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Research Article

Research on the Optimization Model of the Abrasive Blocks Using Weighted Case-Based Reasoning

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Barrel finishing process is a universal method to improve the surface quality of parts. It is widely used in high-performance parts of high-end equipment. As a necessary tool consumable for barrel finishing process, the characteristic parameters of the abrasive blocks affect the processing quality and production efficiency. However, the current method for selecting the abrasive blocks requires large number of experiments based on the operator's extensive experience, which does not meet the rapid development needs of the barrel finishing process. Therefore, this paper proposes a case-based reasoning model with variable weights to achieve the intelligent optimization of the abrasive blocks. Based on the in-depth analysis of the characteristics of the barrel finishing process, a reasonable case base is established firstly, which is to determine the comprehensive case features and the solution of the case. AHP (analytic hierarchy process) is proposed to determine the weight of case features and to dynamically adjust the weight of case features according to the characteristics of the parts to be processed and users' processing requirements. The results show that the proposed case-based reasoning model with variable weights can quickly, accurately, and reasonably select the abrasive blocks during the process of making processing technique of the barrel finishing, which will lay a necessary foundation for the effective implementation of the barrel finishing process and contribute significantly to the improvement of its efficiency.

1. Introduction

Barrel finishing technology is a basic manufacturing technology in the field of machining. This technology aims to improve the surface quality and integrity of parts. It belongs to the category of precision and ultraprecision machining [1]. The barrel finishing process is widely used because of its adaptability, good processing performance, relatively low processing cost, and friendly process environment [2]. Connotation of the barrel finishing is as follows: the granular media (i.e., abrasive blocks, which have the functions of grinding, polishing, finishing, and microgrinding) and the liquid media (i.e., grinding fluid and water, which have the functions of cleaning, antirust, softening, brightening, foaming, lubrication, and buffering) are put into the barrel finishing equipment. According to certain geometric and kinematics constraints, a forced fluid-particle coupled flow field in dynamic equilibrium is constituted. The required parts with free or default movement in different ways keep compulsory constraints in the coupled flow field. After certain processing time and period of reasonable motion vector control, abrasive blocks with different degrees of forces affect the work piece surface with comprehensive microgrinding function, such as colliding, rolling, sliding, and scratching so as to realize the finishing processing on the surface of the required parts. Connotation of the barrel finishing is shown in Figure 1 [3].

With the continuous expansion of the barrel finishing process market, the demand for rapid response to the R&D and promotion of professional enterprises engaged in barrel finishing technology is increasing [4], facing the ever-changing and diverse requirements of finishing parts. In fact, the traditional mode of experimentation based on experience to lay down an optimal process plan has been unable to

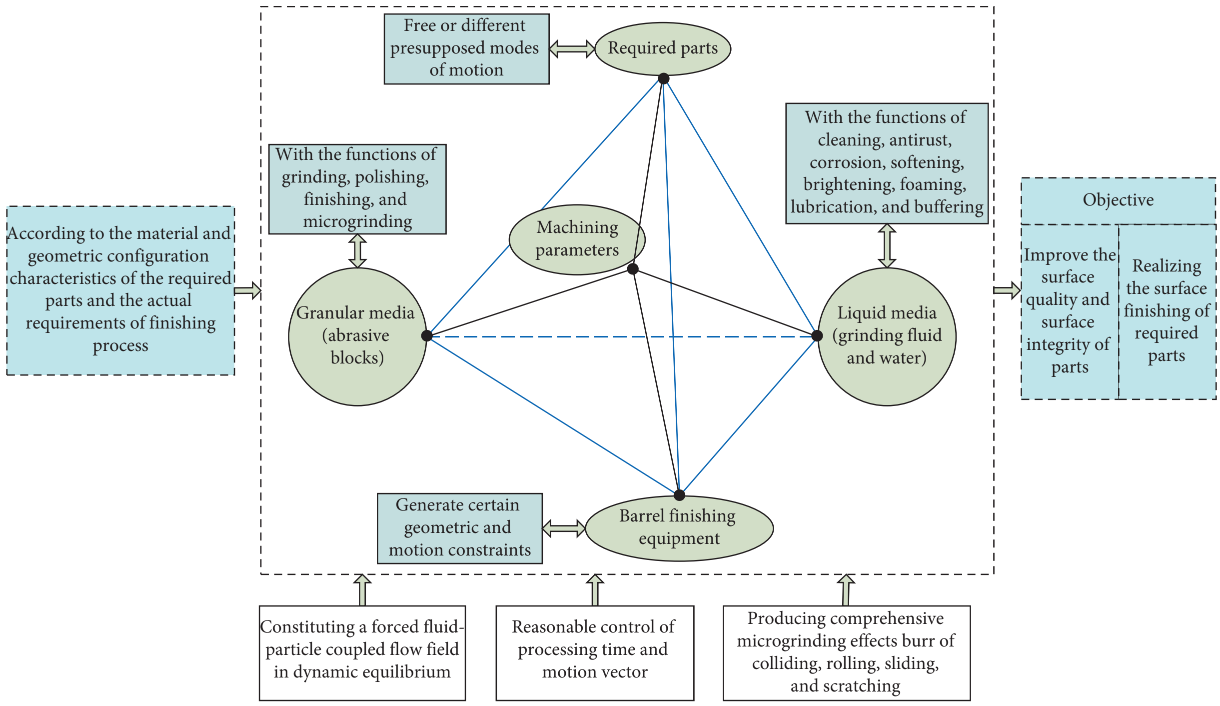

Figure 1: Connotation of the barrel finishing.

meet the rapid development needs. At the same time, the large number of successful data of traditional paper experimental documents and electronic documents as data preservation and utilization cannot play a role in the development of new process plans.

In the application of barrel finishing process, the abrasive blocks are the key factor affecting the processing ability, processing effect, and processing efficiency [1, 5, 6], but there are currently few studies on the optimization of abrasive blocks. In the traditional abrasive blocks selection process, the expert needs to give the selected abrasive blocks according to the information and processing requirements of the required parts, combined with his or her own extensive experiences and then following a large number of tests to determine the final abrasive blocks. The choice is overly dependent on expert experiences. In addition, due to many factors affecting the selection of abrasive blocks, along with a large number of complicated reasoning processes, the following problems arise: (1) The reasoning process needs to be completed via a large number of experiments conducted by the operator, and the efficiency is not high. (2) The expert's experienced knowledge cannot be timely accumulated. Therefore, this paper studies the optimization model of abrasive blocks based on case-based reasoning technology by using fully a large number of successful data preserved by the traditional paper experimental documents or electronic documents in the barrel finishing process.

