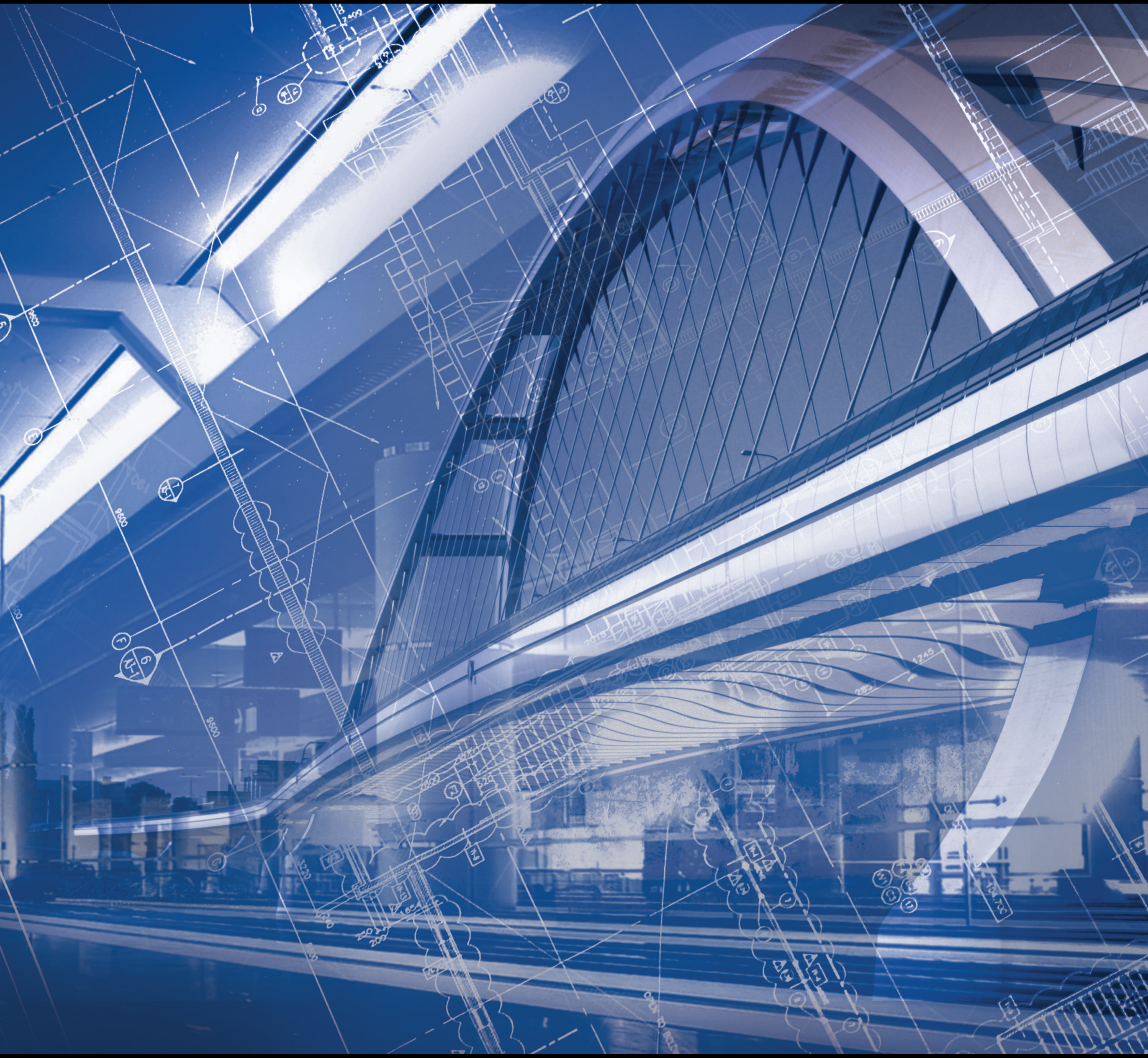
Advances in Civil Engineering

Digital Twins in Civil Engineering

Lead Guest Editor: Zhihan Lv
Guest Editors: Huihui Wang and Konstantinos E. Psannis



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Research Article

Use of Digital Twins-Based Intelligent Navigation Visual Sensing Technology in Environmental Art Design of Scenic Spots

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The study expects to solve the bottleneck problem in the field of intelligent navigation visual sensing and build a network system of information physics, to achieve a visual sensor which can correspond the depth and color of a scene. It aims to improve the robustness and accuracy of color recognition of color structured light in a complex environment. Based on the digital twins (DTs) technology, the effective transformation of logistics process and physical entity to quasi-real-time digital image is realized. The omnidirectional vision sensing technology of a single viewpoint and the panoramic color volume structured light generation technology of a single emission point are integrated. The new active 3D panoramic vision sensor is achieved for which makes the current visual sensing technology developed into the visual perception of body structure. This technology is adopted in the preliminary design of environmental art in the scenic spot, and it can predict the design feasibility of environmental art in the scenic spot, avoid mistakes in decision-making to a great extent and save human and material resources. And also it can analyze and predict some possible dangerous situations, which can greatly improve the environmental safety factor of the scenic spot. In the improvement stage of environmental art design in the scenic spot, using active 3D vision sensing technology can obtain more comprehensive information and is more conducive to the selection of design schemes.

1. Introduction

With the integration and application of a new generation of information technology (such as cloud computing, Internet of things (IoT), big data, and spatial computing) and industry, countries around the world have issued their own advanced manufacturing development strategies to realize the interconnection and intelligent operation of the industrial physical world and the information world so as to realize the intelligent industry. The *Notice on Accelerating the Digital Transformation of State-owned Enterprises* issued by the State-owned Assets Supervision and Administration Commission of the State Council in September 2020 clearly pointed out that it is necessary to use 5^{th} generation mobile communication technology (5G), cloud computing, blockchain, artificial intelligence, digital twins (DTs), BeiDou communication, and other new-generation information technologies to explore and build a new IT architecture modes such as "data center" and "business center" to meet the business characteristics and development needs of enterprises and build an agile, efficient, and reusable new generation of digital technology infrastructure. DTs are to create a virtual model of physical entities in a digital way, simulate the behavior of physical entities in the real environment with the help of data. It adds or expands new capabilities for physical entities through virtual and real interactive feedback, data fusion analysis, decision iterative optimization, and other means. DTs products face the whole product life cycle process, play the role of bridge and link between the physical world and the information world, and provide more real-time, efficient, and intelligent services. At present, the main way for humans to obtain information is vision, and vision can give people intuitive images, which are easy to be accepted and understood. However, the perception of human vision is not unlimited, and as an extension of human vision, visual sensing technology has the advantages of strong adaptability, uninterrupted work, high speed, high efficiency, and objective judgment standard and other advantages. Thus, visual sensors are more and more widely used in all walks of life in contemporary society. With the development of society, visual sensing technology is constantly improving and perfecting, and its role in the environmental art design of scenic spots is also changing, but there are still some technical problems to be solved. For example, how to realize intelligent visual perception has become a key technical problem to be solved urgently in China's social development.

At present, intelligent visual perception technology is facing a bottleneck problem, which is how to improve the signal source quality of the acquired video image. When converting a three-dimensional space scene into a two-dimensional image through the system, important information such as the object point depth and azimuth information will be lost. These will affect the judgment of the real environment. The ideal visual sensing technology can help to obtain the three-dimensional panoramic image "centered on the visitors in the scenic spot" [1]. At present, the technology for which is widely used in product quality detection, target detection and tracking, reverse engineering, obstacle detection, robot positioning, and navigation is called passive stereo vision perception technology. It has many advantages, such as simple structure, rich information, and convenient use. However, there is a bottleneck problem in the field of computer vision, that is, how to improve the accuracy of binocular stereo matching and analyze and calculate quickly. The effective way to solve this problem is to use active vision technology instead of passive stereo vision perception technology [2, 3]. But, there is still an urgent problem to be solved in active vision technology, that is, how to improve the accuracy and robustness of color recognition of color structured light in complex environments.

The study mainly explores the following two aspects: (1) combined the omnidirectional vision sensor and panoramic color structured light generator, it makes the current visual sensing technology be further developed into the visual perception of body structure; (2) through research, the accuracy of color recognition of projected light in the environment is further improved, achieving the panoramic vision sensor with scene depth corresponding to color one by one. Based on the above studies, it greatly improves the visual perception of visual sensing technology and more effectively applies it to the design of environmental art in scenic spots.

2. Materials and Methods

The active 3D panoramic vision sensor is obtained by combining ODVS (omnidirectional vision sensor) and PCSLG (panoramic color structured light generator). Through the application of ASODVS (active stereo omnidirectional vision sensor) in practice, it can obtain the color map and scene depth corresponding to the actual environment.

The omnidirectional vision sensor with a single viewpoint and the panoramic color volume structure light source with a single emission point are fused, and a certain connection mode is adopted to assemble them on the same main axis. According to the relevant working principle of ODVS and the relevant definition of epipolar geometry, the radiation whose origin is the center point of the panoramic image can correspond to the epipolar line of the stereo image pair obtained by ODVS. Through the above methods, it can become a constraint condition for stereo matching [4]. The active stereo vision can simplify the epipolar matching step in passive panoramic stereo vision. Because the color light is emitted by PCSLG and the reflected light is received by ODVS are on the same epipolar plane and also because the used technology is time-sharing control technology, when the power supply state of the light source of panoramic color projection is inconsistent, the color of the collected object points is also different. When the power state is ON, the color information in the object point A contains the information of the projected light source; when the power state is OFF, the color information of the object point B is that of the object point itself [5], as shown in Figure 1.

2.1. DTs. Based on the development of DTs technology, remarkable results have been achieved in various industries. Meanwhile, it effectively accommodates various technologies such as big data technology, 5G technology, and artificial intelligence technology so as to promote China's construction to a new level, as shown in Figure 2.

Generally, it is considered that the information between the human interaction interface and the database needs to be retrieved or interconnected, which can break the information isolation more conveniently and timely. Nowadays, with the development of related technologies, the industrial IoT as a DTs communication system has been realized. The application of this technology is more conducive to realize the real-time and intelligent independent access, and effectively collect and analyze the process, service information, and products in the actual industrial environment. The industrial IoT is connected by multiple communication software. Based on this, it can also realize the required operations such as monitoring, exchange, collection, and analysis of the information at the equipment layer and at all levels on the equipment layer network. In practice, enterprises can use sensors, software, and mechanical learning at the same time, and realize the collection and analysis of physical objects and other related big data flow data in the application of a series of technical means. After that, the data can be managed and operated after the collection and analysis are completed.

The above is an overall description of the DTs application technology, which will give more new vitality to the environmental management system of the scenic spot. Later, a virtual digital environment will be built based on this technology to realize the seamless switching of multiple applications of the environmental management system of the scenic spot.

2.2. ODVS Structure Analysis. As one of the components of an active 3D panoramic vision sensor, an omnidirectional

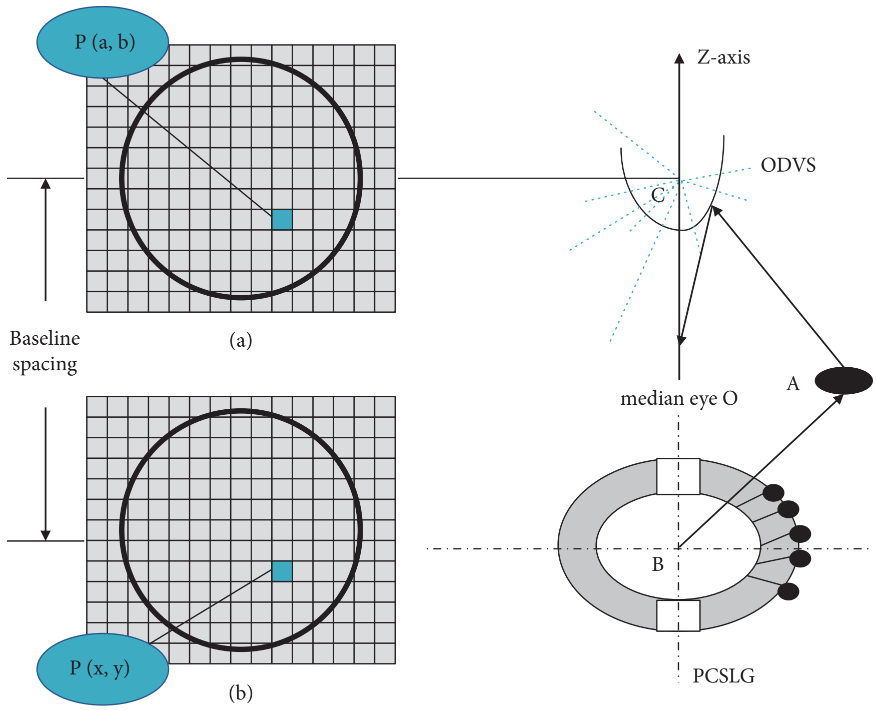

FIGURE 1: Active stereo panoramic vision sensor model. O_v—single view of omnidirectional vision sensor (ODVS); O_p—single reflection point of panoramic color structured light generator (PCSLG); baseline distance—the distance between a single viewpoint O_v and a single emission pointO_p; central eye O-midpoint of baseline distance; A—a certain object point in space. The positions of *a* and *b* determine the incident angle, the color of *P* (a, b) determines the projection angle, the position of *x* and *y* determines the incident angle, and the color of *P* (*x*, *y*) determines the actual color of the object point in space. Figure 1(a) shows a schematic diagram of the image ON the panoramic vision sensor when the power supply of the color panoramic projection light source is ON. Figure 1(b) presents the image schematic on a panoramic vision sensor when the power of the color panoramic projection light source is OFF.

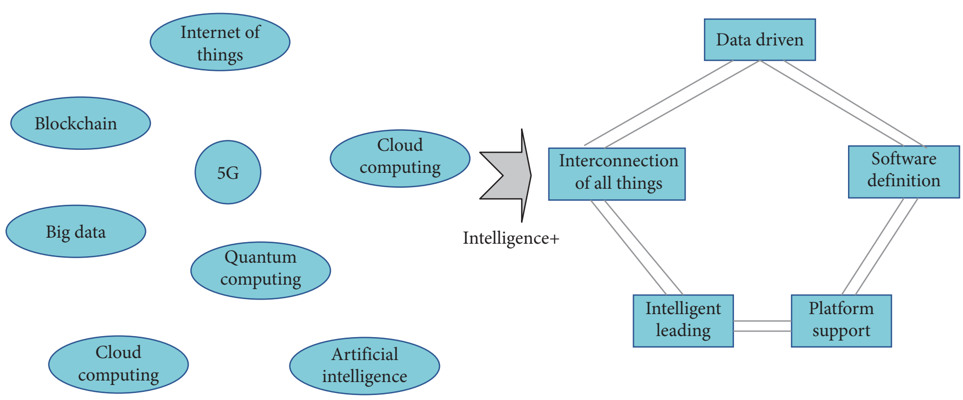

FIGURE 2: Concept map of DTs technology.

vision sensor can collect the video information of the whole environment and further analyze it through the system. This design adopts the single view imaging method, which has the advantage of ensuring the image unique for which is formed by perspective at any point in the scene, and it makes the whole process conforms to the imaging principle [6, 7]. Then in practice, knowledge for the relevant parameters of the omnidirectional vision sensor is enough. Based on this, the incident angle information of any point in the scene by inverse operation can be calculated.

When placing the perspective camera, it should be noted that the optical center and the focus O_c of the mirror should be placed to keep them coincident.

The optical imaging process of ODVS can be expressed by equations (1)–(5):

$$\frac{(Z-c)^2}{b^2} - \frac{X^2+Y^2}{a^2} = 1, \quad (1)$$

$$a^2 + b^2 = c^2, \quad (2)$$

$$\beta = \tan^{-1}\left(\frac{Y}{X}\right) = \tan^{-1}\left(\frac{y}{x}\right), \tag{3}$$

$$r = \tan^{-1}\left(\frac{2c - Z}{\sqrt{X^2 + Y^2}}\right), \tag{4}$$

$$a = \frac{\pi}{2} - \tan^{-1}\left[\frac{\left(b^2 + c^2\right)\sin\gamma - 2bc}{\left(b^2 + c^2\right)\cos\gamma}\right]. \tag{5}$$

X, Y, Z are the space point coordinates of points on hyperboloid; x, y are the imaging point coordinates; c is the distance between focus and origin of hyperboloid mirror; $2c$ is the distance between two focal points; a, b are the length of real and imaginary axes of hyperboloid mirror; $ß$ is the included angle of incident light on the knife projection plane; λ is the angle between the incident light and the horizontal plane; α is the angle between the principal axis of the hyperboloid and the catadioptric light of the space point. The imaging principle of a single viewpoint is shown in Figure 3.

As Figure 3 suggests, point P is generated after object point G is imaged through hyperboloid, and then the camera optical center point O_c is formed through reflection. Then an intersection is generated after intersecting with the imaging plane, which is set as the point Q. After the main axis of ODVS intersects with the reflected light at the point Q an included angle is generated, for which is set as α. After the incident light intersects with the reflected light at a point Q on the plane, an included angle xy will also be generated, which is set as β. If β and λ are known in practice, the incident light GP can be further obtained. The camera position of the omnidirectional vision sensor is placed behind the hyperboloid mirror, and the camera lens is placed at the virtual focus generated by the catadioptric mirror. The advantage is that it can monitor most object points in real time [8].

Before calculating the depth of the object point, it is necessary to determine the incident angle of the corresponding light, which can be determined by calibrating the position of the pixel in the panorama [9].

The imaging steps of single view ODVS are as follows: first, the light is transmitted to the sensor plane through the mirror, then to the image plane, and then the image is integrated and analyzed. However, the following two planes must be considered: Image plane $(u, v$ and sensor plane $(u'', v''$. Suppose the observation point is projection point of X, then point u'' is the projection point of X for which is generated on the plane of the camera. Set the coordinates of the point u'' to

$$u'' = \left[u'', v''\right]^T, \tag{6}$$

$u\prime$ is a point on the image plane corresponding to point u'', and its coordinates are

$$u' = \left[u', v'\right]^T. \tag{7}$$

The imaging model is constructed according to the principle of single view imaging, as shown in Figure 4.

In the actual operation process, due to various reasons, it can lead to a certain degree of error between the approximate collinearity of the camera focus and the mirror axis. Further, a certain offset occurs between the sensor center point O_c and the image center point I_c. The relationship between the sensor center point O_c and the image center point I_c can be expressed by

$$u'' = Au' + tu''. \tag{8}$$

In (8), $A\varepsilon R^{2*2}$- fixed transformation matrix; $A\varepsilon R^{2*1}$-translation vector. In Figure 3, the midpoint A and the center point O together form a vector P'', and the space vector $P\prime\prime$ generates a projection through the optical center point C Point X is projected through the plane u''. It is assumed that the relationship between spatial point X and spatial vector $P\prime\prime$ can be described by

$$\exists\varphi > 0:\ \varphi\begin{bmatrix} x'' \\ z'' \end{bmatrix} = \varphi\begin{bmatrix} h\left(\|u''\|\right)u'' \\ g\left(\|u''\|\right) \end{bmatrix} = PX. \tag{9}$$

In (9), the projection matrix of $P\varepsilon R3 \times 4$ and the function g describes the mirror shape. The function h can describe the relationship between u'' and $|h(|u''||)u''$. All the above functions are related to the parameters of the catadioptric mirror of the camera.

Saramuzza further explained functions h and $|g$ based on the perspective projection model, and proposed that function $f = (g/h)$ can be added to replace function h, g. Then the equation can be changed to

$$\exists\varphi > 0:\ \varphi\begin{bmatrix} x'' \\ z'' \end{bmatrix} = \varphi\begin{bmatrix} u'' \\ f\left(\|u''\|\right) \end{bmatrix} = PX. \tag{10}$$

Assuming that function f has rotational symmetry and that the plane where the catadioptric mirror and the sensor are located is perpendicular to the camera lens, the error between the approximate collinearity of the camera focus and the mirror central axis described above can be compensated. Taylor polynomials [10, 11] can be used in functional representation, specifically shown as

$$f\left(\|u''\|\right) = a_0 + a_1\|u''\| + a_2\|u''\|^2 + \cdots + a_N\|u''\|^N, \tag{11}$$

where $\|u''\|$ is the distance from sensor plane point to sensor center point O_c.

The parameters in the above equation include $A, t, a_0, a_1, \ldots, a_N$, the above parameters can be solved by using the relationship between a given reference point and the corresponding imaging point. The incident angle of each pixel in the panoramic picture can be obtained through equation (12) and the relevant parameters of ODVS. The specific equation is as follows:

$$\tan\varphi = \frac{f\|u''\|}{\|u''\|} = \frac{a_0 + a_1\|u''\| + a_2\|u''\|^2 + \ldots + a_N\|u''\|^N}{\|u''\|}. \tag{12}$$

2.3. PCSLG Structure Analysis. The panoramic color structured light generator is an important part of ASODVS. It can obtain more three-dimensional information from a given

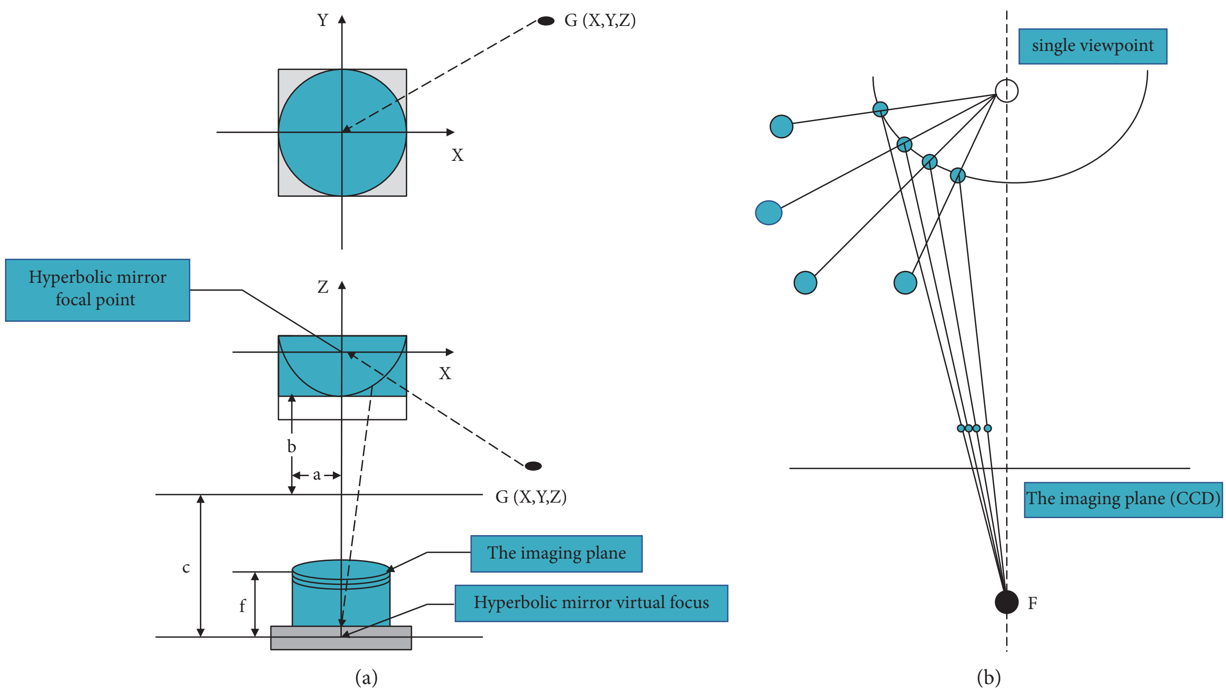

FIGURE 3: Schematic diagram of omnidirectional vision sensor with a single viewpoint. (a) ODVS structure; (b) single view constraint properties in ODVS.

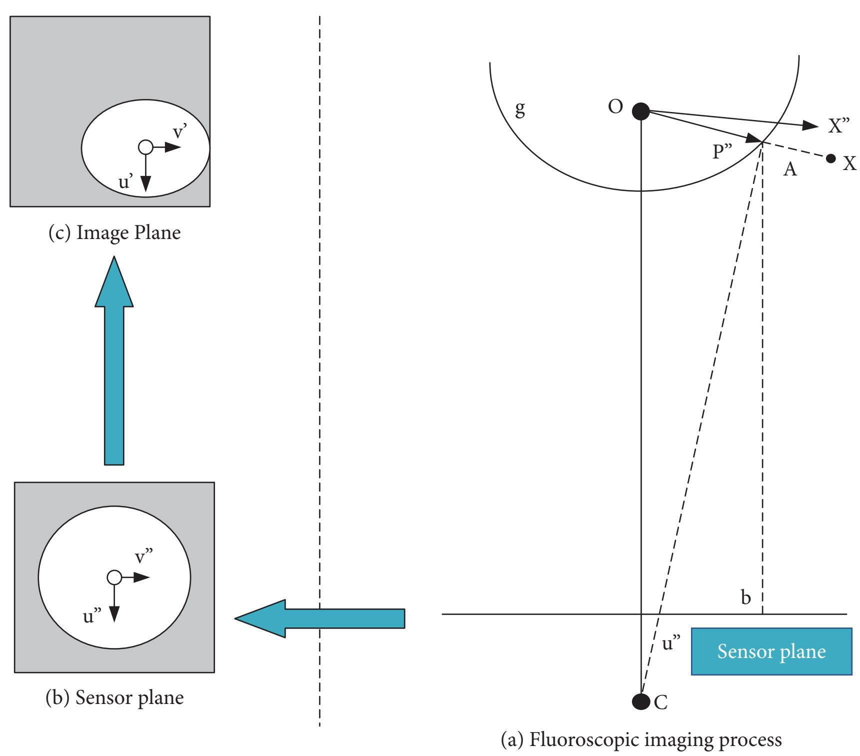

FIGURE 4: Single view imaging model.

image under the problems of object point matching and simplifying sensor calibration [12, 13]. The panoramic color structured light generator used is a single emission point. The reason for using a single emission point is that it can solve the problems of accuracy, real-time, and robustness in the field of visual sensing technology [14].

PCSLG can be realized in the following three methods: (1) after fusing the mirror where the catadioptric reflection is located with the shape wavelength variable filter when a visible light source with white color is used to irradiate any focus placed on it. The color peak wavelength of each circular wavelength variable filter emitted along different angular positions of the circular substrate will show a linear variation relationship. Panoramic color light coding will be formed after refraction or reflection through the plane. At this time, each color peak wavelength aperture will correspond to a unique projection angle. Although the normal of each LED light will pass through the center of the spherical body, the color and wavelength of the light emitted by different LED lights are different. Therefore, they can be placed on different longitude and latitude lines of the spherical surface. At this time, the light wavelength generated by LEDs of different colors will correspond to a projection angle. Method (3) is similar to the method (2), but the slight difference is that because the laser semiconductor has the advantages of long propagation distance and good performance, the laser semiconductor is selected to replace the LED as the emission light source, but the basic principle has not changed [15].

The study verifies the influence of LED lamps on brightness under different wavelengths and chromaticity through experiments [16]. Red and blue LED lights are used to illuminate the wall, respectively, and measure the points in the aperture emitted by the LED lights. The specific experimental process is shown in Figure 5.

The red "×" in the figure is the set measuring point.

2.4. ASODVS Imaging Principle Analysis. The spatial point $A(X, Y, Z)$ is determined by combining ODVS and PCSLG, and the projection angle ap and incidence angle $|ao$ of the point $P(X, Y)$ is determined, that is, the relevant depth information of point $A(X, Y, Z)$ is obtained. Theoretically, the different colors generated by the light source emitted by PCSLG after plane projection will include the color of a pixel in ODVS. By analyzing the color of the light generated by the panoramic color structure light source after plane projection, the projection angle of each pixel ap can be determined. If the calibration parameters of ODVS are known at this time, the incident angle of the reflected light corresponding to the projected light source of the pixel ao can be calculated according to the relevant parameters. The imaging principle of ASODVS is verified through the following examples, place the light emitted by PCSLG at 30° north latitude. It is known that the color of the emitted light source is red and the wavelength is 650 nm. It is refracted and reflected through the object point, and then it is imaged. According to the known correspondence between the color emitted by PCSLG and the projection angle, the analysis shows that the projection angle α_p of the object point is 30°, and the incident angle α_o of the object point can also be calculated according to the calibration parameters of ODVS. At this time, if the baseline distance is known, the distance between the object point and the central eye point can also be calculated according to [17, 18]

$$R = B\sqrt{\left[\frac{\cos(\alpha_p)}{\sin(\alpha_0 + \alpha_p)}\right]^2 + 0.25 + \frac{\cos(\alpha_p)}{\sin(\alpha_0 + \alpha_p)}\sin(\alpha_p)}, \tag{13}$$

where B is the baseline distance; α_p is the incident angle of light; and α_o is the emission angle.

In addition, the azimuth of object points a relative to the central eye β [19] of the active 3D panoramic vision sensor can be calculated.

$$\beta = \begin{Bmatrix} \varphi, & 0 \le \varphi < \dfrac{\pi}{2} \\ \pi + \varphi, & \dfrac{\pi}{2} \le \varphi < \dfrac{3\pi}{2} \\ 2\pi + \varphi, & \dfrac{3\pi}{2} \le \varphi < 2\pi \end{Bmatrix}, \quad \varphi = \arctan\frac{y_p - y_{center}}{x_p - x_{center}}, \tag{14}$$

where $x_p y_p$ is the coordinate values of pixels on panorama; $x_{center} y_{center}$ is the coordinate value of center point pixel.

3. Results

3.1. Experimental Results. The ODVS parameter results obtained through experiments are shown in Figure 6.

In this essay, the calculation method of equation (12) is verified by setting the measured points in the real scene. The experimental environment is shown in Figure 7.

The measured points set in Figure 7 are black spots on the left white wall. The actual incident angle is calculated through the geometric relationship between ODVS and the set pixel points, and the theoretical incident angle is calculated according to the relevant parameters of ODVS. Record relevant data as shown in Figure 8.

Figure 8 presents that the difference between the theoretical incidence angle and the actual incidence angle is not large, and the resulting absolute error is relatively small. Figure 8 is drawn using the data measured after illumination with red and blue LED lights. The test data of red and blue LED lamps under different brightness are shown in Figure 9.

When designing the panoramic color structured light generator, it expects to achieve the ideal effect that the color of the light generated after plane projection will change with the different positions of the emitted light sources. In short, each emission angle generated by PCSLG can correspond to the color generated in the image one by one, as shown in Figure 10.

3.2. Existing Problems. Although many researchers are studying the active vision system, there are still some problems, and no suitable solutions have been found. For example, the current technology cannot recognize the color of projected light in a more complex environment. Through further research, in the future, the projection angle can be determined according to the corresponding relationship between the color and the projection angle of the projection light source and the color recognized in the image [20–22]. However, this is only an expectation, and it is difficult to achieve this effect in practical application. The reflected light received by any pixel in ASODVS will contain the following two aspects of information: color information of projected

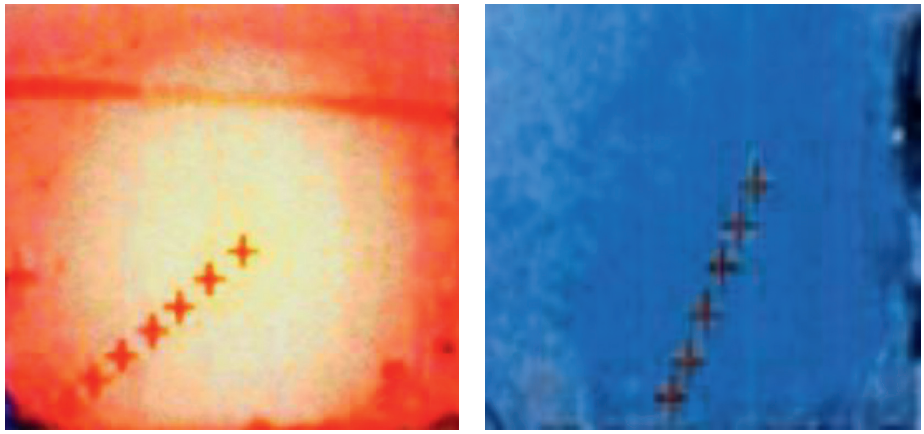

Figure 5: Scene illuminated by LED lights of different colors. (a) Red LED light; (b) blue LED light.

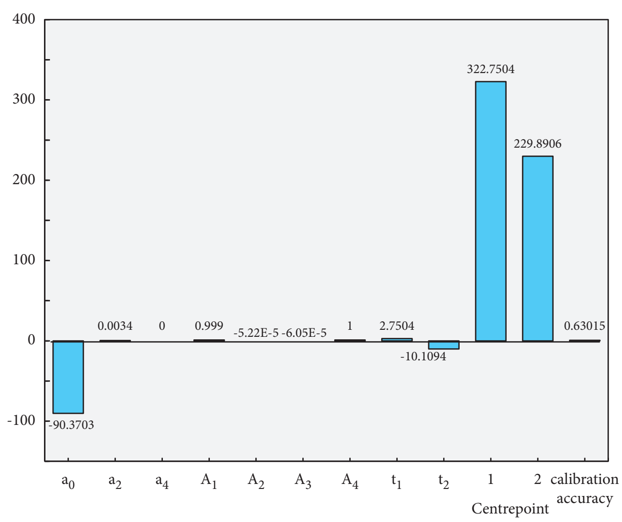

Figure 6: ODVS calibration results.

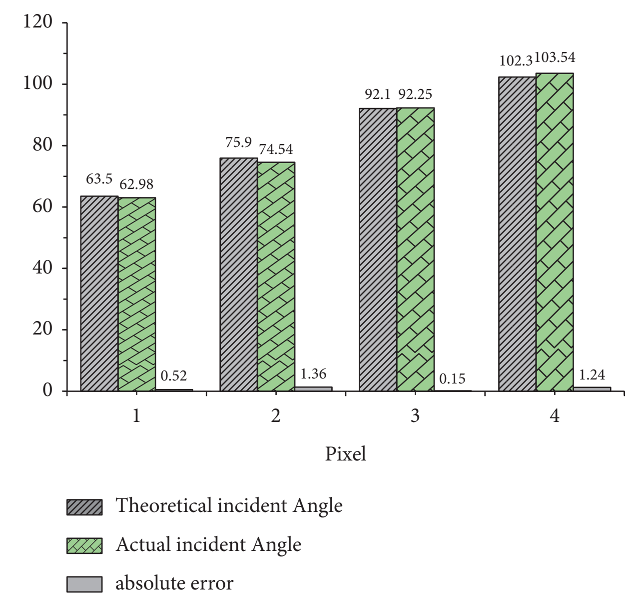

Figure 8: Calculation error of incident angle.

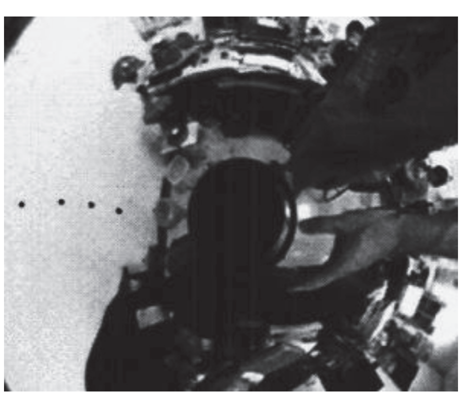

Figure 7: Experimental environment for incident angle verification.

light (panoramic color volume structured light), object color, and environment color. In addition to the above problems, the recognition of projected light color will also be affected by factors, such as the coupling difference between imaging equipment and projection equipment. Therefore, in practical application, in order to obtain the spatial position attribute (such as object point depth), it is expected to avoid the interference of other factors, and the obtained color information of light is relatively accurate.

3.3. Application. The application of visual sensing technology in the environmental art design of scenic spots is not limited to a certain stage, but it is interspersed with the whole design process [23–26].

In the early stage design of environmental art in the scenic spot, any small mistake in the early stage may cause a waste of various human and material resources. If we only rely on manpower to estimate the indicators, there will inevitably be some errors, resulting in unnecessary waste of resources. However, if the visual sensing technology is used to predict the design feasibility of environmental art in the

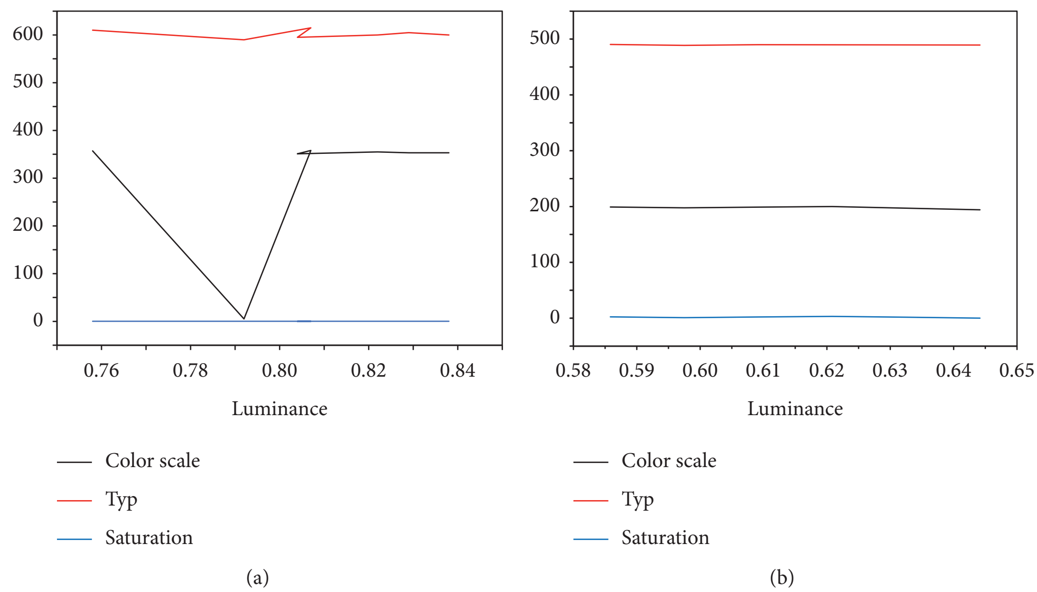

FIGURE 9: Test data of different brightness under different color LED lamps. (a) red LED light; (b) blue LED light.

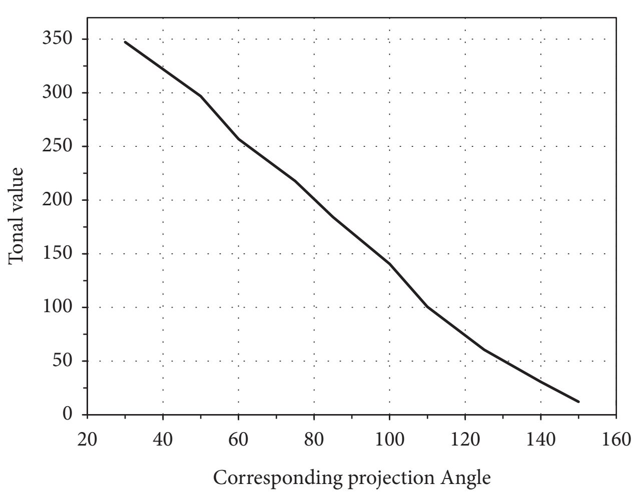

FIGURE 10: Corresponding relationship between hue value and projection angle of PCSLG.

scenic spot in the early stage, it can greatly avoid mistakes in decision-making and save human and material resources. In the early stage of design, the safety of the environmental art project needs to be inspected and evaluated in advance. However, in order to ensure safety, people generally do not experience it in person. Then, visual sensing technology is particularly important at this time. It can detect the environment in real-time, and analyze and predict some possible dangerous conditions, to greatly improve the safety factor of the scenic spot environment.

The design of environmental art in scenic spots is not achieved overnight. It often needs continuous deliberation, and then improves the problems. In practice, visual sensing technology can be used to compare the scheme design. For example, the water body and greening in the scenic spot design, although these elements are fixed, the feelings of visitors are indeed changing. Another example is large-scale sculpture, visitors will get completely different feelings from different angles, so the use of visual sensing technology can obtain more comprehensive information, which is more conducive to the selection of design schemes.

Through the DTs application technology, the top-level planning of the energy management system can replan the matching relationship such as pipeline layout and energy type in the holographic mirror display environment and can also be integrated with additive manufacturing. This will shorten the construction cycle of remote diagnosis, operation, and maintenance upgrading of the energy management system. The data information of each energy equipment can be presented in the DTs system, including equipment fault type data, historical data, and real-time data. Based on this, the system can be operated and maintained more intuitively to provide support for remote diagnosis and operation and maintenance. The energy management system is a multi-business collaborative, and the future development of the smart park will be more intelligent and digital. As an important part, the energy management system will play an important role in realizing synergy with other management business systems.

4. Conclusion

Human beings perceive the real world through vision and perceive the depth of space objects from the parallax of two eyes. The ideal visual perception device is a large field of vision sensor that can obtain the scene depth and color map corresponding to the actual space object one by one. However, the current imaging technology loses the depth information of the space object in the process of obtaining the image. The stereo vision technology in computer vision can enable machines to perceive the stereo information of objects like humans. Therefore, the stereo vision has become a research hotspot of computer vision.

Based on DTs technology, a new active three-dimensional panoramic vision sensor is realized by combining ODVS with PCSLG, and its architecture and stereo imaging principle is introduced. DTs technology is applied to environmental art design. Through analysis, it can be seen that visual sensing technology is indeed widely used in the environmental art design of scenic spots. On the basis of DTs technology and visual sensing technology, the interpersonal interaction interface can realize the real-time information interaction between all personnel and DTs, which can greatly improve work efficiency, save human, material, and financial resources, and predict some possible dangerous situations in advance. However, in the practical application, the influence of the projected light source and the light in the environment on the object surface illumination model has not been considered, which is still a problem of the active vision sensor. In further research, the above factors need to be analyzed through modeling. There are still many problems to be solved in future research. For example, the current experimental research has not deeply studied the inherent color, ambient natural light, and specular reflection of the object in the case of panoramic vision. Future experimental research needs to solve the problem of rapid differentiation of solid color, conditional color, and light source color of the object in the case of panoramic vision. In the specific implementation, the correction model algorithm needs to be added to the three-dimensional detection algorithm to further improve the accuracy and robustness of light source color detection.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Acknowledgments

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References

[1] G. Peng, B. Chang, B. Xue, G. Wang, Y. Gao, and D. Du, "Closed-loop control of medium-thickness plate arc welding based on weld-face vision sensing," *Journal of Manufacturing Processes*, vol. 68, pp. 371–382, 2021.

[2] F. C. Holsinger, A. C. Birkeland, and M. C. Topf, "Precision head and neck surgery: robotics and surgical vision technology," *Current Opinion in Otolaryngology & Head and Neck Surgery*, vol. 29, no. 2, pp. 161–167, 2021.

[3] S. C. Yun and T. L. Jing, "Intelligent position recognition algorithm for color vision image of medical service robot," *Computer Informatization and Mechanical System*, vol. 3, no. 3, pp. 371–382, 2020.

[4] W. Kong, M. Yang, and Q. Huang, "Hilbert stereo reconstruction algorithm based on depth feature and stereo matching," *Journal of Intelligent and Fuzzy Systems*, vol. 39, no. 5, pp. 8027–8038, 2020.

[5] Y. Zhang, S. Li, X. Cao, and W. Xu, "Time-sharing control of multi-inverter-module parallel system for frequency multiplication," *Journal of Engineering*, vol. 2019, no. 16, pp. 2371–2374, 2019.

[6] H. M. Gregg, G. M. Romolo, L. M. Samuel et al., "Comparison of four views to single-view ultrasound protocols to identify clinically signficant pneumothorax," *Modernization of education*, vol. 23, no. 10, pp. 1170–1175, 2016.

[7] S. Liu, J. Nie, Y. S. Li, and T Yu, "Three-dimensional, isotropic imaging of mouse brain using multi-view deconvolution light sheet microscopy," *Journal of Innovative Optical Health Sciences*, vol. 10, no. 5, pp. 1–7, 2017.

[8] Z. Alam, M. Mohan, K. Pal, and R. Poddar, "Albumin-PEG-based biomaterial for laser-tissue soldering and its real-time monitoring with swept-source optical coherence tomography," *Lasers in Surgery and Medicine*, vol. 53, no. 6, pp. 815–829, 2021.

[9] X. S. Tai and J. X. Hong, "Erratum to: the centre and the depth of the centre for continuous maps on dendrites with finite branch points," *Qualitative Theory of Dynamical Systems*, vol. 16, no. 3, p. 703, 2017.

[10] C. Pietro and C. Gianna, "The functional body: does body representation reflect functional properties?" *Experimental Brain Research*, vol. 238, no. 9, pp. 153–169, 2020.

[11] R. Talebi and S. Izadi, "Investigating surface morphology of Ag-AgCl thin film by scattering pattern at normal and oblique incident angles," *Applied Optics*, vol. 57, no. 36, pp. 10355–10363, 2018.

[12] L. R. Hao, Q. L. Xiao, and S. H. Yuan, "Metasurface cylindrical vector light generators based on nanometer holes," *New Journal of Physics*, vol. 21, no. 12, p. 21, 2019.

[13] K.-M. Lee, C. H. Lin, and C.-H. Lin, "A multiple vehicle object detection algorithm using feature point matching," *The Journal of The Korea Institute of Intelligent Transport Systems*, vol. 17, no. 1, pp. 123–128, 2018.

[14] Q. Yang, Q. Chen, T. Niu, E. Feng, and J. Yuan, "Robustness analysis and identification for an enzyme-catalytic complex metabolic network in batch culture," *Bioprocess and Biosystems Engineering*, vol. 44, no. 7, pp. 1511–1524, 2021.

[15] K. Y. Huang, Y. L. Liu, C. C. Wu et al., "Room-temperature two-dimensional plasmonic crystal semiconductor lasers," *Optics Express*, vol. 29, no. 13, Article ID 19384, 2020.

[16] P. T. Huy, J. Jeong, A. N. Gafurov et al., "Hybrid fabrication of LED matrix display on multilayer flexible printed circuit board," *Flexible and Printed Electronics*, vol. 6, no. 2, 10 pages, 2021.

[17] V. T. Taasti, L. Hong, J. S. Shim, J. O. Deasy, and M. Zarepisheh, "Automating proton treatment planning with beam angle selection using Bayesian optimization," *Medical Physics*, vol. 47, no. 8, pp. 3286–3296, 2020.

[18] A. A. Karetnikov, A. P. Kovshik, N. A. Karetnikov, E. I. Ryumtsev, E. V. Aksenova, and A. V. Svanidze, "Electro-optical response of cells with homeoplanar layers of a nematic liquid crystal with different thicknesses at oblique incidence of light," *Optics and Spectroscopy*, vol. 129, no. 2, pp. 234–238, 2021.

[19] S. Park and A. Carriquiry, "Quantifying the similarity of 2D images using edge pixels: an application to the forensic comparison of footwear impressions," *Journal of Applied Statistics*, vol. 48, no. 10, pp. 1833–1860, 2021.

[20] C. Chen, Y. Wan, and Y. Cao, "Instability of projection light source and real-time phase error correction method for phase-shifting profilometry," *Optics Express*, vol. 26, no. 4, pp. 4258–4270, 2018.
[21] X. Ma, D. Shi, Z. Wang, Y. Li, and G. R. Arce, "Lithographic source optimization based on adaptive projection compressive sensing," *Optics Express*, vol. 25, no. 6, pp. 7131–7149, 2017.
[22] X. Li, G. Yu, N. Wang, D Gao, and H Wang, "Flux projection beamforming for monochromatic source localization in enclosed space," *Journal of the Acoustical Society of America*, vol. 141, no. 1, p. EL1, 2017.
[23] Z. H. Gong, "Research on 3D printing materials used in environmental art design," *IOP Conference Series: Earth and Environmental Science*, vol. 680, no. 1, Article ID 012125, 2021.
[24] L. Lei, W. T. Liu, L. D. Xiao, H Sun, and S Wang, "Environmental protection in scenic areas: traffic scheme for clean energy vehicles based on multi-agent," *Computational Economics*, vol. 52, no. 4, pp. 1069–1087, 2018.
[25] T. Figueiredo Menezes Cavalcanti, C. Pombo Sudré, J. Wesley da Silva Corrêa et al., "Custodians of common bean diversity in Rio de Janeiro state, Brazil: revealing their socioeconomic and environmental profile," *Agroecology and Sustainable Food Systems*, vol. 45, no. 8, pp. 1165–1188, 2021.
[26] Y. Y. Wan, "Research on the application of situational teaching in environmental art design course," *Advances in Higher Education*, vol. 4, no. 2, 59 pages, 2020.