2. Case-Based Reasoning Technology and Its Application

In 1982, Roger C. Schank of Yale University put forward the "dynamic memory" theory based on "memory organization packets" in the book Dynamic Memory [7], which is recognized as the earliest description of the case-based reasoning (CBR) idea in the field of artificial intelligence. CBR is a knowledge-based problem-solving and learning method. Its core concept is to solve new problems by reusing or modifying previous cases. In general, CBR consists of four basic processes: retrieve, reuse, revise, and retain, which is abbreviated as 4R. In practical applications of CBR, the new problem is first characterized and then retrieved to find a matching case in the case base. If there is a matching case, then the solution for the case is directly applied; otherwise, the problem is solved through case revision. After the case evaluation, the qualified cases are stored in the case base. With the accumulation of cases, the knowledge contained in the system is increasingly refined, and the ability to solve the new problems is continuously enhanced so that the case-based reasoning system has the ability to continuously learn new knowledge and to be improved.

CBR has attracted the attention of many scholars due to its advantages of solving problems simply, quickly, and efficiently. Through its development of more than 30 years, the application of CBR has continuously evolved from a single field to multiple fields. Ahn et al. [8] used the weighted Mahalanobis distance to measure the similarity of case-based reasoning and established a cost estimation model based on case-based reasoning. Jiang et al. [9] used rough sets to reduce the dimension of case features and determine the weight of case features. A process planning model for remanufacturing products based on case-based reasoning was established to improve the quality of remanufactured products. Brown et al. [10] established a model of insulin push calculation based on case-based reasoning technology by introducing temporal sequences and dynamic feature weighting. Khosravani et al.

[11] proposed an intelligent fault detection system for injection products based on case-based reasoning. Mohammed et al. [12] combined genetic algorithms with case-based reasoning to provide experience and knowledge of existing fault diagnosis cases to provide solutions for unknown cases. Qiu et al. [13] proposed a modelling method based on the CBR technique to determine the process parameter correction coefficient for small steel grade rolling, which improved the control precision and product quality of the model. Li et al. [14] used case-based reasoning to establish a fault diagnosis model for aerospace engines and improved the fault repair efficiency. Rintala et al. [15] used case-based reasoning techniques to establish an optimization model for metallurgical process flow diagrams, providing useful information and guidance for further process design. The above researches have solved the problems in obtaining rules and establishing models in their respective fields.

This paper proposes a case-based reasoning technology to reasonably select the abrasive blocks during the barrel finishing process, instead of relying on expert knowledge.

3. Abrasive Blocks Optimization Model Using Weighted Case-Based Reasoning

Because each case feature has different importance, different case features have different weights. According to the different processing requirements, a weighted case-based reasoning technique based on analytic hierarchy process (AHP) is proposed. Figure 2 shows the principle block diagram of the optimized abrasive blocks selection process, based on the weighted case-based reasoning technique.

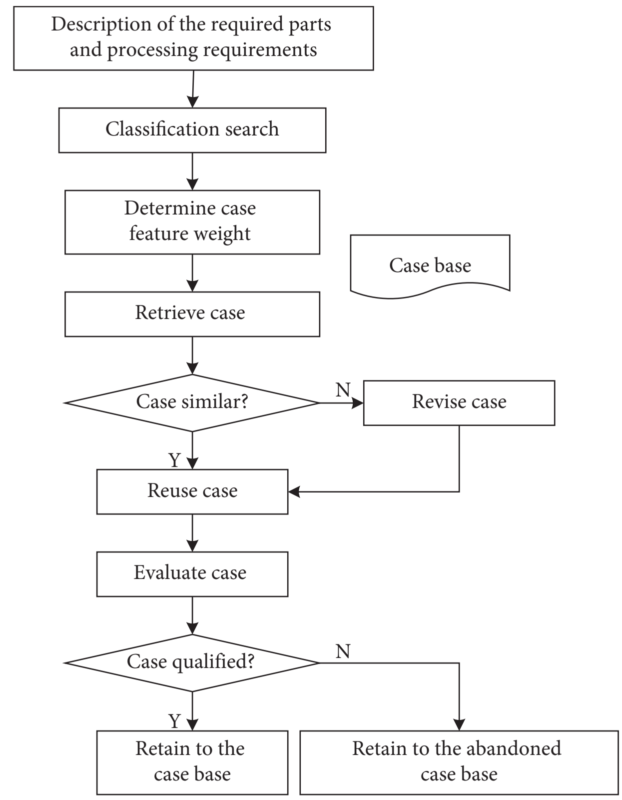

Figure 2: The diagram of the abrasive blocks optimization based on the weighted case-based reasoning.

As shown in Figure 2, the optimization flow of the abrasive blocks is listed as follows: (1) According to the feature description of the required parts and processing requirements, the case classification search is performed to determine the parts' type and material. (2) The weight of the case feature is determined by the AHP. (3) Case matching is performed to retrieve similar cases. If there are no similar cases in the case base, then conduct the case revision to obtain a solution to the new problem. (4) The parts are processed by the preferred abrasive blocks. If the processing requirements are met, the case is stored in the case base; otherwise, it is stored in the abandoned case base for later analysis to find the cause of the failure. In the process (Figure 2), the establishment of the case base is explained as follows. The processing characteristics of the barrel finishing process are analysed, and the case features are selected according to the preferred E-R (entity-relationship) diagram of the abrasive blocks optimization, including the parts to be processed, the processing requirements, and the corresponding information description of the abrasive blocks. Thereby, the case base is established.

3.1. Representation of Case Features. Case construction is the first step to the problem using CBR. Appropriate case representation can reflect the essential characteristics of the solved problems and make the case retrieval system quickly retrieve the desired cases in the case base, thereby improving the efficiency of case retrieval [16]. Case representation means that how to extract the features of the solved problems and the relationship among them and store the features in the database to provide basic conditions for reasoning. For different problems, their representations are different. A reasonable case representation not only makes the problem easy to be solved but also has higher efficiency. In the case base construction, the feature set of a case represents the set of factors that affect the system. The selection and reduction of case features are the key factors that determine the reasoning system performance [17].

Case representation should have a good organizational structure to facilitate querying and storage while improving the query speed and accuracy. Generally, a typical case includes the feature representation of the case and the result of the case [18, 19]. To represent cases more comprehensively, this paper uses the E-R diagram to describe the entity types, entity attributes, and their relationships. Through an in-depth analysis and study on the characteristics of barrel finishing process, combined with actual production data and processing experiment reports, the information description of processing cases is obtained. The main factors affecting the selection of abrasive blocks are the characteristics of the parts and their preprocessing characteristics, as well as processing requirements. The optimum E-R diagram of the abrasive blocks is shown in Figure 3.