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Research Article

Research on Intelligent Dispatching System Management Platform for Construction Projects Based on Digital Twin and BIM Technology

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Building Information Modeling (BIM) adoption along with the recent emergence of Internet of Things (IoT) applications provides many unique knowledge and decision-making abilities all through the built environment's life cycle. The ability to connect online sensors utilized in surroundings in real time has led to the definition of the Digital Twin (DT) of the Building Design. The goal of Digital Twins is to synchronize the physical world with a virtual platform for seamless management and control of the construction process, infrastructure solutions, environmental monitoring, and other life span processes within building design. Most of the researchers focused on either BIM or DT in the construction of building application. In this research work, a novel hybrid model of Digital Twin-Building Information Modeling (DT-BIM) is proposed. This model does the process of identifying the shortage of resources, analyzing requirement, performing decision, dispatching the resources, and updating all the process in the database with the support of Artificial Intelligence (AI). Hence, this hybrid model provides improved results when compared to the implementation of the individual technology to the same application. The study results revealed that these hybrid technologies help in assisting the dispatch systems in the construction projects to a greater extent.

1. Introduction

The construction industry is already one of the largest industries in the world. By 2030, construction output is expected to increase to $15.5 trillion, an increase of 85%, with China, the United States, and India leading the way and accounting for 57% of total growth worldwide, according to the projection [1]. However, the construction industry is still confronted with four challenges: (1) low profitability and productivity; (2) project performance includes budget concerns; (3) a lack of qualified labor; and (4) sustainability issues. Problems like these will persist for some time. The solution is that digital twins can be used as a testing tool [2]. This technology allows for virtual replicating real-world assets, processes, people, and places to be used for a range of different reasons. Before putting anything into production, organizations use Digital Twins to test new assets and procedures as well as to enhance ongoing operations and train people before putting anything into production in the real world, where any problems will be more expensive and more difficult to fix. BIM (Building Information Modeling) is a promising and well-developed theory for managing major healthcare buildings [3]. 3D building elements in BIM give facility managers an easy-to-navigate visual platform with which to retrieve, analyze, and process many types of data. Building Information Modeling-based facility management has had some success. Basic activity logging for routine maintenance was handled using CMMS, which also works well with BIM systems. Although BIM has enabled advancements in the management of building operations, there are still three key challenges, particularly in large medical buildings: Existing software systems do not show buildings in real time like they do in the real world. For example, a sudden flood of patients at the hospital's entrance is dangerous and needs to be reported immediately [4]. This platform largely preserves preimported data. No one has access to the most recent status; thus, managers have no way of knowing. It is still difficult to get digital data from various sources. There are numerous differences across systems when it comes to hardware, user interfaces, and data formats to be used. Furthermore, sensor data accumulate rapidly [5]. It is also necessary to improve the methods for transforming and storing such a big amount of data. It is possible to use 3D models in standard in-use management solutions like BIM platforms to explore or check business data, but this is not possible with 3D models. Offline database analysis would be required to fill this void; however, fast feedback systems would be limited. As a result, rapid decision-making recommendations based on advanced data analysis are essential. To solve these problems, the industrial sector has turned to a relatively new idea known as Digital Twin (DT) [6]. The dispatching system is used for allocating jobs, making calls, coordination, settling payments, and optimizing routes in construction projects. In order to manage these aspects automatically, the study focused on evaluating the performance BIM and Digital Twin and how it helps in intelligent dispatching system in construction projects.

2. Related Studies

Building information modeling (BIM) is used for designing the buildings in construction projects. It has been around since the 1970s, just like Digital Twins. It began with research, like so many software projects do. Before it became known as BIM, early researchers such as Chuck Eastman used the term "Building Description System." After a few years of experimenting with Digital Twins, Autodesk and Bentley Systems became well known for their use of the technology in early 2000 [7]. Although BIM has evolved from its earliest days of research, its core objective remains the same. In the early days of BIM, its creators predicted that contractors working on major projects would benefit from having a visual and quantitative representation of their work. They reasoned that ordering supplies and planning projects would be facilitated by it. BIM proves to be as useful as originally thought. AECs (architects, engineers, and contractors) are still being courted by prominent BIM software companies who explain the cost savings of having a primary building reference in a 3D digital model [8]. When working on in-flight projects, this methodology makes it easier to discuss and revise a design. Its advantages include the decrease of project risk due to fewer errors as well as better management of project timelines and budgets. It has a similar sounding name to the Digital Twin, but there are a few important differences between the two.

BIM is used for design and construction collaboration, not for operations and maintenance. BIM is intended to assist architects and builders in the design and construction process, not to create a working model of a building [9]. BIM software, developed to make cooperation easier, can be used to visualize design and construction processes. AECs must understand spatial relationships during the design and prototyping phases of a new construction. Buildings intended for flight rather than ones occupied and used routinely are targeted by this physical information model [10]. A building's design and construction are addressed in BIM. Humans' relationship to their built environment is depicted in a Digital Twin. It is not designed for Real-Time Operational Reaction. Due to the fact that they provide a complete, real-time image of the structure, digital twins are fast becoming the most useful component in a building's technology stack. Data about the current status of construction subsystems, how occupant activity affects those subsystems, and much more can be found with a Digital Twin [11]. With this strategy, the value delivered evolves across the asset's lifetime, increasing over time. In spite of the fact that BIM is a critical data source for any Digital Twin, it cannot answer all of a facility manager's questions about how to run their organization more efficiently. Structures are more important to BIM than humans. A Digital Twin of an Organization or an entire company will be covered by applications in the future, according to Gartner (DTO). It will be possible to add even more context to Digital Twins by incorporating people, processes, and behaviors as data sources. Even during the asset's design and construction, the Digital Twin will surely replace BIM software if trends favor understanding occupants and competing on the quality of the workplace experience [12]. With a focus on people and flexibility, our building information models will need to expand in order for people's behavior patterns and space design to be taken into account. BIM, as previously stated, is unable to produce these outcomes by itself.

By utilizing this technology, oil rigs, production plants, and buildings might all benefit from an increase in safety, efficiency, and regulatory compliance. One of the most important advantages of using a Digital Twin is being able to forecast failures and suggest solutions to avoid them before they happen [13]. Every industry and circumstance in which digital twins are used is growing increasingly relevant. This is due to the increasing prevalence of digital transformation. In other words, cities and structures are becoming smarter as more data are generated and used. By 2021, according to Gartner, there will be IoT endpoints and Digital Twins for potentially billions of scenarios. The builders benefit from enhanced user experience, competitive differentiation, and more. It is becoming increasingly vital for IoT implementation as more IoT platform providers and analytics companies engaged in Digital Twinning technology Design and development from scratch are all part of this process. New building ideas and concepts must be approved by construction designers and developers in order to meet the necessary safety rules, which limit their originality [14]. As a result of time restrictions, software engineers may be limited in the number of concepts they may experiment with. Developers can test their ideas 100 times faster and get them approved 100 times faster using digital simulation that combines all of the crucial real-world characteristics like scale, gravity, and weather. Simulated tests for the safety, feasibility, and long-term viability of new construction designs may now be undertaken in the same way as a real-world test and will yield the same results both ways. A data-driven approach to energy management can help save money while also helping the environment because electricity accounts for around 19% of total construction expenditures. This is made possible thanks to the use of a digital twin [15]. For instance, there are benefits to be had in this situation. More effective use of resources in operations and maintenance of sensor data from the Industrial Internet of Things (IIoT) can be combined with operational and process data to maintain a Digital Twin up to date as assets are deployed or construction projects are finished. Run-time capture records deviations from the optimal process and asset design, and the Digital Twin is instantly updated to reflect these changes.

Predictive learning technology can be used by digital models to foresee asset breakdowns in the future and even suggest ways to prevent them, given the current state of an asset. By anticipating problems before they occur, a Digital Twin is able to prevent them from happening in the real world altogether [16]. Artificial intelligence can be used in the Digital Twin to perform advanced process control, control strategy design, and process optimization. As a result of these tools, a fully digital value loop and integrated lifecycle management can be achieved for engineering asset or plant data. The most cutting-edge tools and procedures combined with internal subject expertise are required to achieve digital transformation in organizations [17]. Thus, new and current data can be contextualized while also delivering useful insights and information to the end user or the reader. Companies may be able to close the loop on process optimization now that they have these new insights. As companies increasingly value information and data, they must begin to embrace digital transformation as an opportunity to transform themselves. To be successful, digital twin initiatives necessitate the establishment of different asset data services, engineering master data, effective visualization tools, and mechanisms for cooperation and workflow for each asset. Assemble a Digital Twin model with reliable information sources and make adjustments at critical control points to improve product or operation performance over the short and long terms. There is a chance predictive maintenance and Digital Twin simulations will help you save money while also reducing the risk of failure [18]. To assist in the development of digital transformation programs and projects, develop a Digital Twin architectural roadmap. It is critical to be able to derive insight from your data. When delivering or launching a project, employ a Digital Twin to evaluate how an organization connects to its existing state and what it will do if something changes internally or externally. Making better and more accurate decisions with the data you have is easier when using a Digital Twin to evaluate process modifications before they are implemented. This provides a plethora of new options. Because of the revolutionary benefits of Digital Twin technology, these companies stand to benefit greatly, as they will be able to maximize their projects' creative potential without adding to their risk profile [19]. Efficiencies in daily management and operational safety become more crucial as the volume and complexity of freshly completed construction projects grow. Elemental problems arise from the combination of static and dynamic aspects, such as the presence of hundreds of rooms, each with a distinct purpose.

According to national rules, China's hospital space is divided into divisions for the general public: medical, clinical, surgical, and also other specialized technology areas. There are numerous factors that must meet strict O&M quality standards, including temperature, humidity, sewage, exhaust, and air exchange [20]. Complicated crossroads can be created in daily routines by everyone from patients to family members to physicians and office personnel. That is why securing the building appears to be more important than it usually is. Furthermore, many hospital operations in China are delegated to an external team, resulting in additional quality uncertainties and management issues [21]. BIM looks to be more like a single digital shadow and so only partially realizes a digital twin [22]. However, by delivering timely optimization ideas based on the current status mirror, DT can aid decision-making rather than simply reflecting it. Services such as energy forecasting, failure prediction, and operation guidance are all improved by the building's lifetime service through the use of real-time monitoring (RTM) [23]. This study evaluates how DT and BIM help in developing intelligent dispatch system in the construction projects.

2.1. Drawbacks of the Study. The field of Digital Twins for such physical Environment is still very much in infant stages, as well as the need to recognize the developments in the fundamental technological solutions and maintain a convergent frame of reference for long-term development research. This document performed a comprehensive review to recognize the advancement of technological innovations that aid in the transformation of BIM to Digital Twins in building design applications. Nevertheless, investigation in Digital Twins for the Physical Environment is still in its infancy, as well as the need to recognize advances within fundamental technological solutions as well as to establish a concurrent context for future expansion investigation.

2.2. Objectives of the Study. A novel Digital Twin-Building Information Modeling (DT-BIM) hybrid model is proposed. With the help of Artificial Intelligence, this model identifies resource shortages, analyzes requirements, makes decisions, dispatches resources, and updates all processes in the database (AI). As a result, when compared to the implementation of the individual technology to the same application, this hybrid model produces better results. The study's findings revealed that these hybrid technologies aid dispatched systems in construction projects to a greater extent.

3. Methods

Digital Twin (DT) is a technology that aids in the easy access of any user-defined application with ease. This trending technology is a combination of software and hardware implementation for a given on-demand application; and this is a specialized property of the technology. Furthermore, DT works with the support of various sensors required for identification of the required material along with the Internet of Things (IoT) [24]. Hence, it will be a best future technology. On the other hand, another trending technology is Building Information Modeling (BIM). The unique property of this BIM technology is to provide a visual representation of the building with an advanced illustration of physical and functional characteristics of the given place or the building [25]. These two technologies with their advanced features will make the building construction an easier task. Henceforth, in this research work, a novel hybrid model of these two technologies named Digital Twin—Building Information Modeling (DT-BIM) is proposed and the results were discussed.

Figure 1 represents the proposed architectural model of the hybrid DT-BIM model. In the proposed model, BIM supports the prediction support for the simulation work and the AI-based visualization along with the data storage. This AI-based visualization works with the support of DT technology. The predicted or the simulated results are stored in the database for the future prediction process. In the DT-BIM model, two major blocks are used to simulate the dispatching of the required construction materials, and sensors to identify the requirements. In the first block, the decision on the Construction Materials Dispatch (CMD) is performed with the analysis of energy consumption, cost, and the comfortability of the end user who will be occupying the building. After making the analysis with the support of BIM, the materials will be dispatched to the construction site and all the details will be updated in the database. In the Real Building (RB) block, all the required sensors will be fixed in the construction area to analyze the shortage of the construction materials and also certain sensors to identify the issues in the building (if any). These details will be updated in the database along with the data transfer to the CMD block for further processes.

3.1. Digital Twin-BIM-Hybrid Model. To recognize emerging technologies that will aid in the transformation of BIM to Digital Twins in this as the authors created a level ladder classification structure based also on building life cycle to match the actual state-of-the-art in Digital Twin applications in order to systematically classify the multiple studies, implementations were further classified in each level of this taxonomy depending on the study areas.

The difficult part is determining what a delegate test implies and how small or large it must be.

$$\begin{aligned} S_{ml} &= \text{dig}_{s2I}^{\max} T\left(I_Q;\, T_R \,\vdots\, S,\, t^*\right), \\ S_{\text{map}} &= \text{dig}_{s2I}^{\max} P\left(S \,\vdots\, I_Q; T; t^*\right), \end{aligned} \tag{1}$$

where I_Q and T_R are the sets of afflicted and shielded access points at the time and the constants P and Q represent the number of infectious and shielded access points up to time t.

It omits time ‘s’ for matrix multiplication clarity.

To ascertain the generator S,

$$\begin{aligned} S_{\text{map}} &= \text{dig}_{s2I}^{\max} T\left(S \,\vdots\, I_Q; T_R; t^*\right) \\ &= \text{dig}_{s2I}^{\max} \frac{T\left(I_Q;\, T_R \,\vdots\, S,\, p^*\right) T\left(S,\, t^*\right)}{T\left(I_Q; T_R; t^*\right)} \\ &= \text{dig}_{s2I}^{\max} T\left(I_Q;\, T_R \,\vdots\, S,\, t\right) \cdot T\left(S,\, t^*\right), \end{aligned} \tag{2}$$

where $S \,\vdots\, I_Q, T_R$, and t^* represent the maximum number of possible propagations for the same probability occurring in the information source and $T\left(S t^*\right)$ represents the probability and classifies for the information source.

In the BIM model, $T\left(I_Q;\, T_R \,\vdots\, S t\right)$ is the probability which has the realisations I_Q and T_R occurring in a source of information v and p^* denotes protective. As a result, if $T\left(S t^*\right)$ is assumed to be homogeneous over, BIM is equivalent to DT (Digital Twin) and BIM is used to detect the probability:

$$T\left(I_Q; T_R; t\right) = \sum_{\sigma \in \Omega\left(S,\, p^*, I_Q; P_R\right)} T\left(\sigma \mid S,\, t\right), \tag{3}$$

where $\Omega(v,\, t^*,\, I_Q,\, T_R)$ is the set of all likely dissemination classifications given I_Q and T_R.

Let G be consistent.

Based on the K representation for the number of possible propagation sequences, the same σ approach as a source of the information in DT and BIM is used:

$$\begin{aligned} S_{ml} &= \text{dig}_{s \in I_Q}^{\max} K\left(S,\, t,\, I_Q,\, T_R\right), \\ S_{\text{map}} &= dig_{s \in I_Q}^{\max} K\left(S,\, t,\, I_Q,\, T_R\right) \cdot P\left(S,\, t^*\right), \end{aligned} \tag{4}$$

where

$$K\left(S,\, t,\, I_Q,\, T_R\right) = \left|\Omega\left(S,\, t^*,\, I_Q,\, T_R\right)\right| = O\left(R + Q\right)! \prod_{\mu \varepsilon I_Q \bigcup P_R} |T_\mu^v| - 1\,. \tag{5}$$

This presumption for the Ω variety of feasible propagation sequential nodes provides both information and context around the same time for S_{ml} as well as S_{map}.

It calls for S_{ml} and S_{map} in the propagation center. Let $|T_\mu^v|$ be the number of requirements. The subtree T_μ^v rooted at requirements. Let v be the material foundation and BIM and digital twin communication take place between i and j.

Let v be the material foundation and BIM and digital twin communication take place between i and j. Place it at the heart of the framework. Let $S(t)$ denote the network's sensor set:

$$S(t) = S(t\, - 1) + \beta^* a\,(t). \tag{6}$$

There at connection, the $a(t)$ transverse and longitudinal roads may become fractious. The network elements are expected to move directly ahead, $S(t-1)$ turn left as well as right, with a guaranteed connection, where

$$-1 \leq \beta \leq 1. \tag{7}$$

If it is below zero, it indicates that the node is an impacting counter (negative acceleration). Otherwise, it moves at a faster pace.

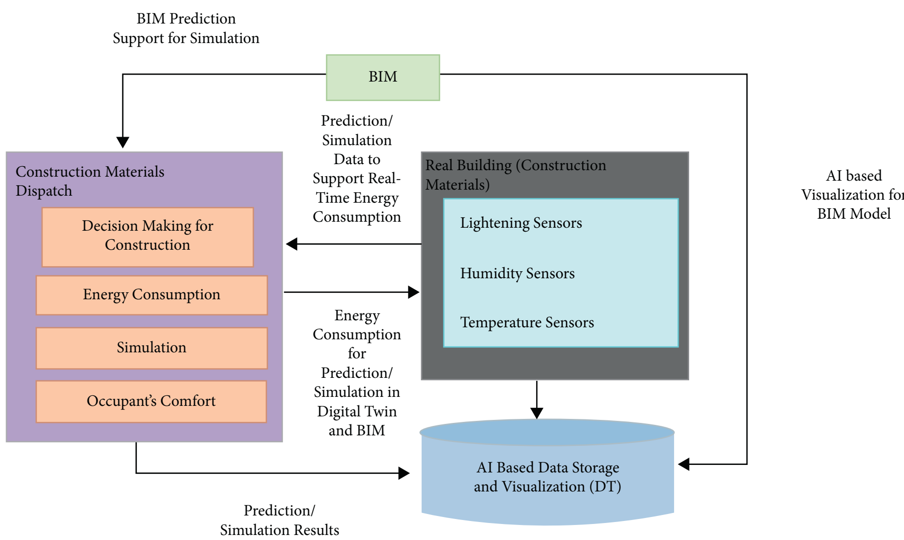

Figure 1: Proposed architecture.

At time t, the remaining battery energy ($R1$) and the ingested energy ($C1$) of an access point are being shown elsewhere here:

$$\beta_{i(t)} = \frac{R1_{i(t)}}{C1_{i(t)}},$$

$$BIM = \frac{\left(T^{i} nd\right)\beta}{\sum j \in Q^{i} d\left(T^{i} jd\right)\beta}, \quad \beta \geq 1,$$

$$\text{if } s(t) < \text{Smax Then } s(t) = \text{Smax}, \tag{8}$$

$$\text{if } s(t) < \text{Smin Then } s(t) = \text{Smin},$$

$$C1_{R1} = \sum_{j=1}^{i=1} C1(i).$$

4. Results and Discussion

In general, scan-to-BIM refers to the process of converting 3D scanning point cloud information from data building structures into a BIM model. Academically, the application of bitmap image technology in construction is still in its early stages, with no unified standard or implementation mode in place. The scan-to-BIM scanner parameters for accuracy (15 mm), positional accuracy (15 mm), and coverage (85 percent) are used to evaluate data collection quality (refer Figure 2). Coverage is determined once the scanned building meets the scanning accuracy and also resolution satellite requirements (Table 1).

It is significant to assess the AI technology retrofitting scheme for existing buildings using a digital twin, which can improve the energy efficiency as well as reduce carbon emissions from buildings. This paper examines in depth the effect of photovoltaic solar module configuration angle on energy consumption in buildings and photovoltaic device electricity production. From Figure 3, the performance analysis of energy consumption using different models has been represented (Table 2).

The scan-to-BIM-based digital twin assessment AI method is suggested in analyses and simulates the impact of the environment building refitting schemes on energy consumption in buildings and photovoltaic electricity production, and the resulting changes contain similar energy consumption. From Figure 4, we can see descriptive statistics of digital twin and BIM (Table 3).

The real-time energy monitoring and management of such a building are essential for creating effective and sustainable structures. Building energy quality management can benefit from BIM and DT applications. Creating a real-time visualization of energy consumption in buildings that resulted in a 17% energy savings attributable to easier data acquisition resulted in improved control of lighting control systems (refer Figure 5), likewise, by integrating BIM and DT gadgets via open sending messages specifications and AI technology (Table 4).

The viability of using AI techniques to predict the infrastructure based on data from the current model was discussed, as were the methodologies as well as challenges of smart building Digital Twins, that also suggested to integrate BIM to analyze the energy usage of buildings. From Figure 6, we can observe that the performance of digital twins performs well compared with that of BIM and DT. It indicates that our hybrid model is suggested to improve the dispatching process easier (Table 5).

It can be seen that a substantial percentage of the previous studies were classified as meaning that many of the previous application areas of "Digital Twins," beginning with BIM-supported simulations for tasks such as 4D building lifecycle simulations and enhancing energy evaluation, have been shown to help with evaluation of the building's lifecycle and accomplish a much more efficient and environmentally building.

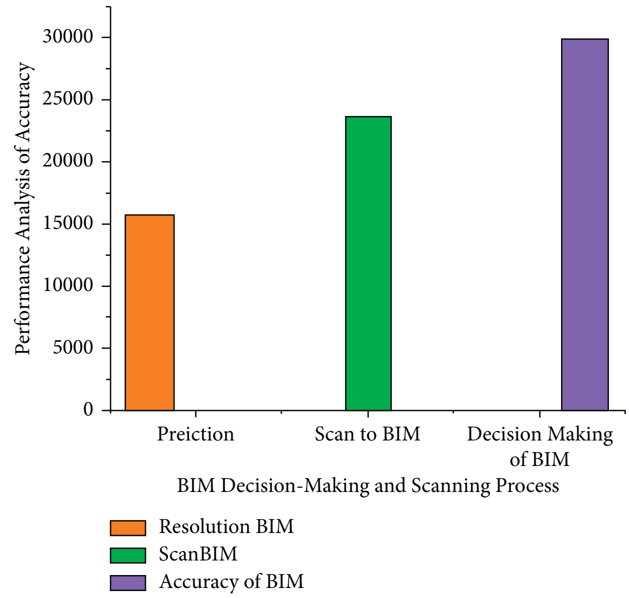

Figure 2: BIM scanning process.

Table 1: BIM scanning process.

BIM decision-making and scanning process				
Number	Object	Accuracy (mm)	Resolution (mm)	Coverage (%)
1	East	1.5	0.6–15	100
2	West	1.5	0.6–7	100
3	North	1.5	0.5–6	100
4	South	1.5	0.6–4	100

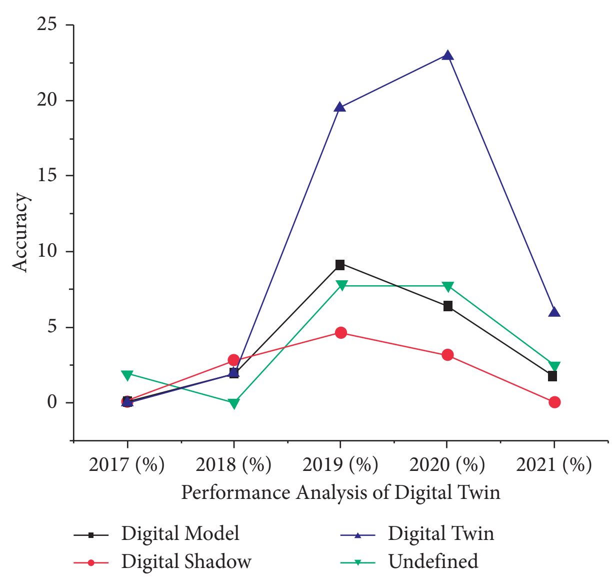

Figure 3: Performance analysis for digital twin with artificial intelligence.

Table 2: Performance result analysis for digital twin with AI.

Data type	Year					Total (%)
	2017 (%)	2018 (%)	2019 (%)	2020 (%)	2021 (%)	
Digital model	0.01	1.92	9.23	6.34	1.78	19.28
Digital shadow	0.01	2.76	4.67	3.12	0.01	10.57
Digital twin	0.01	1.93	19.45	22.92	5.92	50.23
Undefined	1.89	0.01	7.78	7.78	2.45	19.91
Total	1.92	6.62	41.13	40.14	10.16	100

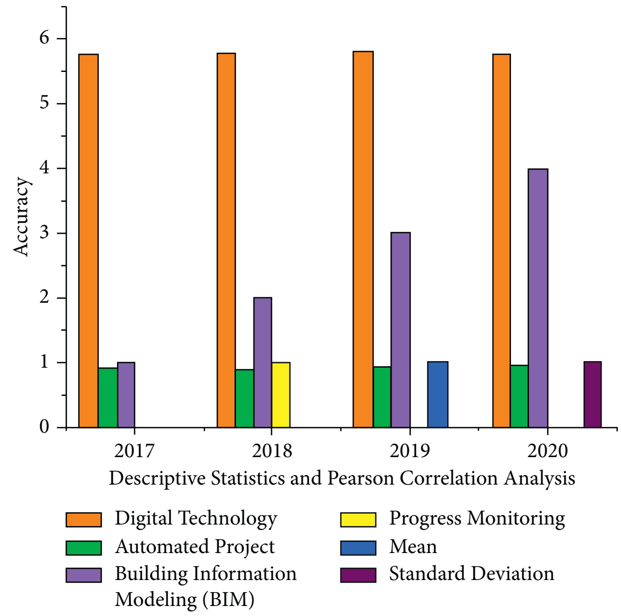

Figure 4: Descriptive statistics and Pearson correlation analysis of digital twin and BIM.

Table 3: Descriptive statistics and Pearson correlation analysis.

Parameters	Mean	Standard deviation	1	2	3	4
Digital technology	5.76	0.92	1.00			
Building information modeling (BIM)	5.75	0.91	0.7564*	1.00		
Automated project	5.79	0.93	0.7634*	0.812**	1.00	
Progress monitoring	5.74	0.96	0.834**	0.845**	0.837**	1.00

Note: $^{*}p<0.1$, $^{**}p<0.05$, $^{***}p<0.01$, and $n=346$.

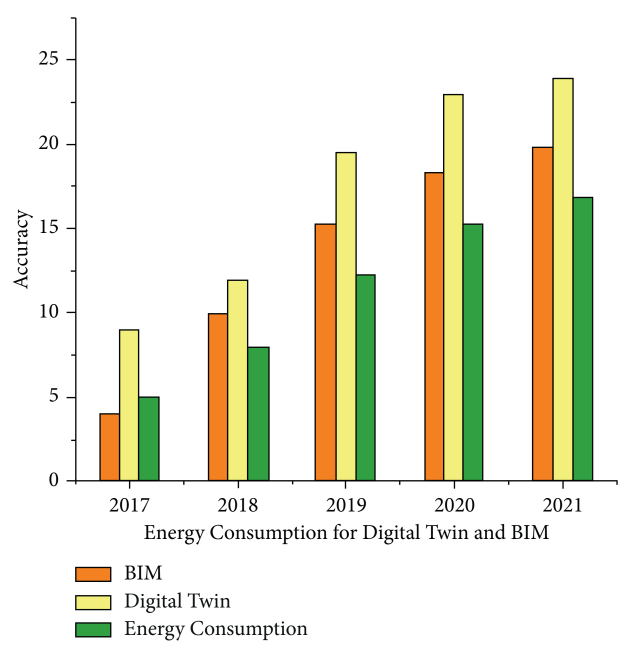

Figure 5: Energy consumption for Digital Twin and BIM using AI technology.

4.1. Future Direction of the Proposed Research. The different algorithms used in BIM technology in construction to improve the visualization of the building project mostly to avoid building collisions at an earlier stage. In the building construction industry, Digital Twins play an important role in gathering information about the organization using

Table 4: Result analysis for energy consumption for digital twin and BIM using AI technology.

Years	Energy consumption for digital twin and BIM		
	BIM	Digital twin	Energy consumption
2017	09.78	15.89	7.92
2018	10.34	14.56	9.23
2019	16.76	19.12	14.67
2020	17.36	25.87	16.12
2021	19.67	26.32	17.65

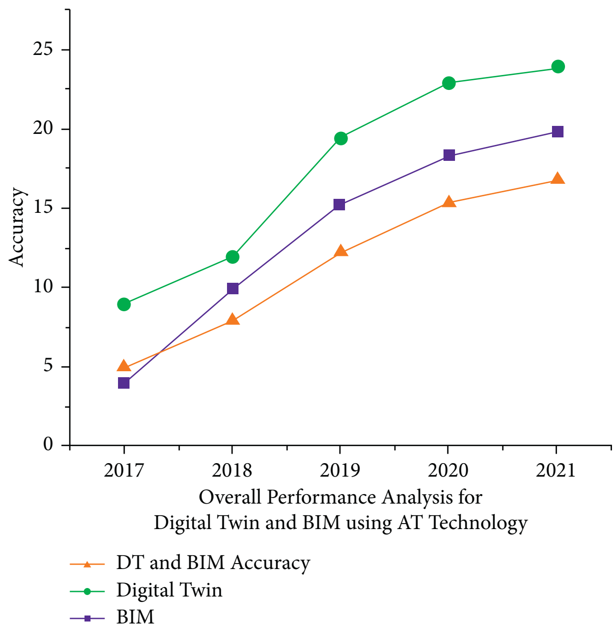

Figure 6: Overall performance analysis for Digital Twin and BIM using AI technology.

Table 5: Overall performance result analysis for Digital Twin and BIM using AI technology.

Years	Performance analysis for digital twin and BIM using AI technology		
	BIM	Digital twin	DT with BIM
2017	4.01	9.01	5.14
2018	9.92	11.93	7.92
2019	15.23	19.45	12.23
2020	18.34	22.92	15.34
2021	19.78	23.92	16.78

advanced technology and the Internet of Things (IoT). So, the intelligence obtained is used to supervise the resources in the constructed building, schedule maintenance, and much more. BIM facilitates a material selection by utilizing previously collected data.

5. Conclusions

Digital Twin and BIM are new emerging technologies that are implemented in all the industrial sectors. In this research work, these technologies are implemented for the construction sector. Digital Twin is a technology that includes the implementation of the application from the software to the hardware. On the other hand, BIM is a technology in the construction sector providing the visualization of the building project to avoid collision of the buildings at the earlier stage. In the building construction sector, Digital Twin plays a significant role in collecting information about the building with the Internet of Things (IoT). The utilization of the information gathered aids in monitoring the assets in the constructed building, scheduling maintenance, and much more. BIM supports the selection of materials with the help of earlier collected information. In this research work, a novel hybrid algorithm named DT-BIM is proposed for combining the two technologies for the better construction and maintenance of the buildings. From the results of the hybrid technology of DT-BIM, this hybrid model provides better results in the dispatch of the required construction materials to the building construction location than the individual technology. It can be concluded that the future of the building construction will depend on these two technologies. As a result, when compared to such a successful execution of an individual technology to the very same application, such a hybrid model provides more accurate results. The results of this analysis of accuracy in (97%) revealed that all these hybrid technologies aid delivery systems in building projects to a larger extent.

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 there are no conflicts of interest.

References

[1] A. Watson, "BIM leaders of the future: engaging the digital generation," *Construction Manager's BIM Handbook*, John Wiley & Sons, Hoboken, NJ, USA, pp. 133–141, 2016.
[2] J. Eynon, "Afterword: BIM, digital life and the third industrial revolution," *Construction Manager's BIM Handbook*, John Wiley & Sons, Hoboken, NJ, USA, pp. 146–150, 2016.
[3] L.-S. Kang, H.-S. Moon, H.-S. Kim, and J.-M. Kwak, "Usability improvement of BIM for construction projects using active BIM functions," *Korean Journal of Construction Engineering and Management*, vol. 14, no. 5, pp. 74–83, 2013.
[4] P. Barnes, "The BIM Tender Stage," in *BIM for Project Managers*, pp. 39–55, ICE Publishing, London, UK, 2020.

[5] P. Barnes, "The BIM Management Roles," in *BIM for Project Managers*, pp. 33–38, ICE Publishing, London, UK, 2020.
[6] M. Deng, C. C. Menassa, and V. R. Kamat, "From BIM to digital twins: a systematic review of the evolution of intelligent building representations in the AEC-FM industry," *Journal of Information Technology in Construction*, vol. 26, pp. 58–83, 2021.
[7] P. Barnes, "BIM Monitoring and Control," in *BIM for Project Managers*, pp. 119–126, ICE Publishing, London, UK, 2020.
[8] G. Kapogiannis and A. Mlilo, "Digital Construction Strategies and BIM in Railway Tunnelling Engineering," in *Tunnel Engineering - Selected Topics,* IntechOpen, London, UK, 2020.
[9] D. Lee, S. H. Lee, N. Masoud, M. S. Krishnan, and V. C. Li, "Integrated digital twin and blockchain framework to support accountable information sharing in construction projects," *Automation in Construction*, vol. 127, Article ID 103688, 2021.
[10] F. Tao, M. Zhang, and A. Y. C. Nee, "Digital twin and big data," *Digital Twin Driven Smart Manufacturing*, Elsevier, Amsterdam, Netherlands, pp. 183–202, 2019.
[11] R. Sacks, I. Brilakis, E. Pikas, H. S. Xie, and M. Girolami, "Construction with Digital Twin Information Systems," *Data-Centric Engineering*, vol. 1, 2020.
[12] Y. Wang, A. Liu, F. Tao, and A. Y. C. Nee, "Digital twin driven conceptual design," *Digital Twin Driven Smart Design*, Elsevier, Amsterdam, Netherlands, pp. 33–66, 2020.
[13] L. Wang, F. Tao, A. Liu, and A. Y. C. Nee, "Digital twin driven design evaluation," *Digital Twin Driven Smart Design*, Elsevier, Amsterdam, Netherlands, pp. 139–164, 2020.
[14] V. Jain, N. Luthra, and D. Saini, "Digital twin technology," *Digital Twin Technology*, CRC Press, Boca Raton, FL, USA, pp. 1–21, 2021.
[15] A. Costin, A. Adibfar, H. Hu, and S. S. Chen, "Building Information Modeling (BIM) for transportation infrastructure - literature review, applications, challenges, and recommendations," *Automation in Construction*, vol. 94, pp. 257–281, 2018.
[16] L. Barazzetti, M. Gianinetto, and M. Scaioni, "Automatic processing of many images for 2D/3D modelling," *Digital Transformation of the Design, Construction and Management Processes of the Built Environment*, Springer International Publishing, Berlin, Germany, pp. 355–365, 2019.
[17] M. Zhang, F. Sui, A. Liu, F. Tao, and A. Y. C. Nee, "Digital twin driven smart product design framework," *Digital Twin Driven Smart Design*, Elsevier, Amsterdam, Netherlands, pp. 3–32, 2020.
[18] S. Fabozzi, S. A. Biancardo, R. Veropalumbo, and E. Bilotta, "I-BIM based approach for geotechnical and numerical modelling of a conventional tunnel excavation," *Tunnelling and Underground Space Technology*, vol. 108, Article ID 103723, 2021.
[19] C. I. Papanagnou, "A Digital Twin Model for Enhancing Performance Measurement in Assembly Lines," in *Internet Of Things*, pp. 53–66, Springer International Publishing, Berlin/Heidelberg, Germany, 2019.
[20] S. A. Biancardo, A. Capano, S. G. de Oliveira, and A. Tibaut, "Integration of BIM and procedural modeling tools for road design," *Infrastructure*, vol. 5, no. 4, p. 37, 2020.
[21] A. Grosso, "Reliability of SHM procedures and decision support in infrastructure management," *Bridge Maintenance, Safety, Management and Life-Cycle Optimization*, p. 322, CRC Press, Boca Raton, FL, USA, 2010.
[22] M.-H. Shin and J.-H. Baek, "Design and construction of rail infrastructure BIM integrated management system for systematic management of rail infrastructure BIM design performance products," *Journal of the Korean Society for Railway*, vol. 23, no. 9, pp. 886–894, 2020.
[23] C. Boddupalli, A. Sadhu, E. Rezazadeh Azar, and S. Pattyson, "Improved visualization of infrastructure monitoring data using building information modeling," *Structure and Infrastructure Engineering*, vol. 15, no. 9, pp. 1247–1263, 2019.
[24] M. U. Khalid, M. K. Bashir, and D. Newport, "Development of a building information modelling (BIM)-Based real-time data integration system using a building management system (BMS)," *Building Information Modelling, Building Performance, Design and Smart Construction*, Springer International Publishing, Berlin, Germany, pp. 93–104, 2017.
[25] K. K. Han and M. Golparvar-Fard, "Appearance-based material classification for monitoring of operation-level construction progress using 4D BIM and site photologs," *Automation in Construction*, vol. 53, pp. 44–57, 2015.

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Research Article

Digital Visual Sensing Design Teaching Using Digital Twins

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Digital twin technology can support teachers in this major to complete monitoring related topics and application research and serve teaching and scientific research through the establishment of automatic monitoring teaching model laboratory and in-depth combination with the current students' skill training needs in this major. This exploration aims to make the visual sensor industry have a steady stream of talents. Promoting the development of visual sensor technology is to promote the development of science and technology. Based on the teaching research of visual sensing design using digital technology, a set of teaching systems of visual sensing design is designed by using the methods of literature research and investigation and analysis. Special topics are set up from the aspects of professional subjects; regarding course content, various sensor principle research courses, visual sensor design courses, experimental courses, and example courses are set up; teaching methods are divided into online and offline synchronous classes; the evaluation method should focus on the distribution, examples, and practice. The results show that traditional classroom teaching is seriously separated from extracurricular learning. Most students are in a state of passive acceptance of knowledge and have few thinking activities. The established teaching system integrates brain and cognition, photoelectric foundation, sensory imaging, visual sensing imaging, visual sensing technology courses, computer technology, virtual experiment courses, and physical experiment courses. It can carry out more than 30 experiments of optical microscopic imaging and X-ray imaging based on the principle of visual sensing. Therefore, the teaching effect and teaching mode of the proposed digital visual sensing teaching system have been greatly improved.

1. Introduction

In the twenty-first century, people are used to digitization and seek the optimal solution of learning and life through big data. It means that people have unknowingly entered the digital age, such as the music app that judges and recommends users' favorite songs through big data, lists of popular film and television dramas, and online shopping of favorite items. People have experienced great changes brought about by the digital age. Now, everyone cannot live without numbers. Digital twins (DTs) complete the mapping of the physical model in virtual space in the real world. Physical model refers to all kinds of equipment in the real world: human, mechanical arm, numerically controlled machine tool, automatic instrument, and mobile phone. The virtual world can be simply understood as a digital world composed of various intelligent computing devices; through the DTs technology, every device in the real world will have a digital entity in the virtual world, which has exactly the same appearance and internal structure The characteristics of the digital age include intelligence, integration, and parallelism [1]. The traditional teaching mode needs to invest a lot of physical equipment, venues, and personnel. It also has to face the problems of normal loss and accidental damage of physical objects, which cannot reduce the cost. Applying DTs technology to online teaching can break the traditional teaching mode and realize digital teaching.

Li and Wang (2017) [2] introduced the teaching exploration of sensor technology based on artificial intelligence (AI). Compared with traditional network teaching, sensor intelligent teaching system needs a more complex computer operation mechanism, which is mainly reflected in the following three aspects. (1) Models are established according to the characteristics of different students. (2) Suggestions are shared according to existing teaching strategies such as teaching objectives and training programs and combined with data resources. (3) Human-computer interaction is adopted in an intelligent teaching system. Liu et al. (2019) [3] proposed teaching reform and explored the postgraduate course of new sensor principle and application theory. Based on the introduction of theory, the explanation and analysis of application cases were added. For example, target recognition technology based on image acquisition and pattern recognition was introduced into vision sensing technology. The explanation of application cases was convenient for students to master the basic principle, application, and data processing methods of sensors and enriched the theoretical teaching content; the teaching mode adopted multimedia teaching; the assessment method was "30% theoretical written test + 30% experimental practice + 20% usual results + 20% report display." Tao et al. (2019) [4] put forward the information-based teaching design before, during, and after class based on "craftsman spirit." With the course of robot vision and sensing technology as an example, it showed the concept of allowing students to integrate into enterprises and participate in scientific research, exhibitions, and other activities, shaping the spirit of workers and craftsmen, and carrying out "one lesson, one lecture." The second class, skill competition, discipline training, science and technology festival, and other activities encourage cooperation, exploration, and excellence. They used the process of preclass guidance, classroom learning research, simulation exercises, and after-class expansion.

This study uses a combination of literature research and investigation and analysis to study the visual perception instructional design of DTs. Pure AI or multimedia teaching is used separately, and there is no combined teaching method. The innovation is that the visual sensing design teaching system is designed to be different from traditional teaching. The establishment of the visual sensor design discipline makes up for the regret that there is no professional visual sensor design course in the major. This system pays more attention to teaching practice, helps reduce the phenomenon that the input and output of education are not proportional, and provides research ideas for other professional settings such as auditory perception design.

2. Materials and Methods

2.1. DTs. DTs are the simulation processes that make full use of physical model, sensor update, operation history, and other data; fuse different disciplinarians, physical quantities, scales, and probabilities; and complete the mapping in the virtual space, so as to reflect the whole life cycle process of the corresponding physical equipment. DTs create a virtual model for physical objects in a digital way to simulate their behavior in the real environment. Building a DTs production system integrating the manufacturing process can realize the digitization of the whole process from product design to production planning to manufacturing execution and raise the level of product innovation and manufacturing efficiency and effectiveness to a new level. The DTs body refers to a virtual model completely corresponding and consistent with the physical entities in the real world, which can simulate its behavior and performance in the real environment in real time, also known as the DTs model. It can be said that DTs are technology, process, and method, and DTs body is object, model, and data.

The application of DTs technology to the design of efficient teaching experiments can enable students to be exposed to the current monitoring technology in an all-round way and deeply understand the current situation of the industry. It can train massive scarce talents in the direction of deformation monitoring and improve the social service function of the laboratory. The construction of the DTs world is not only for graphical viewing but also for rapid quantitative statistics and intelligent analysis. In the "DTs," one of the twins is an entity existing in the real world, ranging from parts to factories, simple as screws and complex as the structure of the human body. The other twin only exists in the virtual and digital world, which is a symmetrical mirror image of the real world created by digital technology. It can map various attributes of physical equipment into virtual space to form a digital image that can be disassembled, copied, transferred, modified, deleted, and repeated with the help of design tools, simulation tools, internet of things, virtual reality, and other digital means.

2.2. Digital Technology. Digital technology, as its name implies, is a technology that is based on numbers. From its category, it is a computer technology and the basic application category of modern computer technology. Digital technology flourished after the twentieth century and has been closely related to human development. Its basic principle is to turn nonmeasurable data into measurable data, and then the corresponding data model is established, enabling it to be recognized by a computer. Digital code is restored after operation, processing, storage, and transmission [5]. The principle of digital technology is shown in Figure 1.

2.3. Sensing Technology. The original circuit of the sensor is similar to the principle of digital technology. It converts the measured quantity into a certain physical quantity convenient for application according to a certain law. A sensor includes the sensitive element, conversion element, and measuring circuit [6]. It has four concepts, and one of them is the working principle of the sensor, as shown in Figure 2.

2.4. Visual Sensing Technology. Visual sensing design, as its name implies, is one of a variety of sensing designs. It is a visual processing system based on computer technology. Human perception of external environmental information is generally carried out through sensory organs. Among industry production, 80% of the information comes from vision. Therefore, vision is the foundation and core in the research field of sensing technology. At present, there are two polarity methods for research on visual sensing technology. And researchers use two completely different methods to study visual perception. The first one is to

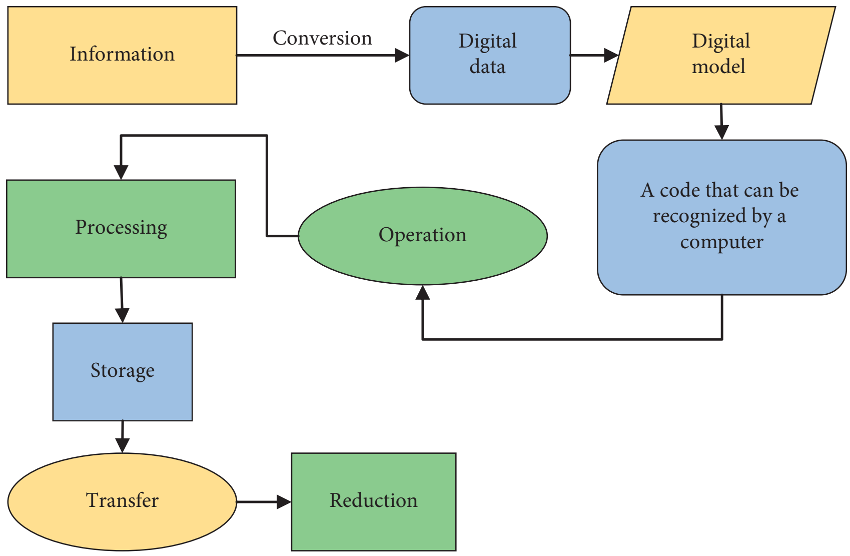

Figure 1: Schematic flow chart of digital technology.

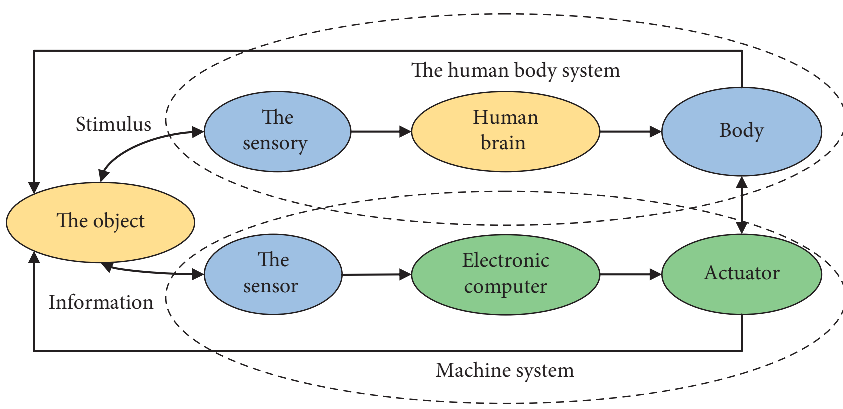

Figure 2: Schematic diagram of sensing technology.

establish a model structure to simulate the "biological eye," which is called biological vision. Biological vision is similar to building a single-lens camera eye to imitate the human eye. Caltech has established a silicon biological structure model, including silicon retina and silicon ear. People pay more attention to the biometric system, but with the limitation of low human eye pixel technology, it is hard to break through the pixel work of the human eye. Also, since people are with little knowledge about the working process of sensory organs, so the biometric system has been difficult to break through. Then another method is used more often. It is to acquire an image through an image input device and then analyze and distinguish the image, which is called computer vision or machine vision [7]. Therefore, it does not have the limitations of the above biological system. It is developing steadily and is composed of six parts: sensor, lens, auxiliary light source, image acquisition card, computer, and display. Sensors have two kinds: CCD (charge-coupled device) and CMOS (complementary metal-oxide-semiconductor). CCD is not only superior to CMOS in imaging quality but also has the advantages of linear array CCD and area array CCD. Linear CCD can capture a one-dimensional image, and area CCD can capture a two-dimensional plane image. Therefore, most industrial sensors are CCD sensors [8]. According to whether the light source is used or not, visual sensing is divided into passive light vision and active light vision [9]. The principle flow chart of visual sensing technology and the structure diagram of the visual sensor are shown in Figures 3 and 4, respectively.