According to the experimental reports and actual factory production data, the characteristics of the required parts are determined, including the type of parts, the material of the parts,

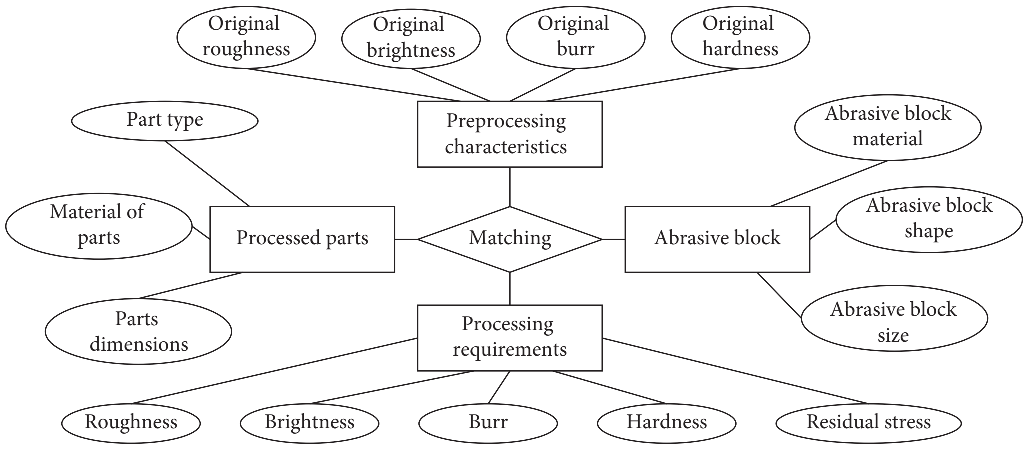

FIGURE 3: E-R diagram of the abrasive blocks optimization.

the size of the parts, and the characteristics before processing (roughness, brightness, burr, hardness, etc.). The processing requirements are set for the specific indicators (roughness, brightness, burr, hardness, residual stress, etc.,) of the parts after processed. The main indexes of the abrasive blocks are the material, shape, and size. Therefore, the case of optimum selection of abrasive blocks includes the case features (i.e., characteristics of the parts to be processed and the processing requirements) and the case solution (i.e., the characteristics of abrasive blocks). Because the dimensional parameters of different types of parts are different, the case base is built according to the type of parts in case construction. The optimum case structure of the abrasive blocks is shown in Figure 4.

3.2. Determination of the Case Feature Weight Based on an Analytic Hierarchy Process. In case-based reasoning, different factors have different effects on the final results. These factors are important features in the process of case retrieval. It is necessary to set different weight values for different features so that the features with larger impacts have a larger weight in order to reduce the impact of secondary features and improve the accuracy of retrieval matching [20, 21]. Therefore, the weights of the case features reflect their relative importance. It is extremely important to give reasonable weight to case features. In case retrieval, the weights of case features determine the similarity between cases and then have a significant impact on the correctness of reasoning results [22].

The AHP is a combination of qualitative, quantitative, systematic, and hierarchical analysis method proposed by Professor Saaty. The steps to determine the weight of case features using the AHP are as follows:

Step 1. Establishing the hierarchical structure model:

First, there are many factors that affect each other of the decision-making problems in a large system. To hierarchize these problems, a multilayer analytical structure model is formed. Through the analysis of the case features of barrel finishing, after the material and type of parts are determined by classification search, a three-layer structure model can be established. Taking gear parts as an example, the case feature hierarchy model is shown in Figure 5.

Step 2. Constructing a judgment matrix in each layer:

The weights of each index in the comprehensive evaluation are different at the criterion layer and the scheme layer. Based on the 1–9 scale method and expert knowledge, a two-to-two comparison judgment matrix is constructed. Obtain the comparative judgment matrix $B = (a_{ij})_{n\times n}$. Here, n is the order of the judgment matrix at each layer, and a_{ij} is the importance ratio of two indexes in the comparison judgment matrix.

The scale definition of the comparative judgment matrix is shown in Table 1.

Generally, the comparative judgment matrix is a positive and reciprocal matrix, which has the following properties: $a_{ij} > 0$, i.e., the elements in the comparative evaluation matrix are greater than 0; $a_{ji} = 1/a_{ij}$, i.e., the ratio of the importance of index i to index j is reciprocal to that of index j to index i; and $a_{ii} = 1$, i.e., the ratio of the importance of the index itself is 1.

Through expert opinions and the analysis of actual processing data of the barrel finishing process, the relative importance of the case features is obtained. Then, the comparative evaluation of A, A_1, A_2, and A_3 at different layers is obtained, as shown in Tables 2–5, respectively.

Step 3. Single weight calculations at different layers and consistency test:

The maximum eigenvalues and the corresponding eigenvectors of the comparison judgment matrices are calculated. The formula is as follows:

$$BW = \lambda_{\max} W, \tag{1}$$

where B is the comparative judgment matrix, namely, A, A_1, A_2, and A_3; $\lambda_{\max}$ is the maximum eigenvalue of the comparative judgment matrix; and W is the corresponding eigenvector. In this paper, the geometric averaging method is used to calculate the maximum eigenvalues and eigenvectors of the comparative judgment matrix.

The steps of using the geometric averaging method to calculate $\lambda_{\max}$ and W are shown as follows:

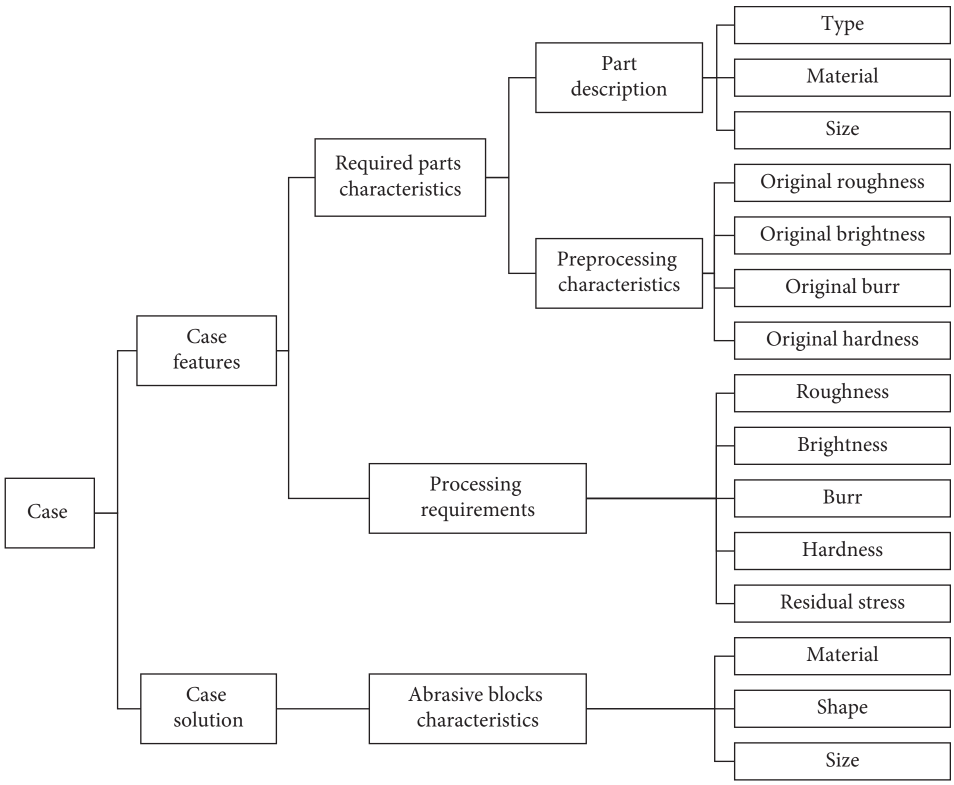

FIGURE 4: Case structure of the abrasive blocks optimization.