2.5. Measurement Method. Visual sensing technology aims to obtain depth information through a direct connection, and it is an important development direction of visual sensing technology. It includes volume vision measurement, single-camera measurement, beam adjustment measurement, and so on. The volume vision measurement is based on the principle of stereo parallax, and it uses two or more cameras using the known spatial position relationship. Through the theories of epipolar geometry and parallax principle, the scene image of the same measured object is obtained, and the three-dimensional geometric information

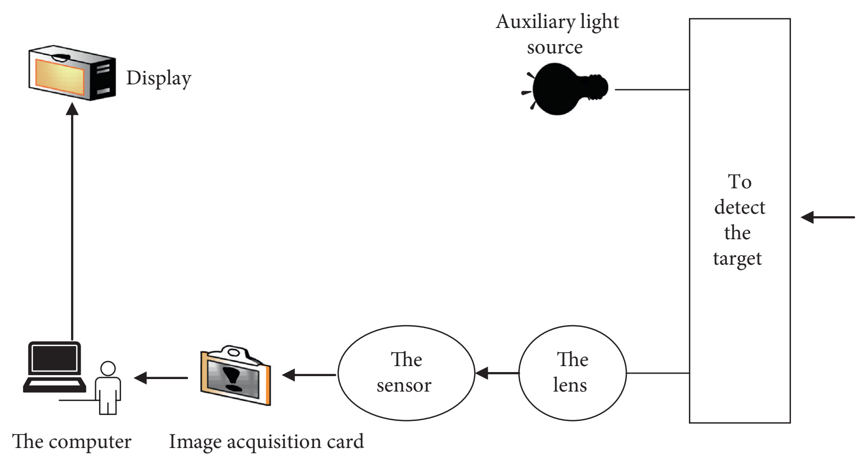

Figure 3: Principle flow chart of visual sensing technology.

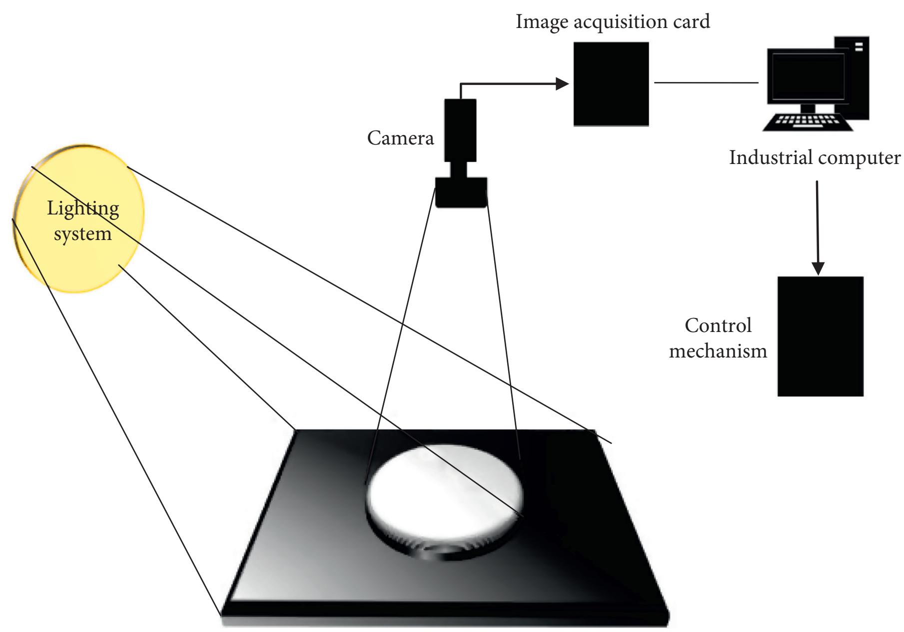

Figure 4: Structure diagram of a vision sensor.

of the measured object is solved. Single-camera measurement refers to the use of a single camera to image the measured object. It combines the control point technology to realize the real measurement, which is a method to measure the spatial three-dimensional geometric information of the measured object. People cannot reverse it from a single two-dimensional image through control point technology. Then, an accurate target probe is used, by adding the single image 3D information to the prospective model, to add additional geometric constraints. Consequently, the accurate target probe can measure 3D geometric information of space objects. Beam adjustment measurement is a geometric model that is based on the spatial intersection of imaging beams. It takes the beam adjustment algorithm to optimize it as the core. Multiple measuring points are set at different positions in the measurement space through the camera. Through a high-precision image processing algorithm and automatic image point registration technology, it collects measuring points from different positions and attitudes to obtain the iterative strip for beam adjustment. And then, it obtains the accurate three-dimensional coordinates of the measuring points by using the beam adjustment optimization algorithm. The measurement method is used in the teaching reform and exploration theory of the above new sensor principle and application postgraduate course. The measurement method is the basis and core of visual sensing technology. Without a measurement method, everything cannot continue. The teaching method of measurement method is multimedia teaching. The assessment method adopts the proportion of "30% theoretical written test + 30% experimental practice + 20% usual results + 20% report and display." The contents of the new sensor principle and application course are shown in Figure 5.

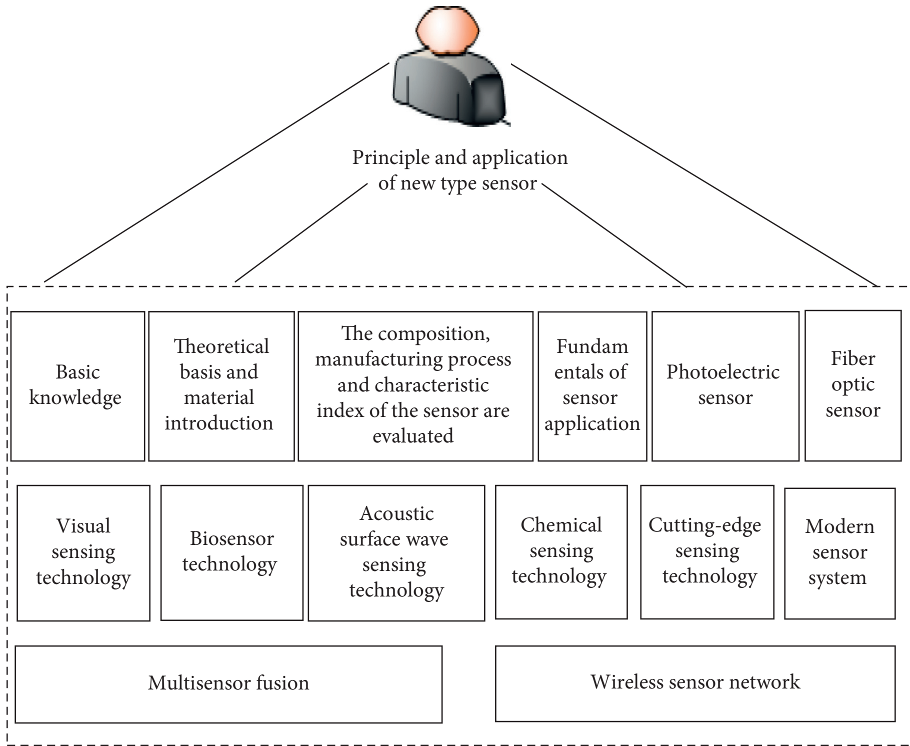

Figure 5: Course content diagram of new sensor principle and application.

3. Methods of Precision Teaching

Precision teaching is a new teaching method. It was used for targeted education at the beginning of its birth, aiming to obtain relevant data by designing and measuring the teaching process, track students' learning performance, and provide data decision support for teaching. The main measure is fluency, which is composed of "accuracy" and "proficiency speed" of students' corresponding knowledge and skills. The traditional monitoring method of precision teaching is to analyze by manually drawing measurement tables, which is too cumbersome. And the results are often not accurate enough due to the lack of big data and AI in the early stage. However, the development of technology has become mature and used in all aspects of life, such as precision marketing. It can intelligently set the minimum value of reliability and confidence of the data mining algorithm. For students, it can automatically prompt the knowledge points that may not be good in the follow-up. For teachers, it can automatically predict the overall teaching effectiveness of the class and analyze the associated knowledge points.

3.1. A Priori Algorithm. An algorithm based on precise teaching and big data is proposed. Based on the unique digital mining technology in the digital age, it analyzes students' weak subjects to launch courses suitable for students. In the background, teachers can also identify the shortcomings of classes through observation data to adjust learning methods over time.

Basic definition. *Definition 1* (support): let $I = \{i1, i2, \ldots, in\}$ be a set containing N items, transaction T be a set of items, $T \subseteq I$ and D be a set of T. Let A be a set of items, transaction T contain X, and only $X \subseteq T$, that is, X is contained in T, $X \longrightarrow Y$ is an expression of an association rule, and $X \subset I$, $Y \subset I$, $X \cap Y = \varnothing$.

$$\begin{aligned}\text{Support}(X \longrightarrow Y) &= P(X \cup Y)\\ &= \frac{\{T\colon X \cup Y \longrightarrow T, T \in D\}}{D \times 100\% = a}.\end{aligned} \quad (1)$$

Definition 2 (confidence). the confidence of association rules $X \longrightarrow Y$ refers to the ratio of the number of transactions containing X and Y to the number of transactions containing only X, expressed as follows:

$$\begin{aligned}\text{confidence}(X \longrightarrow Y) &= P(X|Y\\ &= \frac{\text{support}(X \cup Y)}{\text{support}(X) \times 100\%}.\end{aligned} \quad (2)$$

4. Results

4.1. Analysis of Existing Problems. It is found that there are few professional projects on visual sensing design in colleges and universities. And, at present, the teaching content of sensing design is biased towards junior college, for example, bionic intelligent sensing design, robot visual sensing and technology, image sensing technology, and application belong to photoelectric information science and engineering.

As a result, the curriculum content is more inclined to junior college than visual sensing design. Then, the visual sensing design discipline is needed. Also, some students still do not realize that they are the main body of the learning process, their learning enthusiasm and initiative are not high, and they cannot actively participate in teaching activities. Besides, the limitation of teaching time and insufficient interaction time between teacher and students are still the traditional teaching state of "teachers say and students listen" [10]. The separation between classroom teaching and extracurricular learning is serious. Most students are in a state of passive acceptance of knowledge, and they have few thinking activities. It is difficult to cultivate students' thinking ability and innovative spirit. Students will find theory teaching boring. The course evaluation method is not perfect, and it is difficult to judge students' comprehensive ability. Therefore, it is necessary to improve the traditional teaching methods and assessment methods. The reformed teaching system is described below.

4.2. Reformation of Teaching System. Firstly, in terms of course content, it establishes a major in visual sensing technology. It is minor in computer technology, sensor technology, principle, and application of new sensors. The teaching content should also be continuously improved with the development of the times. It refers to intelligent sensing and detection technology [11], sensor and detection technology [12], and image sensing technology and application [13]. For the established professional courses, it considers the scientific system, the basic framework of visual sensing technology courses, and the relationship between various parts. It integrates brain and cognition, photoelectric foundation, sensory imaging, visual sensing imaging, visual sensing technology course, computer technology, virtual experiment course, physical experiment course, and so on. And it establishes this new professional basic course. The teaching structure and content of the prepared handout are shown in Figure 6.

The first module is the learning of various sensor principles, including pressure and force sensors, position sensors, liquid level sensors, energy consumption sensors, speed sensors, acceleration sensors, radiation sensors, thermal sensors, vibration sensors, humidity sensors, magnetic sensors, gas sensors, vacuum sensors, biosensors, and so on. It introduces the sensing technology, the concept of the sensor, the application, development, significance, principle, and general application scope of the sensor.

The second module is the study of computer technology. In the digital age, all processes are inseparable from numbers and computers. Therefore, computers are a key step to learning visual sensing design well. They mainly explain the basic principles of computers and programming-related knowledge.

The third module is the learning of visual sensors, and it is mainly focusing on the visual sensing imaging of information. For example, in optical microscopic imaging, it introduces the principles of optical Fourier analysis, diffractive optics, and Abbe imaging. And it also introduces the basic principles and technologies of fluorescence microscopic imaging, phase contrast microscopic imaging, polarization microscopic imaging, and electron microscopic imaging. The basic principle and devices of X-ray imaging, the basic principle of CT imaging, and the image reconstruction algorithm of projection are also introduced. Learning of visual sensor introduces the basic principle of nuclear magnetic resonance imaging, the basic principle of nuclear magnetic resonance imaging (MRI), Fourier-transform image reconstruction, and so on. It introduces ultrasonic imaging and medical B-ultrasound imaging. Figures 7 and 8 show optical microscopy and X-ray imaging, respectively [14].

The fourth module is the study of virtual and physical experiments. It directly combines the teaching of the experimental process with the theory. The study of virtual and physical experiments enables students to design virtual animation experiments independently. This enhances students' creative ability, reduces the consumption of experimental equipment, and lays a foundation for students to conduct physics experiments. The teaching of the experiment should be designed and comprehensively applied experiments, and more than 30 experiments based on various visual sensing principles such as optical microscopy and X-ray imaging can be carried out. Therefore, teachers should encourage students to conduct self-designed experiments and 12-hour experimental classes. It is important to simplify the experiment. Figure 9 shows an example of animation when students are doing experiments. It clearly expresses the concentration and earnestness of students in the practical courses of visual perception.

The key point is to verify the compression principle and increase the proportion of design and comprehensive experiments so that students cannot be limited to reading the experimental data only. People should also be able to combine electronic circuit knowledge with computer control technology, collect data on the computer, build a basic automatic test system, enable students to give free play to the space, and improve their hands-on ability and practical ability in the process of free experiment [15].

The fifth module is an example of a visual sensing design system. Firstly, the principle of visual sensing technology and the imaging technology of visual sensing are briefly introduced and reviewed, and it recalls the experimental process through animation. Next, it introduces the application examples of visual sensing design, such as the relevant foundation of the robot, intelligent robot and its software and hardware system, robot vision, and intelligent robot examples [16].

In terms of teaching methods, it is recommended to use offline new media teaching and teacher teaching, as well as online video playback, animation interaction, and other methods to provide learning for students. In the teaching process, teachers should pay more attention to the introduction of teaching content, pictures, animation, and other forms of expression. In normal teaching, the text should be combined with theoretical and experimental teaching content. Students' understanding of knowledge concepts is more vivid and intuitive using new media teaching and

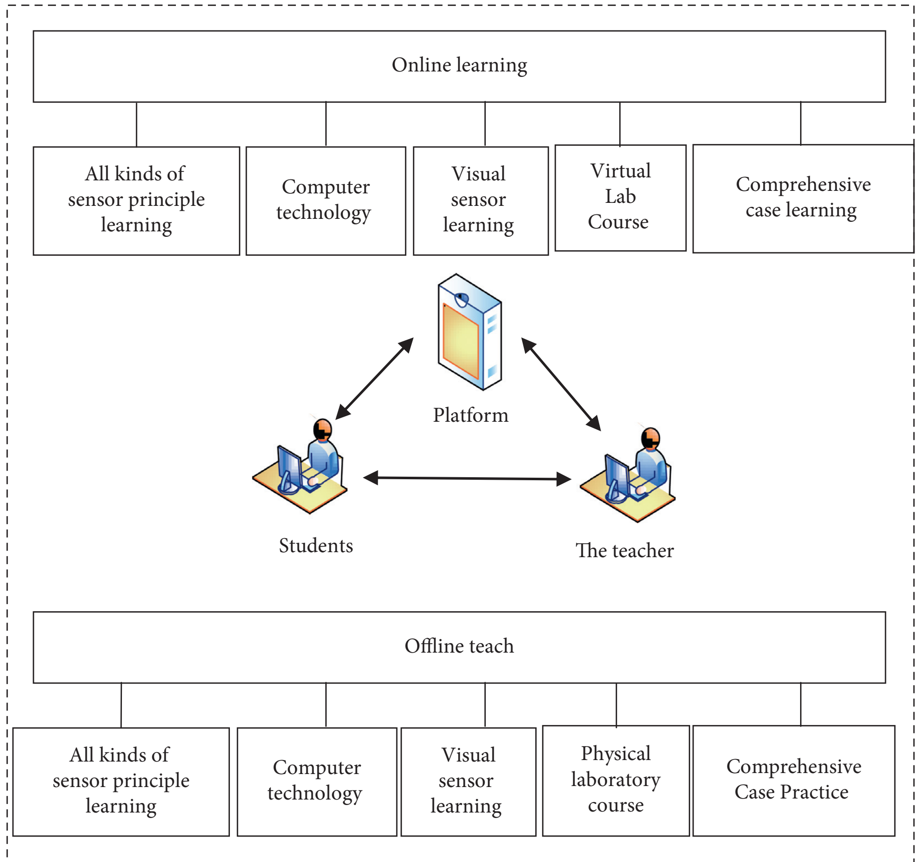

FIGURE 6: Content map of improved visual sensing design course.

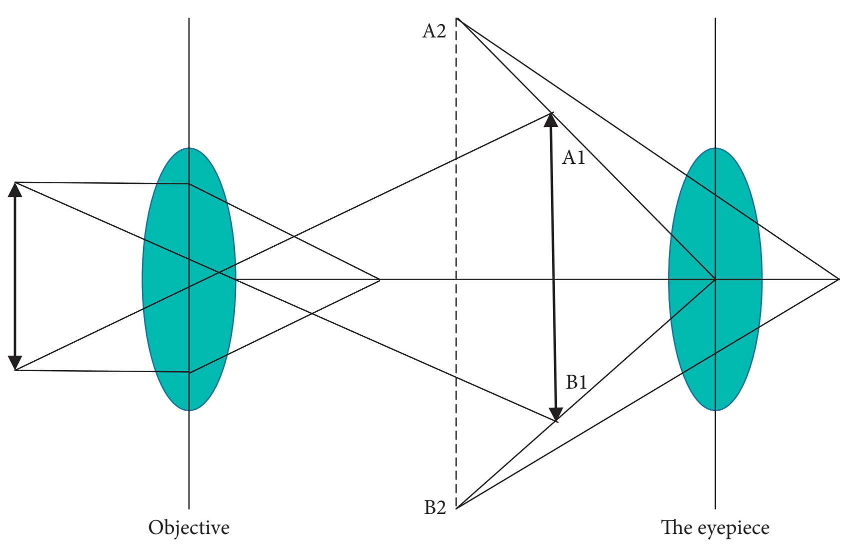

FIGURE 7: Optical microscopy.

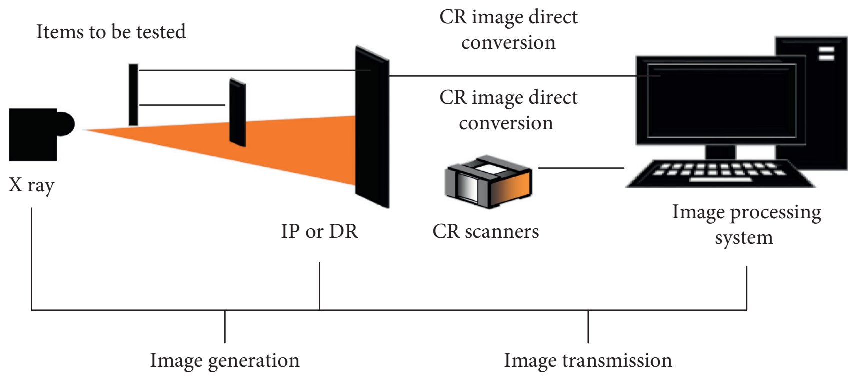

FIGURE 8: X-ray image.

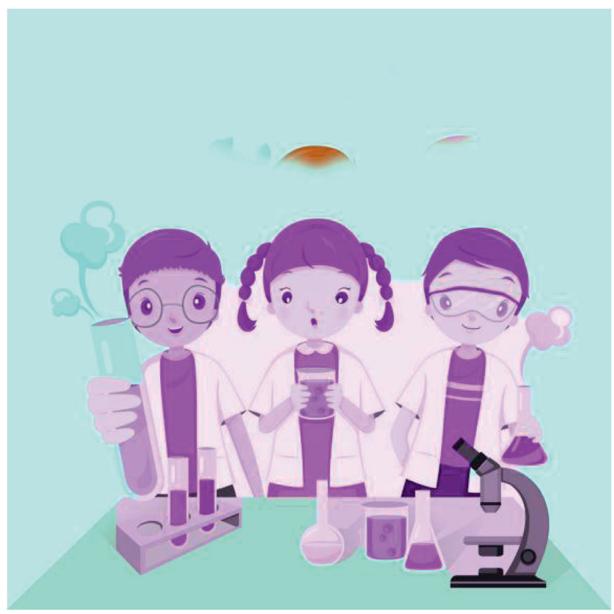

FIGURE 9: Reference relative experimental animation.

animation. The use of new media teaching and animation allows students to understand the structure of the visual sensor and clarify the working principle of the visual sensor and its application examples. It can also improve the learning efficiency of students [17]. Figure 10 is an example of students' interactive learning through online animation. The advanced computer system provides a new research direction for the teaching mode.

4.3. Visual Sensing Design Course. The teaching effect is scored according to a full score of 100. The proposed precision teaching method is compared with the teaching effect of similar teaching methods in the literature [18, 19]. The levels of student knowledge, classroom activity, and teacher-student interaction are compared, as shown in Figure 11.

In Figure 11, the precision teaching model proposed has the highest scores in the three dimensions of student knowledge mastery, classroom activity, and teacher-student interaction, all reaching more than 90 points. Among them, the score of teacher-student interaction is 96 points, indicating that the proposed teaching method based on visual sensor design can greatly increase teacher-student interaction and improve the overall effect of teaching.

5. Discussion

New media mainly adopts PowerPoint teaching and animation interaction in this process. Before this, the workload is often tedious and trivial, with huge content and many knowledge points. Students are very tired during class, lack concentration, or cannot recall previous knowledge points. The knowledge points of learning classroom content must be focused, and the process of content teaching must be logical. The important formula derivation process still needs to be combined with the teacher's handwritten presentation so that the students can understand it by themselves. The understanding of knowledge points is deeper than simple formula memorization and straightening out the thinking of the whole class. Meanwhile, the teacher arranges for students

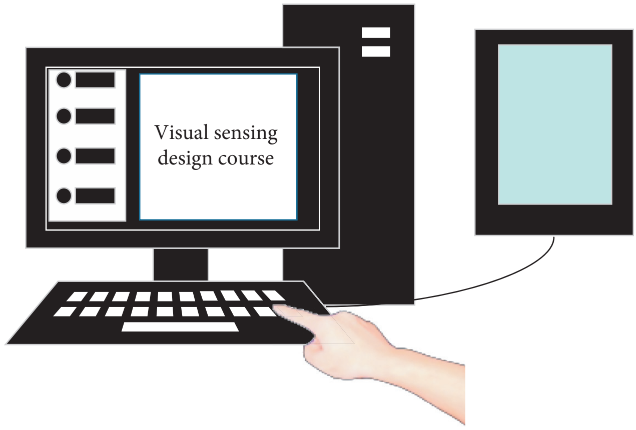

Figure 10: Interactive learning example diagram.

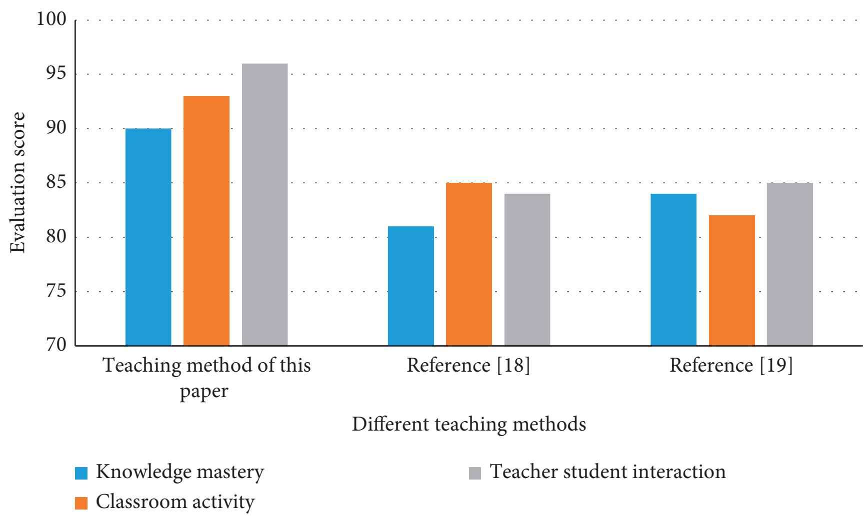

Figure 11: Comparison of different teaching methods.

to study, organize, and analyze some key content. In the first 10 minutes of each class, the teacher asks the students to summarize the learning content of the previous class and briefly introduce the content of this class. This not only can achieve classroom interaction and improve students' enthusiasm but also can set an example and exercise for some people who are eager to work as teachers. As for other students, the teaching process is also an opportunity to consolidate learning [20, 21].

When the intelligent visual sensor is introduced, students are asked to review the content of the previous class and cooperate with the teacher's explanation of the intelligent visual sensor to fully mobilize students' learning enthusiasm and give full play to the role of autonomous learning. Through classroom multimedia theory teaching, key content teaching, and application case analysis, students' theoretical learning level can be improved, and students can actively develop online learning and independent learning and make interactive courseware for an explanation. It can effectively stimulate students' interest and enthusiasm in teaching activities and promote the improvement of students' learning methods. Through the combination of college student training projects and scientific research projects, students are encouraged to combine the research content and interest projects of the sensor major and invited to participate in experimental research and design innovative experiments. This promotes the organic combination of theoretical research and scientific research practice. In the process of teaching practice, the course gradually established a teaching method that combines classroom learning, online learning, experimental learning, and autonomous learning [22, 23].

If only changing the course content and teaching methods, teachers will only take temporary solutions not effect a permanent cure. The reform of the teaching effect assessment and evaluation methods should be further explored based on changing the weight ratios of various aspects of the assessment results. The proposed method adjusts the final score composition of the examination evaluation and converts the ratio of the traditional "70% written test + 20% experiment + 10% usual score" to "30% theoretical written test + 30% experimental practice + 20% usual score + 15%

report display + 5% practice" ratio to increase the proportion of practice sessions [24–26]. The changed test evaluation standards are more practical. Finally, a demonstration evaluation system is constructed based on basic theoretical knowledge and experimental practical skills, supplemented by a comprehensive evaluation method of classroom student learning efficiency, interaction, and the display and explanation of the final practical results. Basic theoretical knowledge should fully cover knowledge points and comprehensive application capabilities.

The experimental design focuses on the candidates' practical ability, the ability to design experiments in combination with theoretical knowledge, the ability to complete the experimental process, and the ability to analyze the results. The usual assessment results are mainly the usual attendance, the interactive knowledge questions and answers with teachers and students in the classroom, and the completion of homework [27–29]. At the end of term, the display of research results is conducive to the combination of theory and knowledge, focusing on the comprehensive ability of subject investigation, data sorting, thinking and summarizing, report writing, and oral expression. This method can cultivate students' comprehensive quality in asking questions, analyzing problems, and solving problems. Finally, the level of the internship score mainly depends on the candidate's ability to adapt to society [30–32].

6. Conclusion

Since entering the digital age, people rely more and more on the use of machines. Nowadays, sensors are the core and foundation of machine manufacturing, and the observation of the world mostly depends on the eyes. Therefore, the teaching and research of visual sensing design are very crucial. A scheme to cultivate the ability of visual sensing design, experiment, innovation, and practice are designed. The system can be adopted by talents in intelligent machines, biological systems, and machine detection, that is, set up special disciplines from the perspective of professional disciplines and set up various sensor principle research courses, computer technology courses, visual sensor design courses, experimental courses, and example courses in the course content. Teaching methods are divided into online and offline synchronous classes. Moreover, an accurate teaching method based on a data mining algorithm is added and applied, which has the effect of checking leaks and filling vacancies. Regarding evaluation methods, the evaluation proportion is "30% theoretical written test + 30% experimental practice + 20% usual score + 15% report and display + 5% practice," focusing more on students' practical operation ability and practical application ability. The disadvantage is that it cannot go deep into everyone's requirements to make everyone learn better through their own learning habits. The learning methods applicable to each student based on this topic will be further explored so as to make the research of this discussion more detailed.

Data Availability

The experimental 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 regarding this work.

Acknowledgments

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References

[1] M. J. Liu, F. R. Yang, and D. Bin, "A strategic study on the development of high school science curriculum resources based on digital sensor platform," *Journal of Fujian Institute of Education*, vol. 18, no. 2, pp. 95–97, 2017.

[2] L. Li and Y. Wang, "Teaching and exploring sensor technology based on artificial intelligence," *Advances in Textile Science and Technology*, vol. 1, no. 12, pp. 54-55, 2017.

[3] M. R. Jimenez-Liso, M. Martinez-Chico, L. Avraamidou, and R. López-Gay Lucio-Villegas, "Scientific practices in teacher education: the interplay of sense, sensors, and emotions," *Research in Science & Technological Education*, vol. 39, no. 1, pp. 44–67, 2021.

[4] L. P. Tao, X. Tang, and W. H. Huang, "Design of information teaching based on "craftsman spirit" before, during and after class -- taking robot vision and sensing technology as an example," *Mechanical management development*, vol. 199, no. 11, pp. 264–266, 2019.

[5] H. B. Su and Y. L. Ma, "Application of digital technology in industrial electrical automation," *Modern industrial economy and informationization*, vol. 8, no. 162, pp. 43-44, 2019.

[6] P. Bettini, R. Torchio, F. Lucchini, D. Voltolina, and P. Alotto, "Fast Fourier transform-volume integral: a smart approach for the electromagnetic design of complex systems in large fusion devices," *Plasma Physics and Controlled Fusion*, vol. 63, no. 2, Article ID 025010, 2020.

[7] Z. Zheng, "Research progress and application prospect of intelligent sensor technology," *Tech review*, vol. 34, no. 17, pp. 72–78, 2016.

[8] K. Asibu, "Modeling of conduction mode laser welding process for feedback control," *Journal of Manufacturing Science and Engineering*, vol. 122, no. 3, pp. 420–328, 2016.

[9] X. D. Xu, "Application of sensor technology in mechatronics system," *Technology outlook*, vol. 26, no. 8, p. 78, 2016.

[10] X. A. Fan, X. Gao, G. Liu, N. Ma, and Y. Zhang, "Research and prospect of welding monitoring technology based on machine vision," *The International Journal of Advanced Manufacturing Technology*, vol. 115, no. 11, pp. 3365–3391, 2021.

[11] W. Wang and X. Wu, "Reform and practice of teaching a sensor technology course based on engineering concepts," *International Journal of Continuing Engineering Education and Life Long Learning*, vol. 28, no. 3-4, pp. 358–372, 2018.
[12] X. Yu, Y. F. Fang, and Y. L. Ge, "Exploration and research on the ideological and political teaching of sensor and detection technology course under the background of intelligent robot," *Modernization of education*, vol. 6, no. 99, pp. 48-49, 2019.
[13] G. Chen, H. Cao, J. Conradt, H. Tang, F. Rohrbein, and A. Knoll, "Event-based neuromorphic vision for autonomous driving: a paradigm shift for bio-inspired visual sensing and perception," *IEEE Signal Processing Magazine*, vol. 37, no. 4, pp. 34–49, 2020.
[14] D. Dziob, M. Krupiński, E. Woźniak, and R. Gabryszewski, "Interdisciplinary teaching using satellite images as a way to introduce remote sensing in secondary school," *Remote Sensing*, vol. 12, no. 18, p. 2868, 2020.
[15] L. Morra, S. P. Mohanty, and F. Lamberti, "Artificial intelligence in consumer electronics," *IEEE Consumer Electronics Magazine*, vol. 9, no. 3, pp. 46-47, 2020.
[16] D. Amo, P. Fox, D. Fonseca, and C. Poyatos, "Systematic review on which analytics and learning methodologies are applied in primary and secondary education in the learning of robotics sensors," *Sensors*, vol. 21, no. 1, p. 153, 2021.
[17] S. L. Chen, J. L. Huang, and W. W. Zeng, "Design of industrial automation sensor teaching experiment platform," *Chemical automation and instrumentation*, vol. 45, no. 8, pp. 640–643, 2018.
[18] A. L. Evans, A. J. Bulla, and A. R. Kieta, "The precision teaching system: a synthesized definition, concept Analysis, and process," *Behavior Analysis in Practice*, vol. 14, pp. 1–18, 2021.
[19] A. J. Bulla, A. Calkin, and M. Sawyer, "Introduction to the special section: precision teaching: discoveries and applications," *Behavior Analysis in Practice*, vol. 14, no. 3, pp. 555–558, 2021.
[20] Z. C. Liang, "Application and case study of ultrasonic motion sensor in teaching," *Digital teaching in primary and secondary schools*, vol. 30, no. 6, pp. 84–87, 2020.
[21] L. Liu, "Sensor application technology "information teaching practice -- taking the teaching design of understanding temperature sensor as an example," *The digital world*, vol. 175, no. 5, p. 127, 2020.
[22] M. Chen, "Use a variety of teaching methods to improve the effectiveness of sensor teaching," *Science & Education*, vol. 383, no. 4, pp. 100-101, 2017.
[23] J. Jovaisaite, D. Cirule, A. Jeminejs et al., "Proof of principle of a purine D-A-D′ ligand based ratiometric chemical sensor harnessing complexation induced intermolecular PET," *Physical Chemistry Chemical Physics*, vol. 22, no. 45, pp. 26502–26508, 2020.
[24] W. Wei Dan, R. Ren Xian, and M. Q. Ma Qi Hua, "Research on the construction of courses of automotive electronics and electrical appliances based on the joint training mode of vocational schools and applied undergraduate courses," *Britain International of Humanities and Social Sciences (BIoHS) Journal*, vol. 2, no. 1, pp. 1–8, 2020.
[25] K. Watanabe, Y. Kurihara, K. Kobayashi, and K. Suzuki, "In-bed biosignal acquisition from conventional differential pressure sensor based on thermal flow principle," *IEEE Sensors Journal*, vol. 21, no. 4, pp. 5340–5348, 2020.
[26] H. H. Hong and Y. Ye, "Ideological and political teaching reform of sensor and detection technology course," *International public relations*, vol. 97, no. 1, pp. 72–74, 2020.
[27] F. Yao and A. Zhang, "Integration of education management and mental health in psychological crisis intervention in colleges and universities," *ASP Transactions on Psychology and Education*, vol. 1, no. 1, pp. 31–38, 2021.
[28] L. P. Huang, "Exploration and research on the diversified teaching reform of test technology and sensor course," *Science and Technology*, vol. 32, no. 17, pp. 139-140, 2019.
[29] J. Tang, L. H. Li, and X. J. Huo, "Exploration on teaching reform of sensor courses in agricultural colleges," *Farm staff*, vol. 657, no. 11, p. 229, 2020.
[30] J. Peng, W. Feng, Z. Yue, and X. Yang, "Fiber-optic Fabry-Perot temperature sensor based on the ultraviolet curable glue-filled cavity and two-beam interference principle," *Zeitschrift für Naturforschung A*, vol. 76, no. 2, pp. 175–179, 2021.
[31] T. Liu, "Exploration of "student-centered" teaching method reform in sensor and detection technology course," *Heilongjiang Science*, vol. 10, no. 156, pp. 20–23, 2019.
[32] L. Liang, "Exploration and practice of network teaching of sensor and detection technology based on OBE concept," *The wind of science and technology*, vol. 422, no. 18, p. 71, 2020.

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Research Article

Digital Twins by Physical Education Teaching Practice in Visual Sensing Training System

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The paper expects to improve the efficiency and intelligence of somatosensory recognition technology in the application of physical education teaching practice. Firstly, the combination of induction recognition technology and the Internet is used. Secondly, through the Kinect sensor, bone data are acquired. Finally, the hidden Markov model (HMM) is used to simulate the experimental data. On the simulation results, a gait recognition algorithm is proposed. The gait recognition algorithm is used to identify the motion behaviour, and the results are displayed in the Web (World Wide Web) end built by the cloud server. Meantime, in view of the existing problems in the practice of physical education, combined with the establishment and operation of the Digital Twins (DTs) system, the camera source recognition architecture is carried out since the twin network and the two network branches share weights. This paper analyses these problems since the application of somatosensory recognition technology and puts forward the improvement methods. For the single problem of equipment in physical education, this paper puts forward the monitoring and identification function of the cloud server. It is to transmit data through Hypertext Transfer Protocol (HTTP) and locate and collect data through a monitoring terminal. For the lack of comprehensiveness and balance of sports plans, this paper proposes a scientific training plan and process customization based on Body Mass Index (BMI), analyses real-time data in the cloud, and makes scientific customization plans according to different students' physical conditions. Moreover, 25 participants are invited to carry out the exercise detection and analysis experiment, and the joint monitoring of their daily movements is tested. This process has completed the design of a feasible and accurate platform for information collection and processing, which is convenient for managers and educators to comprehensively and scientifically master and manage the physical level and training of college students. The proposed method improves the recognition rate of the camera source to some extent and has important exploration significance in the field of action recognition.

1. Introduction

In recent years, people's demand for data application in the process of sports and training has been increasing. In the practice of physical education and training, somatosensory recognition technology based on visual sensing systems has attracted more and more attention and research [1]. After 2010, college students' physical health problems were more prominent, showing a downward trend year by year, and the development of college physical education has urgent reform requirements [2]. The state and government attach great importance to the physical fitness of college students and the development of physical education in colleges and universities. Accordingly, with the application of big data and the rise of visual technology, the demand for more intelligent and scientific technology is also more urgent [3]. Based on the motion somatosensory recognition technology of visual sensing, the Kinect bone tracking technology without identification points has been widely developed and applied because of its low cost, portability, easy implementation, and no identification points [4]. In computational mechanics, the introduction of the concept and technology of the Digital Twins (DTs) system can achieve real-time safety monitoring and early warning of solid structures. The DTs system can not only be applied to civil structures. Similarly, it can also be applied to the field of sports science. The system can not only track and monitor the gait in real time but also optimize and improve the computer simulation recognition technology. It is one of the methods used. DTs are of great help to the modification and improvement of structural system redesign and provide a more reliable basis. Source identification of digital images is an important part of image extraction. Source identification of digital images (i.e., imaging equipment identification) refers to a given graph, which determines imaging and identifies types through scientific and technological means and methods. The camera source is identified by the identification architecture of the DTs network. Firstly, the fingerprint of the camera is extracted from the twin network. Secondly, the residual network of attention mechanism is added to extract features, and the camera source recognition can be realized. Finally, the expected effect of the sample number is achieved.

The application of visual sensing technology mainly focuses on three fields: visual monitoring, interface perception, and content retrieval. In the field of elaboration and analysis, all aspects of the human motion process are discussed and analysed by analogy. The identification and understanding of motion behaviours are analysed, but some studies on motion representation are relatively simple. In the research based on the characteristics of the human model, the angle between the various parts of the human body and the trajectory of bone joints are collected and calculated to achieve a more accurate description of the movement and avoid the error caused by the change of the scene. This method mainly describes the state of each part of the human body in a three-dimensional space [5].

In view of the current development and in-depth development of human visual sensing motion recognition technology, it is increasingly necessary to conduct detailed analysis in related fields. Firstly, after the sample data, algorithm model, and motion behaviour characteristics are analysed, the vision sensor training system is designed. Secondly, the collected experimental data are tested in the training system. Finally, through the DTs network, the camera source identification method is proposed. The research aims to provide a certain experience for the further development of the perspective sensor training system in physical education practice.

2. Materials and Methods

2.1. Construction of Kinect V2 System Using Physical Education Practice

2.1.1. Introduction to Kinect V2. Kinect V2 is a new Kinect for Windows product released by Microsoft in 2014. Kinect is a 3D somatosensory camera with a microphone array, infrared transmitter and receiver, and RGB (RGB colour mode) camera. The image of the human part separated from the background is input into the human part recognition model trained by the cluster system, and the 25-node human model is output, and the bone data are output at the speed of 30 f/s. Its official system includes driver, original sensing data flow development interface, user interface, and file data, which can be developed twice. The device uses Time of Flight technology to obtain depth image information by calculating the projected infrared and the return time of reflection. Then, through the corresponding algorithm, the coordinate information of human joint points segmented from the background image is estimated. Among them, the bone data output by RGB intelligent camera provides the basis for human motion recognition and solves the problem of data extraction in computer vision.

Kinect V2 components and functions are shown in Table 1.

2.1.2. Kinect V2 Hardware Requirements. System CPU (Central Processing Unit) uses an Intel 7-generation processor, dx11 (DirectX11), with a 64-bit operating system. The hardware composition is shown in Figure 1.

In Figure 1, the CPU is the core of the computer, and the computer acts as an "intermediary" in the Kinect V2 hardware. Kinect V2 stores the bone data related to the human body and the user's personal information on the card reader and sends it to the computer. The computer sends this information to the cloud space. When users visit the website, they can see their own information on the computer monitor.

2.1.3. Kinect V2 Application Principle. Kinect V2 equipment first uses the infrared receiver to receive the infrared light emitted by the infrared transmitter. By collecting the encoded infrared spectrum, the depth image is processed frame by frame. Then, the device separates the characters and background to obtain the colour image of human motion. Finally, the data are transmitted through Kinect V2. The data flow process is shown in Figure 2.

(1) Depth Imaging. Among the three cameras of Kinect V2, RGB camera is used to collect RGB images, also known as colour camera. Two other cameras (infrared transmitters and infrared cameras) are used to form a depth sensing device.

The depth measurement technology in Kinect V2 is a 3D detection technology based on PrimeSense, which obtains depth information through the optical principle. The infrared ray emitted by the infrared transmitter goes to the different reference planes of the specified scene, and the diffraction grating divides it into multiple beams. The infrared spectrum forms some speckle patterns in these planes, and different speckle patterns show different depth values to determine the depth information.

Assuming that it points to the infrared emitter in the x-axis positive direction and to the object in the z-axis positive direction, the coordinate system conforms to the right-handed spiral rule. Measuring the parallax of t' in the image, there are

$$\frac{C}{c} = \frac{Z_t - Z_o}{Z_t}, \quad (1)$$

$$\frac{C}{e} = \frac{C}{Z_o}. \quad (2)$$

Table 1: Kinect V2 components and functions.

Components	Functions
Infrared projector	Infrared emission
Infrared photosensitive camera	Infrared spectral data analysis
Microphone	Get voice data
RGB camera	Collect colour images and video data
Control the camera motor	Get the best angle by controlling the camera
Serial cable	Signal reception and transmission

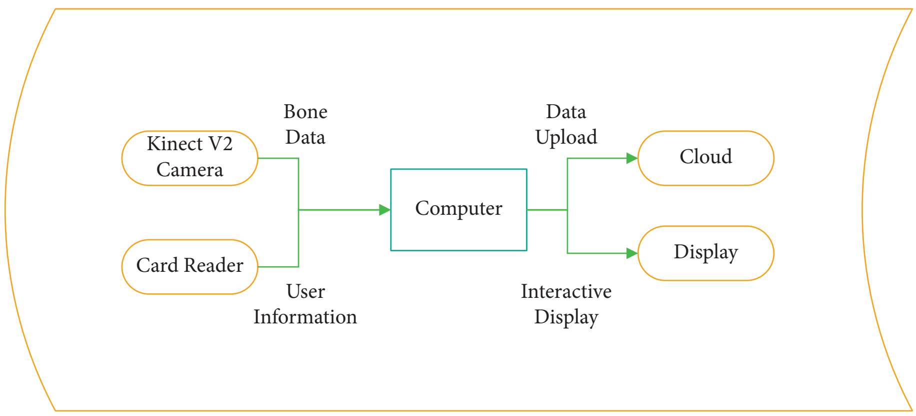

Figure 1: Kinect V2 hardware composition diagram.

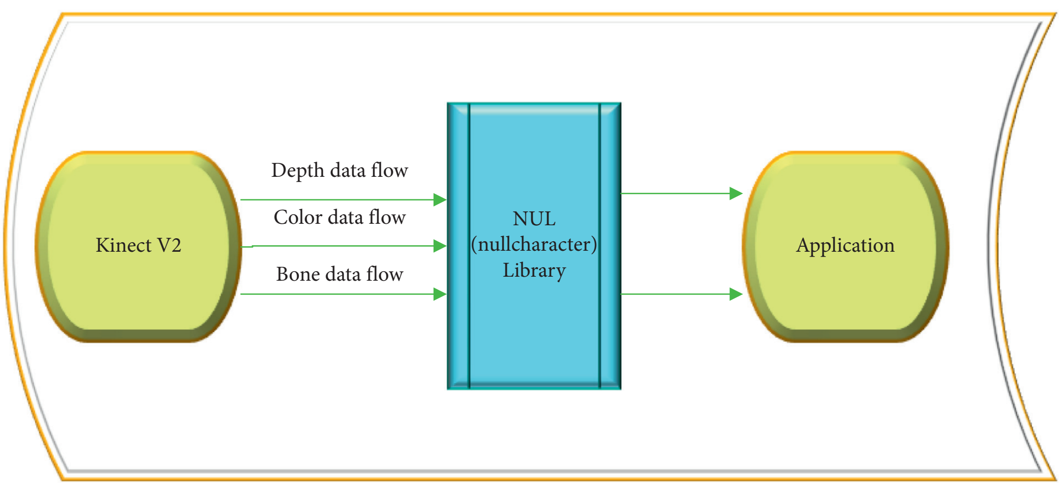

Figure 2: The data stream of Kinect V2.

In equations (1) and (2), Z_o is the depth distance from the real sensor to the object, A is the baseline length, e is the focal length of the sensor, C is the displacement distance of point o, and c is the parallax of the infrared image [6]. Combining equations (1) and (2), there is

$$Z_o = \frac{Z_t}{1 + (Z_t/f.b)d}. \quad (3)$$

The depth distance Z_o is obtained from the above equation. Using the same principle, there are

$$X_o = -\frac{Z_o}{f}\left(X_o - X_t + \delta_x\right), \quad (4)$$

$$Y_o = -\frac{Z_o}{f}\left(Y_o - Y_t + \delta_y\right). \quad (5)$$

In equations (4) and (5), the abscissa of o point is X_o, the ordinate of o point is Y_o, the abscissa and ordinate of original coordinate are X_t and Y_t, respectively, and the correction term is δ_y. The three-dimensional coordinates of o point are calculated, Z_o represents the depth distance from the real sensor to the object, and f represents the depth of the reference plane.

(2) Bone Recognition. Skeleton recognition is a process of extracting the required information from noise, that is, the process of removing interference information except the human body in the picture. The identification process is shown in Figure 3.

Kinect V2 uses the Poisson equation to filter the noise to determine the existence of feature points on the body surface [7]. By grasping the angle and direction of the surface around the feature point, it determines the spatial position of its existence and forms a distance field near the point to obtain a relatively smooth shape.

2.2. Overall Network Architecture for Source Identification of DTs Camera. DTs play an important role in the camera source identification of the Kinect V2 system. Twins parasitize in digital time and space in computers, such as entity space-time and twin brothers in the corresponding digital space-time. DTs have two evolution paths. One is Product Lifecycle Management (PLM) to DTs. The other is from Physical Twins (PTs) to DTs. The establishment of DTs corresponding to entities marks the improvement of computer numerical simulation and simulation concept and technology and is a breakthrough in computational mechanics.

Generally, DTs have five life stages:

(1) Design phase: in this stage, DTs can be optimized by finite element decomposition, which determines the design scheme of the solid structure. In DTs, the layout optimization can determine the design scheme of mechanical sensors in the structure.

(2) Manufacturing phase: in this phase, less computation will focus on manufacturing changes to the design, and DTs will be checked as the entity structure changes to ensure synchronization with the entity.

(3) Operational phase: in this stage, the calculation of the design is relatively large and the most complex. This stage mainly focuses on Tokyo load identification to carry out calculation related to safety monitoring. Because of high difficulty, large quantity, and high complexity, the real-time repeated calculation is needed.

(4) Maintenance phase: in this phase, the amount of computation is concentrated mainly before maintenance and is closely related to the previous phase. Real-time safety assessment does not hinder the proposal and proposal of maintenance.

(5) Retirement phase: in this stage, there are calculation of retirement decision and calculation of rehabilitation. The calculation of decision-making is like the calculation of maintenance suggestions in the previous stage, and the calculation of rehabilitation is like the calculation in the design stage. After the comprehensive analysis of a declaration cycle and the calculation of the optimal design, suggestions for improvement of the redesign are proposed.

In order to realize the identification of the camera source, this paper designs an identification architecture based on a twin network. The overall structure is shown in Figure 4. The virtual frame is two branch networks of twin network sharing weights. In the designed twin network, two samples are needed to enter, the reference image P1 and the test image P2. The input two images are filtered to obtain the camera reference mode noise and the image to be tested. The pattern noise extracted from the reference image P1 is the "fingerprint" of the camera. Using the residual network with an attention mechanism, two noise image features are extracted. By calculating the distance between the feature vectors, the similarity between the noise information of the image to be measured and the "fingerprint" information of the camera C is measured to determine whether the image P2 can be seen as shot by the camera C and realize the camera source discrimination.

For the accuracy of camera source identification, seven different camera models are selected. The test images with different resolutions are unified into 224×224 image blocks to verify the performance of the designed method. The recognition accuracy and receiver operating characteristic curve are used as evaluation indexes to measure the performance of image source recognition. The recognition accuracy is defined as the ratio of the number of correct images to the number of all recognized images.

2.3. Motion Category and Representation. Human movement can be divided into three types based on three different levels of complexity, namely, action, behaviour, and action [8]. Among them, "action" is the most basic movement, the basic elements of movement, and the necessary basis for the formation of other complex movements. The time sequence is short, and the geometric and statistical methods are commonly used for identification. "Behaviour" refers to the sequence of several continuous actions. Its time scale is larger than that of "action," and it can clearly show the purpose of human motion. It is usually identified by statistics. "Behaviour" may contain multiple "action," and the relationship between each action and state needs to be considered and linked in the recognition process. Finally, "action" is the most complex, which is realized through motion. However, it is not a simple mechanical combination of individual motion, but a complete and purposeful motion system with different degrees of complexity. Probability statistics and artificial intelligence algorithms are usually used to identify, among which the Bayesian network is the representative method.

The behaviour process extracted from the video sequence containing human motion that can reasonably and appropriately represent the motion data is called motion representation. In the process of motion recognition, motion representation is an extremely important step. Different occasions and environments need to choose different methods for motion representation. When the motion scene is a large scene, it is necessary to carry out remote camera and monitoring; only the trajectory of the moving target is extracted. When the motion situation is small, such as gesture recognition, it is necessary to model the limb joints of the moving target in two-dimensional (2D) or 3D. In general, four criteria are used to measure the pros and cons of motion representation [9],

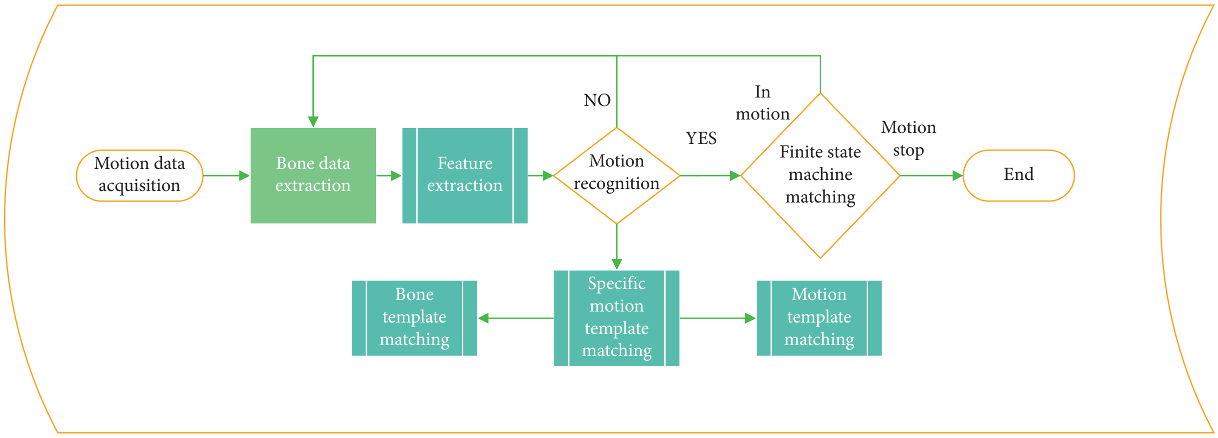

FIGURE 3: Kinect V2 recognition process.

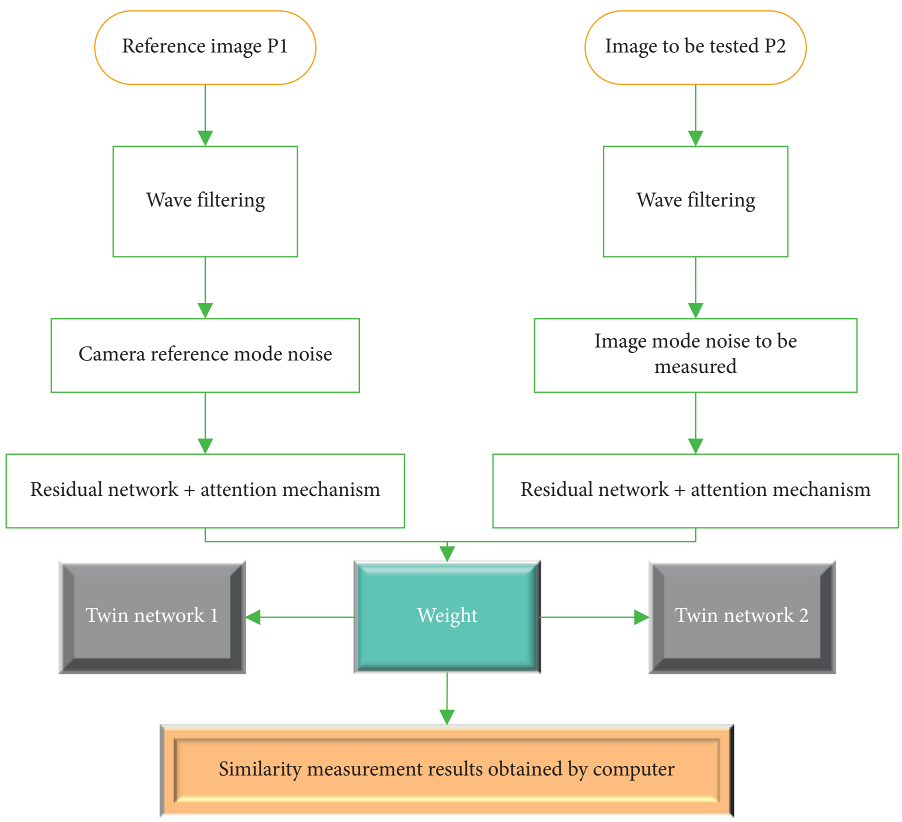

FIGURE 4: DTs network modelling for camera source recognition.

namely, compactness, completeness, continuity, and uniqueness [10]. Most of the current motion representation can only meet part of the above metrics. Generally, there are two representation methods, one based on appearance and the other based on the human model.

The representation method based on representation is to analyse and represent the motion by directly using the colour information or grey information in the image. This method of directly using image information is relatively simple. Yamato et al. (2016) took the two-dimensional network feature as the motion feature [11] and divided the whole image into several networks by binarization of the image extracted from the moving target. They calculated the proportion of the number of target pixels in each network in the whole grid, thus representing the movement of the target.

Another representation method is based on human contour information or region information. Kale et al. (2017) adopted a gait recognition method based on human contour information [12]. They first extract the human contour, calculate the contour width, and use the width vector as the feature vector to complete the recognition. There is also an apparent representation method based on motion information (optical flow, target trajectory, speed, etc.). However, due to a large amount of calculation and insufficient robustness of this method, Psarrou et al. (2017) used spatiotemporal trajectory technology to represent behaviour and further used the Markov process to model [13].

2.4. Identification Method Technology

2.4.1. Template-Based. The template-based method is to transform the motion image sequence into a single or a set of static templates and realize recognition by matching the sample template to be identified and the known template. The matching method is to directly match the sample of the template to be identified and the known template and obtain the category of the known template with the smallest distance as the recognition result. Bobick and Davis (2018) transformed the image sequence into MEI (motion energy image) and MHI (motion history image) and used Mahalanobis distance to measure the similarity between templates [14]. MEI represents the coverage and intensity of motion, and MHI represents the time change of motion.

Due to the different duration of motion in the same mode, template time warping becomes very necessary. Arie et al. (2016) linearized the template sequence before matching and then matched it by voting [15]. The duration of action is often random in the process of movement, so the linear time regulation method cannot completely solve the problem.

2.4.2. Based on Probability Network. As the most important motion recognition method at present, the method based on probability network can fully consider the dynamic process existing in the motion process. Different from the template-based recognition method, the method based on probability network can model the subtle changes in time and space scales through the probability method, so it has good robustness. At present, there are two kinds of probabilistic networks: dynamic Bayesian network and hidden Markov model. The hidden Markov model, as a special form of dynamic Bayesian network, has been used as a conditional random field in behaviour recognition [16]. Because it can avoid the independence assumption in the usual probability model, it is currently used most widely.

2.4.3. Grammar-Based Technology. The grammar technique is also called the syntax technique. Because of its advantages of understanding complex structures and utilizing prior information, there are more and more opportunities for motion recognition. Huber et al. (2016) used the deterministic syntax of adding orders to identify discrete events [17]. Cho et al. (2017) used statistical grammatical reasoning to solve automatic identification [18]. Ivanov and Bobick (2016) used the technology of instant grammar to identify the behaviour interaction of multiagents [19] and divided the identification problem into two levels. The bottom layer was the candidate feature detected by the independent probability event detector, which generated random syntactic analysis services for context-free.

2.5. Hidden Markov Model. It is the simplest dynamic Bayesian network based on training and evaluation in the probability and statistics model. In this paper, this algorithm is used to study the recognition of motion. In the hidden Markov model, the state is not directly visible but is visible by using the output dependence of a specific observation value. The model includes two random processes, as shown in Figure 5.

The hidden Markov model has two parts. The first is the Markov chain, and the output through this process is the state sequence. The other is the random process of the output corresponding to the observation value sequence and the state sequence. Usually, hidden Markov models are defined by five parameters.

2.5.1. N Hidden States. The hidden Markov model (HMM) is a probability model about time series. It describes the process of randomly generating unobservable state random sequences from a hidden Markov chain and then generating an observation from each state to generate an observation random sequence. Hidden Markov states satisfy Markov properties and are actually hidden states in Markov models. However, these states cannot be obtained by direct observation and can be specifically represented by $\theta 1$, $\theta 2$, $\theta 3$, ..., θn.

2.5.2. M Observable States. M is the number of observed values corresponding to a specific state, which can directly observe the state associated with the hidden state in the model. $V1$, $V2$, $V3$, ..., Vm are defined as the observed M observations, and Q_t is defined as the observed value of t at any time.

2.5.3. Initial State Probability Matrix Π. The initial state probability matrix represents the probability matrix of the implicit state at the initial time. For instance, when the initial state probability matrix defining $\Pi = (\Pi_1, \Pi_2, \Pi_3 \ldots, \Pi_n)$,

$$\Pi_i = P(q_i = \theta_i), 1 \leq i \leq N. \quad (6)$$

2.5.4. Implicit State Transition Probability Matrix A. The implicit state transition probability matrix A describes the transition probability between states in the HMM. If defining $A = (a_{ij})_{NN}$, than there is

$$a_{ij} = P(q_{t+1} = \theta_j \mid q_t = \theta_i). \quad (7)$$

At time t, when state θ_t is established, Equation (7) indicates the probability of the observation state being at time t and the implicit state of $t+1$.

2.5.5. Observation State Transition Probability Matrix B. The probability of θ_j is observed when the implicit state is θ_j at t. B represents the observation matrix of the observation value; defining $B = (b_{jk})_{NM}$, there is

$$b_{ij} = P(O_t = V_k \mid q_t = \theta_j) 1 \leq j \leq N, 1 \leq k \leq M. \quad (8)$$

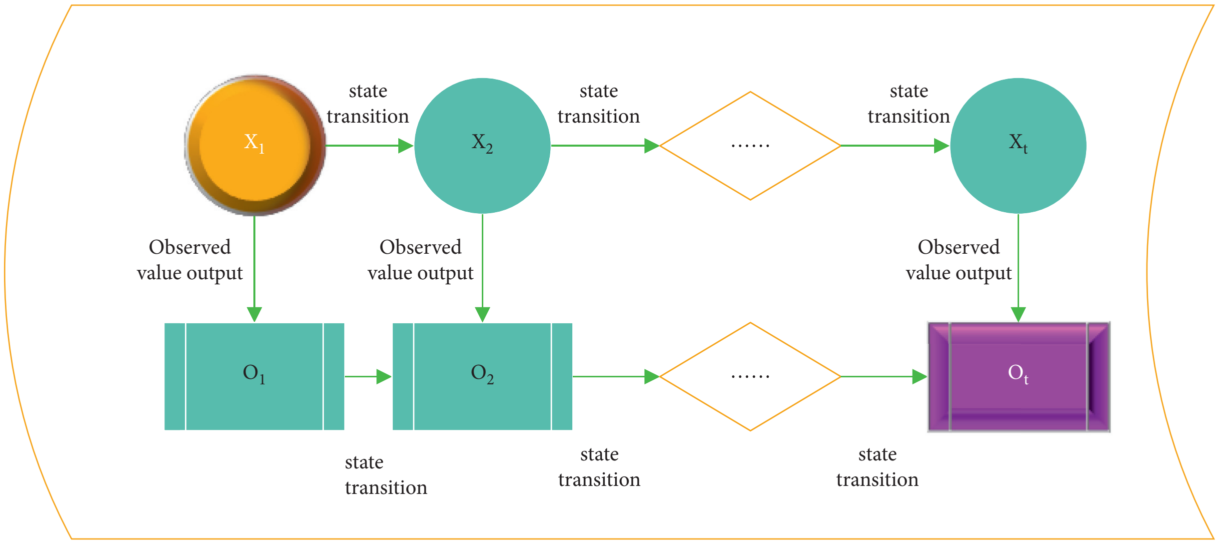

FIGURE 5: The process diagram double random about the hidden Markov model (HMM).

Therefore, in the hidden Markov model, there are

$$\lambda = (N, M, \Pi, A, B). \tag{9}$$

Briefly,

$$\lambda = (\Pi, A, B). \tag{10}$$

2.6. Hidden Markov Algorithm

2.6.1. Viterbi Algorithm. The Viterbi algorithm is an algorithm that uses the dynamic programming idea to calculate the hidden Markov chain model prediction so as to find the optimal path problem. Define the observation sequence $O = O_1O_2O_3 \ldots O_T$, $\lambda = (A, B, \Pi)$, with $P = (Q, O \mid \lambda)$ as the maximum premise, and find the specific $Q^* = q_1^*, q_2^*, \ldots, q_t^*$ sequence.

$\delta(i)$ is defined as the maximum probability of $O_1, O_2, O_3, \ldots, O_t$ obtained at time t at the state $q_1, q_2, \ldots, q_t$, when $q_t = \theta_i$.

Initialize:

$$\begin{aligned} \delta_1(i) &= \Pi_i b_i(O_1), \quad 1 \le i \le N, \\ \varphi_1(i) &= 0, \quad 1 \le i \le N. \end{aligned} \tag{11}$$

Reasoning:

$$\begin{aligned} \delta_t &= \max_{1 \le i \le N}\left[\delta_{t-1}(i)a_{ij}\right], \quad 2 \le t \le T, 1 \le j \le N, \\ \varphi(j) &= \arg\max_{1 \le i \le N}\left[\delta_{t-1}(i)a_{ij}\right], \quad 2 \le t \le T, 1 \le j \le N. \end{aligned} \tag{12}$$

Ending is as follows:

$$\begin{aligned} P^* &= \max_{1 \le i \le N}\left[\delta_T(i)\right], \\ qT^* &= \arg\max_{1 \le i \le N}\left[\delta_T(i)\right]. \end{aligned} \tag{13}$$

Optimal path is as follows:

$$qT^* = \varphi_{t+1}(q_{t+1}^*), \quad t = T-1, T-2, \ldots, 1. \tag{14}$$

2.6.2. Baum–Welch Algorithm. This algorithm can solve the parameter estimation problem in the hidden Markov model [20] and can easily calculate the model-related parameters:

$$P(O \mid \lambda) = \sum_{i=1}^{N}\sum_{j=1}^{N} a_t(i)a_{ij}b_j(O_{t+1})\beta_{t+1}(j), 1 \le t \le T-2. \tag{15}$$

The idea of the dynamic algorithm can be used to obtain $\lambda = (A, B, \Pi)$ by making the maximum value of $P = (O \mid \lambda)$ to the local optimal solution.

$\xi(i, j)$ is defined as the probability of θ_i at time t when the training sequence O and the model parameter λ are known, and the Markov chain state θ_i and $t+1$ are defined as follows:

$$\xi(i, j) = P\left(O, q_t = \theta_t, q_{t+1} = \theta_j \mid \lambda\right). \tag{16}$$

Reasoning is as follows:

$$\xi(i, j) = \frac{\left[a_t(i)a_{ij}b_j(O_{t+1})\beta_{t+1}(j)\right]}{P(O \mid \lambda)}. \tag{17}$$

Thus, it is probable that

$$\xi(i) = P\left(O, q_t = \theta_t \mid \lambda\right) = \frac{\sum_{j=1}^{N} \xi_t(i, j) = a_t(i)\beta_t(i)}{P(O \mid \lambda)}. \tag{18}$$

The reevaluation equations are

$$\begin{aligned} \overline{\Pi_i} &= \xi_1(i), \\ \overline{a_{ij}} &= \frac{\sum_{t-1}^{T-1} \xi_t(i, j)}{\sum_{t=1}^{T-1} \xi_t(i)}, \\ \overline{b_{ik}} &= \frac{\sum_{t=1 \text{ 且 } O_t = V_k}^{T} \xi_t(j)}{\sum_{t=1}^{T} \xi_t(j)}. \end{aligned} \tag{19}$$

2.7. Motion Recognition under Hidden Markov Model. In the process of restoring motion recognition, all action sequences are divided into N segments on average so that they correspond to the N state in the hidden Markov model one by one and N state transition sequences are generated for the sequences. The transition process is shown in Figure 6.

The number of t frame states q_i in the m sequence and the number of $t+1$ frame states q_j are represented by equations

$$N_{i,j}^{m} = N^{m}\left(S_{t+1} = q_j \mid S_i = q_i\right). \tag{20}$$

The number of frames 1 in the m state sequence and the state q_i is represented by an equation

$$N_i^m = N^m\left(S_1 = q_i\right). \tag{21}$$

In the probability of the initial state, there is

$$\Pi_i^0 = P\left(S_1 = q_i\right) = \frac{\sum_m N_i^n}{\sum_i \sum_m N_i^m}. \tag{22}$$

According to the above equation, the number of transitions between two adjacent frames in all state sequences is calculated to obtain the transition probability A^0 of the initial state. There is

$$a_{i,j} = P\left(S_{t+1} = q_j \mid s_t = q_j\right) = \frac{\sum_m N_i^n}{\sum_i \sum_m N_i^m}. \tag{23}$$

The Baum–Welch algorithm is used to learn the parameters, and the initial parameters are input into the hidden Markov model for parameter training. Through this process, the maximum motion action is selected as the recognition result. The training and recognition process is shown in Figure 7.

2.8. Technical Architecture. The system collects the bone motion data of the target in real time through the camera of Kinect V2 [21]. Skeleton data after coordinate mapping to get smooth data, using space vector method to calculate the angle characteristics between bone joints and using HMM model to collect the motion characteristics of data model training [22], select the maximum output probability, so as to realize a reliable real-time training system design and output.

2.8.1. Data Collection. The camera of Kinect V2 is used to obtain the motion data of the target, and the bone data flow is applied to the subsequent skeletal motion recognition.

2.8.2. Bone Algorithm Processing. The data collected from the previous layer are filtered to obtain smoother bone data [23], and the angle characteristics of bone joints by spatial vector algorithm are calculated.

2.8.3. Motion Recognition. The data of predefined motion actions in the previous layer are collected and calculated to obtain the initial parameters of HMM, and the motion action model is trained to obtain the output probability of many hidden Markov models. The maximum output probability is selected as the recognition result by comparison.

2.8.4. Application. Through the different training movements identified by the previous layer, the data generated in the process (movement time, movement number, performance settlement, etc.) are stored and uploaded to the cloud server [24]. The scientific analysis and management of the system are carried out, and the scientific training plan that meets the target characteristics is finally generated.

The architecture is shown in Figure 8.

2.9. Software Design. The system software architecture is divided into four layers, including data layer, skeleton algorithm layer, motion recognition layer, and motion performance layer. The software client uses TCP/IP (Transmission Control Protocol/Internet Protocol) communication protocol to communicate with the cloud server [25].

The client function design is shown in Table 2.

Figure 9 shows the software design process.

3. Results

3.1. Bone Joint Confusion Experiment. Motion recognition design is based on bone joint data acquisition. In order to ensure that cameras and software can collect and analyse all the joints, five daily behaviours were monitored and analysed, including sitting, standing, pouring water, drinking water, and using the phone. In the experiment, 100 groups of samples were collected for each of the five behaviours, a total of 500 groups. 40 groups of components were extracted from the samples collected by each behaviour, and other samples were tested according to the standard template library. The matrix results obtained according to the test results are shown in Table 3.

According to the results of sample confusion, the actual motion and template have played a good classification and comparison results, and the identification of behaviour representation features is feasible. Due to the similarity between the behavioural characteristics of some actions and the joint angle, there is a low degree of recognition.

3.2. Training System Test. In order to test the feasibility of the system, 20 men and 5 women were invited to participate in the test for 3 days. In the three days, 25 people used this system for training in the morning and afternoon, once a day, and a total of 250 data samples were obtained. Sample analysis results are shown in Table 4.

Through the comparative analysis of the recognition rate and accuracy, it is found that the training system has a high recognition rate of motion and can accurately measure and analyse the joint angle and motion trajectory for motion recognition. Among them, the accuracy of sit-up and squat is the highest, which can meet the requirements of the market. In contrast, the accuracy rate in monitoring and measuring

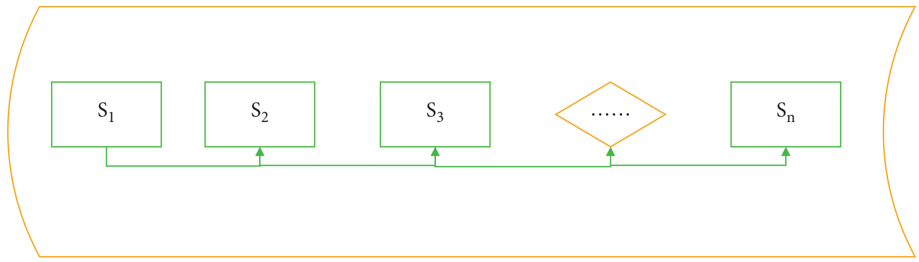

Figure 6: The process of sequence conversion (S_1 represents the distance of the first leg, S_2 represents the distance of the second leg, S_3 represents the distance of the third leg, and S_n represents the distance of the n-th leg).

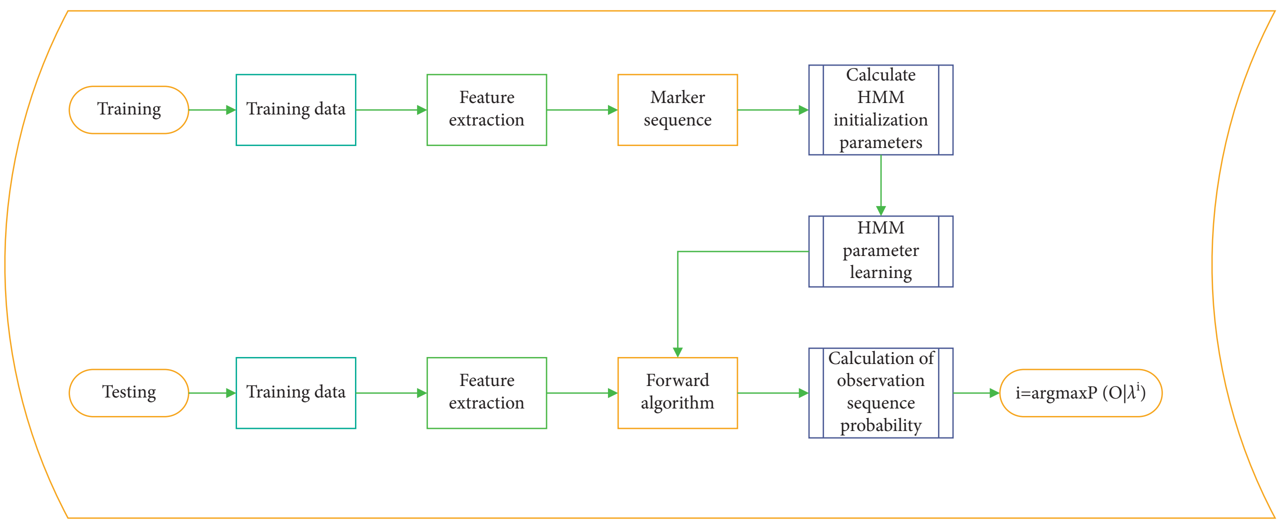

Figure 7: The process of training and recognition.

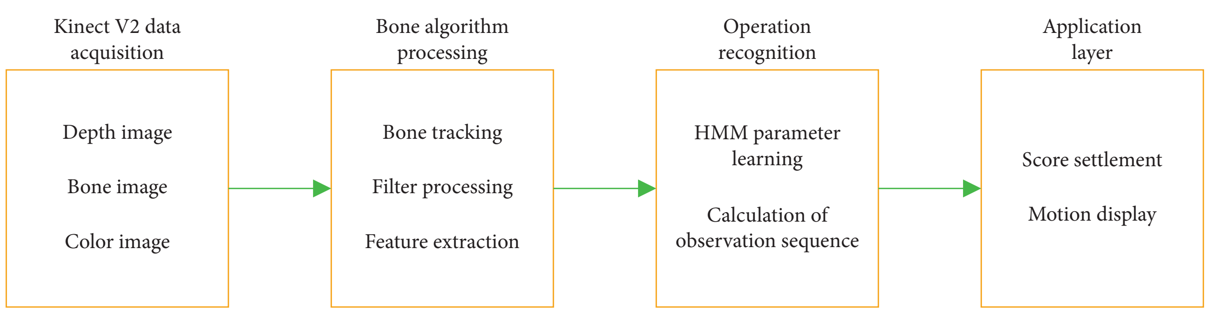

Figure 8: The system of architecture.

Table 2: Client functionality.

Name	Concrete functions
Information acquisition	Through the information collection of students' identity cards (campus card and meal card), the card number is used as the number, and the USB (Universal Serial Bus) is used to read the information and save the record
Motion recognition	4% use USB connection Kinect V2 for training motion data acquisition, through model design in the client for motion recognition, judge the basic information, and save its records
Feedback and interaction	Give feedback on the basic information of the target and real-time motion training data to the user through the front-end display device and realize the interactive function
Cloud upload	Upload the user's basic information and training data to the cloud and save its records. Concurrent information analysis to customize training plans

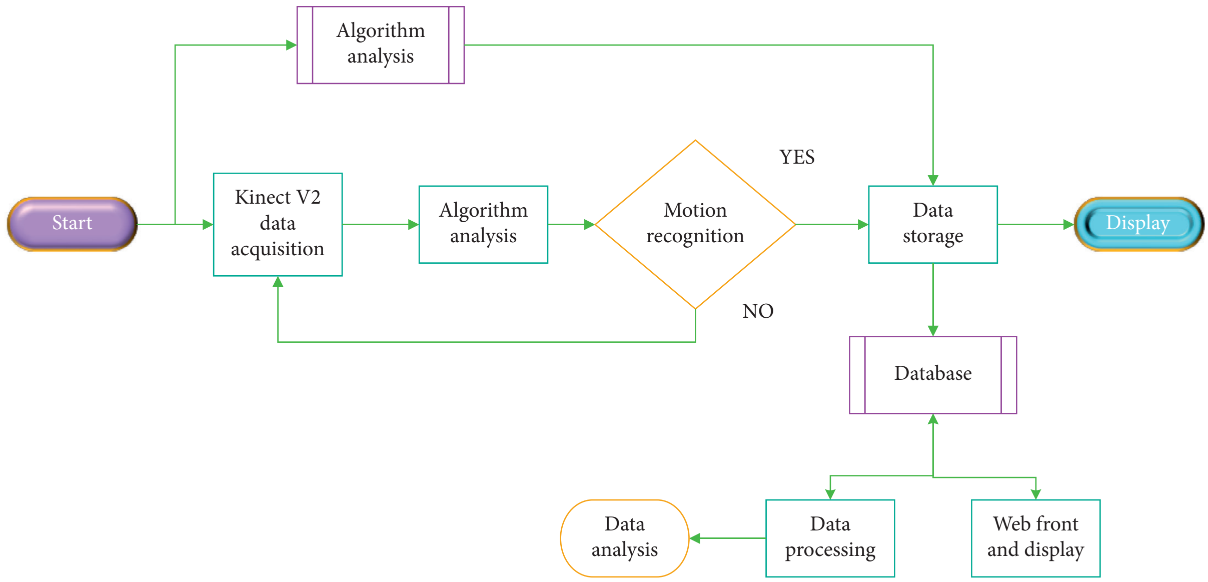

Figure 9: The process of software design.

Table 3: Matrix results.

Final display Actual action	Sitting down	Standing up	Water pouring	Drinking water	Using mobile phone
Sitting down	96%	3.9%	—	—	—
Standing up	4%	97%	—	—	—
Water pouring	—	—	92.5%	5.3%	2.1%
Drinking water	—	—	7.2%	97%	6.7%
Using mobile phone	—	—	—	—	89.9%

Table 4: Test results.

Projects	Numbers	Success rate (%)	Accuracy rate (%)
Setting	600	95.7	89
Squatting	270	96	94.8
The lead upward	200	94.8	92.5
Sit-up	240	97	96.8

Table 5: Accuracy at different take-off points and monitoring points.

Take-off point	Monitoring point	Distance between	Accuracy (%)
1.21	0.532	0.678	92.36
1.963	1.0236	0.9394	91.01
2.635	1.268	1.367	89.26

the standing long jump is low, which may be due to the error in the range of sight. Additionally, the distance between the take-off points and the monitoring point also has a certain impact on the accuracy. The specific results are shown in Table 5.

Table 5 shows that the closer the distance between the take-off point and the monitoring point, the higher the accuracy obtained. The greater the distance between the take-off point and the monitoring point, the lower the accuracy obtained. The comparison of recognition rate and accuracy is shown in Figure 10.

In view of the low error and accuracy in the test of this standing long jump project, the actual situation and test situation of the standing long jump test are compared. The details are shown in Figure 11.

According to the results, the data results can maintain a certain accuracy between 1.25 and 1.75 meters, while the data are not accurate beyond the subrange. The analysis shows that the scene measurement environment may bring light interference to the Kinect V2 camera based on the TOF (Time of Light) principle, resulting in a lack of accuracy. Meanwhile, there may also be site installation location defects and test groups of individual body differences in force majeure.

The skeletal confusion experiment is to ensure that the camera and simulation software can collect and analyse data. The training system test experiment is to check the accuracy of all the collected data in the test system. After analysis, it is found that the accuracy of the standing long jump is the lowest. And then, the standing long jump is tested again. Figure 12 is the comparison of the proposed method and the baseline method for camera source recognition accuracy.

Figure 12 shows that the average accuracy of camera source identification using the basic sensor mode noise

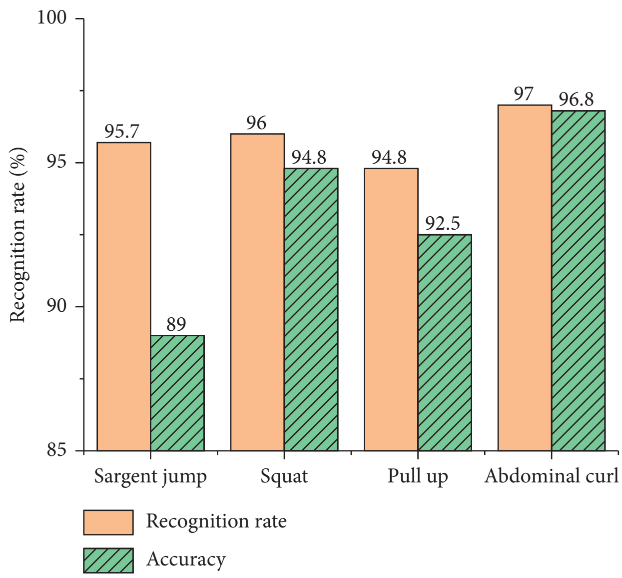

Figure 10: Comparison of recognition rate and accuracy rate.

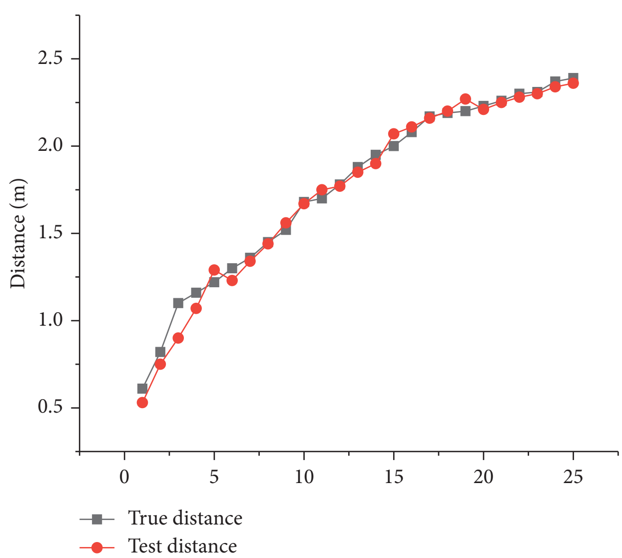

Figure 11: Comparison of standing long jump sample results.

identification method is 93%. When Alexnet is used as the branch network of the twin network for camera source recognition, the recognition accuracy is generally low. The method is greatly affected by the number of samples in the dataset, and the network is more inclined to learn the features related to image content. It is proved that the use of the neural network without pretreatment for camera source recognition may not be as good as the effect of camera source recognition by sensor mode noise. The method designed is used for experiments, and the average accuracy reaches 97%, which is 4% higher than that of the sensor-based noise identification method. The recognition method designed not only is more convenient and automatic than traditional methods but also has a certain improvement in recognition rate.

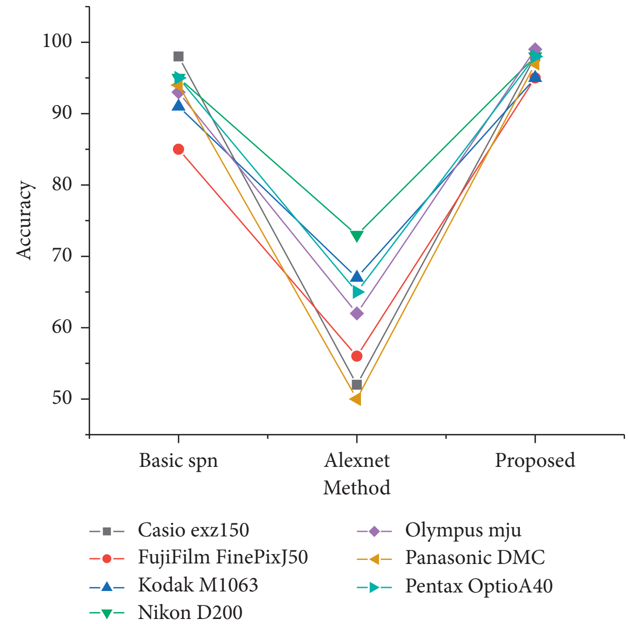

Figure 12: Comparison of recognition accuracy between traditional camera source recognition method and visual sensor training system (%).

4. Conclusions

With the continuous development of the global economy and the reduction of trade barriers, it provides a broad platform for the rapid development of international trade. International trade is the participation of countries in the world in the international division of labour and an important means to realize the smooth progress of social reproduction. Meantime, international trade is also an important medium for economic, political, and cultural exchanges between countries, and it plays an important role in production and life. So, it is necessary to add the use of data to educational practice. Besides, with the rapid development of visual sensing technology, it has the research and development conditions to realize nonwearable sensor monitoring and training system. In this paper, a visual sensor training system is designed by using joint data and an algorithm model to collect and analyse the characteristics of motion behaviour. Finally, the visual sensing training system for physical education practice that can complete data collection without wearing is realized, and the collected data are uploaded to the cloud through the Internet. Meanwhile, the proposed method combines the identification method of sensor mode noise with deep learning and proposes a camera source identification method by DTs network. The recognition results are judged by the similarity measure of the twin network and compared with the experimental results, which proves that the method has better recognition rate advantages. The data are analysed using the national health standards, and reasonable and scientific training plans are developed according to different sports data sources. The software designed in this paper also has defects. The software only simulates the research scene, and there are some differences between the simulated scene and the real conditions. Therefore, when the simulation experiment is carried out, the problems that appeared are not very comprehensive. The corresponding hardware equipment needs to be under suitable temperature and light, not exceeding 30 degrees; otherwise, it will affect the operating speed of the hardware. The hardware equipment mentioned in this paper needs to be in a suitable light environment to ensure complete accuracy. Therefore, the necessary conditions, such as shading of hardware equipment, will be improved in the subsequent research. The management system developed in this paper is intended to solve the problems of old mechanism and malpractice in physical education in colleges and universities and is committed to realizing the scientific, integrated, and standardized management of physical education and sports training for college students.

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.

References

[1] J. Ting, H. Ting, and D. Tan, "Kinect-based badminton motion analysis using intelligent adaptive range of movement Index," *IOP Conference Series: Materials Science and Engineering*, vol. 7, pp. 12–17, 2019.

[2] S. X. Zuo, "Exploration on the reform of college physical education curriculum and the promotion of students' physical health," *Industrial & Science Tribune*, vol. 20, no. 66, pp. 170-171, 2021.

[3] L. Wang, Y. A. Zhang, and L. Wang, "Foreign research progress on the influence of screen time on Teenagers' physical health in recent 10 years," *Journal of Physical Education*, vol. 23, no. 2, pp. 138–144, 2016.

[4] F. Yusuke, M. Keisuke, and A. Isao, "Development of virtual reality cycling training and assessment system to investigate the effect of cycling motions in rehabilitative training," *The Proceedings of JSME annual Conference on Robotics and Mechatronics (Robomec)*, vol. 2, pp. 37–40, 2017.

[5] L. Li, L. Han, and J. G. Xu, "Human model structure segmentation based on semantic and geometric features," *Application Research of Computers*, vol. 33, no. 1, pp. 316–320, 2016.

[6] T. Kato, H. Hino, and N. Murata, "Multi-frame image super resolution based on sparse coding," *Neural Networks*, vol. 66, pp. 64–78, C, 2015.

[7] S. D. Du, "Solution of the first boundary value problem of Poisson equation based on finite difference method," *Bulletin of Science and Technology*, vol. 34, no. 4, pp. 21–24, 2018.

[8] M. U. Islam, H. Mahmud, and F. B. Ashraf, "Yoga posture recognition by detecting human joint points in real time using Microsoft Kinect," in *Proceedings of the IEEE Region 10 Humanitarian Technology Conference*, pp. 668–673, Dhaka, Bangladesh, December 2017.

[9] V. Parameswaran and R. Chellappa, "Quasinvariants for humanaction representation and recognition," in *Proceedings of the 2002 International Conference on Pattern Recognition*, vol. 7, pp. 307–310, IEEE Computer Society Press, Quebec City, QC, Canada, August 2017.

[10] B. Reily, H. Zhang, and W. Hoff, "Real-time gymnast detection and performance analysis with a portable 3D camera," *Computer Vision and Image Understanding*, vol. 159, pp. 154–163, 2017.

[11] J. Yamato, J. Ohya, and K. Ishii, "Recognizing human action in time sequential images using Hidden Markov model," in *Proceedings of the CVPR, IEEE*, vol. 18, pp. 379–385, Champaign, IL, USA, June 1992.

[12] A. Kale, N. Rajagopalan, N. Cuntoor, and V. Kruger, "Gait-based recognition of humans using continuous HMMs,"vol. 21, pp. 321–326, in *Proceedings of the Fifth IEEE International Conference on Automatic Face Gesture Recognition*, vol. 21, pp. 321–326, IEEE Computer Society Press, Washington D.C., USA, 2017.

[13] A. Psarrou, G. Gong, and M. Walter, "Recognition of human gestures and behaviour based on motion trajectories," *Image and Vision Computing*, vol. 20, no. 5, pp. 349–358, 2017.

[14] F. Bobick and W. Davis, "The recognition of human movement using temporal templates," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 15, no. 3, pp. 257–267, 2018.

[15] B. Arie, Z. Wang, P. Pandit, and S. Rajaram, "Human activity recognition using multidimensional indexing," *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 24, no. 8, pp. 1091–1104, 2016.

[16] J. Lafferty, A. Mccallum, and F. Pereira, "Conditional random fields: probabilistic models for segmenting and labelling sequence data," in *Proceedings of the 18th International Conference on Machine Learning*, vol. 7, pp. 282–289, Williamstown, MA, USA, January 2001.

[17] M. Huber, A. L. Seitz, M. Leeser, and D. Sternad, "Validity and reliability of Kinect skeleton for measuring shoulder joint angles: a feasibility study," *Physiotherapy*, vol. 101, no. 4, pp. 389–393, 2016.

[18] K. Cho, H. Cho, and K. Um, "Human action recognition by inference of stochastic regular grammars," *Lecture Notes in Computer Science*, vol. 3138, pp. 388–396, 2017.

[19] A. Ivanov and F. Bobick, "Recognition of visual activities and interactions by stochastic parsing," *IEEE Trans PAMI*, vol. 22, no. 8, pp. 852–872, 2016.

[20] G. Nguyen and T. Phung, "Reducing over-smoothness in HMM-based speech synthesis using exemplar-based voice conversion," *EURASIP Journal on Audio Speech and Music Processing*, vol. 1, pp. 76–89, 2017.

[21] M. Gu and L. Q. Ge, "Natural gamma spectrum processing based on variable parameter double exponential smoothing method," *Computer techniques for geophysical and geochemical exploration*, vol. 6, pp. 506–509, 2018.

[22] S. Yohei, Y. Takeshi, and T. Hiroshi, "Generation of point light source date for animated hologram with motion capture using KinectV2," *ITW Technical Report*, vol. 40, no. 11, pp. 67–69, 2016.

[23] R. Noel, A. Salekin, and R. Islam, "A natural user interface classroom based on Kinect," *IEEE Learning Technology*, vol. 13, no. 4, pp. 59–61, 2017.

[24] G. Rogers and H. Christensen, "A conditional random field model for place and object classification," in *Proceedings of the IEEEE International Conference on Robotics and Automation*, vol. 300, pp. 766–772, Saint Paul, MN, USA, May 2012.

[25] J. Yin, G. Tian, and F. Zhou, "Human activity representation and recognition based on temporal order histogram in intelligent space," *Chinese Journal of Computers*, vol. 37, no. 2, pp. 470–479, 2016.

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Research Article

The Modelling of Digital Twins Technology in the Construction Process of Prefabricated Buildings

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In the process of building construction, traditional architectural design and construction methods take a long time. The built buildings perform poorly in terms of energy usage and energy conservation. The study expects to explore the potential safety hazards of prefabricated buildings during the construction process. On this basis, a modelling study of the construction process is carried out. The study uses Digital Twins (DTs) technology and prefabricated Building Information Modelling (BIM) to conduct in-depth modelling research on the building construction process. The prefabricated building construction system oriented to DTs technology can well solve the problems of structural damage and deformation in the production, transportation, and assembly process of building components. Especially in prefabricated buildings, it can monitor and accurately predict the damage of building components that may occur in the entire system due to structural problems and material problems in real time. Regarding the building information model, the study uses third-party software to transfer the assembly information to the network cloud to further realize the display of the BIM. The study shows that the maximum value of the effective risk cases selected is 130, and its effective rate is 100%; after processing the data, it is found that the initial value is always stable, and its value is 1; the extracted value is always changing, the maximum value is 0.86, and the minimum is 0.75. By this result, the conclusion is that DTs technology and BIM can effectively monitor the indicators of risk problems during the construction of prefabricated buildings and can further reduce potential safety hazards. Through building information modelling, the development of intelligent industrialization of building construction design and the in-depth study of construction modelling has practical application value.

1. Introduction

With the vigorous development of science and technology, society is advancing rapidly, and the country's economic development is getting faster and faster. These changes and developments are inseparable from the contributions made by the construction industry [1–3]. The construction field has gradually changed from the traditional building of houses to the mode of intelligent and scientific construction. With the acceleration of the process of urbanization in China, the construction of prefabricated buildings [4–6] has gradually become a new trend of the times. Under this new trend, the system design and modelling of prefabricated buildings [7–9] have become the focus of attention by related researchers in the architectural field.

The in-depth analysis is conducted from a broader perspective. By the traditional architectural system, prefabricated buildings [10–12] optimize the allocation and combination of resources for the structure, system, and management of traditional buildings according to the needs of customers. Prefabricated buildings enable customers to further experience more efficient, comfortable, and acceptable humanized building clusters. The biggest difference between prefabricated buildings and traditional buildings is that prefabricated buildings are essentially industrialized manufacturing. It can customize all the construction of the building according to the customer's predetermined order and transport the new construction to the job site for reasonable assembly. The advantage of prefabricated buildings is that they can save a lot of time and complete tasks with high quality. The disadvantage of prefabricated buildings is that the cost is too high and the height of the building is limited. Relevant researchers have conducted a lot of research on the construction of prefabricated buildings. Studies have shown that the rapid development of prefabricated buildings in Denmark is very prominent. Meanwhile, researchers put forward the legalization of modulus and successfully used it as a standard blueprint for modulus coordination. For the building assembly system, this overcomes the original assembly monotonous architectural style and realizes the diversification of the building construction process. The development of prefabricated buildings in China is to gain experience from Soviet architecture and develop in-depth. In recent years, Digital Twins (DTs) technology [13–15], as a concept beyond reality, has been widely used in product design, product manufacturing, medical analysis, and engineering construction. The DTs technology can map the building entities in the real physical space to the virtual space, which has a certain impact on the construction of prefabricated buildings. DTs technology [16–18] is applied to prefabricated buildings, enabling the entire system to realize intelligent engineering from a single building component, a single device to a large-scale building. On the construction and safety issues in the building process, Li et al. [19] used solar-driven photoelectrochemical technology to study building materials. The results show that low-viscosity dopants can increase the construction strength of buildings. Shams et al. [20] studied the safety construction restoration planning in building renovation projects. They have combined the cost and duration of the project to evaluate alternative construction schedules. The results show that the construction of fire safety facilities can have an impact on the final construction schedule. Kochovski et al. [21] used the fog computing method to construct smart and safe building applications. The privacy protection data management through the smart contract of Ethereum shows that the use of fog computing helps to improve the response rate, privacy, and security.

According to the existing research and the problems, to make the prefabricated building more efficient in the construction process, the study adopts the DTs technology and the Building Information Modelling (BIM) to discuss the process modelling of prefabricated building. The innovation here is that the construction process in the real physical environment is easily affected by factors such as weather conditions and air pollution. The DTs technology is introduced to map the actual situation of the prefabricated building to the virtual space and to conduct further modelling research. Combining BIM and DTs technology, prefabricated building construction has been studied. The prefabricated building is provided with theoretical support, which is of great significance.