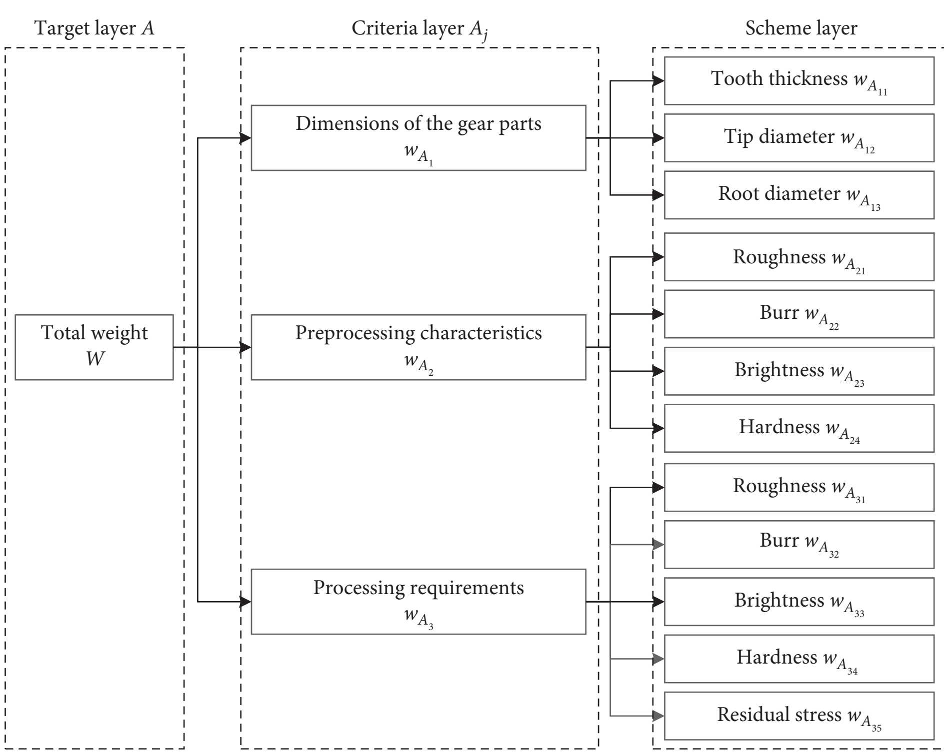

FIGURE 5: Feature hierarchy model of the gear parts.

TABLE 1: The scale definition of the comparative judgment matrix.

Scale	Meaning
1	Indicates that index i is of the same importance as index j
3	Indicates that index i is slightly more important than index j
5	Indicates that index i is moderately more important than index j
7	Indicates that index i is substantially more important than index j
9	Indicates that index i is very strongly more important than index j
2, 4, 6, 8	Represents the median value of the above adjacent evaluations

TABLE 2: Criteria layer judgment matrix.

A	A_1	A_2	A_3
A_1	1	1/3	1/2
A_2	3	1	2
A_3	2	1/2	1

TABLE 3: Gear type parts size judgment matrix.

A_1	A_{11}	A_{12}	A_{13}
A_{11}	1	1/2	1/3
A_{12}	2	1	1/2
A_{13}	3	2	1

TABLE 4: The characteristics of the parts judgment matrix.

A_2	A_{21}	A_{22}	A_{23}	A_{24}
A_{21}	1	2	3	4
A_{22}	1/2	1	3	3
A_{23}	1/3	1/3	1	2
A_{24}	1/4	1/3	1/2	1

TABLE 5: Processing requirement judgment matrix.

A_3	A_{31}	A_{32}	A_{33}	A_{34}	A_{35}
A_{31}	1	2	3	4	5
A_{32}	1/2	1	3	3	4
A_{33}	1/3	1/3	1	2	3
A_{34}	1/4	1/3	1/2	1	2
A_{35}	1/5	1/4	1/3	1/2	1

Step 1. Compute the product of each element in each row of the comparative judgment matrix B:

$$m_i = \prod_{j=1}^{n} a_{ij}, \quad i = 1, 2, \ldots, n. \tag{2}$$

Step 2. Calculate the n-th root:

$$\overline{w}_i = \sqrt[n]{m_i}. \tag{3}$$

Step 3. Normalize vectors $\overline{W} = (\overline{w}_1, \overline{w}_2, \ldots, \overline{w}_n)^T$:

$$\widehat{w}_i = \frac{\overline{w}_i}{\sum_{j=1}^{n} \overline{w}_j}. \tag{4}$$

Let the vector $\widehat{W} = (\widehat{w}_1, \widehat{w}_2, \ldots, \widehat{w}_n)^T$ be the desired eigenvector.

Step 4. Calculate the maximum eigenvalue $\lambda_{\max}$ of B:

$$\lambda_{\max} = \frac{1}{n} \sum_{i=1}^{n} \frac{(B\widehat{W})_i}{\widehat{w}_i}, \tag{5}$$

where $(B\hat{W})_i$ is the i-th element of $(B\hat{W})$.

To make the calculation results consistent with the actual situation, it is necessary to check the consistency of B. The consistency index CI represents the degree of consistency of B. It is calculated as follows:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1}, \tag{6}$$

where n is the order of the comparative judgment matrix.

If B has complete consistency, $\mathrm{CI} = 0$. In general, the larger the order of the matrix, the greater the probability of random deviation of consistency. In order to measure the size of CI under different orders, the random consistency index RI is introduced, and the ratio of CI and RI, i.e., the consistency ratio (CR), is taken as the unified index to measure the consistency of the matrix. When the order of the judgment matrix n is between 1 and 11, the value of RI is as shown in Table 6 [23].

The consistency ratio CR indicates the degree of consistency of the comparison judgment matrix. When $\mathrm{CR} < 0.1$, it is considered that B is consistent. Otherwise, judgment matrix B should be corrected appropriately. CR is calculated as follows:

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}. \tag{7}$$

For matrix A, the maximum eigenvalue is $\lambda_{\max} = 3.0092$. CI is calculated as 0.0046 by formula (6). See Table 6, $\mathrm{RI} = 0.58$; then CR is calculated as 0.0079 by formula (7), which is less than 0.1. The consistency test is passed. Finally, the weight of each index in the criterion layer is $W_A = [w_{A_1}, w_{A_2}, w_{A_3}] = [0.1634, 0.5396, 0.2970]$.

For matrix A_1, the maximum eigenvalue is $\lambda_{\max} = 3.0092$. CI is calculated as 0.0046 by formula (6). See Table 6, $\mathrm{RI} = 0.58$; then CR is calculated as 0.0079 by formula (7), which is less than 0.1. The consistency test is passed. Finally, the weights of the dimensions of gear parts in the scheme layer are obtained as follows: $W_{A_1} = [w_{A_{11}}, w_{A_{12}}, w_{A_{13}}] = [0.1634, 0.2970, 0.5396]$.

For matrix A_2, the maximum eigenvalue is $\lambda_{\max} = 4.0813$. CI is calculated as 0.0271 by formula (6).

Table 6: Average random consistency index.

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

See Table 6, RI = 0.90; then CR is calculated as 0.0301 by formula (7), which is less than 0.1. The consistency test is passed. Finally, the weight of each index of parts characteristics in the scheme layer is obtained as follows: $W_{A_2} = [w_{A_{21}}, w_{A_{22}}, w_{A_{23}}, w_{A_{24}}] = [0.4586, 0.3048, 0.1432, 0.0934]$.

For matrix A_3, the maximum eigenvalue is $\lambda_{\max} = 5.1206$. CI is calculated as 0.0302 by formula (6). See Table 6, RI = 1.12; then CR is calculated as 0.0269 by formula (7), which is less than 0.1. The consistency test is passed. Finally, the weights of each index of processing requirements in the scheme layer are obtained as follows: $W_{A_3} = [w_{A_{31}}, w_{A_{32}}, w_{A_{33}}, w_{A_{34}}, w_{A_{35}}] = [0.4117, 0.2853, 0.1469, 0.0954, 0.0607]$.

Step 5. Total weight and its consistency test:

To obtain the total weight of each case feature to the target layer, it is necessary to calculate the weight of each layer index to obtain the total objective of the system and check the consistency. The calculation method is as follows:

From Figure 4, we can see that there are three kinds of indicators in the criterion layer: parts size A_1, parts characteristics A_2, and processing requirement A_3, whose single weight vector is $W = [w_{A_1}, w_{A_2}, w_{A_3}]$. In the scheme layer, there are 12 indicators: the gear parts size indexes are A_{11}, A_{12}, and A_{13}, and their single weight vector for indicator A_1 is $W_{A_1} = [w_{A_{11}}, w_{A_{12}}, w_{A_{13}}]$; the parts characteristics indexes are A_{21}, A_{22}, A_{23}, and A_{24}, and their hierarchical single weight vectors for indicator A_2 are $W_{A_2} = [w_{A_{21}}, w_{A_{22}}, w_{A_{23}}, w_{A_{24}}]$; and the processing requirements are A_{31}, A_{32}, A_{33}, A_{34}, and A_{35}, and their hierarchical single weight vectors for indicator A_3 are $W_{A_3} = [w_{A_{31}}, w_{A_{32}}, w_{A_{33}}, w_{A_{34}}, w_{A_{35}}]$, while the total weight vectors for target layer are expressed in W:

$$W = \left\{w_{A_1}W_{A_1}, w_{A_2}W_{A_2}, w_{A_3}W_{A_3}\right\}. \tag{8}$$

If the consistency index for criterion layer A_j is CI_j and the average random consistency index is RI_j, then the overall consistency index for the scheme layer is

$$\mathrm{CR} = \frac{\sum_{j=1}^{3} w_{A_j}\mathrm{CI}_j}{\sum_{j=1}^{3} w_{A_j}\mathrm{RI}_j}, \tag{9}$$

where j is the j-th criterion layer indicators, $j = 1, 2, 3$.

According to the CI and RI of the judgment matrix of each layer calculated above, the total consistency ratio CR is calculated as 0.0267 by formula (9), which is less than 0.1. The case features of the scheme layer pass the consistency test for the total weight of the target layer. Formula (8) calculates the total weight vector of each case feature to the target layer as $W = \{0.0267, 0.0485, 0.0882, 0.2475, 0.1645, 0.0773, 0.0504, 0.1223, 0.0847, 0.0436, 0.0283, 0.0180\}$. In practical applications, according to the different processing requirements of different parts, experts can change the scale value in the comparison judgment matrix to realize the calculation of the similarity degree with variable weight, which makes the optimization model more adaptable.

3.3. Case Matching. Case matching is used to retrieve and select potentially available cases from the source case base using retrieval information and to make a reasonable evaluation of the similarity between new cases and stored cases so that the retrieved cases can be used to solve new problems. The similarity measurement is a key cornerstone of CBR [24].

3.3.1. Steps of Hierarchical Case Retrieval. According to the feature matching of parts processing cases, the steps of case retrieval are as follows:

Step 1. In case retrieval, the corresponding case base is first retrieved from the parts type, and then the case with the same material in the corresponding case base is retrieved as the candidate case set. The optimization of abrasive blocks based on CBR is to find the optimal abrasive blocks by searching for the most similar case to the new case among the historical cases. Its core is the similarity calculation during the case retrieval process. The larger the similarity value, the higher the similarity between the cases, and the more accurate the selected abrasive block is. Therefore the method of calculating similarity is used to retrieve similar cases in the candidate case set.

Step 2. The method of similarity calculation adopts the weighted nearest neighbor method [25–27]. The formula is as follows:

$$\mathrm{SIM}(T, S) = \frac{\sum_{i=1}^{n} \mathrm{sim}(T_i, S_i) \times w_i}{\sum_{i=1}^{n} w_i}, \tag{10}$$

where SIM (T, S) is the overall similarity of two cases; T is the new problem; S is the case in the case base; T_i is the value of the i-th feature of the new problem; S_i is the value of the i-th feature of the case in the case base; n is the number of case features; $SIM(T_i, S_i)$ is the similarity of the features of T and S cases, and the corresponding similarity calculation algorithm should be selected according to the type of case feature data; and w_i is the weight value of the case features, and the analytic hierarchy process (AHP) described in Section 3.2 is used to determine the weights of case features.

3.3.2. Similarity Calculation of Case Features. According to the case description information in the barrel finishing test reports, the data types of the case features can be divided into three classes: numerical type, fuzzy logic type, and switch type. The similarity calculation methods of different data types are as follows:

(1) The formula for calculating the similarity of numerical case features [28, 29] is

$$\operatorname{sim}\left(T_i, S_i\right) = \exp\left[-\left(\frac{d\left(T_i, S_i\right)}{\sqrt{2} \times \sigma_i}\right)\right], \tag{11}$$

$$\sigma_i = \sigma \times \left(i_{\max} - i_{\min}\right), \tag{12}$$

where d (T_i, S_i) is the absolute distance between the two case features; σ_i is the flexural point; $i_{\max}$ and $i_{\min}$ are the maximum and minimum values of the i-th feature, respectively; and σ is a constant within the range of values of [0, 1].