2. Materials and Methods

2.1. DTs Technology. The prefabricated building construction system of DTs technology [22–24] can solve the problems of structural damage and deformation in the production, transportation, and assembly process of building components. It should be noted that the DTs technology in prefabricated buildings can monitor and accurately predict the damage of building components in the entire system, which may occur due to structural problems and material problems. The realization of this process can effectively improve the safety and reliability of the prefabricated building in the entire construction process. In addition, DTs technology [25–27] can also effectively improve the construction process of prefabricated buildings. Figure 1 is a framework diagram of the DTs application.

DTs technology is the digital representation of physical processes, people, places, systems, or equipment. DTs technology can promote the development of industry towards intelligent development, and it is an important guarantee for the development and construction of modern cities. Many scientific research scholars have conducted research on the digitalization process of intelligent industry. In response to the challenges faced by traditional manufacturing, some scholars have proposed a DTs-driven sustainability evaluation information system structure for intelligent manufacturing and dynamic evolution throughout the life cycle. In the end, the effectiveness of the proposed DTs information architecture and sustainability evaluation method is verified. Related researchers have constructed a virtual intelligent network space architecture Intelligent DTs-Software Defined Virtual Networks (IDT-SDVNs). Simulation and performance analysis of IDT-SDVNs have verified its effectiveness. Others have used machine learning and DTs technology to build an ECG heart rhythm classifier to diagnose and detect heart diseases. Experts in related fields have found that the combination of accurate BIM and big data generated by Internet of Things (IoT) sensors makes the data in modern cities more accurate and transparent. The public and open DTs model makes smart city industrialization planning more precise. The meaning of DTs technology is to simulate the real objects in real life through digital models in the real world, to construct virtual models of different dimensions and different disciplines. The characteristics of this virtual model are the combination of virtual and real, iterative operation, and real-time interaction. Prefabricated buildings can fully apply this technology. Figure 2 is a framework of the interaction between the virtual space and the real space of DTs.

DTs technology is widely used. Due to its technical characteristics, the difficulty of integrating intelligent manufacturing and physical space, and the key characteristics in practice, it is used by various industries. The management and control system for DTs technology includes three parts: the prefabricated building application layer, the prefabricated building model layer, and the prefabricated building. Each part is divided into different subsystems. The subsystems of the application layer are collaborative process planning, optimization of production parameters, and management and control of the production environment. The subsystems of the model layer are the design and manufacturing collaboration model, the production management optimization model, and the quality control management model. The subsystems of the data layer are environmental data, material data, and machine data. Figure 3 presents the operation and maintenance of the prefabricated building system oriented to DTs.

Prefabricated buildings are complicated in the process of component transportation and assembly, and knowledge of

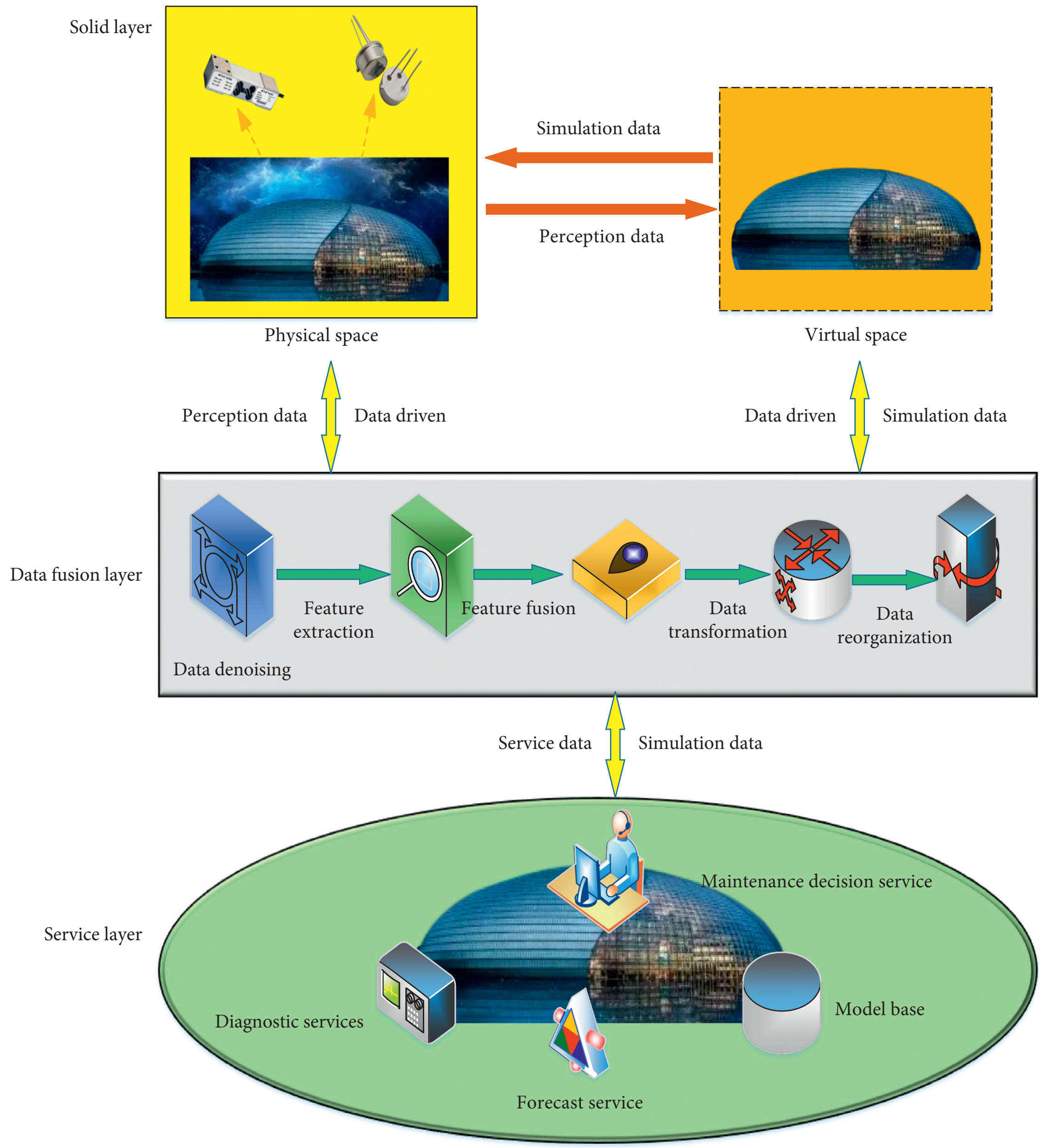


Figure 1: DTs application framework.

many disciplines has been applied. The management control system is designed and constructed, and the construction of this system has brought great benefits. The management and control system oriented to DTs can carry out good scheduling control in all aspects of building structure and materials. Figure 4 is a frame structure diagram of DTs and the production process.

The measurement and control of prefabricated building entities is an important communication method between DTs technology and building entities. The data collection of the prefabricated building is completed through monitoring sensors, which further drives DTs. In this process, the displacement and rotation torque of the building components during the assembly process will be effectively monitored. The data are transmitted and processed, and each element of the assembly process is effectively controlled. Figure 5 is the solid frame of the survey and assembly building.

In the model algorithm, the collected prefabricated building image data are expressed as the following objective function. The principle of the objective function can be expressed as follows:

$$\min_{w,b,s,y_u} \frac{1}{2} w^T w + \lambda_1 \sum_{i=1}^{n} u_{ii}\left(1 - \left(w^T x^i + b\right) y_i\right). \quad (1)$$

In Equation (1), w represents the weight matrix, w^T represents the transposition of the weight matrix, x^i represents the input, y_i represents the output, b represents the deviation, λ_1 represents the eigenvalue of the matrix, and u_{ii} represents the element value of the i-th row and the i-column.

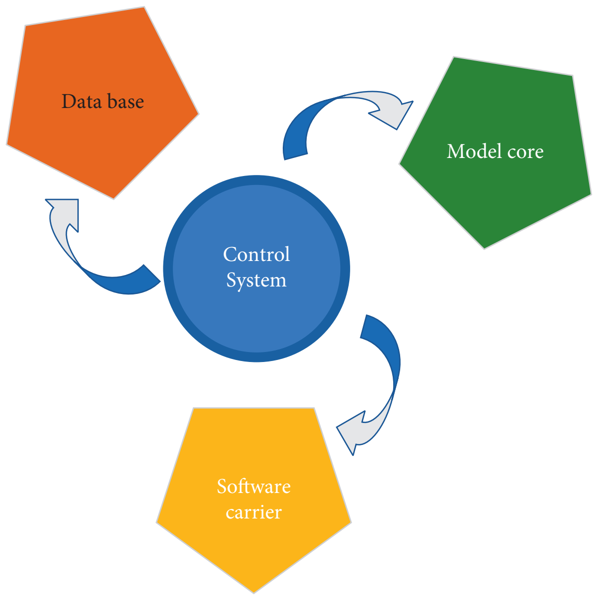


Figure 2: A framework of the interaction between the virtual space and the real space of DTs.

$$s.t. \forall i, s_i 1 \geq 0, F \in R^{n\times c}, F^T F = I. \quad (2)$$

In Equation (2), s is the similarity matrix between samples. Equation (2) is a supplement to Equation (1).

$$L_s = D_s - \frac{s^T + s}{2}. \quad (3)$$

In Equation (3), $D_s \in R^{n\times n}$ refers to a diagonal element, s represents the coefficient matrix and s^T represents the transposition of the coefficient matrix.

$$\sum_j \frac{\left(s_{ij} + s_{ji}\right)}{2} \leftarrow y_u^{(t)} t = t + 1. \quad (4)$$

When further training the constructed model algorithm, the learning rate update strategy and the polynomial decay learning rate adjustment method are adopted, specifically expressed as follows:

$$init_l r \times \left(1 - \frac{\text{epoch}}{\text{max\_epoch}}\right)^{\text{power}}. \quad (5)$$

The initial learning rate is 0.0004, and the power is set to 0.8. In the training process, weighted cross entropy (WCE) is used as a cost function to optimize model training. $z_k(x, \theta)$ refers to the unnormalized log probability value of the pixel x of the k-th category under the given network parameters. The definition of softmax function $p_k(x, \theta)$ is shown as follows:

$$p_k(x, \theta) = \frac{\exp\{z_k(x, \theta)\}}{\sum_k^K \exp\left\{z_{k_l}(x, \theta)\right\}}. \quad (6)$$

In Equation (6), K represents the total number of image data categories. In the prediction phase, when Equation (6) takes the maximum, pixel x is marked as the k-th category; $k* = \arg\max\{P_k(x, \theta)\}$. For ease of description, note N as the total number of pixels contained in the training batch image data. y_i means the true semantic annotation of pixel x_i. $p_k(x_i, \theta)$ represents the prediction probability that pixel x_i belongs to the k-th semantic category. In other words, the probability value after logarithmic normalization is simply marked as p_{ik}. The training process aims to find the optimal network parameter $\theta*$ by minimizing the WCE loss function $\ell(x, \theta)$; that is, $\theta*$ is $\theta* = \min_\theta \ell(x, \theta)$. In the process of assembly building construction, the unbalanced training samples in the extracted image data usually make the network focus on some easily separable categories. In order to solve the problem of poor sample identification, Online Hard Example Mining (OHEM) strategy is used in the experiment to optimize the network training process. The improved loss function is shown as follows:

$$\ell(x, \theta) = -\frac{1}{\sum_{i=1}^N \sum_{k=1}^K \delta(y_i = k, p_{ik} < \eta)} \sum_{i=1}^N \sum_{k=1}^K \delta(y_i = k, p_{ik} < \eta) \log p_{ik}, \quad (7)$$

$\eta \in (0, 1]$ means a predefined threshold, and $\delta(\cdot)$ means a symbolic function. When the condition satisfies, it is equal to 1; otherwise, it is 0. The definition of loss function of assembly building construction fusion weighting is shown as follows:

$$\ell(x, \theta) = -\sum_{i=1}^N \sum_{k=1}^K w_{ik} q_{ik} \log p_{ik}, \quad (8)$$

$q_{ik} = q(y_i = k|x_i)$ refers to the true label distribution of pixel x_i in the k-th category. w_{ik} is the weighted coefficient. In the training process, the calculation strategy in Equation (9) is adopted:

$$w_{ik} = \frac{1}{\ln(c + p_{ik})}. \quad (9)$$

In Equation (9), c refers to the extra super parameter, which is set to 1.0 during the experiment.

2.2. Prefabricated BIM. In the prefabricated building system, if the building is compared with a physical system, then the intelligent building is the effective integration of people, building entities, and building information virtual entities. The life cycle (LC) of prefabricated buildings is to use artificial intelligence, big data, and IoT to predict. When some scholars evaluated the LC of prefabricated buildings, they proposed a link prediction method by similarity, which only relies on limited known data to estimate the missing unit process data. This calculation method shows the potential of LC prediction and estimation in prefabricated buildings. Some foreign experts proposed an energy management system model of fabricated building microgrid by battery energy storage. The simulation suggests that the framework can estimate the construction operation cost more accurately and improve the overall performance of the battery as a flexible resource in the construction microgrid. In addition, some people have proposed a two-stage optimization model framework for the integrated optimization planning of renewable energy resources (RERs)

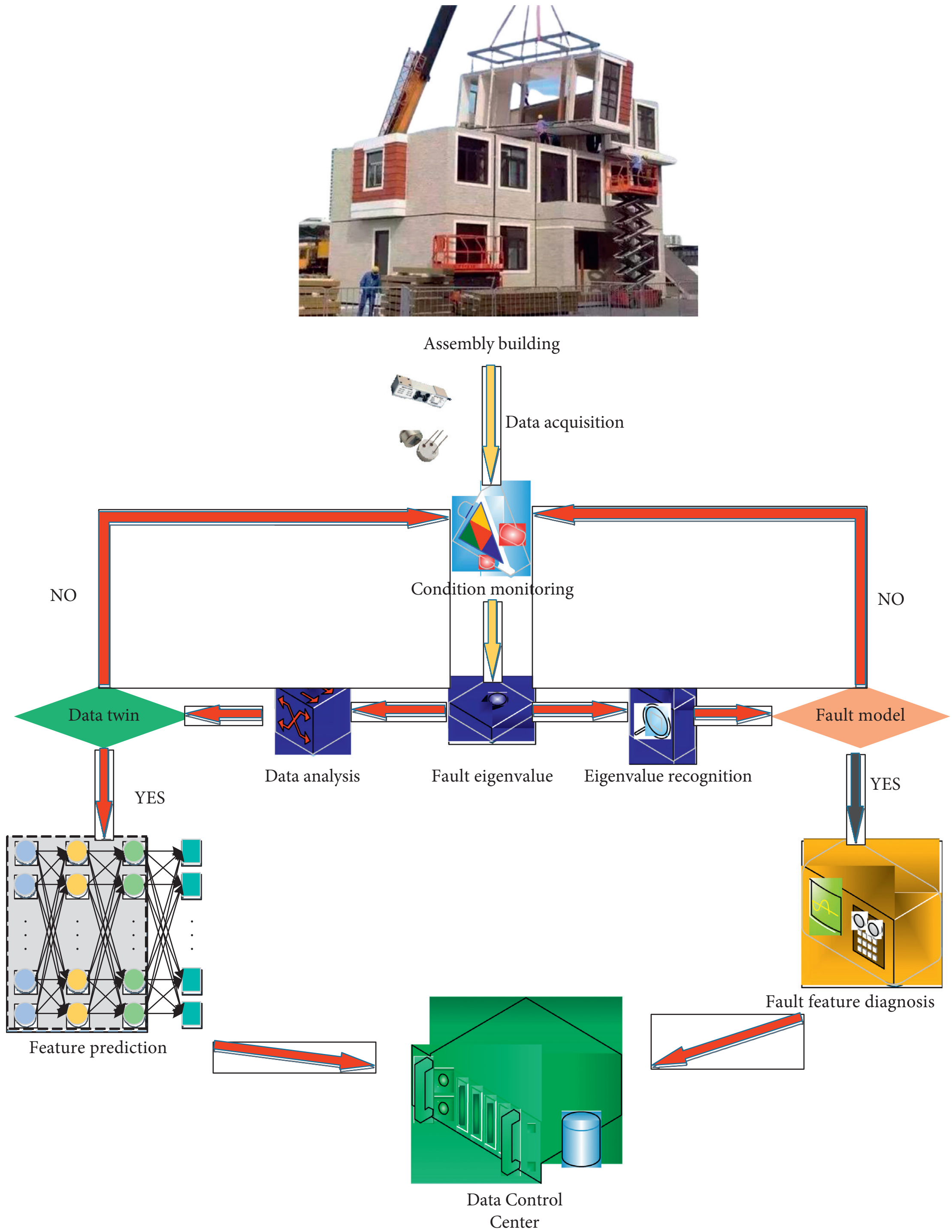


Figure 3: Operation and maintenance of the prefabricated building system for DTs.

and batteries in prefabricated buildings by prosumer energy management. Finally, the effectiveness is verified by performance evaluation. In the field of prefabricated buildings, some scholars have predicted the LC of power transformers. It is found that the mean absolute percentage error (MAPE) of the model on the test set is only 5.20%, and the accuracy is significantly higher. Although there are many data analysis studies on prefabricated buildings in the urban process, there are few studies on the analysis of prefabricated buildings in smart cities by using DTs technology, and there are few studies on the digital development of prefabricated buildings. A risk prediction model by DTs technology is proposed for the feature extraction of multisource data of prefabricated buildings, which is of great significance to the digital development and safety maintenance of prefabricated buildings in modern cities.

BIM [28–30] can be displayed in the form of web pages. By its complexity, the study uses third-party software to transmit assembly information to the network cloud to

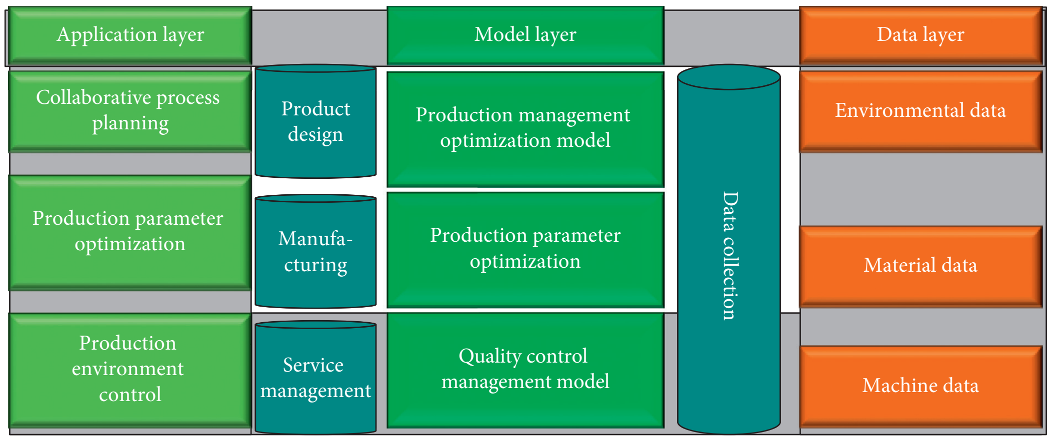


Figure 4: Frame structure of DTs and production process.

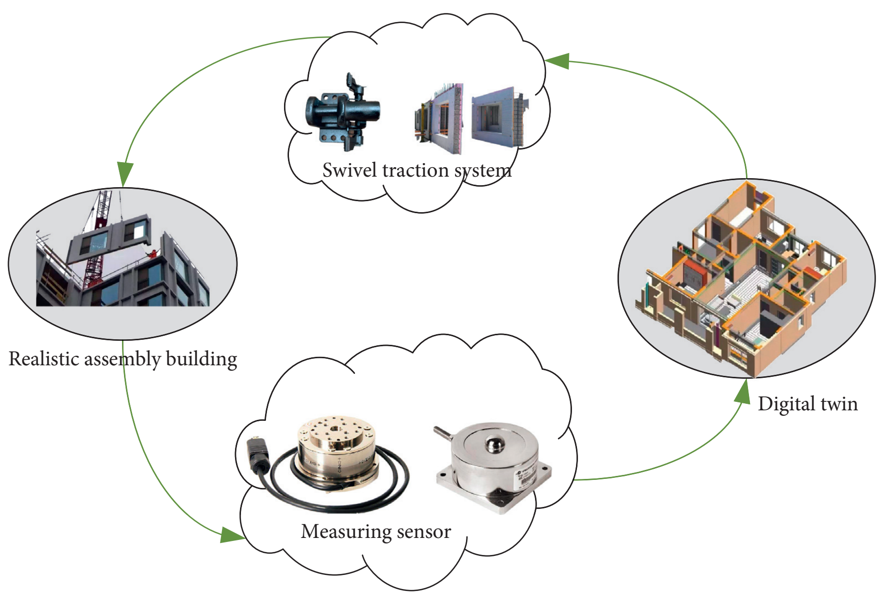


Figure 5: Measured and assembled building entities.

further realize the BIM model presentation. In the BIM platform, the study can zoom in and zoom out the BIM model. Figure 6 shows the BIM model of assembly building rotating cloud.

The assembly BIM can conduct in-depth and effective modelling research on the construction process. In addition, the prefabricated construction system for DTs technology can well solve the structural damage and deformation of construction components in the production, transportation, and assembly process. It can real-time monitor and accurately predict the damage of building components due to structural and material problems in the whole system. The practical application of the BIM model in China can be reflected in the four stages of design, assembly, maintenance, and operation management. Figure 7 is the process diagram of BIM technology application.

The monitoring data of the assembly construction process are simulated and analysed, and the whole construction process is effectively monitored by feedback control. The construction monitoring process of the building is shown in Figure 8. First, the drawings are designed, and the specific construction scheme is formulated into equations. Second, the design compliance calculation and presimulation calculation are carried out. Third, the monitoring instruction file is issued for the next stage of construction, and further construction monitoring is carried out. Finally, data are analysed. Figure 8 is the schematic diagram of the assembly building construction monitoring process.

3. Results

3.1. Analysis of Construction Results of Prefabricated Buildings Oriented to DTs Technology. The study models according to the DTs technology prefabricated building. Regarding the risk in construction, data processing of specific indicators is carried out, and the specific results are shown in Figure 9. Cronbach's alpha is used to measure the reliability of the

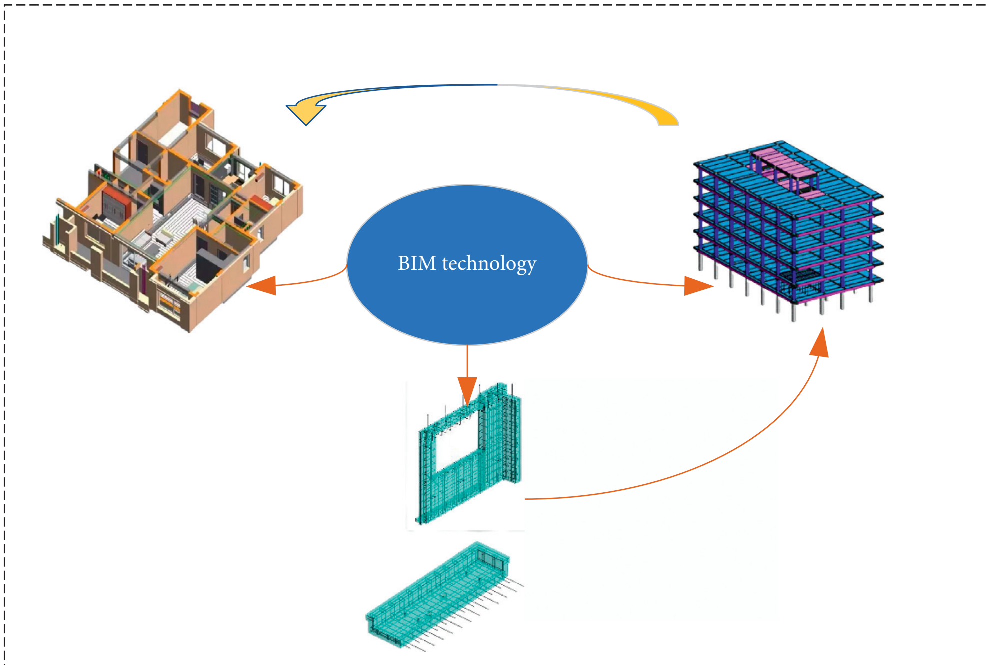


Figure 6: BIM model of assembly building turning cloud.

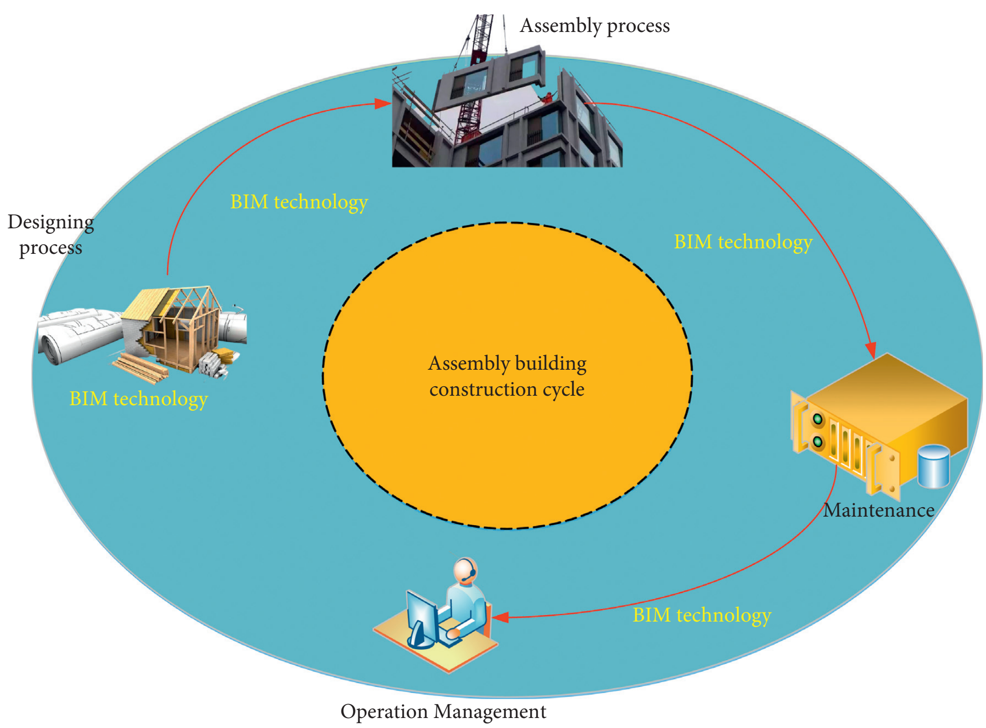


Figure 7: Diagram of BIM technology application process.

data. Cronbach's alpha value is between 0 and 1, and the value in the 0.8–0.9 interval is considered to be very reliable. For valid risk cases, when the maximum value is 130, the effective rate is 100%. For invalid cases, its value is 0, which means that the collected data are all valid. Figure 9 is a data diagram of the risk index situation of the prefabricated building construction.

Figure 9 shows the common factor variance data of the risk indicators during the construction of the prefabricated building, so the Kaiser–Meyer–Olkin (KMO) factor needs to be verified. In general, the value of KMO is greater than 0 and less than 1. The closer the KMO value to 1, the stronger the correlation between the factors. If the value of KMO is closer to 0, the correlation between the factors is poor. If the

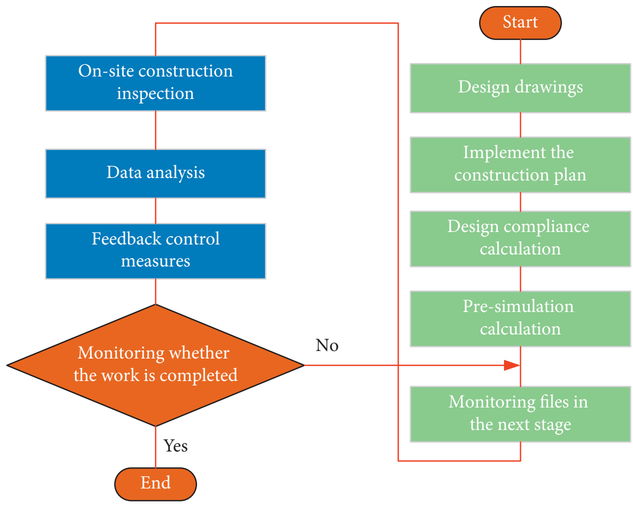


Figure 8: Schematic diagram of the monitoring process of prefabricated building construction.

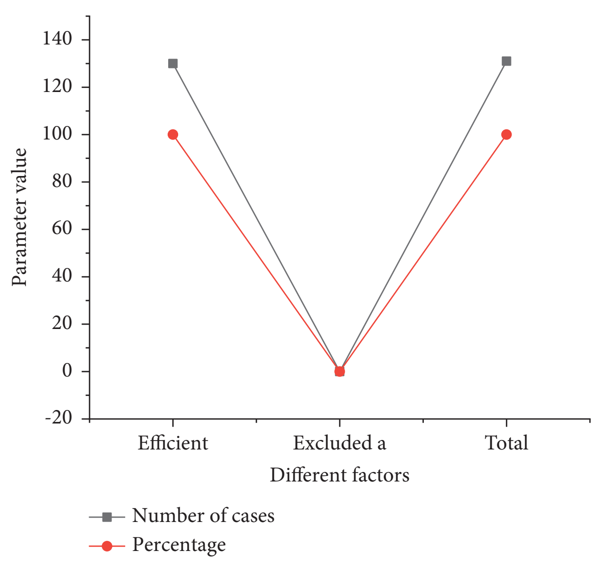


Figure 9: Data diagram of risk indicators for prefabricated building construction.

value of KMO is less than 0.5, the selected index is not suitable for factor analysis. After processing the data, it is found here that the initial value has been very stable, and its value is 1. The extracted value is always changing, the maximum is 0.86, and the minimum is 0.75. The experimental results show that the correlation between the factors is better. Figure 10 is a data diagram of the variance of the common factor of the risk indicators of the prefabricated building during the construction process.

3.2. Analysis of BIM Results. The research analyses the data through BIM, combined with the specific conditions of the risk indicators, and the results shown in Figure 11 are obtained. In Figure 11(a), the maximum value of variance is 52.12% and the maximum cumulative value of each indicator is 65.02%. In Figure 11(b), the maximum value of variance is 52.12% and the maximum cumulative value of each indicator is 58.97%. In Figure 11(c), the maximum value of variance is 18.45%, and the maximum cumulative value of each indicator is 45.02%. The influence of the indicators on the total variance is analysed and extracted, and the cumulative explanatory rate of these three indicators is 65.02%. Figure 11 shows the total variance data of the risk indicators during the construction process.

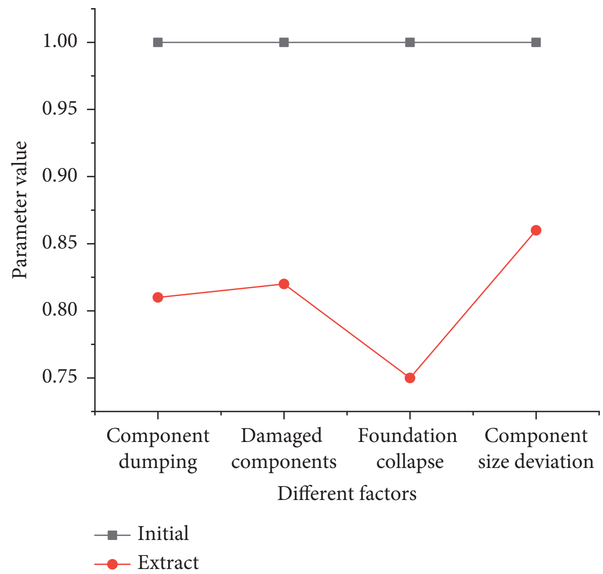


Figure 10: Data diagram of common factor variance of risk index of prefabricated building construction.

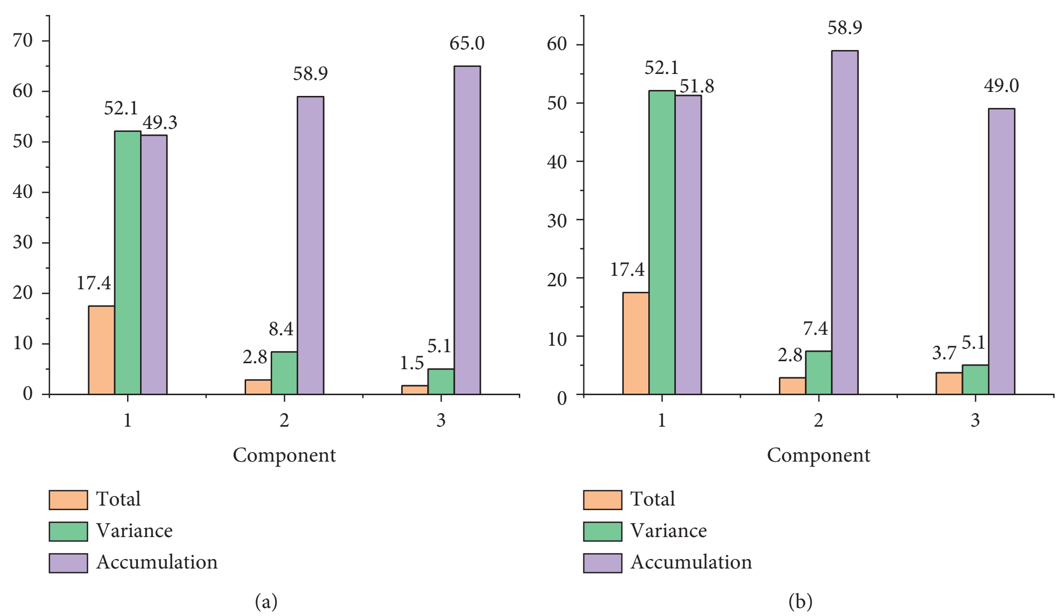
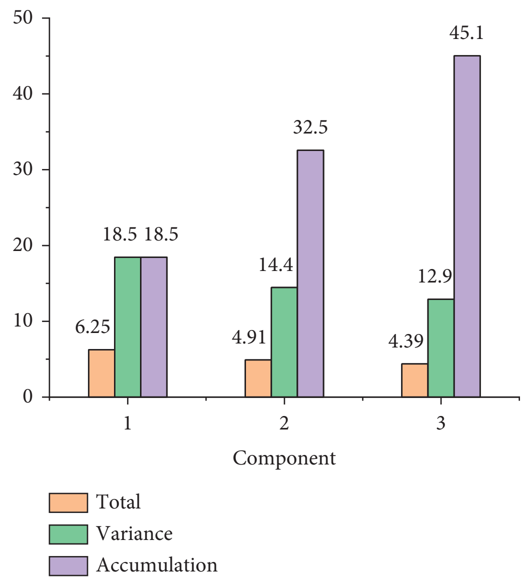


Figure 11: Continued.



(c)

Figure 11: The total variance data of the construction risk index situation are as follows: (a) the initial feature value; (b) the extraction of the sum of squares and loaded; (c) the rotation of the sum of squares and loaded.

4. Conclusions

With the acceleration of China's urbanization process, prefabricated building construction has gradually become a new trend of the times. Under the trend of this new era, the system design and modelling of prefabricated buildings have become the focus. DTs technology and prefabricated BIM are used to conduct in-depth modelling research on the building construction process. The method of building an information model is adopted, and third-party software is used to transmit the assembly information to the network cloud. Through the in-depth modelling research of the building construction process, the BIM display is further realized. The prefabricated building construction system oriented to DTs technology can well solve the problems of structural damage and deformation that occur during the production, transportation, and assembly of building components. Prefabricated buildings can monitor and accurately predict the damage of building components that may occur in the entire system in real time. This study uses third-party software to transfer the assembly BIM to the network cloud to further realize the BIM model display. The conclusion is as follows: DTs technology and BIM effectively monitor the indicators of risk problems in the construction process of prefabricated buildings. Monitoring can effectively guide the designer on the potential safety hazards that may arise when building components are assembled. The disadvantage here is that the index selection in the construction process is not comprehensive enough, and the data collection area is narrow. These deficiencies have a certain impact on the universality of research. In the future, multilevel data will be selected, research data will be supplemented, and the deviation of research results will be reduced.

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 there are no conflicts of interest.

References

[1] S. Navaratnam, T. Ngo, T. Gunawardena, and D. Henderson, "Performance review of prefabricated building systems and future research in Australia," *Buildings*, vol. 9, no. 2, p. 38, 2019.

[2] L. Luo, G. Qiping Shen, G. Xu, Y. Liu, and Y. Wang, "Stakeholder-associated supply chain risks and their interactions in a prefabricated building project in Hong Kong," *Journal of Management in Engineering*, vol. 35, no. 2, Article ID 05018015, 2019.

[3] X. Li, C. Wang, A. Alashwal, and S. Bora, "Game analysis on prefabricated building evolution based on dynamic revenue risks in China," *Journal of Cleaner Production*, vol. 267, Article ID 121730, 2020.

[4] Y. Wang, X. Xue, T. Yu, and Y. Wang, "Mapping the dynamics of China's prefabricated building policies from 1956 to 2019: a bibliometric analysis," *Building Research & Information*, vol. 49, no. 2, pp. 216–233, 2021.

[5] L. Luo, X. Liang, C. Fang, Z. Wu, X. Wang, and Y. Wang, "How to promote prefabricated building projects through internet of things? A game theory-based analysis," *Journal of Cleaner Production*, vol. 276, Article ID 124325, 2020.

[6] N. Sebaibi and M. Boutouil, "Reducing energy consumption of prefabricated building elements and lowering the environmental impact of concrete," *Engineering Structures*, vol. 213, Article ID 110594, 2020.

[7] X.-J. Li, "Research on investment risk influence factors of prefabricated building projects," *Journal of Civil Engineering and Management*, vol. 26, no. 7, pp. 599–613, 2020.
[8] J. Liu, E. Gong, D. Wang, and Y. Teng, "Cloud model-based safety performance evaluation of prefabricated building project in China," *Wireless Personal Communications*, vol. 102, no. 4, pp. 3021–3039, 2018.
[9] K. M. A. El-Abidi, G. Ofori, S. A. S. Zakaria, and A. R. A. Aziz, "Using prefabricated building to address housing needs in Libya: a study based on local expert perspectives," *Arabian Journal for Science and Engineering*, vol. 44, no. 10, pp. 8289–8304, 2019.
[10] A. Alkhalidi, A. Abuothman, A. AlDweik, and A.-H. Al-Bazaz, "Is it a possibility to achieve energy plus prefabricated building worldwide?" *International Journal of Low Carbon Technologies*, vol. 16, no. 1, pp. 220–228, 2021.
[11] Z. Yuan, G. Ni, L. Wang et al., "Research on the barrier analysis and strength measurement of a prefabricated building design," *Sustainability*, vol. 12, no. 7, p. 2994, 2020.
[12] M. Ma, K. Zhang, L. Chen, and S. Tang, "Analysis of the impact of a novel cool roof on cooling performance for a low-rise prefabricated building in China," *Building Service Engineering Research and Technology*, vol. 42, no. 1, pp. 26–44, 2021.
[13] G. Bhatti, H. Mohan, and R. Raja Singh, "Towards the future of smart electric vehicles: digital twin technology," *Renewable and Sustainable Energy Reviews*, vol. 141, Article ID 110801, 2021.
[14] R. He, G. Chen, C. Dong, S. Sun, and X. Shen, "Data-driven digital twin technology for optimized control in process systems," *ISA Transactions*, vol. 95, pp. 221–234, 2019.
[15] K. J. Wang, T. L. Lee, and Y. Hsu, "Revolution on digital twin technology-a patent research approach," *International Journal of Advanced Manufacturing Technology*, vol. 107, no. 11, pp. 4687–4704, 2020.
[16] R. Anderl, S. Haag, K. Schützer, and E. Zancul, "Digital twin technology - an approach for Industrie 4.0 vertical and horizontal lifecycle integration," *It - Information Technology*, vol. 60, no. 3, pp. 125–132, 2018.
[17] B. R. Barricelli, E. Casiraghi, and D. Fogli, "A survey on digital twin: definitions, characteristics, applications, and design implications," *IEEE access*, vol. 7, pp. 167653–167671, 2019.
[18] J. Ma, H. Chen, Y. Zhang, and H. Guo, "A digital twin-driven production management system for production workshop," *International Journal of Advanced Manufacturing Technology*, vol. 110, no. 5, pp. 1385–1397, 2020.
[19] H. Li, B. Liu, S. Feng, H. Li, T. Wang, and J. Gong, "Construction of uniform buried pn junctions on pyramid Si photocathodes using a facile and safe spin-on method for photoelectrochemical water splitting," *Journal of Materials Chemistry*, vol. 8, no. 1, pp. 224–230, 2020.
[20] S. T. Shams Abadi, N. Moniri Tokmehdash, A. Hosny, and M. Nik-Bakht, "BIM-based co-simulation of fire and occupants' behavior for safe construction rehabilitation planning," *Fire*, vol. 4, no. 4, p. 67, 2021.
[21] P. Kochovski and V. Stankovski, "Building applications for smart and safe construction with the DECENTER fog computing and brokerage platform," *Automation in Construction*, vol. 124, Article ID 103562, 2021.
[22] A. Liljaniemi and H. Paavilainen, "Using digital twin technology in engineering education - course concept to explore benefits and barriers," *Open Engineering*, vol. 10, no. 1, pp. 377–385, 2020.
[23] G. P. Agnusdei, V. Elia, and M. G. Gnoni, "Is digital twin technology supporting safety management? a bibliometric and systematic review," *Applied Sciences*, vol. 11, no. 6, p. 2767, 2021.
[24] M. Liu, S. Fang, H. Dong, and C. Xu, "Review of digital twin about concepts, technologies, and industrial applications," *Journal of Manufacturing Systems*, vol. 58, pp. 346–361, 2021.
[25] C. Zhuang, T. Miao, J. Liu, and H. Xiong, "The connotation of digital twin, and the construction and application method of shop-floor digital twin," *Robotics and Computer-Integrated Manufacturing*, vol. 68, Article ID 102075, 2021.
[26] Q. Liu, J. Leng, D. Yan et al., "Digital twin-based designing of the configuration, motion, control, and optimization model of a flow-type smart manufacturing system," *Journal of Manufacturing Systems*, vol. 58, pp. 52–64, 2021.
[27] T. R. Wanasinghe, L. Wroblewski, B. K. Petersen et al., "Digital twin for the oil and gas industry: overview, research trends, opportunities, and challenges," *IEEE Access*, vol. 8, pp. 104175–104197, 2020.
[28] A. Costin, A. Adibfar, H. Hu, and S. S. Chen, "Building Information Modeling (BIM) for transportation infrastructure - literature review, applications, challenges, and recommendations," *Automation in Construction*, vol. 94, pp. 257–281, 2018.
[29] S. Tang, D. R. Shelden, C. M. Eastman, P. Pishdad-Bozorgi, and X. Gao, "A review of building information modeling (BIM) and the internet of things (IoT) devices integration: present status and future trends," *Automation in Construction*, vol. 101, pp. 127–139, 2019.
[30] F. Rezaei, C. Bulle, and P. Lesage, "Integrating building information modeling and life cycle assessment in the early and detailed building design stages," *Building and Environment*, vol. 153, pp. 158–167, 2019.

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Research Article

Application of Visual Sensing Image Processing Technology under Digital Twins to the Intelligent Logistics System

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Since the founding of the People's Republic of China, the advantages of logistics are neglected, and the scale operation and the welfare in the industry are difficult to achieve due to the influence of the economic system and social environment. Therefore, a new intelligent logistics distribution management system based on machine vision and visual sensor image processing technology is constructed to respond to the shortcomings of the traditional system, including slow efficiency, huge cost, complex data, and low degree of informatization. Through the analysis and research on the visual sensor image processing technology and the order processing, receipt management, distribution management, scheduling management, and return management that affect logistics distribution, a simulation experiment is used to verify that the visual sensor image processing technology is rigorous, intelligent, and efficient and has high precision. The intelligent logistics distribution management system can effectively solve the problems existing in the traditional logistics distribution management. The experimental results show that the visual sensor image processing technology can collect and analyze the target image and effectively track and monitor it in the logistics distribution process. The average distribution precision of the intelligent logistics distribution management system reaches more than 99.5%, which is greatly improved compared with 90% of the traditional logistics distribution. And it can greatly improve the distribution efficiency, which increases by about 26.5%. The study realizes the information management of the logistics system and automatically completes all the work according to the designed program, so that the real-time dynamic distribution can be transmitted to the urban logistics distribution at any time.

1. Introduction

Logistics management is called the "third profit source" of modern society, and it is reflected in the potential and economic benefits of logistics systems [1]. With the proposal of "Made in China 2025" and "Industry 4.0", China's industrial structure gradually shifts to intelligent informatization [2, 3]. The development of e-commerce promotes the prosperity of logistics distribution and prompts more and more people to engage in the logistics distribution industry. However, due to the development of the logistics distribution industry, the number of data generated is becoming increasingly huge. The traditional manual method usually causes data confusion and loss, increases the workload, and reduces work efficiency. The problem of "inefficient and high consumption" in the logistics distribution industry gradually becomes a bottleneck restricting the development of the industry. Reducing logistics distribution costs and improving logistics distribution services and logistics distribution efficiency pose a challenge to the current logistics distribution system [4, 5].

Therefore, constructing an intelligent logistics distribution management system becomes necessary and urgent [6]. In this case, an intelligent logistics distribution management system based on machine vision can update the traditional logistics distribution system, and it can promote the all-around development of the current logistics distribution system and help it develop intelligently [7]. Sternberg and Norrman [8] analyzed scientific papers, project reports, specifications, and other publications related to The Physical Internet (PI) to help researchers and decision makers develop efficient logistics systems, and PI is tested based on four factors, namely organizational readiness (technical blueprint), external pressure (commitment effect), perceived benefits (business model), and adoption. Liu et al. [9] applied collaborative business intelligence systems to hospital supply, processing, and distribution logistics management models. The business process theory is improved by using data mining technology to identify knowledge and collaborative technology from complex data. For the application of the system, a hierarchical collaborative system is proposed for the intelligent management of hospital logistics, and a database for the collaborative system is established. Yang and Wu [10] discussed the vehicle routing and its extension and introduced the ant colony algorithm, focusing on the principle of the ant colony algorithm, to improve the ant colony algorithm, so that the problems in vehicle routing can be solved. The results show that the improved algorithm can improve the efficiency of logistics transportation, reduce transportation costs, and increases economic benefits. The development of Internet technology promotes the development of intelligent logistics distribution management system. More and more new technologies are gradually applied to the intelligent logistics distribution management system. Sensor technology and sensor networks are widely used in target recognition in the logistics distribution system.

Based on visual sensor image processing technology and intelligent management, DTs are used to manage the distribution process efficiently, and the "black box" mode is transparent. And an efficient, high-quality, low-cost intelligent logistics distribution management system is built to realize the integration, agility, automation, visualization, and specialization of the logistics distribution management system. The innovation is to construct a new intelligent logistics distribution management system based on visual sensor image processing technology through the analysis and research on the visual sensor image processing technology, order management, receiving management, distribution management, scheduling management, and return management that affect the logistics distribution. The demand, functional elements, operation process, and data flow of the distribution center system are analyzed according to the principle of software engineering. The overall architecture of the urban logistics distribution system is designed, the functional levels and main functional modules of the system are analyzed, and the system database is established.

2. Materials and Methods

2.1. Analysis of Relevant Concepts

2.1.1. Machine Vision. Machine vision is a new technology developed based on artificial intelligence (AI), and it uses machine observation to replace human eyes to identify, measure, and judge things. It combines optical imaging, image processing, sensors, digital simulation, computer technology, and mechanical engineering technology together [11]. In real life, the objective model is created to identify and obtain the target image and complete the observation and analysis of practical problems. And the application of robots is expanded, and the microscopic and macroscopic visions of things are developed [12]. The machine vision system has the characteristics of high flexibility and strong automation and is usually used to identify things in extreme working environments and scenes, which is difficult to do by human eyes.