The size, original roughness, original burr, original hardness before machining, roughness after machining, and residual stress all are the numerical data. The similarity is calculated by using formulas (11) and (12). Among the parameters, the size index of the original burr before processing can be characterized by the height or thickness B1 and B2 of the burr [30], and the burr can be quantitatively characterized by measuring the size index of the burr by an instrument.

(2) The formula for calculating the similarity of case features of fuzzy logic type is [31]

$$\operatorname{sim}\left(T_i, S_i\right) = 1 - \frac{\left|T_i - S_i\right|}{M}, \tag{13}$$

where M is the maximum value of the case features.

According to the national standard of brightness, the brightness attributes have four grades: distinguishable processing trace direction, no brightness, low and no abrasion, and very high brightness. They are assigned to the corresponding values of 1, 2, 3, and 4. The similarity of luminance can be calculated by formula (13), where $M = 4$.

(3) The formula for calculating the similarity of switch-type case features [32] is as follows:

$$\operatorname{sim}\left(T_i, S_i\right) = \begin{cases} 1, & T_i = S_i, \\ 0, & T_i \neq S_i. \end{cases} \tag{14}$$

The "burr" parameter in some "processing requirement" is usually described by "yes" or "no." In this case, formula (14) is used to calculate its similarity.

3.4. Case Processing. Case processing includes case revision, case application, and case preservation. According to formula (10), the similarity is calculated, and the case whose similarity is greater than threshold S_{th} is taken as a similar case. S_{th} is given by experts according to processing experience. If similar cases exist, the results are as follows:

(1) If the similar case is unique, the abrasive blocks of the case will be directly applied

(2) If there are many similar cases, the experts will perform an analysis and make a decision regarding the abrasive blocks

If the similar case cannot be retrieved, case revision is needed. According to the importance of case features, this paper chooses case features with weights greater than w_{th} and calculates the similarity again by formula (10). If the highest case similarity is greater than S_{th}, the solution of the case will be taken as a solution to the new problem; otherwise, the expert will perform an analysis and make decision to select the abrasive blocks.

Through case matching and case revision, the abrasive blocks for new parts are selected to process the new parts. After processing, the case needs to be evaluated to determine whether the case can be stored in the case base. This evaluation adopts the method of "postevaluation of the processing effect." The optimized abrasive blocks are applied to machine the new parts. If the processing effect of the new parts meets the processing requirements, the case will be retained to the case base; otherwise, it will be retained to the abandoned case base.

4. Design of the System Interface for the Abrasive Blocks Optimization

A friendly man-machine interface is aimed to be designed for easy operation and real-time display of the process parameters of the abrasive blocks optimization, which adopts the weighted case-based reasoning. This paper designs the optimization interface of the abrasive blocks with the procedure shown in Figure 6.

As shown in Figure 6, users first select the types and materials of the processed parts, then click the bottom of "Confirm selection completed." The case feature of different parts types and the corresponding comparative judgment matrix will appear on the interface. Users can input "Criteria layer judgment matrix," "Parts size judgment matrix," "Before processing feature judgment matrix," and "Processing requirement judgment matrix" in turn according to the relative importance of case features and the prompt message in the box. And then click "OK" to obtain the case feature weights, in addition to display the case features corresponding weight values on the left side of the interface.

5. Simulation Research

Many simulation researches are carried out using the actual data of the gear parts, shaft parts, and blade parts of a factory. In the similarity calculation formula, the parameter σ affects the similarity calculation of the numerical case features and then affects the comprehensive similarity between cases, and the value of w_{th} also affects the final result. To determine the values of σ and w_{th}, in this paper, the three type cases "existing cases," "similar cases," and "large-different cases" in the case base are used to perform the simulation researches. Due to space constraints, only the partial simulation results of the gear

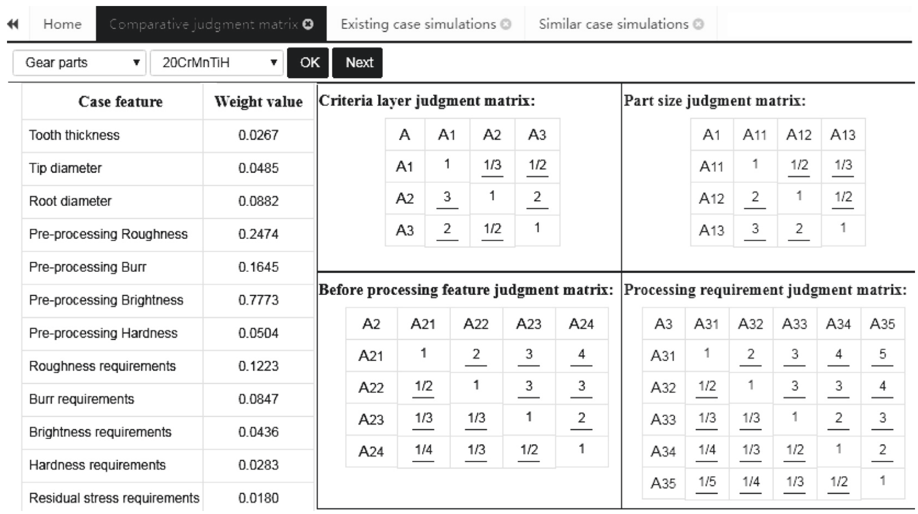

FIGURE 6: The interface of the abrasive blocks optimization.

parts are given. According to the expert experience, the similarity threshold $S_{th} = 0.7$. The dimension characteristics of the gear parts are the height, outer diameter`, and inner diameter.

For ease of analysis, the case information is represented by the following symbols: case number (No.), material number (M), tooth thickness (H), tip diameter (O), root diameter (I), original roughness (Ra1), original burr (B1), original brightness (Br1), original hardness (H1), roughness (Ra2), residual stress (Rs), brightness (Br2), hardness (H2), burr (B2), and the abrasive blocks.

Through a large number of simulations, it is determined that the change in the σ value does not affect the ranking of the case similarity but affects only the size of the similarity value. When $\sigma = 0.4$, the test case can find similar cases and distinguish the cases with large differences. Therefore, this paper sets the parameter σ to 0.4.

When the threshold w_{th} of the case feature weight increases gradually, the similarity of the calculated case also increases gradually, which makes the similarity of the searched case to meet the threshold requirement. When the threshold increases to a certain value, the similarity decreases with the threshold continually increasing. Through the simulation studies of many cases, when the threshold $w_{th} = 0.09 - 0.12$ of the case feature weight, the similarity between the cases is high.

5.1. Existing Case Simulations in the Case Base. The existing cases in the case base are selected for testing. For example, No. 16 of gear parts is selected as the test case, which is an existing case in the case base. The simulation results are shown in Table 7.

As seen from Table 7, if the information of the new problem to be processed (No. 16 in the first line) is consistent with the parameter information of a case in the case base, the similarity is 1. The abrasive blocks in the case can be directly applied to process the new parts.

5.2. Similar Case Simulations. Select the case base similar to certain cases to test. For example, No. 13 of gear parts is selected as the test case which is similar to certain cases in the case base. The simulation results are shown in Table 8.

As seen from Table 8, if the information of the new problem to be processed (No. 13 in the first line) is similar to the information of some cases in the case base, similar cases whose similarity is larger than the threshold can be found by calculating the similarity between the cases. The information of the abrasive blocks in the similar case is consistent with the information of the abrasive blocks in the test case, and the selected abrasive blocks can be used to process the new parts. Further analysis of case data shows that both case No. 11 and case No. 10 can meet the processing requirements, but case No. 11 is closer to the processing requirements with higher processing efficiency than case No. 10.

5.3. Simulation of Large-Difference Cases. To verify the accuracy of the similarity threshold selection in this paper, some cases that are quite different from those in the case base are selected for testing. For example, No. 6 of gear parts is selected as the test case in the case base, and the simulation results are shown in Table 9.

As shown in Table 9, if the information of the new problem to be processed (No. 6 in the first line) is quite different from all the case information in the case base, their similarity is smaller than the threshold S_{th}, and the similarity of the four cases is close. At this time, quick and effective selection cannot be made by technical personnel. Therefore, case revision needs to be used to find the available abrasive blocks for the new parts. In this paper, determine $w_{th} = 0.1$, and according to Section 3.2 and Figure 4, case features are as follows: roughness before machining, roughness after machining, and burr before processing. The correction results are shown in Table 10.

Table 7: Simulation results of the existing case of gear parts.

No.	M	H (mm)	O (mm)	I (mm)	Ra1 (μm)	B1 (mm)	Br1	H1 (HV)	Ra2 (μm)	Rs (MPa)	Br2	H2 (HV)	B2	Similarity	Abrasive blocks
16	Alloy steel	83	206	100	0.618	1.9	1	50	0.515	−250	4	55	No		No. 3 rough blocks
16	Alloy steel	83	206	100	0.618	1.9	1	50	0.515	−250	4	55	No	1	No. 3 rough blocks
18	Alloy steel	64	200	80	0.594	1.873	1	48	0.487	−245	4	52	No	0.762	No. 3 rough blocks

Table 8: Simulation result of similar case of gears.

No.	M	H (mm)	O (mm)	I (mm)	Ra1 (μm)	B1 (mm)	Br1	H1 (HV)	Ra2 (μm)	Rs (MPa)	Br2	H2 (HV)	B2	Similarity	Abrasive blocks
13	20CrMnTiH	42	109	44	0.376	1.38	1	48	0.355	−215	4	53	No		Triangle 2
11	20CrMnTiH	42	116	44	0.384	1.380	1	48	0.379	−210	4	55	No	0.819	Triangle 2
10	20CrMnTiH	66	128	46	0.368	1.397	1	48	0.357	−205	4	52	No	0.766	Triangle 2

Table 9: Simulation result of a case with substantially different gears.

No.	M	H (mm)	O (mm)	I (mm)	Ra1 (μm)	B1 (mm)	Br1	H1 (HV)	Ra2 (μm)	Rs (MPa)	Br2	H2 (HV)	B2	Similarity	Abrasive blocks
6	Cast steel	48	135	54	0.66	1.9	1	55	0.464	−255	4	63	No		No. 3 rough blocks
2	Cast steel	5	32	13	0.565	1.8	3	47	0.351	−240	4	51	No	0.675	No. 3 rough blocks
4	Cast steel	21	95	30	0.478	1.457	1	40	0.323	−267	4	55	No	0.622	Triangle 3
1	Cast steel	21	80	20	0.453	1.458	1	46	0.351	−257	4	53	No	0.620	Triangle 3l
7	Cast steel	60	269	130	0.842	1.32	2	42	0.467	265	4	50	No	0.597	No. 3 medium mill

Table 10: Simulation results of case correction with substantially different gears.

No.	M	H (mm)	O (mm)	I (mm)	Ra1 (μm)	B1 (mm)	Br1	H1 (HV)	Ra2 (μm)	Rs (MPa)	Br2	H2 (HV)	B2	Similarity	Abrasive blocks
6	Cast steel	48	135	54	0.66	1.9	1	55	0.464	−255	4	63	No		No. 3 rough blocks
2	Cast steel	5	32	13	0.565	1.8	3	47	0.351	−240	4	51	No	0.745	No. 3 rough blocks
7	Cast steel	60	269	130	0.842	1.32	2	42	0.467	265	4	50	No	0.560	No. 3 medium mill
4	Cast steel	21	95	30	0.478	1.457	1	40	0.323	−267	4	55	No	0.526	Triangle 3
1	Cast steel	21	80	20	0.453	1.458	1	46	0.351	−257	4	53	No	0.519	Triangle 3

As shown in Table 10, the similarity between case No. 6 and case No. 2 is increased after the case is modified, whose similarity is larger than the threshold for the new problem. But the other similarities between case No. 6 and respective case No. 7, No. 4, and No. 1 are decreased. As a result, a similar case can be matched. At the same time, it can be seen from Table 10. The abrasive blocks of the similar case No. 2, which is the same as the abrasive blocks of the new problem, can be used to process the new parts.

As shown in Figure 7, the similarity value of case No. 2 after case revision is obviously improved compared with that of the other three cases, which meets the threshold requirement. At the same time, the differentiation between case similarity is more obvious, which is easier for technical personnel to select the abrasive blocks.

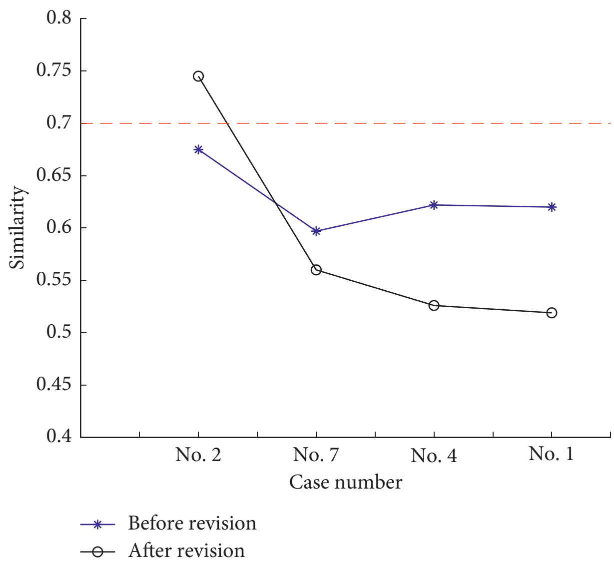

FIGURE 7: Comparison of similarity before and after case revision.