The classical machine vision system is generally composed of a light source system module, an image capture module, a digitization module, a digital image processing module, an image intelligent judgment decision module, and a mechanical control execution module. First, the machine vision system captures and converts the target image by using the image recognition shooting device and sends the converted image signal to the dedicated image processing system, obtaining the basic morphological characteristics of the target. Second, the target color, brightness, pixel distribution, and other information are digitized, and the digitized image is processed to obtain the significant characteristics of the target. Finally, the field equipment is controlled to achieve the existing purpose according to the results of the intelligent discriminant decision. The optical sensing equipment used in the process includes the complementary metal-oxide-semiconductor (CMOS) and the charge coupled device (CCD). The device can realize the automatic acquisition of the target image and analyze the target image to obtain the morphological information of the target object, making judgments and decisions and realizing the control of the target image [13, 14]. The structure of the machine vision system is shown in Figure 1.

2.1.2. Intelligent Logistics. Intelligent logistics is based on the current intelligent integrated system. The existing sensors, bar code, radio frequency identification, and global positioning and other more advanced technical means of logistics industry involved in packaging, warehousing, transportation, distribution, and handling links are used to make the logistics system simulate human intelligence. After that, the system has the ability to think, perceive, learn, and solve problems. Intelligent logistics is automatic and efficient, and it can reduce freight costs and resource consumption and improve service levels [15]. In freight transportation, intelligent logistics should ensure six "exactness", namely, exact goods, quantity, location, quality, time, and price. And it should also perform the identification, tracking, traceability, monitoring, and real-time response of goods. Because of the impact of economic globalization on transport costs, the competition in the logistics industry is increasingly fierce, and the rational allocation of resources and effective cost control attract much attention. The development of science and technology and the rise of the network make intelligent logistics an effective means to reduce the cost of enterprises, improve their service quality, and enhance their competitiveness [16]. Under the requirements of the new era, intelligent logistics gradually becomes a system with intelligence,

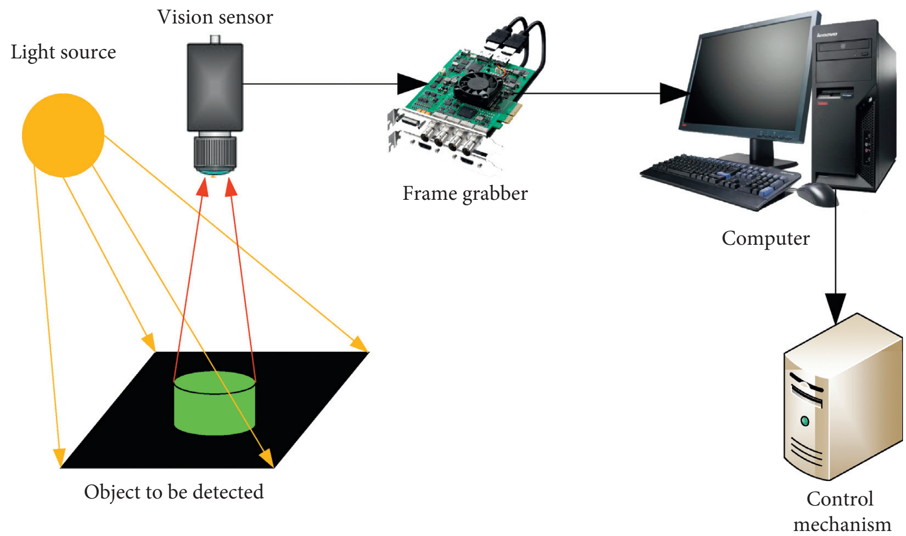

Figure 1: Composition of the machine vision system.

informatization, environmental protection, industrial synergy, globalization, and internationalization. Intelligent logistics has the characteristics of intelligence, integration, hierarchy, flexibility, and socialization, which is reflected by intelligent decision-making in the process of freight transportation. The integration and hierarchy of the rational allocation of freight transport links are realized. And resource allocation is carried out according to consumers' demands. The structure of the intelligent logistics system is shown in Figure 2.

The intelligent logistics distribution management system (ILDMS) is based on AI, network information technology, and the intelligent transportation system (ITS). It collects real-time data in the process of logistics distribution, analyzes and processes them, and makes intelligent decisions. And then the high efficiency and low consumption are realized, and detailed information and consulting services for personnel involved in various links are provided. In the intelligent logistics distribution management system, "intelligence" is the core, "ability" is the key, "goods" is the premise, "flow" is the realization, and "distribution" is the organic combination of "distribution" and "delivery". "Intelligence" reflects the efficiency of information perception and decision-making. "Ability" is the fast and effective collaboration, the strong implementation ability, and high automation between various facilities. "Goods" mainly refers to the type, quantity, and quality of goods in the distribution process. "Flow" refers to the flow of goods, and it is also the core transportation link in logistics distribution. In the whole logistics service, "distribution" is the nearest link to the product terminal. How to send the customer's required goods in time under complex road conditions within a period becomes the primary task of the intelligent logistics distribution management system.

2.1.3. DTs. A model of DTs combined with the specific logistics distribution system is proposed based on the five-dimension of DTs and the modeling method, making DTs applied to the specific logistics distribution. The five dimensions are physical distribution operation, virtual distribution operation, the physical distribution service system, the twin data of logistics distribution, and system connection. The model is shown in Figure 3.

2.2. Target Image Processing Based on Visual Sensor Image Processing Technology

2.2.1. Visual Sensors. The vision sensor is also known as an intelligent camera. It is an embedded small machine vision system that combines image acquisition, image processing, information transmission, and I/O (Input/Output) control modules. It is also a new technology in the field of machine vision in recent years [17, 18]. The visual sensor is responsible for capturing and shooting the information of the whole machine vision system. It is generally composed of one or two sensors, and it needs auxiliary equipment, such as optical projectors, to complete the operation. The most important function of the visual sensor is to capture and shoot a large number of original images of the target and complete image processing and analysis [19]. The integrated design of the visual sensor greatly reduces the complexity of the device, improves its reliability, and broadens its application fields. The visual sensor is generally composed of the image acquisition module, the image processing module, the image processing software, the communication device, and the I/O control interface. The visual sensor has the characteristics of high integration and strong functional modularization. It combines the light source, camera, image processor, standard control, and communication interface to realize the fast communication between personal computers (PC) and programmable logic controllers (PLC). As an independent intelligent image acquisition and the processing module, the internal memory of the visual sensor can store the downloaded image processing algorithm [20]. The visual sensor system is shown in Figure 4.

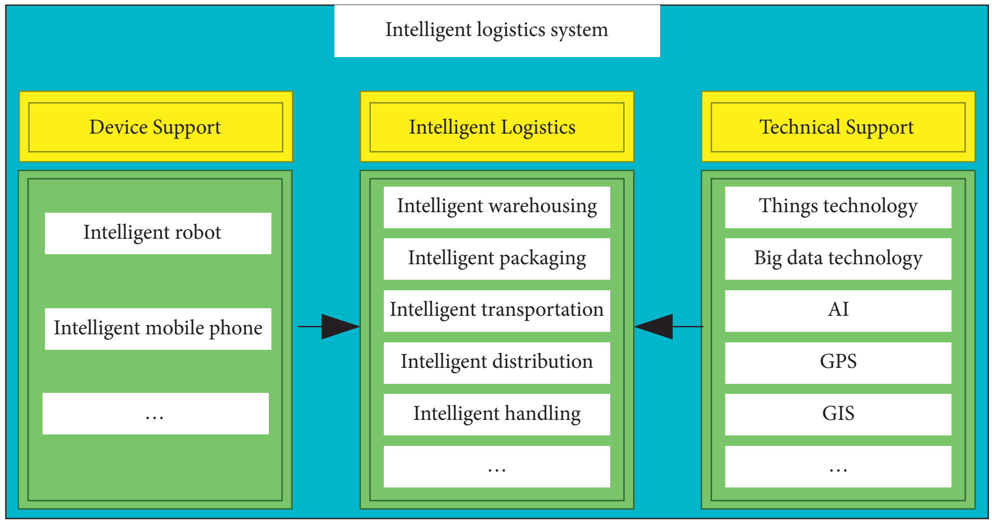

Figure 2: Intelligent logistics system.

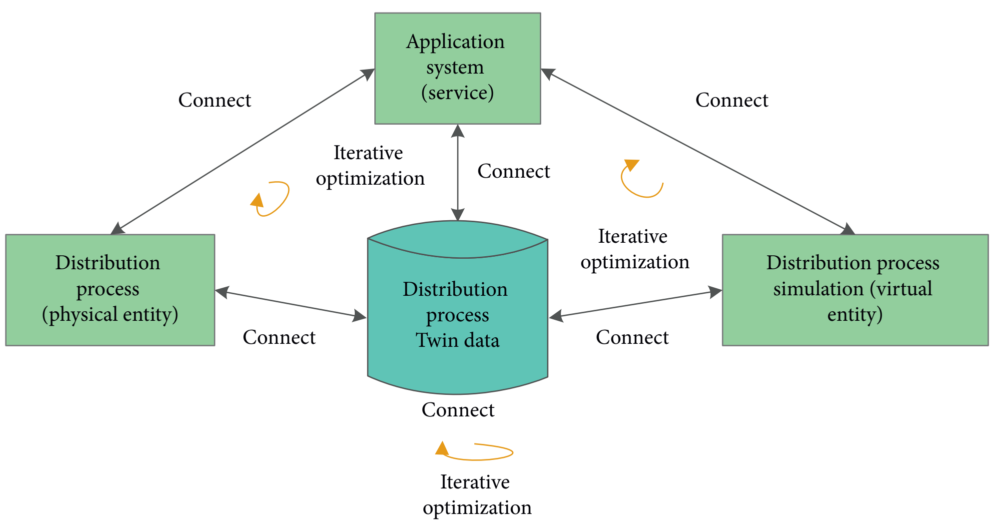

Figure 3: DTs five-dimensional model of logistics distribution.

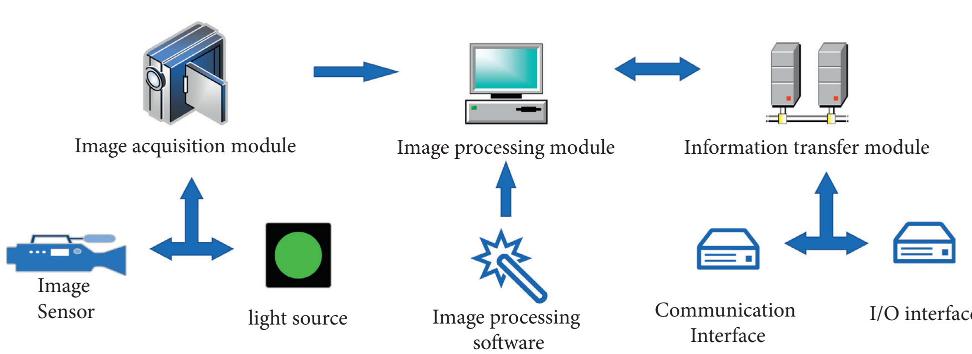

Figure 4: Composition of the visual sensor system.

In short, under the increasingly complex situation of the logistics distribution industry, object recognition and detection based on visual sensor image processing technology has high precision, high intelligence, high anti-interference, and simple composition, which meet the requirements of intelligent control in modern logistics distribution. Therefore, the target recognition detection is conducted based on visual sensor image processing technology, hoping to build a more excellent intelligent logistics distribution management system.

2.2.2. Process Analysis of Target Image Processing. In logistics distribution, a large number of images are taken on roads and in an open space. According to image engineering, the target image should be analyzed and processed by three steps, namely image preprocessing, image analysis, and image feature extraction. The image analysis process is shown in Figure 5.

The image enhancement algorithm is as follows:

$$\overline{f} = 1 - \left(\frac{f}{M}\right). \tag{1}$$

In equation (1), the range of gray function f is $[0, M)$. For the image of 8bit, $M = 256$. The simplified algorithm is as follows:

$$\log\left(\overline{f}'(i, j)\right) = \alpha \log(\overline{a}(i, j)) + \beta[\log(\overline{f}(i, j)) - \log(\overline{a}(i, j))]. \tag{2}$$

In equation (2), $\overline{f}(i, j)$ and $\overline{f}'(i, j)$ are the original and the processed gray functions, respectively, and α, s, and β are constants.

$$\log(\overline{a}(i, j)) = \frac{1}{n^2}\left(\sum_{k=i-n/2}^{i+n/2}\sum_{l=j-n/2}^{j+n/2}\log(\overline{f}(k.l))\right). \tag{3}$$

In equation (3), $\overline{a}(i, j) \in (0, 1]$ and $\alpha \log(\overline{a}(i, j))$ can enhance the degree of the image especially in the dark or bright area. The enhanced image $f(i, j)$ can be obtained by substituting $\overline{f}'(i, j)$ for $\overline{f}$ to calculate its inverse operation $f = (1 - \overline{f})M$. The above equation can enhance the image details and the noise in the image, so equation (2) can be converted to the following equation.

$$\log(\overline{f}\prime(i, j)) = \log(T(a'(i, j))) + \beta_s[\log(\overline{f}\prime(i, j) - \log(\overline{a}(i, j)))]. \tag{4}$$

In the above equation, β_s is β in equation (2) and T is α in equation (2).

$$\beta_s = \beta_0\left|I_g(x, y)\right|\mathrm{MAXI}_g(\beta_0 = 3.0). \tag{5}$$

$I_g(x, y)$ is the image gradient and MAXI_g is the maximum image gradient. Its gradient operator is as follows:

$$\begin{cases} P_0[i, j] = I[i-1, j] - I[i+1, j], \\ P_{45}[i, j] = 2 \times (I[i+1, j-1] - I[i-1, j+1]), \\ P_{90}[i, j] = I[i, j-1] - I[i, j+1], \\ P_{135}[i, j] = 2 \times I[i-1, j-1] - I[i-1, j+1]. \end{cases} \tag{6}$$

$P_0[i, j]$ is the horizontal partial derivative, $P_{45}[i, j]$ is the partial derivative at the direction of 45°, $P_{90}[i, j]$ is the vertical partial derivative, and $P_{135}[i, j]$ is the partial derivative at the direction of 135°.

$$I_g(i, j) = \sqrt{P_0^2[i, j] + P_{45}^2[i, j] + P_{90}^2[i, j] + P_{135}^2[i, j]}. \tag{7}$$

$I_g(x, y)$ is the image gradient. Equation (7) can be simplified as follows:

$$I_g[i, j] = |P_0[i, j]| + |P_{45}[i, j]| + |P_{90}[i, j]| + |P_{135}[i, j]. \tag{8}$$

In the above equation, $I_g[i, j]$ is the gradient image.

2.2.3. B/S Architecture. The B/S architecture, namely the Browser/Server architecture, is the continuation and improvement of the traditional C/S architecture. In the B/S architecture, the server handles various complex business logic, and the browser is responsible for the interaction with users and interface display. The user sends a request to the server through the interface displayed by the browser, and the server receives the user's request and processes it accordingly. Then the results of the user's request are returned to the browser, and all the displayed content on this page is generated by the web browser. The traditional C/S architecture is the client/server architecture. It reduces the amount of server computing and network data transmission through the reasonable allocation of data computing and processing on the client and server. The client also has some processing ability. However, it is gradually replaced by B/S due to the poor compatibility, poor scalability, and high maintenance.

Compared with C/S, B/S has the following advantages:

(1) It is convenient and flexible. Users do not need to install any client program on the computer, and just open the browser to access texts, images, videos, and audios. But in C/S, each client needs to install software. If there are problems in installation, each device needs to be maintained alone, which increases the cost considerably.

(2) It has high compatibility. B/S has the ability to cross platforms. Unlike C/S, users need not care whether their operating system is compatible with software.

(3) It is easy to upgrade and maintain. The upgrading and maintenance of B/S architecture are mainly concentrated on the server and all systems can be updated synchronously by changing the web page, while C/S cannot be separated and each client must manually install the upgrade system, which costs a lot.

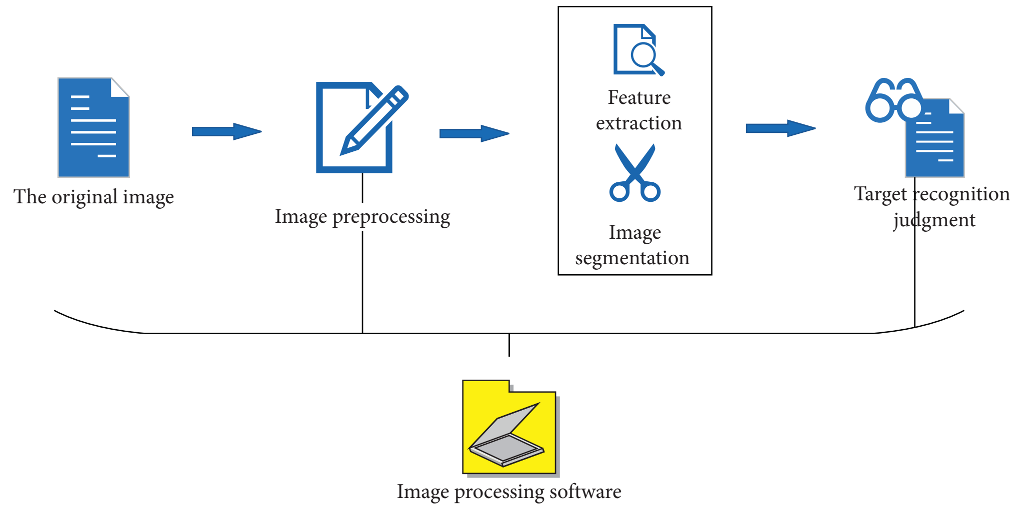

Figure 5: Analysis of target images.

3. Construction and Analysis of the Intelligent Logistics Distribution Management System Based on Visual Sensor Image Processing Technology

Distribution management is the top priority in the intelligent logistics distribution management system. How to reasonably optimize the distribution route and scientifically schedule the distribution vehicle in the process of logistics distribution directly affect the efficiency and cost of the whole logistics distribution [21]. Logistics distribution starts from the order and ends when customers receive goods and pay for it. The general process is as follows: the operator receives the order and knows about the relevant information. The system dispatches an appropriate vehicle to collect and load the goods, and the distribution route is planned. Deliverers load goods according to orders and complete distribution according to the planned route. In the process of goods distribution, vehicles and distribution personnel are tracked and managed according to the logistics distribution management system, and logistic information is sent to customers in real time. When customers receive goods, the clerk returns confirmation and cost settlement, and the whole distribution management is completed [22, 23]. The influencing factors in the distribution management include the number and size of goods, customers' requirements, distribution costs, distribution routes, and distribution modes. Enterprises should make scientific and reasonable decisions on distribution routes and distribution modes, realizing intelligent management of logistics distribution.

3.1. Requirements for the Functions of the System

3.1.1. Order Processing. Order processing is performed in the external window of the intelligent logistics distribution management system, and it can be observed by customers directly. It includes order receiving, order auditing, order query, and order data processing. First, the operator should arrange the distribution time and distribution distance and upload them to the database of the system after receiving customers' orders. Second, the system verifies the information of the order to judge whether to accept the order. Then, the operators, distributors, and customers can query the feedback of the system on the orders in real time and know about the order distribution information. Finally, the system responds to the orders promptly and evaluates the delivery cost according to the time, place, distance, weight, and other factors. The process of order processing is shown in Figure 6.

3.1.2. Receipt Management. Receipt management is the most basic and important link in logistics distribution. It includes several parts, namely a receiving plan, a receiving route, and replenishment processing. After receiving the audited information, the salesman sorts the goods to be delivered according to the demand, plans the receiving route, replenishes the source in time, and makes the corresponding replenishment order. The specific process of receipt management is shown in Figure 7.

3.1.3. Physical Distribution Management (PDM). Distribution management is the core of the logistics distribution management system, and it includes loading decisions, route decisions, and vehicle scheduling decisions. The intelligent logistics distribution management system makes the loading decision according to the actual situation of the order and sends the generated order to the clerk, who takes the goods from the warehouse. And then the goods are delivered by vehicles. The system optimizes the distribution route according to the real-time road conditions and tracks the distribution in real time. The process of distribution management is shown in Figure 8.

3.1.4. Scheduling Management. Scheduling management refers to scheduling vehicles and dispatchers according to the distribution plan generated by the system and tracking the distribution process. Scheduling management includes

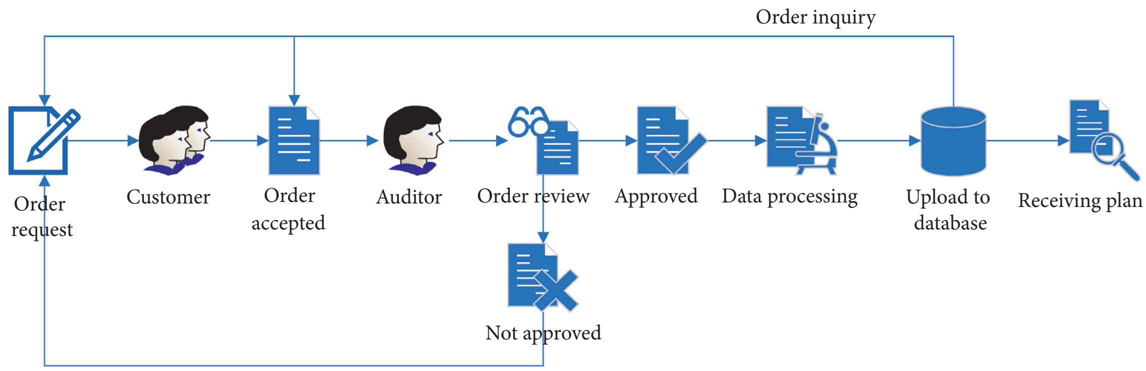

Figure 6: Order processing flow.

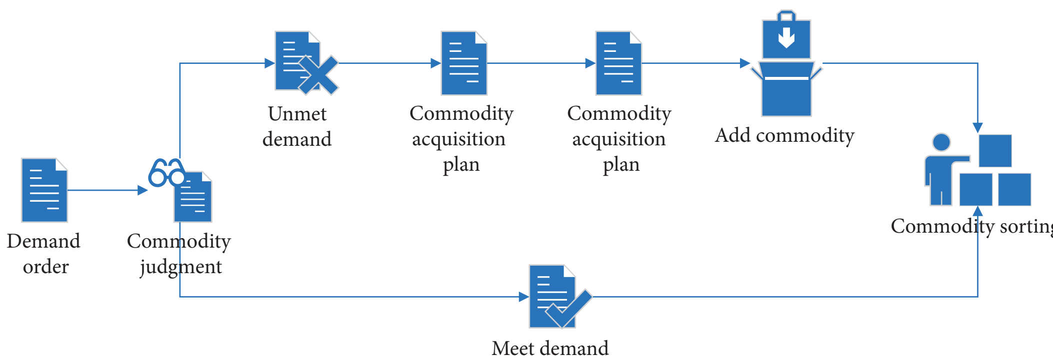

Figure 7: Receipt management process.

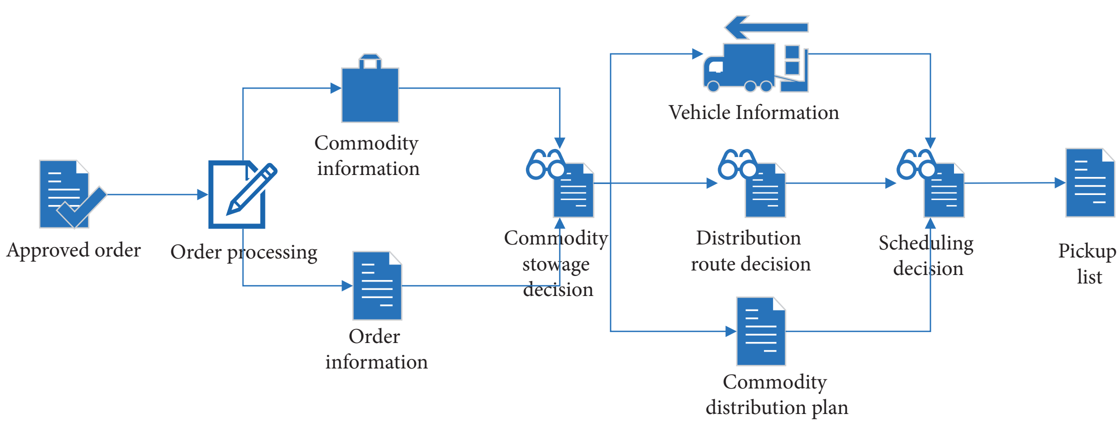

Figure 8: Distribution management process.

vehicle scheduling, dispatcher management, vehicle data management, and distribution tracking management. In the process, the distribution vehicles and distribution personnel are arranged according to the decision, and the real-time state in the distribution process is tracked and supervised by the proper management and maintenance. The specific process of scheduling management is shown in Figure 9.

3.1.5. Return Management. Return management is based on customers' returns, including return entry, return audit, and return sorting. The salesman inputs the customer return into the database in the system as the basis and audits the returned goods. Returns are processed by an audit, and the audit needs to communicate with customers when there are some conflicts. The specific process of return management is shown in Figure 10.

3.2. Construction and Analysis of the Intelligent Logistics Distribution Management System. The intelligent logistics distribution management system uses a geographic

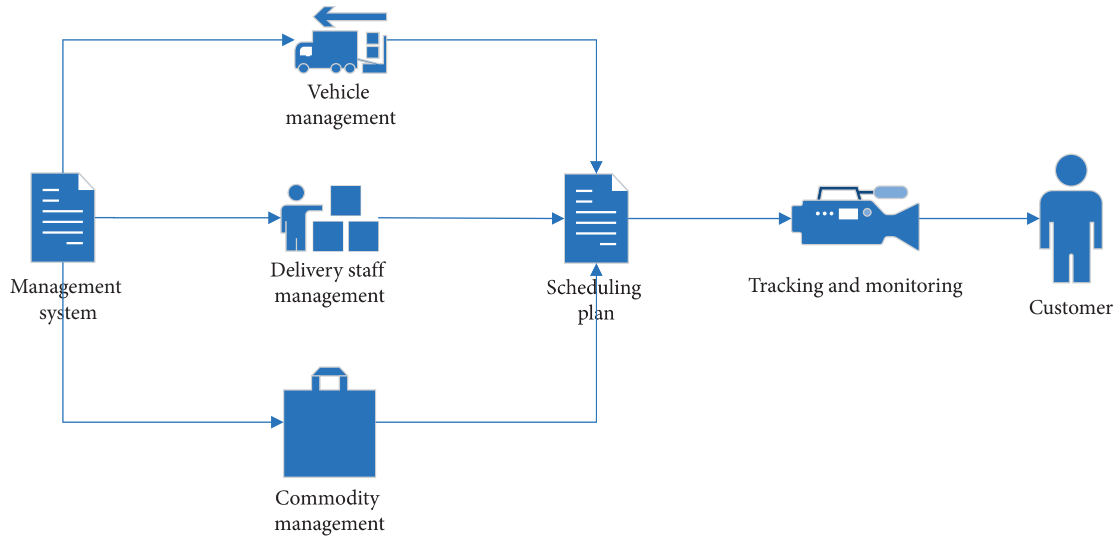

Figure 9: Scheduling management process.

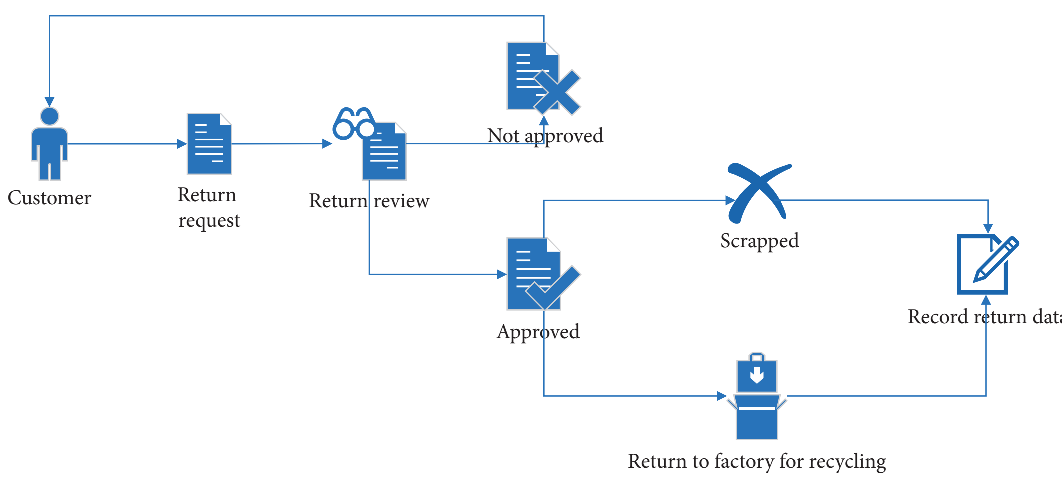

Figure 10: Return management process.

information system (GIS), a global positioning system (GPS), an optimized distribution route, a multiobjective decision-making device, and a high-precision digital map and other advanced technologies to scientifically distribute and schedule orders and vehicles, realizing intelligent distribution. According to the requirements for a wide, diverse, dynamic, and complex intelligent logistics distribution system, Browser/Server (B/S) is used to construct such a system. The B/S architecture is the server and browser architecture, and it is composed of the presentation layer, application layer, and data layer. It has low requirements for computers and simple maintenance procedures [24, 25]. The architecture of the system is shown in Figure 11.

A large number of investigations are carried out on the logistics industry, and the procedures involved in logistics distribution should be familiar with. According to the research results and the above framework, an intelligent logistics distribution management system is designed according to distribution management, customer management, and financial management. Among them, distribution management includes basic units, such as information management, order management, scheduling management, distribution management, warehousing management, return management, and report management. The specific structure of the intelligent logistics distribution management system is shown in Figure 12.

3.3. Simulation Experiment

3.3.1. Target Recognition Verification Based on Visual Sensor Image Processing Technology. The visual sensor image processing technology is used to identify the vehicle and goods in the process of intelligent logistics distribution. The collected images are analyzed and processed by using the image filtering algorithm and the image segmentation algorithm, and the practical value is verified by analysis and comparison.

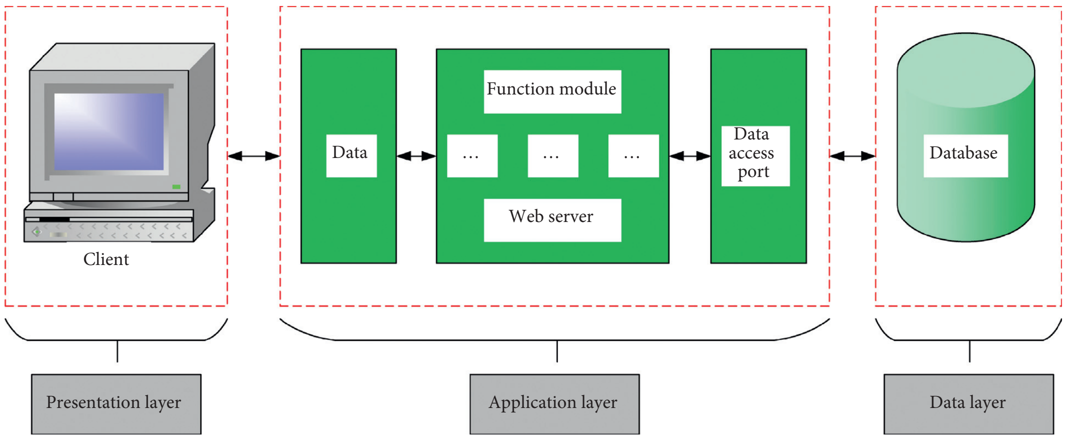

FIGURE 11: B/S system.

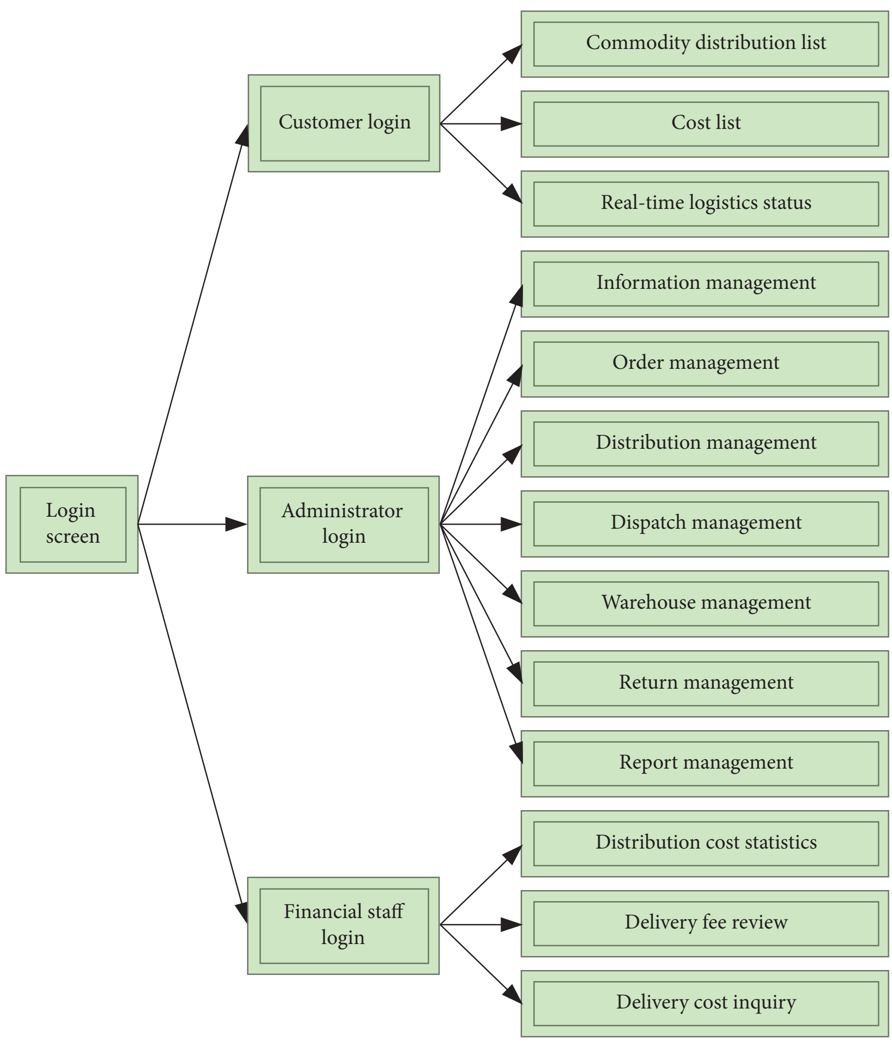

FIGURE 12: Structure of the intelligent logistics distribution management system.

3.3.2. Design of Intelligent Logistics Distribution Management System. A good environment is the premise of system design because the intelligent logistics distribution management system needs to deploy a good environment in the process. The parameters set in the system design are shown in Table 1.

In the actual verification, the same or similar logistics distribution scenarios are selected, and the traditional

Table 1: Parameters of the intelligent logistics distribution management system.

Name	Parameters
Operating system	Linux 16.04
Database	SQL Server2005
System structure	Browser/Server
Development tools	Microsoft visual studio.NET 2010
Technical support	.Net framework, ASP.NET, ADO.NET

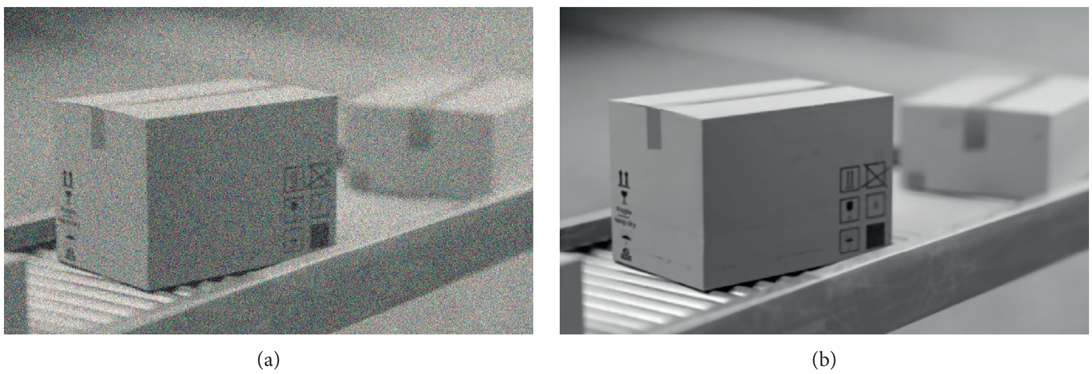

Figure 13: Processing results by using the median filtering optimization algorithm (a) original image; (b) the image after median filtering.

logistics distribution mode and intelligent logistics distribution management system are used for distribution activities, and the feedback results are compared and analyzed.

4. Results

4.1. Influence of Visual Sensor Image Processing Technology on Target Image Processing

4.1.1. Influence of the Filtering Optimization Algorithm on Image Processing. The original images are usually collected on roads or in an open area, so there are different kinds of noise in them. Therefore, the image filtering algorithm is used to remove the noise in the image. The processing results by using the median filtering optimization algorithm are shown in Figure 13.

Figure 13 shows that the noise in the original image can be well filtered out by using the median filtering algorithm, and the quality of the image is greatly improved in the process. That is to say, the median filtering algorithm based on visual sensors can better remove noise and remain image details. Therefore, goods can be accurately identified and distinguished to meet the requirements of logistics distribution.

4.1.2. Influence of the Image Segmentation Algorithm on Image Processing. Road images are randomly selected to be analyzed and processed in the process of logistics distribution by the target detection algorithm and the semantic segmentation algorithm. The results of different algorithms are shown in Figure 14.

Figure 14 shows that the detection algorithm only identifies road conditions, and the recognition rate is limited in identifying complex road conditions. The semantic segmentation algorithm can identify the road conditions, distinguish the details of the road conditions, and recognize any road conditions. Therefore, the semantic segmentation algorithm has obvious advantages in optimizing road conditions.

4.2. Influence of the Intelligent Logistics Distribution Management System Based on Visual Sensor Image Processing Technology on Logistics Distribution

4.2.1. Impact Dsof the Logistics Distribution on the Accuracy. In a similar logistics distribution scenario, the comparison results of the type, quantity, and quality of the delivered goods are shown in Figure 15.

Figure 15 shows that the intelligent logistics distribution management system based on visual sensor image processing technology is improved in types, quantity, and quality of goods compared with the traditional logistics distribution system. The average precision rate of the intelligent logistics distribution management system reaches more than 99.5%, which is greatly improved compared with about 90% of the traditional logistics distribution. The quality of distribution goods also reaches 98.4%, and the gap of the precision rate, the quantity, and the types of goods is narrowed.

4.2.2. Impact on Logistics Distribution Efficiency. For the size of customers, the optimal route of distribution scheduling obtained by using the model based on DTs is shown in Figure 16.

(a) (b)

Figure 14: Comparison of the processing results of road images between the target detection algorithm and the semantic segmentation algorithm. (a) Analysis and processing of images by target detection algorithm; (b) analysis and processing of images by semantic segmentation algorithm.

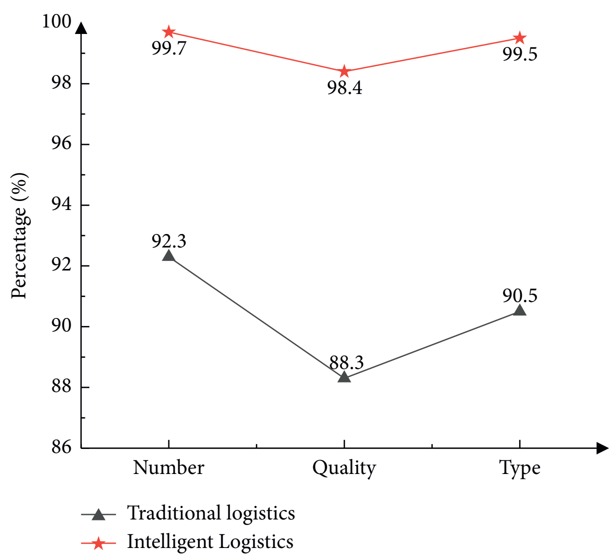

Figure 15: Comparison of the distribution accuracy.

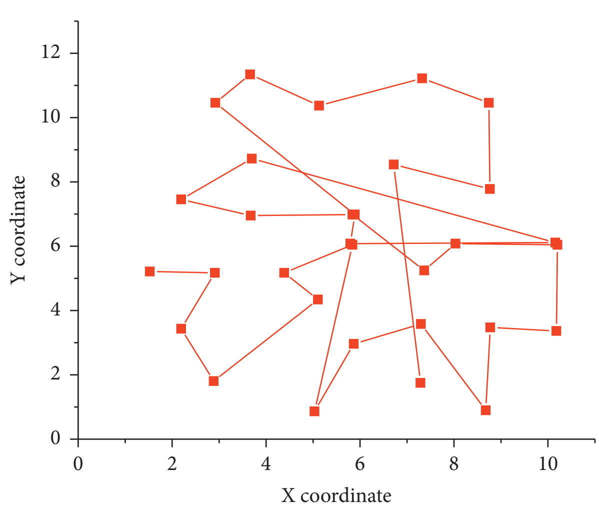

Figure 16: Optimal scheduling path based on digital twin.

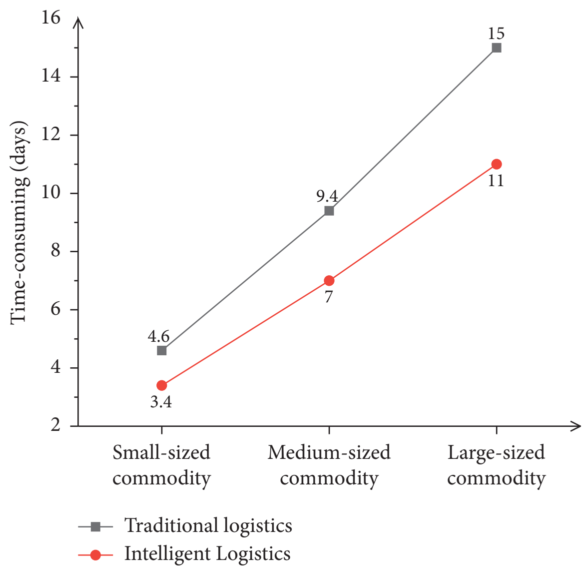

Figure 17: Comparison of the distribution efficiency.

Figure 16 shows that the cost of the optimized distribution route obtained is reduced by about 9.92%. The optimal distribution method simulated by DTs is transmitted to the physical layer through 5G wireless technology. In this case, the driver receives real-time information through the vehicle system, so that the distribution route and scheme can be reasonably adjusted.

In similar logistics distribution scenarios, the distribution efficiency and cost of different goods are compared, and the comparison results are shown in Figure 17.

Figure 17 shows that when the logistics distribution scenario is consistent, the volume of the goods delivered also affects the delivery time. Compared with the delivery time of small goods, the delivery time of medium goods is doubled, and the time required for transporting large goods is about four times higher. However, compared with the traditional logistics distribution system, the distribution time of the intelligent logistics distribution management system based on visual sensor image processing technology is significantly improved. The time of transporting small goods is shortened by about 1 day, the time of transporting medium goods by about 2 days, and the time required for transporting large goods by about 4 days. It is found that the distribution efficiency is improved by about 26.5% by using the intelligent logistics distribution management system.

5. Conclusions

Affected by the economic system and social environment, the problems in the logistics management system are exposed. For example, the management mechanism is not clear, and the material circulation channel is not smooth; the advantages of logistics management is neglected, and scale operation and enterprise benefits cannot be achieved, making goods detained and increasing the cost. Based on machine vision, the intelligent logistics distribution management system is designed by using visual sensing image processing technology and B/S architecture under DTs. Through the analysis and research on the visual sensor image processing technology, it is found that receipt management, distribution management, scheduling management, and return management affect logistics distribution, and it is verified by the experiments, and the visual sensor image processing technology has the characteristics of precision, intelligence, efficiency, and perfect details. The intelligent logistics distribution management system designed can effectively solve the problems existing in traditional logistics distribution management. The experimental results show that the visual sensor image processing technology can not only complete the acquisition and analysis of the target image in logistics distribution but also effectively track and monitor the target. The distribution process is simulated by the algorithm kernel, and the path and total cost of logistics distribution are obtained. Compared with the traditional method, it is verified that the distribution optimization method based on DTs can adjust the plan timely and effectively according to road and traffic conditions. The intelligent logistics distribution management system can effectively improve the efficiency of data processing, and the distribution accuracy is more than 99.5%. Also, the response time is shortened by about 26.5%. The research broadens the application of visual sensor image processing technology in the intelligent logistics distribution industry. The study realizes the informationization of the logistics management system and the real-time control of the whole distribution process. In this way, the real-time dynamic distribution can be transmitted to the city logistics distribution at any time, which helps management and decision-makers work out solutions in real time. However, there is a shortcoming that needs to be improved. The model constructed needs to be expanded and improved. Based on the actual needs, the system is just designed with single-line logistics as the model, and multiline logistics should be expanded and optimized.

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 there are no conflicts of interest.

References

[1] D. C. Wang, “Construction of logistics engineering undergraduate professional curriculum system,” *Journal of Liaoning University of Technology (Social Science Edition)*, vol. 21, no. 118, pp. 118–120, 2019.

[2] Y. F. Chen, S. L. Wang, and J. Zheng, “Enterprise knowledge chain innovation under the background of green manufacturing-logistics co-evolution,” *Science and Technology Management Research*, vol. 39, no. 9, pp. 192–196, 2019.

[3] Y. B. Wang, “Design and application of intelligent logistics warehouse management system based on Internet of things,” *Automation Technology and Application*, vol. 39, no. 303, pp. 78–81, 2020.

[4] H. Y. Ding, “Problems and countermeasures of rural E-commerce “last kilometer” logistics distribution,” *Technology and Market*, vol. 27, no. 323, pp. 150-151, 2020.
[5] D. M. Lu, “Research on the optimization of rural logistics distribution system under the background of ‘Internet+,” *Technological Innovation and Productivity*, vol. 312, no. 1, pp. 40–43, 2020.
[6] S. Y. Tang, “Discussion on the influence of artificial intelligence on the development of logistics industry,” *Modern Business Industry*, vol. 42, no. 3, pp. 34-35, 2021.
[7] Y. Y. Ding, Q. Q. Gao, and X. Zhou, “Application of machine vision system in intelligent logistics conveying system,” *Industrial Design*, vol. 165, no. 4, pp. 129-130, 2020.
[8] H. Sternberg and A. Norrman, “The Physical Internet - review, analysis and future research agenda,” *International Journal of Physical Distribution & Logistics Management*, vol. 47, no. 8, p. 12, 2017.
[9] T. Liu, A. Shen, X. Hu, G. Tong, and W. Gu, “The application of collaborative business intelligence technology in the hospital SPD logistics management model,” *Iranian Journal of Public Health*, vol. 46, no. 6, pp. 744–754, 2017.
[10] D. Yang and Y. Wu, “Intelligent algorithm of vehicle routing optimization for logistics distribution,” *Boletin Tecnico/ Technical Bulletin*, vol. 55, no. 18, pp. 512–520, 2017.
[11] C. H. Pan, L. M. Duan, and Y. S. Deng, “Research on the application of machine vision technology in automated logistics system,” *Journal of Kunming Metallurgical College*, vol. 35, no. 152, pp. 101–106, 2019.
[12] A. Poudel, A. Meddah, and M. Witte, “Machine learning for machine vision systems,” *Railway Age*, vol. 222, no. 7, pp. 26-27, 2021.
[13] B. Santra, A. K. Shaw, and D. P. Mukherjee, “An end-to-end annotation-free machine vision system for detection of products on the rack,” *Machine Vision and Applications*, vol. 32, no. 3, pp. 1–13, 2021.
[14] Y. J. Han, “Exploring the design principles of robot vision system,” *Science & Technology Communication*, vol. 11, no. 2, pp. 115-116, 2019.
[15] H. Z. Zhao, “Research on the support system of my country’s smart logistics development under the background of ‘Internet+,” *Journal of Changchun Normal University*, vol. 39, no. 366, pp. 70–72, 2020.
[16] X. M. He, “Analysis of the core competitiveness of logistics enterprises-research based on artificial intelligence,” *Logistics Technology*, vol. 42, no. 285, pp. 19–21, 2019.
[17] X. Yang, “On the application of computer graphics and image processing technology in visual communication systems,” *Digital Technology and Application*, vol. 37, no. 344, pp. 75-76, 2019.
[18] B. W. Sun, Z. M. Zhu, J. C. Guo et al., “Visual sensor detection algorithm and image processing flow optimization based on combined laser structured light,” *Journal of Tsinghua University*, vol. 59, no. 6, pp. 445–452, 2019.
[19] H. B. Guo, “Weld feature extraction based on line structured light vision sensor,” *Electronic Technology and Software Engineering*, vol. 174, no. 4, pp. 121–123, 2020.
[20] Z. X. Xie and X. M. Wang, “Small multi-AUV system formation based on vision sensor,” *Control and Decision*, vol. 35, no. 3, pp. 60–68, 2020.
[21] L. He, “Analysis of the optimization model for selecting the shortest distribution path of intelligent logistics,” *Journal of Changchun Normal University*, vol. 38, no. 359, pp. 76–80, 2019.
[22] H. M. Qian and Y. Y. Xie, “Research on the factors influencing the distribution efficiency of smart logistics enterprises,” *Logistics Engineering and Management*, vol. 42, no. 307, pp. 10-11+19, 2020.
[23] S. C. Hao, “Research on the development of logistics distribution under the cloud service model,” *Journal of Guangzhou City Vocational College*, vol. 14, no. 52, pp. 88–92, 2020.
[24] W. Yang, J. Li, and F. F. Yang, “The application of smart logistics based on Internet of Things technology in expressway service area,” *Transportation Enterprise Management*, vol. 35, no. 360, pp. 80–82, 2020.
[25] M. Zhang, W. J. Guo, Q. Tang et al., “Design and implementation of third-party logistics management system based on B/S,” *Enterprise Technology and Development*, vol. 455, no. 9, pp. 101–103, 2019.

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Research Article

A Theoretical Analysis Method of Spatial Analytic Geometry and Mathematics under Digital Twins

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In recent years, online education in China has made considerable achievements. But there are also some problems: the teaching quality of online education is unsatisfactory; students' online learning effects are frustrating, and students' autonomous learning ability is poor. Based on analysis, teachers' literacy and Internet technology are important factors restricting the online teaching reform, and online teaching easily falls into the dilemma of "shallow learning." Digital twins can effectively realize the intelligent interconnection and interaction of the physical world and the information world, optimize the remote teaching process, and provide high-quality remote learning experience for learners. Based on this, the technology is used to the teaching of space geometry to help students understand it and improve their performance. First, the principle and advantages of digital twins are expounded. Second, the platform system based on digital twins is constructed. Then, the corresponding digital model is drawn by using the drawing function of MATLAB software, and the system based on virtual reality (VR) is established. Finally, the students of four classes of the same major are selected as the research subjects to test the teaching effect of advanced mathematics on the digital platform. The results show that students' scores in the traditional classrooms are form 2.5 to 5.5 and their average score is 4.049, while the scores of the students in the digital twin classrooms are between 5.5 and 9.5 and their average score goes up to 7.986. This shows that students' performance in the digital twin classrooms is 97.2%, higher than that in the traditional classrooms. A fully digitized spatial geometric model is implemented by using digital twins, and it can help students understand the mathematical theory of spatial analytic geometry, and their learning effect is greatly improved. This study provides a new direction for the application of new technologies in mathematics teaching.

1. Introduction

In the section of "spatial analytic geometry" of advanced mathematics, a large number of spatial graphics are required. If the lecturer just draws some graphs on the blackboard, it is difficult for students to understand them due to the poor intuitiveness of the graphics when some complex spatial geometric graphics are involved, affecting the teaching effect.

A digital twin is a simulation technology that applies multiple technologies to many disciplines, including a variety of physical quantities and scales. It applies physical models, various kinds of sensors, and the previous model to map the physical model image into the virtual space to construct a digital model. Thus, the whole manufacturing cycle of digital equipment which fully corresponds to the physical model and reflects the characteristics of the physical model is obtained. The concept of digital twins has been separated from the traditional realistic environment, and it is a digital platform system composed of one or more interconnected and cooperative system modules [1–3].

The application of emerging computer technology is studied by many scholars in China and foreign countries. Qi and Tao (2018) sorted out the big data of the manufacturing industry by using digital twins, including their concepts and applications in product design, production planning, manufacturing and predictive maintenance, and the application fields to new industries. On this basis, they compared the similarities and differences between big data and digital twins [4]. Zhuang et al. (2018) proposed a framework of intelligent production management and control methods for complex product assembly workshops based on digital twins, and three core technologies are established: real-time acquisition and management of physical data in assembly workshops, the use of digital twins to construct relevant digital models for product assembly, and the use of big data and digital twins for auxiliary work [5]. Lv (2019) proposed a comprehensive technology according to the relevant achievements to realize the human-computer interaction of the Internet of Things (IoT) naturally and intelligently [6]. Skobelev et al. (2020) established an intelligent information physics system based on digital twins to manage agriculture and proposed a calculation method of plant growth period prediction and yield prediction. And then a "tube" model of parameter change in each stage of plants is established. A method for calculating yield prediction is also introduced, as well as the method for calculating the start and end dates of each stage [7]. Lopez et al. (2020) developed a hybrid soft sensor to monitor and predict the evolution of cellulosic ethanol fermentation. This combination of real-time data and the high-fidelity kinetic model is realized by digital twins [8]. Chen et al. (2020) established a evaluation model for teachers' ability and a data acquisition model for teachers' professional ability based on machine learning and digital twins. They also fused the data collected by the two models, and the fusion includes data cleaning and integration, data screening, and clustering strategy screening [9]. Wu et al. proposed a new method called "RegARD." First, RegARD is used to detect the symmetry reflected by buildings to constrain rotation and reduce degrees of freedom. Second, the nonlinear optimization equation and advanced optimization algorithm are used to solve the quadratic optimization [10]. In short, digital twins are mainly applied to mold manufacturing in various intelligent manufacturing environments, or to the evaluation of the teaching level of lecturers. The studies on the application of digital twins to subject teaching, especially to mathematics teaching, are few, which is also the innovation of this article. The analysis method of the mathematical theory of spatial analytic geometry based on digital twins is studied. This provides a reference for the application of emerging computer technology to mathematics teaching.

Nowadays, various new computer technologies emerge one after another. Here, digital twins are studied and used to improve the traditional teaching method of advanced mathematics, and the digital twin podium system is constructed, making the digital model of the teaching model and providing an overall spatial map. The standardized teaching process is proposed. The study makes a prominent contribution to applying digital twins to the teaching of solid geometry in colleges and universities. First, the principle and advantages of digital twins are expounded and the platform based on digital twins is constructed. Second, the corresponding digital model is drawn by the drawing function of MATLAB software, and the system under virtual reality (VR) is constructed. Finally, the learning effect of advanced mathematics on digital twin platform is tested. The results show that the teaching effect is greatly improved, and the students' ability to understand spatial analytic geometry is also enhanced. The innovation is that the teaching mode and the teaching classroom of space geometry are constructed based on digital twins. The practicability and effectiveness of the teaching mode proposed are proved by examples.

2. Construction of the Teaching System of the Spatial Analytic Geometry Theory

2.1. Internet of Things (IoT). IoT is born at MIT (Massachusetts Institute of Technology) in 1999. It is a new information service architecture based on Internet and identification technology and communication technology [11]. The objective of establishing this architecture is to enable the information technology infrastructure to provide safe and reliable "goods" information through the Internet and create an intelligent environment to identify and determine "goods," promoting the information exchange within the supply chain. IoT develops rapidly and brings changes to human life and going deep into all aspects of human life, causing a series of technical ethics problems, security problems, and legal problems that need to be solved urgently [12]. IoT is usually deployed in four layers to the consumer side: the device domain, the network domain, the data domain, and the application domain, which gives the device the means to intelligently perceive the surrounding environment, automatically assemble connection and deployment strategies, solve the problems in data centralization, provide users with some help, and give the device simple processing ability. With the arrival of the second decade of the 21st century, various traditional information technologies begin to combine with IoT to create new means to serve human society [13]. IoT architecture and its application fields are shown in Figures 1 and 2, respectively.

2.2. Digital Twins Podium

2.2.1. Digital Twins. All companies are actively promoting digital transformation to trigger the core value of the industrial Internet. A large number of "physical entities" are merging with "digital virtual institutions," which is commonly known as "digital twins." In 2002, Professor Dr. Michael Grieves of the University of Michigan put forward the concept of digital twins for the first time in an article. In the Technical White Paper in 2013, the U.S. military called the digital thread [14] and the digital twins as an important force to change the future war situation. The U.S. military believes that using this physical level data can create a set of digital projections corresponding to the physical object of the physical space in the virtual information space, and this projection includes various equipment modules, which are dynamically linked together and always coordinated in the whole life cycle of products.

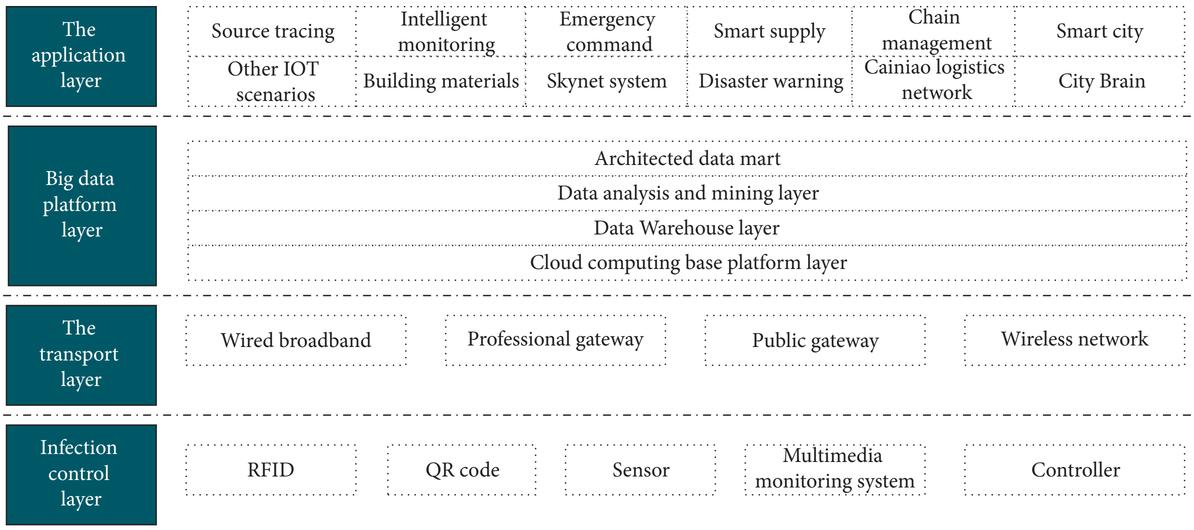


Figure 1: IoT architecture.

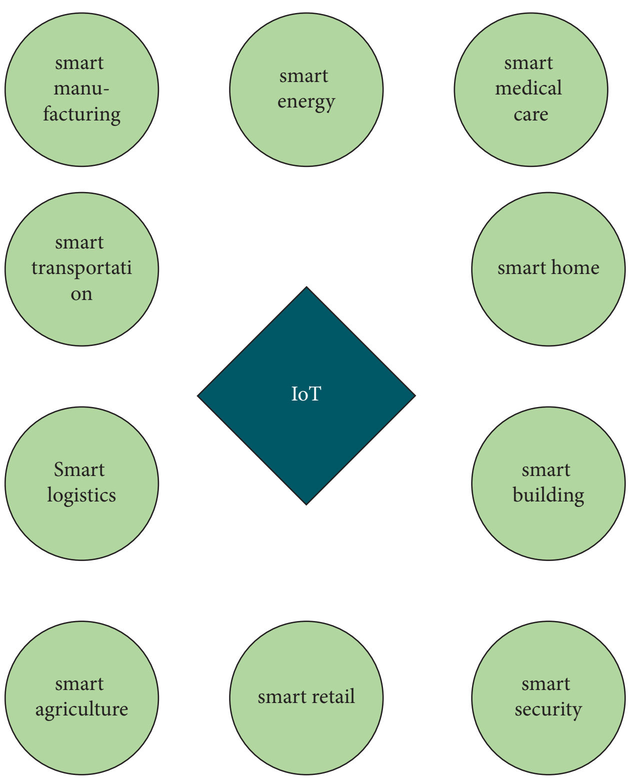


Figure 2: Application fields of IoT.

Since then, the application field of digital twins is expanding, and a series of applications such as analog simulation, virtual assembly, and 3D printing are developed. After 2014, AI is applied to various industrial products and equipment that have not been used before with the continuous development of IoT and AI (artificial intelligence), and the application of digital twins is also applied to complete production and service links. Moreover, digital twins no longer only refer to the technology applied in the product design stage but are fully extended to the whole production process and external service links. However, digital twins are only proposed rather than applied a few years ago because computer technology is not developed [15].

Digital twins run through different stages of the life cycle of products, which perform the same function as PLM (product lifecycle management) [16]. In other words, digital twins really apply the original route of product lifecycle management to the whole production process. Digital twins take the product as fundamental and add various other modules in each period of the whole life cycle to meet different needs. Figure 3 shows the operation process of digital twins.

2.2.2. Application Field of Digital Twins. Application of digital twins to the design stage: digital twins are applied to making digital models to simulate and test the performance of their manufactured products. The main functions of the technology applied at this stage are as follows: (a) digital model design: the computer-aided design (CAD) drawing software is used to construct a digital model that meets the predetermined requirements, accurately expressing the real physical parameter performance of the product and constructing a visual model in digital form so that a large number of technical means can be used to verify and adjust the accuracy of the original model; (b) simulation: a large number of reproducible and variable parameter simulation model tests are used to test the performance of the constructed product model under various actual conditions, achieving the purpose of the performance test in the design link [17].

Application of digital twins to the manufacturing stage: digital twins are used for simulation, which can significantly shorten the time required for offline products, and are very effective for product quality assurance and reduce production costs. The technology used in the production stage requires high coordination of various production modules. The virtual production line is built with computer technology to achieve the integration of production modules and processes, and finally realize the

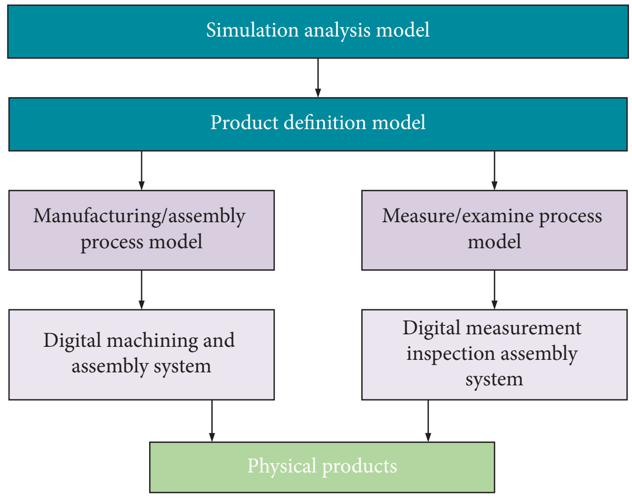


Figure 3: Operation process of digital twins.

simulation of the production process. Before product production, the simulation of the whole production process and products with different performance can be realized. Finally, the prediction of the production process and possible product problems is achieved, shortening the time of offline products [18].

Application of digital twins to the service stage: due to the rapid development of IoT and the popularity of various industrial sensors, many products that do not use intelligent production can use a large number of sensors in the production process to obtain a large number of parameters and performance parameters, ensuring the accuracy of the production process and the stability of product performance parameters, and finally improving product performance and increasing user's satisfaction. The application of digital twins to the service stage includes the following functions: (a) it gives early warnings in the remote monitoring and production mechanical performance; various installed sensors and production system monitoring means are used to build a visual remote monitoring system and carry out regular data maintenance and data analysis to analyze the hidden dangers of production equipment, component modular and hierarchical orderly production system; deep learning and other technologies are used to predict the trend, optimizing the production equipment maintenance plan and parts procurement plan according to the above results and reducing the loss caused by machine failure; (b) optimize customers' production indicators: equipment manufacturers can use big data for analysis and establish equipment parameter adjustment models for different actual environments to help their customers adjust equipment parameters, improving the product quality and production efficiency of downstream product manufacturers; and (c) product use feedback: real-time analysis can be carried out by using the monitoring data of the equipment to understand the real needs of downstream customers [19].

2.2.3. Digital Twins Podium. The digital twins platform is a teaching system that connects real teaching and data teaching space through the network. The relationship between virtual and reality is mapped, coordinated, and interactive one by one. That is, the digital twins podium includes virtual learning feature analysis technology and teaching space interaction technology, and they are used to improve the teaching effect and give students better learning conditions. The application of virtual learning feature analysis technology is to teach students according to their aptitude, make the lecturer's teaching plan match the specific situation of students, and pay attention to the interaction between teachers and students, realizing the accurate management of the classroom and the high efficiency of teaching. The interactive technology of teaching space refers to the use of various technical means to construct a network space containing all elements corresponding to the actual teaching space and can realize the visualization of this space, ensure real-time interaction, and construct a virtual teaching space [20, 21]. Figure 4 shows the specific system of the digital twins podium.

The digital twins podium includes four layers: the data support layer, the modeling computation simulation layer, the function layer, and the immersive experience layer. Table 1 shows the structure of four layers of digital twins podiums.

2.3. Graphics of Spatial Analytic Geometry

2.3.1. Drawing Software. Matlab is the abbreviation of Matrix Laboratory [22, 23]. It is made by American commercial companies. This software is mainly used for mathematical analysis. Its functions include algorithm development, data analysis, computer language numerical simulation, and human-computer interaction. Its function of drawing functions/data images is used in the study.

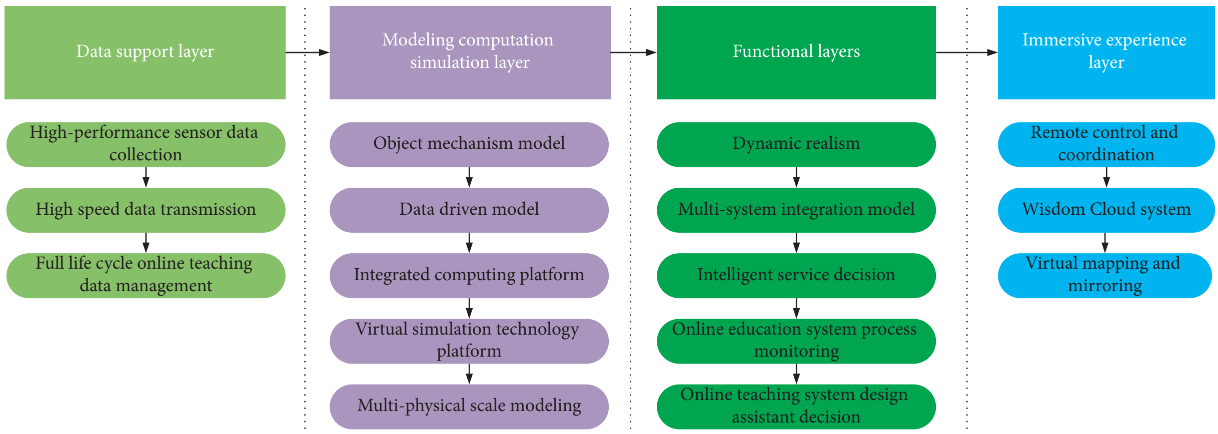


Figure 4: System of digital twins podium.

Table 1: Hierarchy of digital twins podium.

Number	Name	Function	Composition
1	Data support layer	Because the construction of a digital twins podium needs the interaction and IoT perception between real and virtual space, the data layer is built and all kinds of sensors and technical equipment are used to collect information and realize the accurate mapping between the two spaces. This can achieve a comprehensive, three-dimensional, and profound collection of classroom situations.	High-performance sensor data acquisition, high-speed data transmission, life cycle online teaching data management
2	Modeling computation simulation layer	It is mainly used in simulation experiments. The establishment of the virtual model involves all-around compound modeling, that is, it is necessary to model the teaching process in real space from different fields and basic principles. The focus of this process is data analysis, which is the perfect combination of virtual and reality.	Modeling algorithm, integrated computing platform, virtual simulation technology platform
3	Functional layer	First, reality and the online teaching process need to be the same in all aspects, and can accurately and dynamically simulate the real process. Second, the simulation results of a large number of models need to be comprehensively summarized and integrated, which is also the main advantage of the digital twins system. The third is to use a series of data visualization transformations to map the real operation scene to the online virtual space in a multidimensional and dynamic way, simulating the actual (e.g. smart logistics scene) and virtual interaction.	Virtual teaching space and its mapped real teaching space, multiscale and integrated description of students' learning state and environment, realizing the dynamic, visual and realistic operation scene of students' online learning state and environment

Table 1: Continued.

Number	Name	Function	Composition
4	Immersive experience layer	First, teachers use big data visualization, AI (artificial intelligence), and intelligent cloud systems to present the full picture of the actual teaching space in detail. Second, students can immerse themselves in the process of students' learning and development based on the intelligent cloud system through remote cooperation. Third, teachers use detailed data modeling, simulation, visualization, and other technologies to realize highly expressive operation scenes, and present virtual learning places in an all-round way without boundaries through augmented reality technology; the learning environment is based on real technology and remote control, which makes students highly interactive. Combined with the "big data + AI" platform and analysis software, the mapping and mirroring of real application scenes are digitally controlled in the virtual learning space, the digital and seamless communication and interaction between teachers and students are felt, and their virtual control virtual reality and practicality are used to achieve the goal of innovative learning and educational activities based on digital twins platform.	User interface

2.3.2. Drawing with Matlab Drawing Function. The Mesh grid function in Matlab is used to draw spatial geometry. First, the equation of spatial graphics is provided, and it can be in the form of the parametric equation, polar coordinate equation, general equation, spherical coordinate equation, cylindrical coordinate equation, and so on. Then, the number of grids needed to draw the graphics is determined, and plot3, surf, and mesh are used to draw the spatial geometry. Matlab has a function view that can observe spatial geometry from different angles. The view (0, 0) can be set as the front view, view (90,0) as a side view, view (0,90) as top view, and (x, y, z) point as an observation point. When spatial geometry is drawn, the outside of the surface can be set to a transparent state. The alpha function in the software can achieve this effect. H in alpah (h) is the transparency and it is between 0 and 1, where 0 is the fully transparent state and 1 bit is the fully opaque state.

2.4. Virtual Reality Technology and Teaching Equipment

2.4.1. VR (Virtual Reality) Technology. VR is first proposed in the United States around 1980. It is a comprehensive technology integrating computer technology, sensor technology, human psychology, and physiology. It simulates the external environment by using a computer simulation system. The main simulation objects include the environment, skills, sensing equipment, and perception and provide users with multi-information, three-dimensional dynamic, and interactive simulation experience. So far, it has been combined with IoT [24, 25].

VR has three main characteristics: immersion, interactivity, and imagination. Immersion means that the simulated environment created by the computer is very similar to reality, which makes the user think the scene is real, and then carry out real interactive activities in this environment. Interactivity means that users can manipulate and respond to objects in the virtual world. For example, in the virtual world, users can perceive objects with their hands and eyes. Eyes can perceive the shape of objects, and hands can perceive the weight of objects and can process objects independently. Mobile imagination means that the virtual world broadens people's imagination in the real world. It can not only imagine the real existence of the real world but also imagine the existence or nonexistence of the real world. The application of this technology can greatly improve the students' research on the theoretical analysis methods of spatial analytic geometry and mathematics.

2.4.2. Student Learning Equipment. During the teaching of the theoretical analysis of spatial analytic geometry and mathematics, students need to use HTC VIVE wearable equipment with two handles and a VR helmet, as shown in Figure 5. HTC VIVE is developed using a unity development engine and network communication technology based on Network View.

The built-in system of HTC VIVE is developed with a unity engine. Computer configuration for development: GTX2080 for the graphics card, Intel i7-7300 for CPU, HDMI 1.4 for video output, windows 10 for the operating system, and C#.

2.5. Mixed Teaching and Management Platform.

This platform enables the learning and practice resources in the teaching process to be allocated according to the teaching needs, and the language points and skill points in the current learning resources are fragmented. It is convenient for teachers to use in the classroom and students to study

Figure 5: HTC VIVE wearable device.

independently after class [26–28]. Figure 6 shows the modules contained in the teaching platform, and Table 2 shows the overview of the functions of the platform.

2.6. Analysis of the Teaching Process of Spatial Analytic Geometry. Figure 7 shows the overall flow chart.

Figure 7 shows the online immersion teaching system based on digital twins, which includes three parts: (1) teaching data collection and management based on hybrid platform; (2) teaching data analysis and modeling based on multidimensional analysis; and (3) online immersive teaching experience based on augmented reality technology.

Figure 8 shows the data acquisition and management.

Figure 8 shows the teaching data acquisition and management on the hybrid platform using image acquisition and recognition technology. Multiple technologies are used to collect students' features during online learning, and image data acquisition is completed by camera and facial expression, as well as their limb behavior recognition. Here, students are required to open the camera in Tencent Classroom, and mobile phones take the photos of students regularly in front of the camera. The convolutional neural network (CNN) in deep learning is used to recognize the facial expressions and behaviors of students, and then classify them.

Figure 9 shows the application data based on precision teaching and management.

Figure 9 shows the analysis and modeling of teaching data, and the teaching process and materials can be visualized in multiple dimensions. The teaching materials include electronic teaching materials, electronic lesson plans, and courseware.

Figure 10 shows the teaching experience of the augmented reality technology.

Figure 10 shows the online immersive teaching experience based on augmented reality technology, which mainly includes the interaction and integration of real and virtual teaching space. The digital virtual scene is constructed by using big data and artificial intelligence. In terms of integration and innovation, a variety of technologies are used, including 3D modeling, big data modeling, big data simulation, big data visualization, and virtual reality technology.

Digital twins are used to build a digital twins platform, and the augmented reality technology is used to assist in teaching so that students can learn the theory of analytic geometry and mathematics in three-dimensional space in the virtual reality environment. The teaching process of this system includes (a) a hybrid platform is used for teaching data collection and management, and multiplatform and multisource data are used for data collection; (b) the system is used for accurate teaching data management, the teaching through multidimensional, dynamic, and visual process, and teaching material collection and teaching process; and (c) the constructed system is used for teaching on the VR digital twins platform, and the digital virtual system constructed by the interactive system of reality and virtual teaching space is used for teaching [29, 30].

2.7. Matlab Program Procedures. Matlab is used to construct the surface, and the program diagram is shown in Table 3.

3. Design of the Teaching Platform

3.1. Case Analysis. The students in four classes of the same major of a university are randomly selected to investigate the effect of the teaching program. The teaching program based on digital twins is not carried out on the students in two classes, and the numbers of students in these two classes is 29 and 30, respectively, named group A and group B. The students in other two classes are taught by using the teaching program based on digital twins. The numbers of students in these two classes is 31 and 28, respectively, called group C and group D. A week later, some exercises with a certain difficulty are used for in-class test, and there are 10 questions, of which 7 are conventional questions, 2 are difficult questions, and 1 is highly difficult questions. The scores of the four classes are shown in Table 4.

Through the Matlab virtual graphics of the teaching system as shown in Figure 11 above, it is found that the effect of the graphics is good, the spatial curve can be observed from different directions, and the grid lines can depict the spatial quantitative relationship, which shows that the Matlab software is effective in describing the spatial three-dimensional geometry and can be observed from multiple angles, which helps students understand the mathematical theory easily.

3.2. Comparison of the Teaching Effect. Figure 12 shows the statistical data of each student's performance in the four classes. Figure 13 shows the comparison of the teaching effects of the traditional classroom and the digital twin classroom.

Figure 12 shows that the four classes A, B, C, and D are taught in different classrooms. Classes A and B are in traditional classrooms, and classes C and D are in digital twin

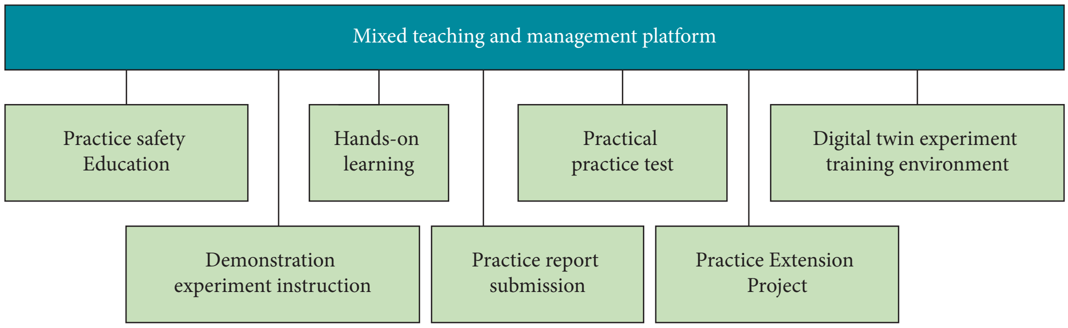


FIGURE 6: Modules included in the teaching platform.

TABLE 2: Overview of the functions of the platform.

Objects	Functions
Students	The platform enables students to master the learning process independently and carries out orderly learning according to their plans and processes. Way of autonomous learning is used to stimulate students' enthusiasm and interest in autonomous learning, exercise their learning ability, practical ability, and innovation ability, finally forming the habit of lifelong learning.
Teachers	The system should also provide teachers with relevant function settings, help release learning resources and practice resources, and guide and supervise teaching activities. Teachers use the platform to complete teaching resources before the beginning of the course, such as course teaching, theoretical animation, reference materials and operation manuals, organization of design and teaching process, and the release of design and practice. In the teaching process, teachers use the tasks provided by the forum to guide, monitor, and evaluate students' learning progress, adjust the teaching process according to students' teaching ability, and improve students' teaching skills.

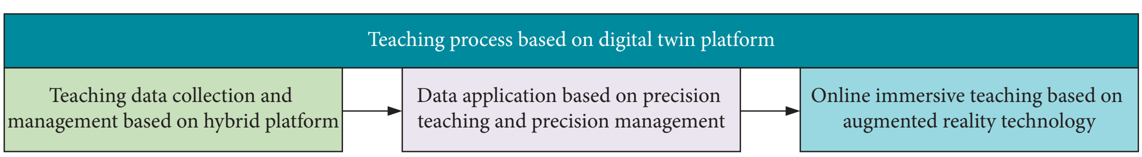


FIGURE 7: Overall flow chart.

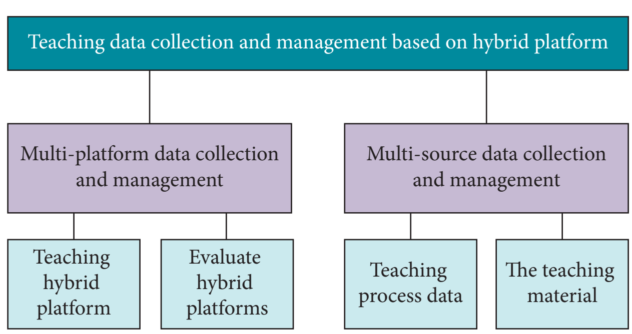


FIGURE 8: Data acquisition and the structure of the management module.

classrooms. The figure shows that there are differences in the scores of each student. The scores of the students in Classes A and B are from 2.5 to 5.5, and those of the students in Classes C and D are between 5.5 and 9.5. Obviously, the scores of each student in Classes C and D are higher than those in other two classes. This shows that the teaching mode based on digital twins can significantly improve the performance of each student in the class. The average scores of the four classes are counted, as shown in Figure 12(e). The average scores of Classes A and B are 4.045 and 4.053 and those of Classes C and D are 7.861 and 8.111. The average score of the students in Classes C and D is 7.986, which is 97.2% higher than that of the students in Classes A and B, indicating that the use of digital twins in mathematics teaching can significantly improve the students' performance and enhance the teaching effect.

Figure 13 shows that the average score of the students in the digital twin classrooms is higher than that of the

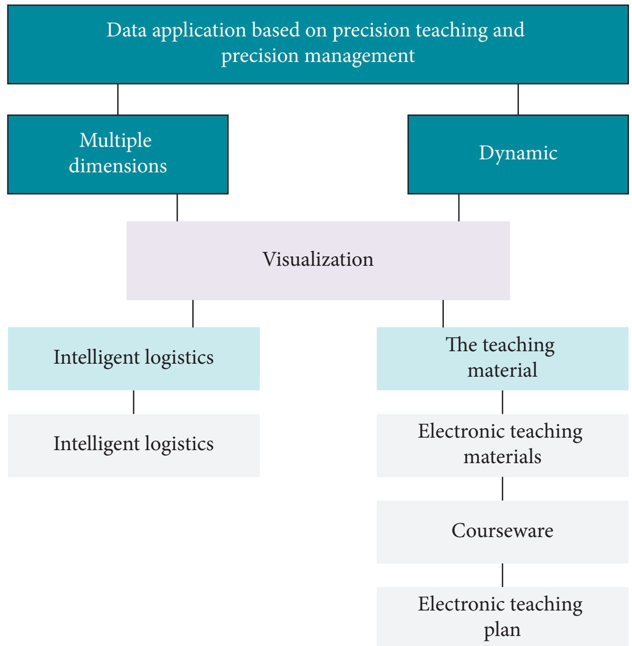


Figure 9: Application data of precision teaching and management.

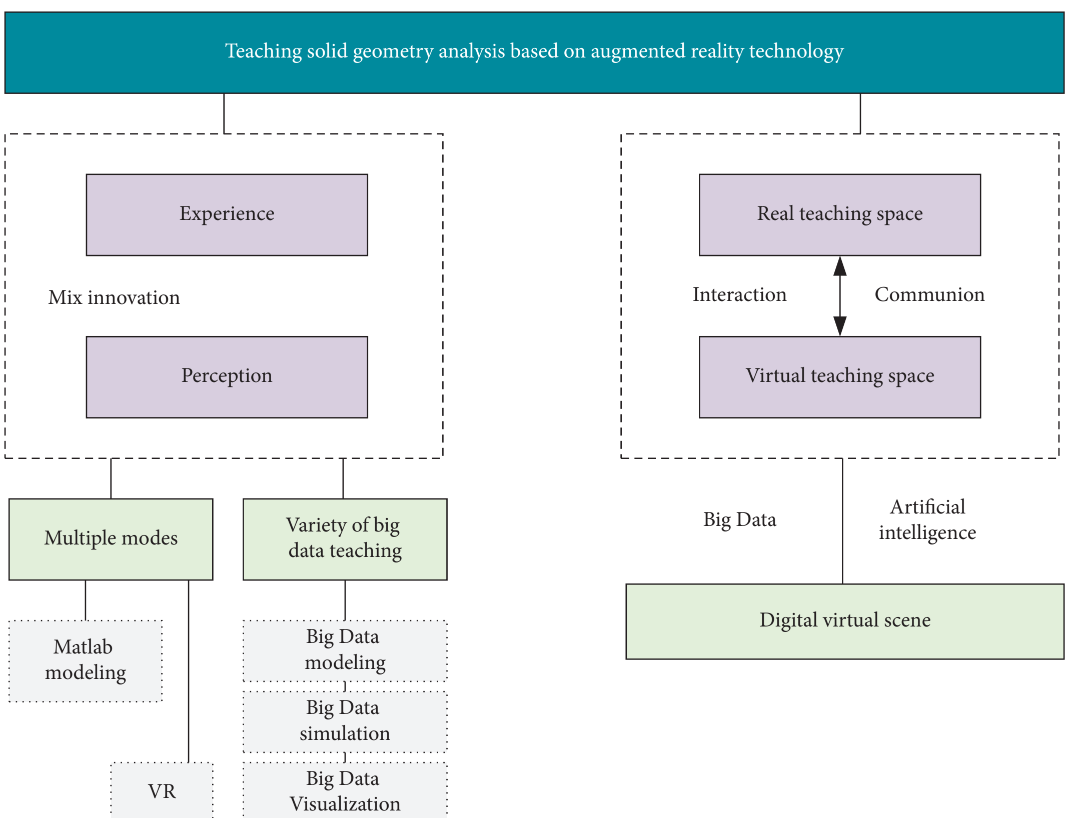


Figure 10: Teaching experience of the augmented reality technology.

students in the traditional classroom. The average number of correct answers in the two classes in the conventional classroom is 7.4 and 7.6, respectively, while the average number of correct answers is more than 8 for the teaching mode with digital twins platform; the average score of the students on the digital twins platform is more than that in the conventional classroom; the difference between medium and high difficulty questions

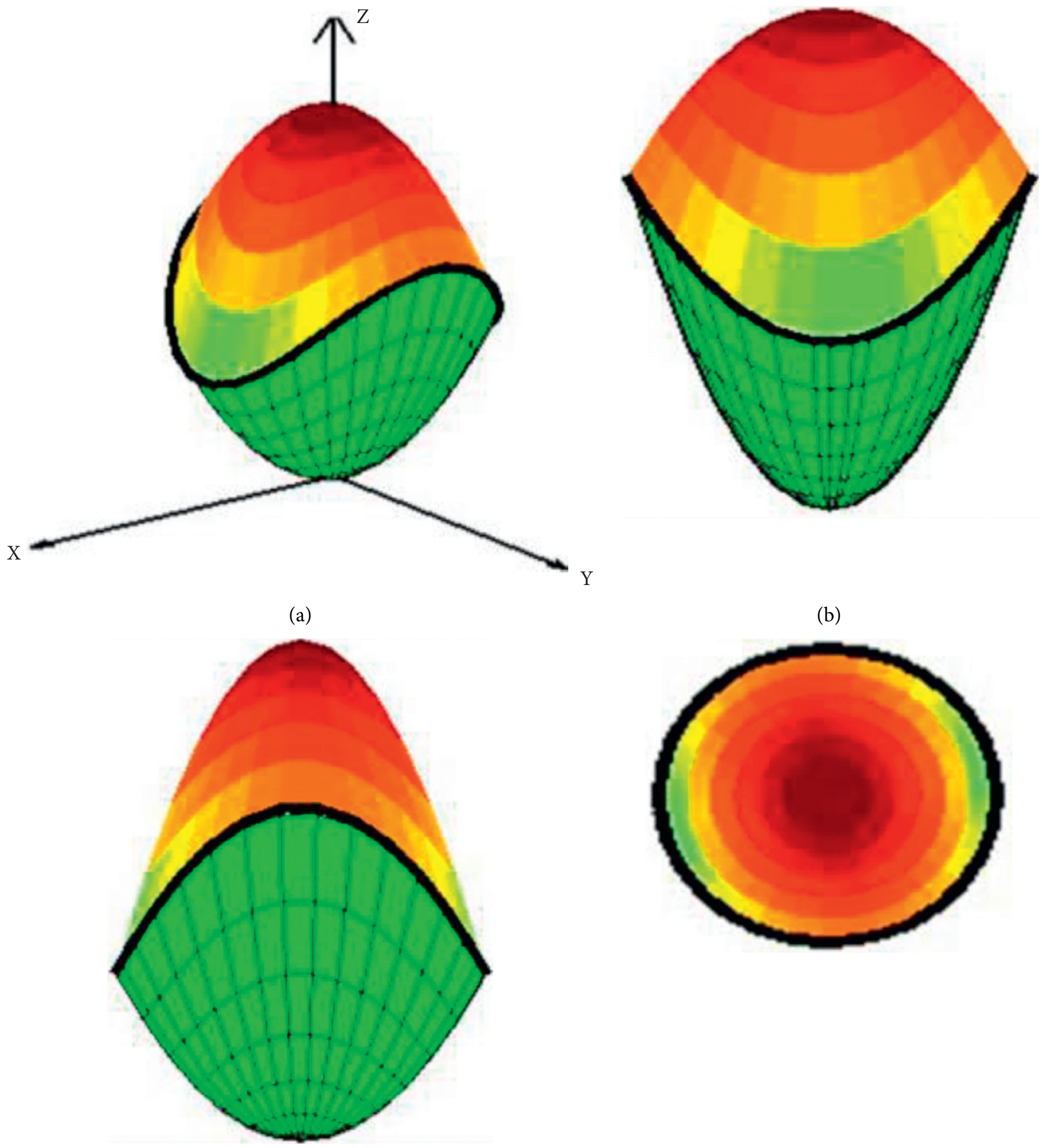
Table 3: Matlab program of geometry.

r = 0 : 0.2:sqrt(2);
t = 0 : 0.2 : 2 * pi + 0.2;
[T, R] = mesh grid(t, r);
X = cos(T). * R;
Y = sin(T). * R;
Z = X.^2 + 2 * Y.^2
axis([−3, 3, −3, 3, −15]);
hold on;
quiver3(0, 0, 0, −1.5, 0, 0, 2.2, "k," "filled" "LineWidth,"1.6)
quiver3(0, 0, 0, 0, −1.5, 0, 2.2, "k," "filled" "LineWidth", 1.6)
quiver3(0, 0, 0, 0, 0, 0, 2.5, 3, "k," "filled" "LineWidth," 1.6)
text(0, −0.6, 8, "Z");
text(0, −4, 0, "Y");
text(−4, 0, 0.2, "X");
axis off;
hold on;
set(gef, "color,"[1 1 1]);
surf(X, Y, Z, "FaceColor," "g");
z = 6-2 * X.^2- Y.^2
surf(X, Y, Z, "EdgeColor,""None");
hold on;
X = squrt(2) * cos(t)
Y = squrt(2) * sin(t)
Z = X.^2 + 2 * Y.^2;
plot3(X, Y, Z, "k","LineWidth," 3);
hold on;
view(0, 90)

Table 4: Score statistics of four classes.

Students/classes	A	B	C	D
1	2.5	3.3	7.9	6
2	3.4	4	7.1	8.2
3	4	4	9.4	8
4	4.9	3.9	8.1	8.3
5	4.6	3.4	5.6	7.5
6	5	3.5	6.9	7.7
7	3.6	3.5	9.9	8.2
8	3	3.3	9.3	8.9
9	2.5	5	6.4	7.5
10	3.7	4.1	7.9	8.8
11	4.9	4.2	9.3	8
12	3.9	3.4	5.5	9.1
13	3.8	3.1	9.6	9.9
14	3.7	5.2	8.4	9
15	5.3	2.5	10	7.4
16	4	2.9	6.1	7.8
17	3.7	5.1	6.4	9.3
18	4.1	5.3	9.8	9.7
19	3	4.4	6.8	6.2
20	4.4	4.5	7	7.6
21	5.1	4.4	7.2	9.6
22	4.8	2.9	9.6	9.1
23	5.4	5	7.2	7.6
24	2.8	4.2	9.4	9.8
25	4.6	5.5	5.9	9.5
26	4.1	3	5.6	6.1
27	5.1	3	9.9	5.5
28	3.6	5.3	9.5	6.8
29	3.8	5.2	6.6	
30		4.5	8.9	
31			6.5	

$z = x^2 + 2y^2$ and $z = 6 - 2x^2 - y^2$ are the three-dimensional geometries, and the program provided in Section 2.7 is used to construct the surface. Figure 11 shows the effect diagram drawn by Matlab.



(a) (b)

(c) (d)

Figure 11: Actual effect graphics drawn by Matlab: (a) stereoscopic view, (b) front view, (c) side view, (d) top view.

is not great because medium and high difficulty questions are based on a complete understanding of knowledge and related to personal talents and conditions, so they have little impact. This test shows that the mathematics class with a digital twins podium is beneficial to students' understanding and can significantly accelerate students' understanding of new concepts of spatial analytic geometry.

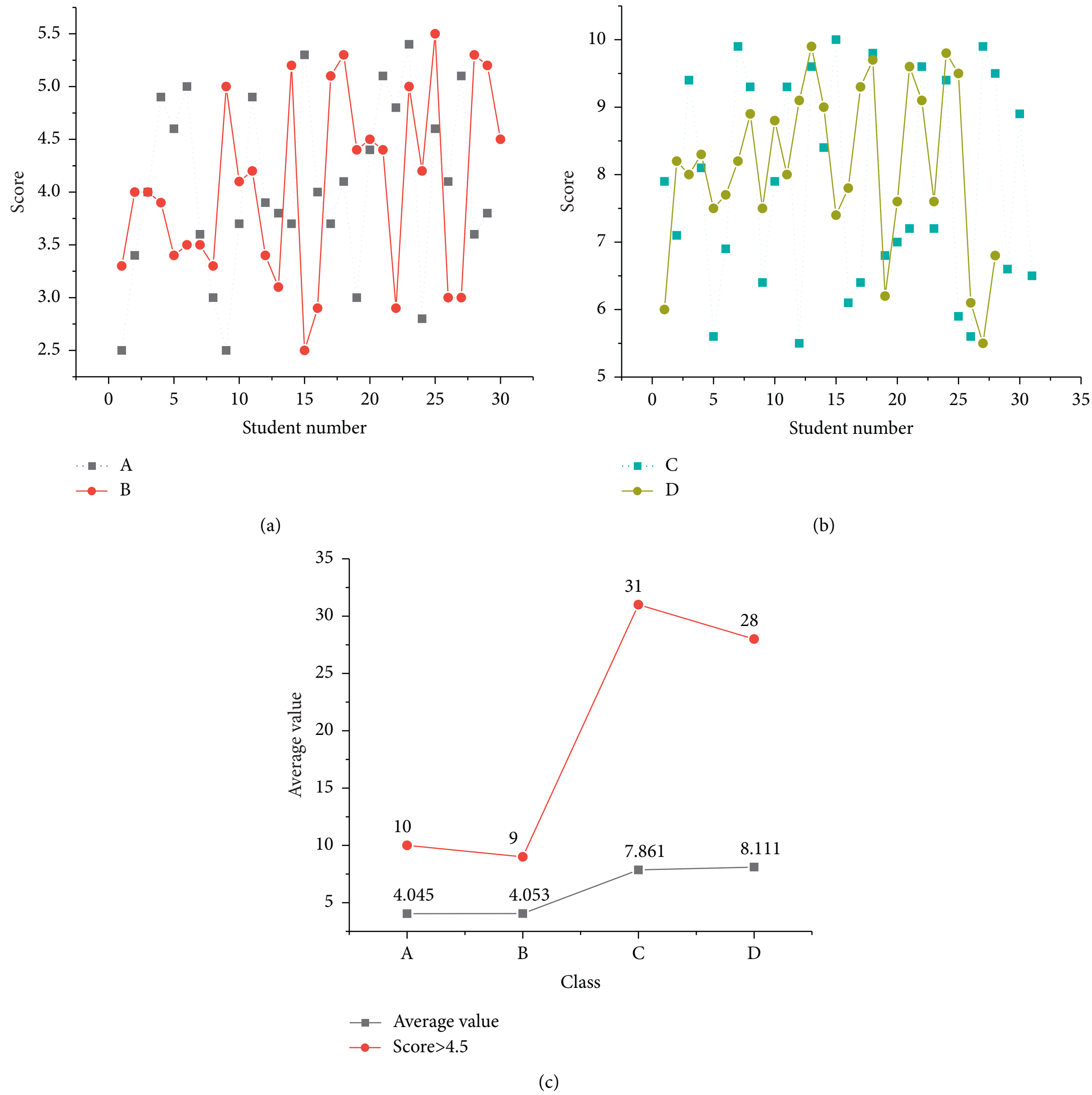


Figure 12: Statistics of students' scores: (a) teaching mode in the traditional classroom; (b) teaching mode in digital twin classroom; (c) average scores.

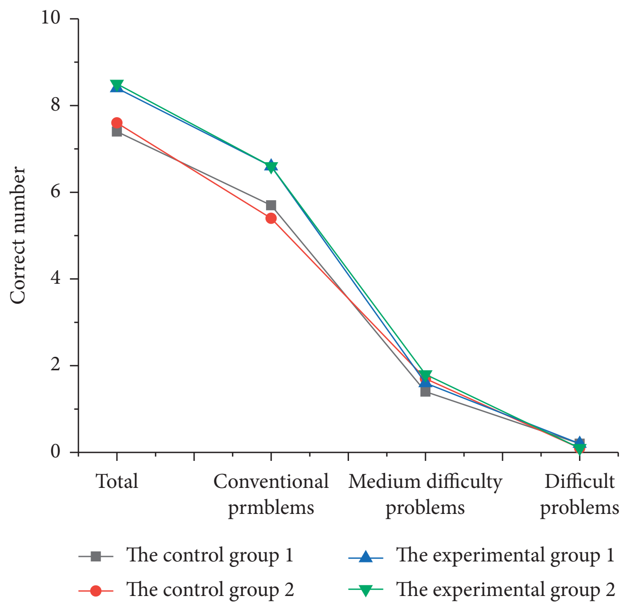


FIGURE 13: Comparison of the scores between the ordinary classroom and the classroom with digital twins podium.

4. Conclusion

Digital twins can effectively realize the intelligent interconnection and interaction of the physical world and the information world and optimize the remote teaching process. With the rapid development of computer and Internet technology, "big data + AI" becomes a new driving force, thinking mode and problem-solving method in modern society, and it is also used in the subject teaching nowadays. Theoretical analysis and teaching method of analytical geometry and mathematics are introduced based on digital twins. First, the principles of IoT and digital twins are expounded; second, the related digital twins platform system is constructed; furthermore, the corresponding digital model is drawn by using the drawing function of Matlab software, and it is brought into the classroom for teaching analysis by using virtual reality technology; finally, the effect of digital twins teaching of spatial analytic geometry mathematics is evaluated and tested. The results show that the digital spatial geometric model can be made by using digital twins, which is conducive to analysis and calculation, and the use of virtual reality technology can help students understand the mathematical theory of spatial analytic geometry and improve the teaching effect. This research provides a new direction for the application of new technology in mathematics teaching.

There are still some shortcomings in the work. For example, the system has high requirements for hardware, and the application of the theories and the implementation of the models need certain software and programming language, which will be the direction for the follow-up research. In future, a simple mobile terminal teaching system will be developed and the teaching process will be optimized, making the model more simple. And "big data + AI" will be used to explore a more efficient teaching mode.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares no conflicts of interest.

References

[1] J. Lee, "Integration of digital twin and deep learning in cyber-physical systems: towards," *Smart Manufacturing*, vol. 38, no. 8, pp. 901–910, 2020.

[2] J. Vrana, "Nde 4.0: digital twin, semantics, interfaces, networking, feedback," *New Markets and Integration into the Industrial Internet of Things*, vol. 78, no. 1, pp. 835–851, 2020.

[3] S. Agostinelli, F. Cumo, G. Guidi, and C. Tomazzoli, "Cyber-physical systems improving building energy management: digital twin and artificial intelligence," *Energies*, vol. 14, no. 8, p. 2338, 2021.

[4] Q. Qi and F. Tao, "Digital twin and big data towards smart manufacturing and industry 4.0: 360 degree comparison," *IEEE Access*, vol. 6, no. 5, pp. 3585–3593, 2018.

[5] C. Zhuang, J. Liu, and H. Xiong, "Digital twin-based smart production management and control framework for the complex product assembly shop-floor," *International Journal of Advanced Manufacturing Technology*, vol. 96, no. 1, pp. 1149–1163, 2018.

[6] Z. H. Lv, "Virtual reality in the context of internet of things," *Neural Computing & Applications*, vol. 32, no. 2, pp. 9593–9602, 2019.

[7] P. O. Skobelev, I. V. Mayorov, E. V. Simonova et al., "Development of models and methods for creating a digital twin of plant within the cyber-physical system for precision farming management," *Journal of Physics: Conference Series*, vol. 1703, no. 1, pp. 27–29, 2020.

[8] P. C. Lopez, I. A. Udugama, S. T. Thomsen et al., "Towards a digital twin: a hybrid data-driven and mechanistic digital shadow to forecast the evolution of lignocellulosic fermentation," *Biofuels, Bioproducts and Biorefining*, vol. 14, no. 5, pp. 231-232, 2020.

[9] S. Chen, T. Wang, X. Li, Z. Liu, and D. Wu, "Research on the improvement of teachers' teaching ability based on machine learning and digital twin technology," *Journal of Intelligent and Fuzzy Systems*, vol. 40, no. 1, pp. 1–12, 2020.

[10] Y. Wu, J. Shang, and F. Xue, "RegARD: symmetry-based coarse registration of smartphone's colorful point clouds with CAD drawings for low-cost digital twin buildings," *Remote Sensing*, vol. 13, no. 10, p. 1882, 2021.

[11] A. Palade, C. Cabrera, F. Li, G. White, M. A. Razzaque, and S. Clarke, "Middleware for internet of things: an evaluation in a small-scale IoT environment," *Journal of Reliable Intelligent Environments*, vol. 4, no. 2, pp. 3–23, 2018.

[12] D. Daniel, C. Y. Le, K. Dmitry, L. Perrin, J. Großschädl, and A. Biryukov, "Triathlon of lightweight block ciphers for the internet of things," *Journal of Cryptographic Engineering*, vol. 14, no. 9, pp. 1–20, 2018.

[13] J. H. Pikul and H. Ning, "Powering the internet of things," *Joule*, vol. 2, no. 6, pp. 1036–1038, 2018.

[14] E. Bonham, K. Mcmaster, E. Thomson et al., "Designing and integrating a digital thread system for customized additive manufacturing in multi-partner kayak production," *Systems*, vol. 8, no. 4, p. 43, 2020.

[15] P. D. Urbina Coronado, R. Lynn, W. Louhichi, M. Parto, E. Wescoat, and T. Kurfess, “Part data integration in the Shop Floor Digital Twin: mobile and cloud technologies to enable a manufacturing execution system,” *Journal of Manufacturing Systems*, vol. 48, no. 3, pp. 25–33, 2018.
[16] A. H. Sodhro, S. Pirbhulal, and A. K. Sangaiah, “Convergence of IoT and product lifecycle management in medical health care,” *Future Generation Computer Systems*, vol. 86, no. 9, pp. 380–391, 2018.
[17] L. Broche, R. S. Zamora, and R. Rodriguez, “Digital Twin: an option for the integrated design of upper limb robotic exoskeletons for rehabilitation tasks,” *Journal of Engineering and Applied Sciences*, vol. 16, no. 6, pp. 423-424, 2021.
[18] K. N. Anyfantis, “An abstract approach toward the structural digital twin of ship hulls: a numerical study applied to a box girder geometry,” *Proceedings of the Institution of Mechanical Engineers–Part M: Journal of Engineering for the Maritime Environment*, vol. 235, no. 3, pp. 146-147, 2021.
[19] R. Wilson, P. H. J. Mercier, B. Patarachao, and A. Navarra, “Partial least squares regression of oil sands processing variables within discrete event simulation digital twin,” *Minerals*, vol. 11, no. 7, p. 689, 2021.
[20] A. Francisco, N. Mohammadi, and J. E. Taylor, “Smart city digital twin-enabled energy management: toward real-time urban building energy benchmarking,” *Journal of Management in Engineering*, vol. 36, no. 2, pp. 1–11, 2020.
[21] V. Kuts, N. Cherezova, M. Sarkans, and T. Otto, “Digital Twin: industrial robot kinematic model integration to the virtual reality environment,” *Journal of Machine Engineering*, vol. 20, no. 2, pp. 53–64, 2020.
[22] K. Sjostrand and L. S. Clemmensen, “A MATLAB toolbox for sparse statistical modeling,” *Journal of Statistical Software*, vol. 84, no. 10, pp. 25–27, 2018.
[23] G. Silvia, H. P. Christian, and J. G. Nagy, “IR tools: a MATLAB package of iterative regularization methods and large-scale test problems,” *Numerical Algorithms*, vol. 81, no. 1, pp. 773–811, 2018.
[24] C. Frishmuth, “Virtual reality,” *Pc Pilot*, vol. 14, no. 120, pp. 48–51, 2019.
[25] M. S. Elbamby, C. Perfecto, M. Bennis, and K. Doppler, “Toward low-latency and ultra-reliable virtual reality,” *IEEE Network*, vol. 32, no. 2, pp. 78–84, 2018.
[26] C. Anda, S. Medina, and K. W. Axhausen, “Synthesising digital twin travellers: individual travel demand from aggregated mobile phone data,” *Transportation Research Part C: Emerging Technologies*, vol. 128, no. 1, pp. 118–121, 2021.
[27] H. C. Kim, Y. H. Son, J. Bae, and S. D. Noh, “A study on the digital twin visualization method for smart factory of dye processing industry,” *Journal of the Korean Institute of Industrial Engineers*, vol. 47, no. 1, pp. 77–91, 2021.
[28] J. Vrana, “The core of the fourth revolutions: industrial internet of things, digital twin, and cyber-physical loops,” *Journal of Nondestructive Evaluation*, vol. 40, no. 2, pp. 46–467, 2021.
[29] M. Rus-calafell, P. Garety, E. Sason, T. J. K. Craig, and L. R. Valmaggia, “Virtual reality in the assessment and treatment of psychosis: a systematic review of its utility, acceptability and effectiveness,” *Psychological Medicine*, vol. 48, no. 3, pp. 1-2, 2018.
[30] M. Meissner, J. Pfeiffer, T. Pfeiffer, and H. Oppewal, “Combining virtual reality and mobile eye tracking to provide a naturalistic experimental environment for shopper research,” *Journal of Business Research*, vol. 100, no. 6, pp. 445–458, 2018.

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Research Article

Construction and Application of Recognition Model for Black-Odorous Water Bodies Based on Artificial Neural Network

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In the water environment, construction, and civil engineering industries, digital twins have gradually become a popular solution in recent years, and in digital twins, accurate data prediction and category recognition are important parts of it. Artificial neural network (ANN), a widely used data-driven model, can accurately identify nonlinear relationships in the water environment. In this paper, a recognition model for black-odorous water bodies based on ANN was established to directly identify the sensory description of water bodies. This study used water quality data and sensory description (color and odor) as samples to train backpropagation (BP) neural networks. The training results show that the accuracy of the color and odor models reaches 86.7% and 85.8%, respectively. It can thus be suggested that the sensory description can be accurately recognized by BP neural network. The application results indicate that all seven rivers had black-odorous phenomenon within a year. The recognition models have been instrumental in water resource management. Meanwhile, the models provide a reference for the evaluation and early warning of black-odorous water bodies in other regions.

1. Introduction

Digital twins can take the real data of the physical world as the input, and the generated data can be used to predict and identify the physical object, so as to know how the system is affected by these inputs. At the same time, technologies related to the Internet of Things are gradually being promoted [1]. In the water environment industry, digital twins have gradually become a popular solution in recent years. Besides, at present, more and more attention has been paid to the researches on water resources in sustainable cities. Because the black-odorous water bodies cause serious pollution to cities, it is particularly important to accurately identify the degree of the black-odorous water bodies. Urban rivers are an important part of urban ecology, but they are often used as a way to discharge sewage due to the inconsistency between urbanization and sewage treatment [2], and a considerable amount of sewage was discharged into urban rivers. The water quality of urban rivers deteriorates with the accumulation of pollutants, which makes urban rivers turn black with an odor. The identification and evaluation of black-odorous water bodies is the prerequisite for water resource management. Water quality index or pollution index are common methods for water quality assessment. However, the weights of index change with the regions, which leads to the geographical limitation of the index-based methods. Moreover, it is difficult for an index to describe the black-odorous phenomenon intuitively. Therefore, a concise model without geographical limitations for describing black-odorous water is necessary. "Black-odor" is a sensory description of polluted rivers [3]. Chinese Ministry of Housing and Urban-rural Development defines black-odorous waters as urban water bodies with unpleasant colors and odors (working guidelines for the treatment of urban black-odorous water issued by Chinese Ministry of Housing and Urban-rural Development). Therefore, the color and odor, the concern of residents, can directly express the black-odorous phenomenon of water. Environmental protection departments have a large amount of water quality monitoring data, but only after site visits can obtain an objective description of water bodies, it is obviously difficult to perform continuous site investigations. Therefore, finding out the nonlinear mapping between the water quality monitoring data and the sensory description of the water body can use the existing monitoring data to directly identify the color and odor of water body, which can greatly facilitate water resource management.

Machine learning methods have been gradually applied in various fields in recent years [4]. Artificial neural network (ANN) can identify the nonlinear mapping by adjusting the interconnected relationship between internal nodes. ANN has the ability to learn autonomously and find optimal solutions rapidly, so it has been widely used in water environment.

The aim of this study is to explore the relationship between water quality monitoring data and water sensory description. For this purpose, a recognition model for black-odorous water bodies based on ANN was established. The water quality monitoring data and sensory description (color and odor) of an inland river system in Linyi were selected as samples to train the models. The models proposed in this study can directly use existing monitoring data to identify black-odorous water bodies, which provide a reference for identifying black-odorous water bodies in other regions and facilitate water resource management. The rest of the paper is structured as follows. Section 2 introduces the related research of black-odorous water and ANN. Section 3 introduces the data and method for building the model. The results and conclusions are presented in the Sections 4 and 5.

2. Related Works

2.1. Black-Odrous Water Bodies. Sustainable development is an essential part of the smart city construction. And water pollution is a key factor hindering the sustainable development of smart cities. The black color and odor of rivers are caused by a series of biogeochemical processes mainly related to Fe, Mn, S, N, and C [5]; among them, the biological transformations related to the sulfur cycle are the main reason. FeS and MnS blacken the water, and volatile sulfur compounds make water smelly [3, 6]. The sources of these pollutants are mainly from urban sewage and other natural factors, such as dissolved organic matter from large plant litter [7]. The rapid proliferation of algae and bacteria caused by the above phenomena has greatly reduced the dissolved oxygen (DO) in the water and exacerbate the deterioration of water quality [8, 9]. Moreover, bottom sediments of black-odorous water bodies may cause secondary pollution [10]. The primary task to solve such environmental problems is to identify and evaluate black-odorous water bodies. Ji et al. [11] evaluated the black-odorous river by calculating the Nemerow index. Wei et al. [12] monitored and evaluated two black-odorous rivers in Wuhan based on the Nemerow index and remote-sensing technology. Moreover, the evaluation of black-odorous rivers belongs to the water quality assessment, so methods of water quality assessment are also valuable.

2.2. Water Quality Assessment and Early Warning. Yan et al. [13] proposed a weighted comprehensive index based on the geometric weighting method to evaluate water bodies in Shanghai. Pan et al. [14] proposed a multivariate statistical method that can assess the spatial variations of groundwater quality. Miao et al. [15] established a correlation model between water quality index and satellite data based on Canadian water quality index and remote sensing to evaluate surface water quality. Liu et al. [16] integrated Bayesian regression and isolation forest algorithms to predict the trend of water quality. However, from the formulas of above models change with regions, the established models cannot be generalized to other water bodies.

2.3. Artificial Neural Network. In the study of water quality assessment, Wu et al. [17] utilized an unsupervised learning ANN to evaluate the impact of seasonal factors and human activities on water quality. Bo et al. [18] established a risk assessment model for groundwater pollution based on ANN. Gebler et al. [19] evaluated the ecological status of rivers by using ANN models. Bansal and Ganesan [20] proposed an ANN-based water quality index calculation method.

ANN can make accurate predictions through a mass of data [21]. Yang et al. [22] established a turbidity early warning system using ANN and probability analysis. Delpla et al. [23] used trend analysis and ANN to predict major events and daily time series of turbidity. Jin et al. [24] analyzed the internal trend of surface water quality based on ANN integrated with improved genetic algorithm. Azimi et al. [25] applied ANN and fuzzy clustering to predict probability of adverse changes in drinking water quality.

ANN is widely applied in simulation [26]. Jiang et al. [27] used a combination of Monte Carlo simulation and ANN to assess water quality risks. Wang et al. [28] utilized a least squares support vector machine to quantitatively determine the concentration of pollutants. Salari et al. [29] applied polynomial least squares method and feedforward neural network to simulate the concentration of DO, total dissolved solids, and other indicators. Garcia-Alba et al. [30] built an ANN based on a spatiotemporal evolution model for analyzing estuary water quality. Pradhan et al. [31] took ANN to simulate daily runoff.

The studies mentioned above show that ANN can deal with nonlinear problems in environmental science. Therefore, the nonlinear mapping between the water quality monitoring data and the sensory description can be recognized by the ANN. In addition, the established model can directly use the the monitoring data on water quality, which greatly facilitates the management of water resources.

3. Materials and Methods

3.1. Data and Samples. Bacteria consume a large amount of DO due to the high content of dissolved organic carbon, which makes the water body turns black with an odor [8], so DO is an important indicator. In fact, the black-odor phenomenon is caused by a series of biochemical reactions

Table 1: Mean and standard deviation of the color model.

	Yellow-green		Deep green		Gray-black		Black	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DO	5.94	0.65	5.76	0.40	5.54	1.49	5.47	0.21
COD	26	12.91	33.27	13.14	44.09	14.62	46	6.16
BOD_5	6.6	3.25	8.7	3.56	11.17	3.55	12.1	2.75
$NH_3 - N$	3.26	2.21	4.16	4.21	6.67	4.15	19.7	1.25
TP	0.59	0.36	0.75	0.38	1.17	0.52	2.75	0.99

Table 2: Mean and standard deviation of the odor model.

	Odorless		Slight		Odorous		Severe	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DO	5.94	0.65	5.76	0.40	5.54	1.49	5.47	0.21
COD	26	12.91	33.27	13.14	44.09	14.62	46	6.16
BOD_5	6.6	3.25	8.7	3.56	11.17	3.55	12.1	2.75
$NH_3 - N$	3.26	2.21	4.16	4.21	6.67	4.15	19.7	1.25
TP	0.59	0.36	0.75	0.38	1.17	0.52	2.75	0.99

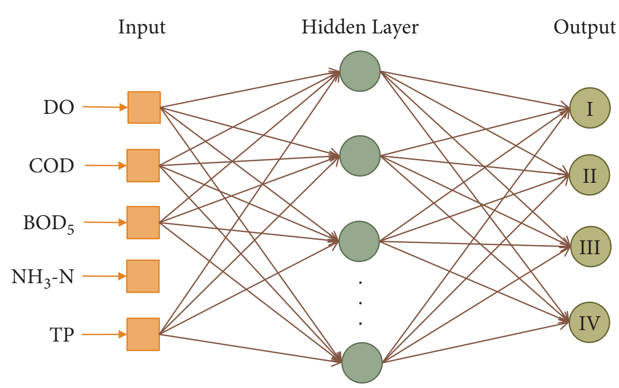


Figure 1: Topology of the color model.

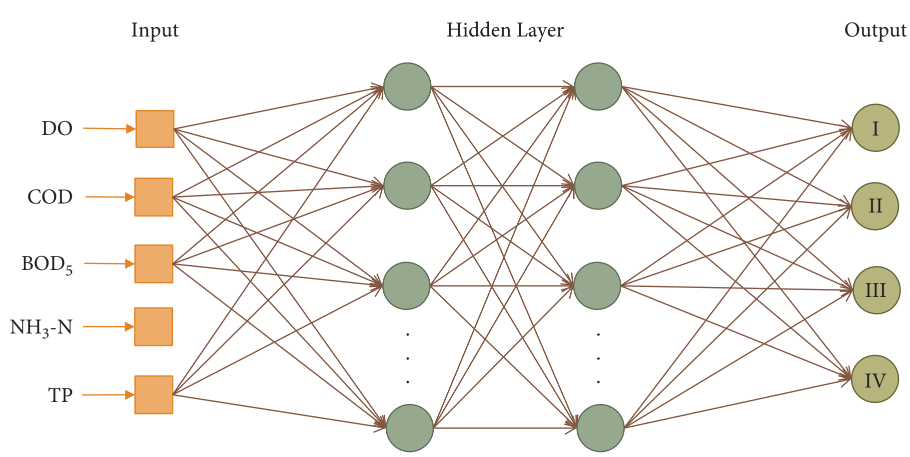


Figure 2: Topology of the odor model.

related to Fe, Mn, S, N, and C. Moreover, N and P are important causes of eutrophication of water bodies. Therefore, it is unreasonable to select DO as the only indicator. However, sulfur-containing organic compounds, Fe and Mn sulfides, are not conventional water quality monitoring items. Only the selection of conventional water

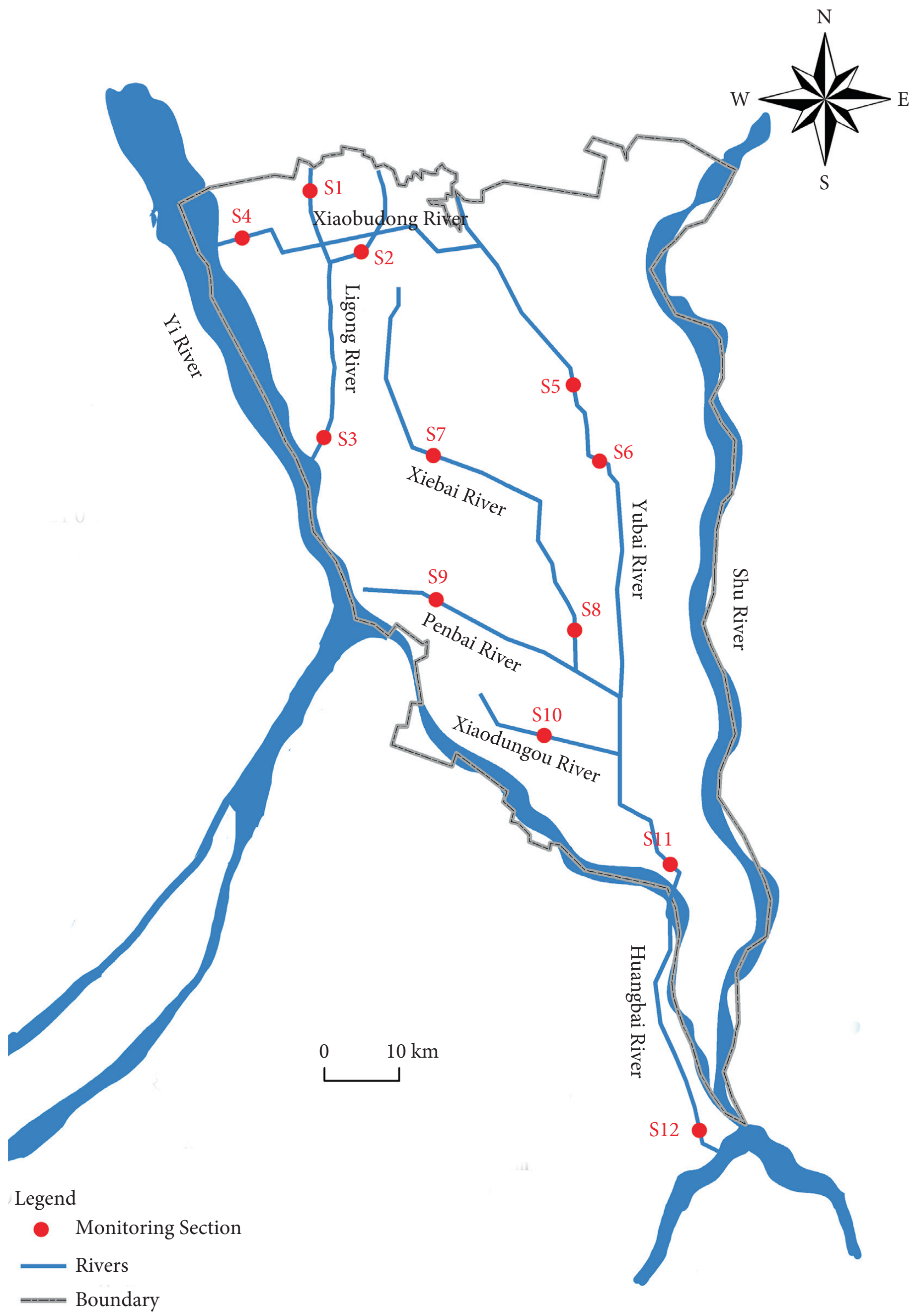
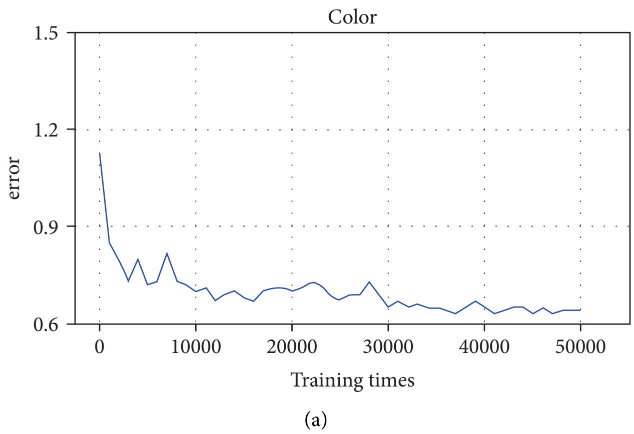


FIGURE 3: Distribution of monitoring sections in the study area.

quality indicators can improve the applicability of black-odorous water identification models. This paper refers to the indicators of black-odorous water bodies in several studies [32–35] and working guidelines for the treatment of urban black-odorous water (Chinese Ministry of Housing and Urban-rural Development); meanwhile, this paper considers the correlation between indicators and black-odorous water bodies, and the universality of monitoring items, DO, COD (chemical oxygen demand), BOD_5 (biochemical oxygen demand), $NH_3 - N$ (ammonia nitrogen), and TP (total phosphorus) are selected as the indicators of black-odorous water.

The sensory description of the water body is also added to the model. In this study, two apparent elements, color and odor, are selected as the outputs. The water color is divided into yellow-green, dark green, gray-black, and black; the odor is divided into odorless, slight, odor, and severe. The odor is judged at 1 m from the river bank. In the on-site investigation, full consideration is given to the diversities in perception, and 20 experimenters provided the sensory data (water color and odor) at the same time. The results are determined by majority principle. The mean and standard deviation (SD) of water quality monitoring data are shown in Tables 1 and 2 (the unit of the mean value is mg/L).



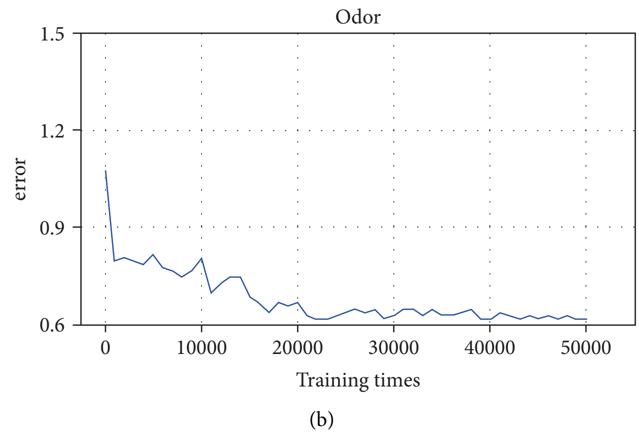


FIGURE 4: Training results of models.

3.2. BP Neural Network. BP neural network, using back-propagation learning algorithm, is a classic feedforward neural network. Theoretically, it has been proved that a three-layer neural network can achieve arbitrary accuracy with approximate functions. In this paper, the BP neural network is used to build two models: color model and odor model.

In both the color and odor model, the input variables are the monitoring data, including DO, COD, BOD_5, NH_3-N, and TP, so the input layer has five nodes. The output results are I, II, III, and IV indicating the degree of water color and odor. In the color model, I to IV indicate yellow-green, dark green, gray-black, and black; in the odor model, I to IV indicate odorless, slight, odorous, and severe. The number of hidden layer nodes were determined by trial and error. The topology of color model is shown in Figure 1. The topology of odor model is shown in Figure 2.

The rectified linear unit (ReLU) is an activation function with a simple structure (equation (1)), where w^T and b represent weight and bias. It has no saturation region, so there is no problem of gradient disappearance in ReLU. In addition, its unilateral inhibition mechanism is consistent with the neurobiological mechanisms, which makes it have a faster convergence rate than Sigmoid and tanh function. Therefore, ReLU was selected as the activation function of the input layer. The activation function of the output layer used the Softmax function, which can express the results of multiple classifications in the form of probability (equations (2) and (3)), where S_i represents probability, V_i is the output of the prestage unit, and i and N indicate the category index and the total number of categories. In the case of single classification problem, N categories are in the form of one-hot encoding, only one category $y_i = 1$, and the other N−1 categories are 0. The Softmax cross-entropy loss function (equation (4)) was chosen to represent the model error:

$$f(x) = \max\left(0, w^T x + b\right), \tag{1}$$

$$S_i = \frac{e^{V_i}}{\sum_{j=1}^{N} e^{V_j}}, \tag{2}$$

$$\sum_{i=1}^{N} S_i = 1, \tag{3}$$

$$\text{Loss} = -\sum_{i=1}^{N} y_i \ln S_i. \tag{4}$$

3.3. Application. The established model was applied to an inland river system composed of seven rivers in Linyi City. The inland river system is located between Yi River and Shu River, and it is composed of Ligong River, Xiaobudong River, Yubai River, Pengbai River, Xiebai River, Xiaodungou River, and Huangbai River. Those rivers form a complex river system with different functions [36]. The main pollutants in those rivers are DO, COD, BOD_5, NH_3-N, TP, fluoride, petroleum, sulfide, etc. Among them, DO, COD, BOD_5, NH_3-N, TP, and petroleum often exceed the standard; as a result, black-odorous phenomenon occasionally occurs in those rivers. The data of this study are from the routine monitoring data of 12 monitoring sections (June 2016 to May 2017). And the locations of the monitoring sections in the rivers are shown in Figure 3.

4. Results and Discussion

4.1. Training Results of Models. The samples were divided into a train set and a test set at a ratio of 8: 2, and the models were trained to have the ability to recognize the color and odor of water bodies. The color and odor models have been trained 50,000 times. We used the ratio of the number of correctly predicted results to the number of total samples to represent the accuracy of the models. In the color model, the accuracy of train set reached 86.7%, the accuracy of test set reached 84.6%, and the error (loss) is shown in Figure 4. In the odor model, the accuracy of train set reached 85.8%, and the accuracy of test set reached 83.3%, and the error (loss) is shown in Figure 4. The training results confirm that the above two models meet the requirements and can accurately identify the color and odor of the water body through the water quality monitoring data.

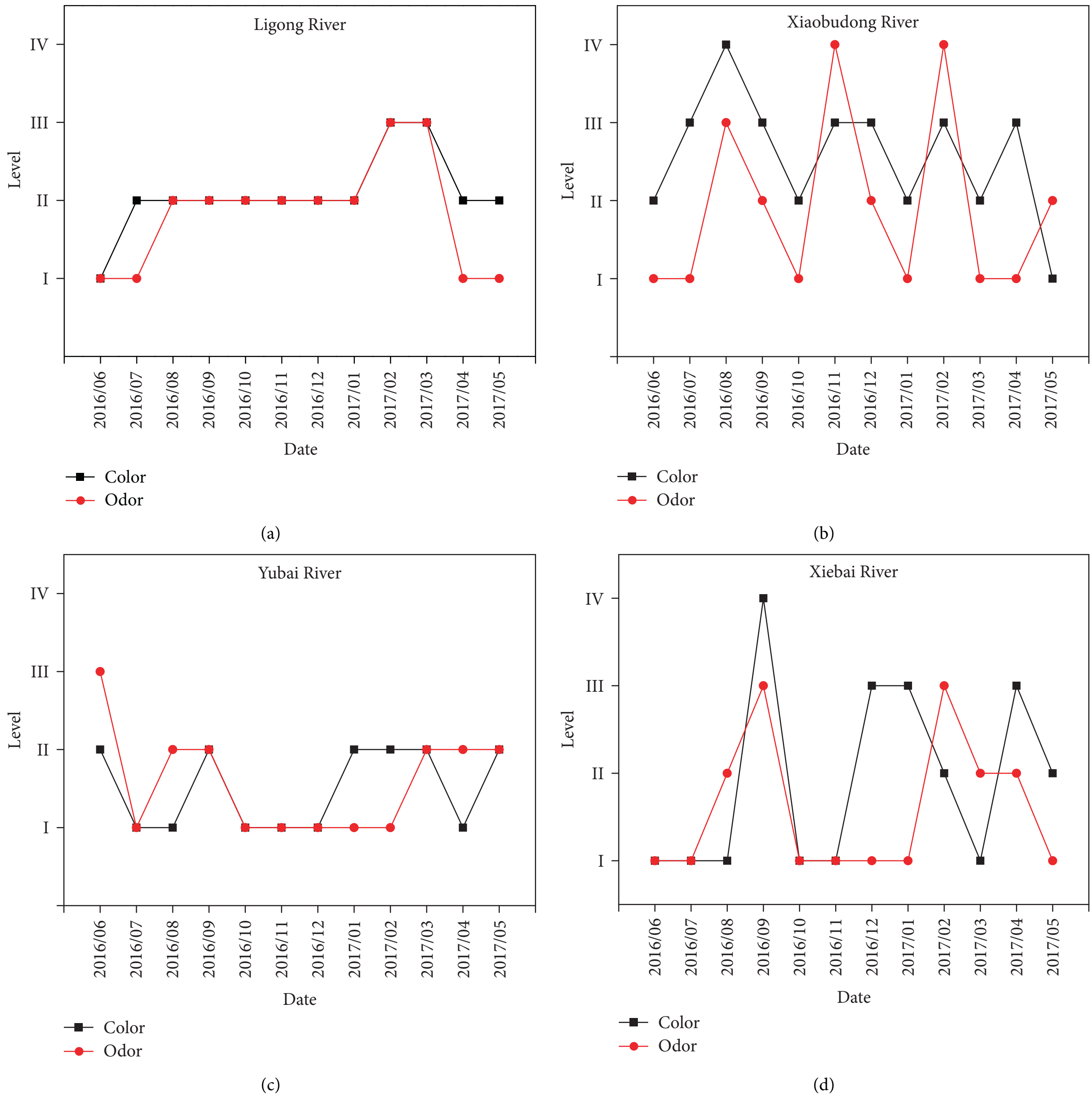


Figure 5: Continued.

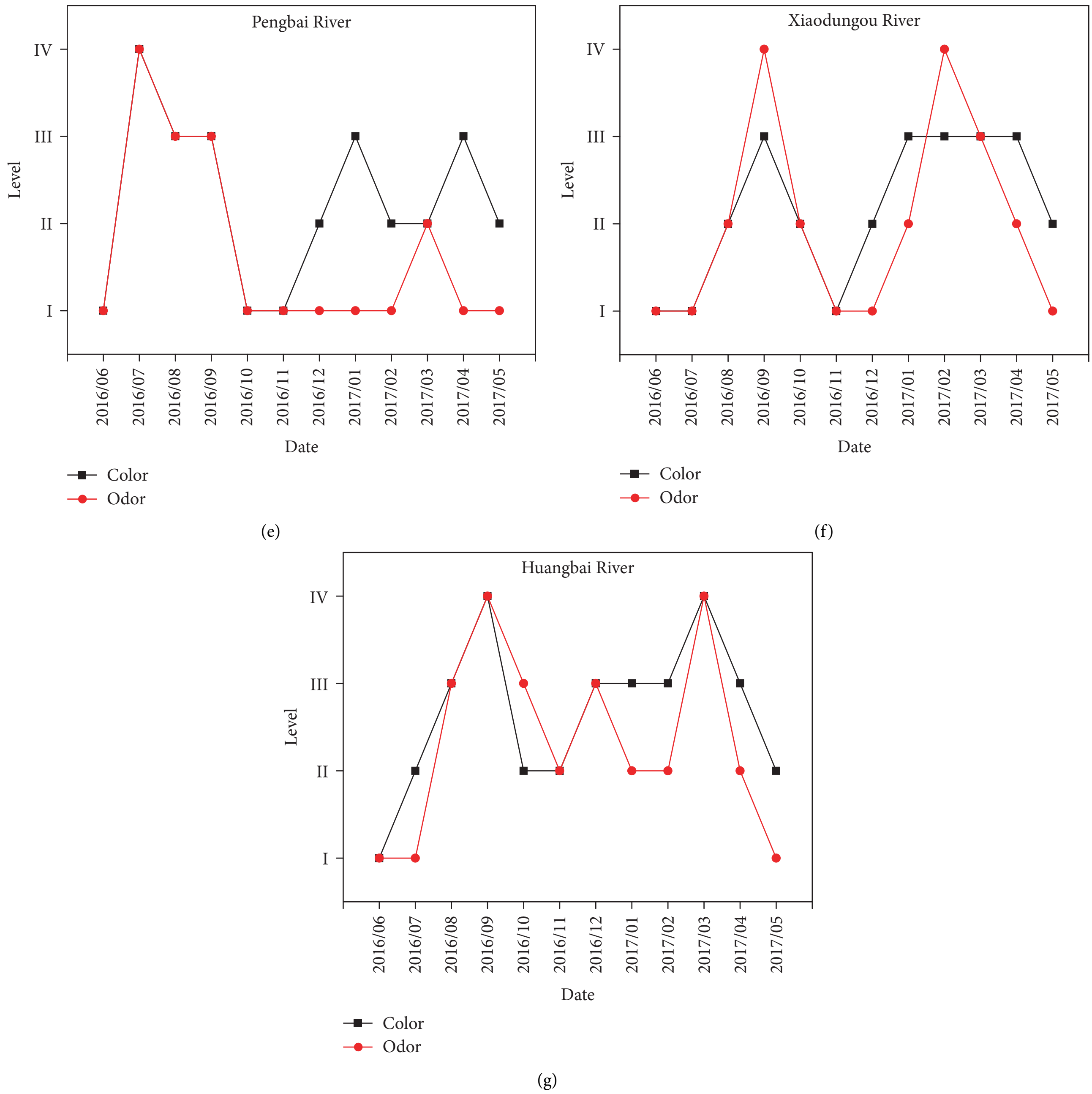


Figure 5: Line chart of water color and odor in each river.

4.2. Applications of Models. The models were applied to identify the color and odor of seven rivers in Linyi Development Zone, and the outputs are shown in Figure 5. Overall, the color and odor of the same river have almost the same trend. This paper regards class III as black-odorous rivers. The output results show that all seven rivers had a black-odorous phenomenon within a year. Among them, the variation trend of color and odor in the Yubai River, Pengbai River, Xiaobudong River, and Huangbai River is highly correlated with the seasons; in the wet season, the water quality tends to deteriorate, while in the dry season, the water quality tends to improve. This is because farmland, and farms are distributed along the rivers, and the polluted soil will enter the river channels with rainwater, which caused the rivers to turn black with an odor. By contrast, the water quality of the Ligong River also changes with the seasons, but the Ligong river is prone to be black-odorous river in the dry season; this inconsistency may be due to the direct discharge of sewage in some regions. The results of Xiebai River and Xiaodungou River have no obvious correlation with the seasons; they are likely to be related to the discharge of wastewater from the surrounding industrial parks. Therefore, the drainage system of the study area needs to be improved. In addition, the walls of the rivers need to be constructed.

5. Conclusion

This paper established recognition models for black-odorous water bodies based on BP neural network. The input variables are the conventional water quality monitoring indicators; they are DO, COD, BOD_5, $NH_3 - N$, and TP, and the outputs are water color and have odor. The accuracy of the color and odor models reached 86.7% and 85.8%, respectively. The results show that the models can accurately recognize the color and odor of water bodies based on water quality monitoring data. The models were applied to seven rivers in Linyi City. The application results show that black-odor phenomenon occurred in those rivers from June 2016 to May 2017. This is the first study to use water quality data to identify the color and odor of black-odorous water bodies, which provides new insights into water resource management.

Being limited to data, this study lacks enough samples, and the accuracy of the models can be improved. In addition, the BP neural network has limited ability to identify nonlinear relationship, so the advanced algorithms should be applied to the research.

Data Availability

The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] H. Zhang, L. Tong, J. Yu, and J. Lin, "Blockchain aided privacy-preserving outsourcing algorithms of bilinear pairings for internet of things devices," *IEEE Internet of Things Journal*, vol. 8, 2021.
[2] L. Yu, Z. Tang, J. Ji, and Y. Song, "Discussion on urban black odor water body treatment and long-term management and maintenance," *IOP Conference Series: Earth and Environmental Science*, vol. 428, no. 1, (5pp), Article ID 012010, 2020.
[3] J. Cao, Q. Sun, D. Zhao et al., "A critical review of the appearance of black-odorous waterbodies in China and treatment methods," *Journal of Hazardous Materials*, vol. 385, Article ID 121511, 2020.
[4] H. Zhang, P. Gao, J. Yu, J. Lin, and N. N. Xiong, "Machine learning on cloud with blockchain: a secure, verifiable and fair approach to outsource the linear regression," *IEEE Transactions on Network Science and Engineering*, 2021.
[5] Z. Liang, M. Siegert, W. Fang, Y. Sun, and S. Wang, "Blackening and odorization of urban rivers: a bio-geochemical process," *FEMS Microbiology Ecology*, vol. 94, no. 3, 2018.
[6] W. Cai, Y. Li, Y. Shen et al., "Vertical distribution and assemblages of microbial communities and their potential effects on sulfur metabolism in a black-odor urban river," *Journal of Environmental Management*, vol. 235, pp. 368–376, 2019.
[7] Y. He, N. Song, and H. L. Jiang, "Effects of dissolved organic matter leaching from macrophyte litter on black water events in shallow lakes," *Environmental Science and Pollution Research*, vol. 25, 2018.
[8] J. L. Kerr, D. S. Baldwin, and K. L. Whitworth, "Options for managing hypoxic blackwater events in river systems: a review," *Journal of Environmental Management*, vol. 114, pp. 139–147, 2013.
[9] C. Qingfeng, Y. Zhao, Q. Kemei, and Z. Changsheng, "Different pollutant removal efficiencies of artificial aquatic plants in black-odor rivers," *Environmental Science and Pollution Research*, vol. 26, pp. 1–7, 2018.
[10] Z. Wang, Y. Chen, L. Chen et al., "Ex-situ treatment of sediment from a black-odor water body using activated sludge," *Science of The Total Environment*, vol. 713, Article ID 136651, 2020.
[11] X. Ji, W. Zhang, M. Jiang, J. He, and Z. Zheng, "Black-odor water analysis and heavy metal distribution of yitong river in northeast China," *Water Science and Technology: A Journal of the International Association on Water Pollution Research*, vol. 76, no. 8, pp. 2051–2064, 2017.
[12] L. Wei, C. Huang, Z. Wang, Z. Wang, X. Zhou, and L. Cao, "Monitoring of urban black-odor water based on nemerow index and gradient boosting decision tree regression using uav-borne hyperspectral imagery," *Remote Sensing*, vol. 11, no. 20, Article ID 2402, 2019.
[13] W. Yan, J. Li, and X. Bai, "Comprehensive assessment and visualized monitoring of urban drinking water quality," *Chemometrics and Intelligent Laboratory Systems*, vol. 155, pp. 26–35, 2016.
[14] C. Pan, K. T. W. Ng, and A. Richter, "An integrated multivariate statistical approach for the evaluation of spatial variations in groundwater quality near an unlined landfill," *Environmental Science and Pollution Research*, vol. 26, 2019.
[15] S. Miao, C. Liu, B. Qian, and Q. Miao, "Remote sensing-based water quality assessment for urban rivers: a study in linyi development area," *Environmental Science and Pollution Research*, vol. 27, no. 2, 2020.
[16] J. Liu, P. Wang, D. Jiang, J. Nan, and W. Zhu, "An integrated data-driven framework for surface water quality anomaly detection and early warning," *Journal of Cleaner Production*, vol. 251, Article ID 119145, 2020.
[17] M. L. Wu, Y. S. Wang, and J. D. Gu, "Assessment for water quality by artificial neural network in daya bay, south China sea," *Ecotoxicology (London, England)*, vol. 24, no. 7, pp. 1632–1642, 2015.
[18] L. Bo, Z. Yi-Fan, Z. Bei-Bei, and W. Xian-Qing, "A risk evaluation model for karst groundwater pollution based on geographic information system and artificial neural network applications," *Environmental Geology*, vol. 77, no. 9, pp. 1–344, 2018.
[19] D. Gebler, G. Wiegleb, and K. Szoszkiewicz, "Integrating river hydromorphology and water quality into ecological status modelling by artificial neural networks," *Water Research A Journal of the International Water Association*, vol. 139, 2018.
[20] S. Bansal and G. Ganesan, "Advanced evaluation methodology for water quality assessment using artificial neural network approach," *Water Resources Management*, vol. 33, no. 9, pp. 3127–3141, 2019.

[21] X. Xu, B. Karami, and D. Shahsavari, "Time-dependent behavior of porous curved nanobeam," *International Journal of Engineering Science*, vol. 160, Article ID 103455, 2021.

[22] T.-M. Yang, S.-K. Fan, C. Fan, and N.-S. Hsu, "Establishment of turbidity forecasting model and early-warning system for source water turbidity management using back-propagation artificial neural network algorithm and probability analysis," *Environmental Monitoring and Assessment*, vol. 186, no. 8, pp. 4925–4934, 2014.

[23] I. Delpla, M. Florea, and M. J. Rodriguez, "Drinking water source monitoring using early warning systems based on data mining techniques," *Water Resources Management*, vol. 33, 2019.

[24] T. Jin, S. Cai, D. Jiang, and J. Liu, "A data-driven model for real-time water quality prediction and early warning by an integration method," *Environmental Science and Pollution Research*, vol. 26, no. 29, pp. 30374–30385, 2019.

[25] S. Azimi, M. Azhdary Moghaddam, and S. A. Hashemi Monfared, "Prediction of annual drinking water quality reduction based on groundwater resource index using the artificial neural network and fuzzy clustering," *Journal of Contaminant Hydrology*, vol. 220, pp. 6–17, 2019.

[26] X. Xu, D. Shahsavari, and B. Karami, "On the forced mechanics of doubly-curved nanoshell," *International Journal of Engineering Science*, vol. 168, Article ID 103538, 2021.

[27] Y. Jiang, Z. Nan, and S. Yang, "Risk assessment of water quality using Monte Carlo simulation and artificial neural network method," *Journal of Environmental Management*, vol. 122, pp. 130–136, 2013.

[28] K. Wang, X. Wen, D. Hou et al., "Application of least-squares support vector machines for quantitative evaluation of known contaminant in water distribution system using online water quality parameters," *Sensors*, vol. 18, no. 4, p. 938, 2018.

[29] M. Salari, E. Salami Shahid, S. H. Afzali et al., "Quality assessment and artificial neural networks modeling for characterization of chemical and physical parameters of potable water," *Food and Chemical Toxicology*, vol. 118, pp. 212–219, 2018.

[30] J. García-Alba, J. F. Bárcena, C. Ugarteburu, and A. García, "Artificial neural networks as emulators of process-based models to analyse bathing water quality in estuaries," *Water Research*, vol. 150, pp. 283–295, 2019.

[31] P. Pradhan, T. Tingsanchali, and S. Shrestha, "Evaluation of soil and water assessment tool and artificial neural network models for hydrologic simulation in different climatic regions of asia," *Science of The Total Environment*, vol. 701, Article ID 134308, 2020.

[32] J. Li, W. Li, J. Meng, F. Yan, and X. Shang, "Evaluation and categorization of black and odorous rivers in central urban area of tianjin," *China Water and Wastewater*, vol. 33, no. 19, pp. 90–95, 2017.

[33] W. Wei, H. Jing, L. Hua et al., "Studies on grading assessment methods of urban smelly creeks' blackening and odors in beijing," *Environmental Science and Technology*, vol. 39, no. S2, pp. 407–412, 2016.

[34] H. Defu, C. Ruirui, Z. Enhui et al., "Toxicity bioassays for water from black-odor rivers in wenzhou, China," *Environmental Science and Pollution Research*, vol. 22, no. 3, pp. 1731–1741, 2015.

[35] R. R. Xu, Z. T. Pei, W. Q. Wang et al., "Assessment of biological toxicity and ecological safety for urban black-odor river remediation," *International Journal of Environmental Research and Public Health*, vol. 17, no. 3, 2020.

[36] C. Liu, B. Qian, L. Wang, and Q. Miao, "Research on spatial-temporal distribution characteristics of main pollutants of the rivers in the linyi development zone," *Journal of Water and Climate Change*, vol. 10, no. 2, pp. 285–297, 2019.