6. Conclusion

In this paper, the optimal selection model of the abrasive blocks is established by using the weighted case-based reasoning method to realize the intelligent optimal selection of the abrasive blocks in barrel finishing. The determination of related parameters in this method is emphatically discussed. The implementation of this method is simple and easy to use. Using the actual machining parts data for verification, this method not only can meet the machining requirements but also can quickly and accurately select the abrasive blocks used to machine the new parts. Case-based reasoning is a suitable method for the optimal selection of abrasive blocks. And expert knowledge is spreading and accumulating with the continuous improvement of the case base, and the accuracy of the optimal selection of abrasive blocks is also improving, which will lay a necessary foundation for the effective implementation of the barrel finishing process and contribute significantly to the improvement of its efficiency.

However, due to the complexity of the barrel finishing process and numerous factors affecting the optimal selection of the abrasive blocks, it is necessary to optimize the parameters of abrasive blocks optimization and further improve the construction of the case base in the future work.

Data Availability

The gear parts data used to support the findings of this study have been deposited in the figshare repository (10.6084/m9.figshare.9742439).

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] F. Hashimoto, H. Yamaguchi, P. Krajnik et al., "Abrasive fine-finishing technology," *CIRP Annals*, vol. 65, no. 2, pp. 597–620, 2016.

[2] A. Boschetto and L. Bottini, "Surface improvement of fused deposition modeling parts by barrel finishing," *Rapid Prototyping Journal*, vol. 21, no. 6, pp. 686–696, 2015.

[3] S. Q. Yang, W. H. Li, X. H. Li, J. Hao-zeng, and G. Yun-song, "Research development of mass finishing for high-performance parts," *Surface Technology*, vol. 48, no. 10, pp. 13–24, 2019.

[4] Y. Li, Q. Liu, and W. Zhang, "CNC cutting database system oriented to service manufacturing," *Computer Integrated Manufacturing Systems*, vol. 20, no. 9, pp. 2221–2230, 2014.

[5] S. Q. Yang and W. H. Li, *Surface Finishing Theory and New Technology*, Springer Press, Berlin, Germany, 2018.

[6] Y. W. Wang, S. Q. Yang, S. C. Yang et al., "Effect of characteristic parameters of the abrasive blocks on rolling effect," *Journal of Taiyuan University of Technology*, vol. 26, no. 4, pp. 46–51, 1995.

[7] R. Schank, *Dynamic Memory: A Theory of Reminding and Learning in Computers and People*, Cambridge University Press, Cambridge, UK, 1982.

[8] J. Ahn, M. Park, H. S. Lee et al., "Covariance effect analysis of similarity measurement methods for early construction cost estimation using case-based reasoning," *Automation in Construction*, vol. 81, pp. 254–266, 2017.

[9] Z. Jiang, Y. Jiang, Y. Wang, H. Zhang, H. Cao, and G. Tian, "A hybrid approach of rough set and case-based reasoning to remanufacturing process planning," *Journal of Intelligent Manufacturing*, vol. 30, no. 1, pp. 19–32, 2019.

[10] D. Brown, A. Aldea, R. Harrison, C. Martin, and I. Bayley, "Temporal case-based reasoning for type 1 diabetes mellitus bolus insulin decision support," *Artificial Intelligence in Medicine*, vol. 85, pp. 28–42, 2018.

[11] M. R. Khosravani, S. Nasiri, and K. Weinberg, "Application of case-based reasoning in a fault detection system on production of drippers," *Applied Soft Computing*, vol. 75, pp. 227–232, 2019.

[12] M. A. Mohammed, M. K. Abd Ghani, N. Arunkumar et al., "Genetic case-based reasoning for improved mobile phone faults diagnosis," *Computers & Electrical Engineering*, vol. 71, pp. 212–222, 2018.

[13] H. D. Qiu, J. Y. Tian, S. Q. Yang et al., "Fusion modeling of the hot mill based-on case-based reasoning," *Iron and Steel*, vol. 50, no. 4, pp. 88–94, 2015.

[14] X. M. Li, X. D. Lin, Z. S. Feng, and L. De-gang, "Fault diagnosis case-based reasoning of anti-surge control system of a certain type aero-engine," *Science Technology and Engineering*, vol. 18, no. 21, pp. 320–326, 2018.

[15] L. Rintala, M. Leikola, C. Sauer et al., "Designing gold extraction processes: performance study of a case-based reasoning system," *Minerals Engineering*, vol. 109, pp. 42–53, 2017.

[16] J. F. Han and X. L. Yu, "Research on case-based reasoning technology and its application," *Scientific and Technological Information*, vol. 18, pp. 119-120, 2007.

[17] F. G. Li, Z. W. Ni, S. L. Yang, and H. Ling, "Attribute reduction and its performance evaluation in case-based reasoning," *Journal of Tsinghua University (Natural Science Edition)*, vol. 46, no. s1, pp. 1025–1029, 2006.

[18] G. Finnie and Z. Sun, "R5 model for case-based reasoning," *Knowledge-Based Systems*, vol. 16, no. 1, pp. 59–65, 2003.

[19] B. Smyth, M. T. Keane, and P. Cunningham, "Hierarchial case-based reasoning intergrating case-based and decompositional problem-solving teehniques for plant-control software design," *IEEE Transactions on Knowledge and Data Engineering*, vol. 13, no. 5, pp. 793–812, 2001.

[20] H. J. Liu and S. B. Jing, "Quality traceability of machining process of aerospace large thin-wall parts based on CBR," *Manufacturing Automation*, vol. 40, no. 4, pp. 3–7, 2018.

[21] Y. M. Hou and C. Y. n Xu, "A review of the research on case-based reasoning," *Journal of Yanshan University (Philosophy and Social Sciences Edition)*, vol. 12, no. 4, pp. 102–108, 2011.

[22] A.-J. Yan, Q. Li-min, and P. Wang, "A comparative study of attribute weights assignment for case-based reasoning," *Journal of Automation*, vol. 40, no. 9, pp. 1896–1902, 2014.

[23] T. L. Saaty, "Analytic hierarchy process," in *Encyclopedia of Operations Research and Management Science*, Springer, New York, NY, USA, 2001.

[24] P. Chazara, S. Negny, and L. Montastruc, "Flexible knowledge representation and new similarity measure: application on case based reasoning for waste treatment," *Expert Systems with Applications*, vol. 58, pp. 143–154, 2016.

[25] K. G. Xiang, Z. Q. Liu, and X. Ai, "Development of high-speed cutting database system based on hybrid reasoning," *Computer Integrated Manufacturing System*, vol. 12, no. 3, pp. 420–427, 2006.

[26] W. K. Chen, W. W. Fan, and Z. Q. Li, "Cutting database system of large machine tool parts based on hybrid reasoning method," *China Mechanical Engineering*, vol. 26, no. 7, pp. 923–928, 2015.

[27] F. Zhou, Z. g. Jiang, and H. Zhang, "Remanufacturing process design of waste parts based on improved case-based reasoning," *Journal of Hubei University of Technology*, vol. 29, no. 5, pp. 30–34, 2014.

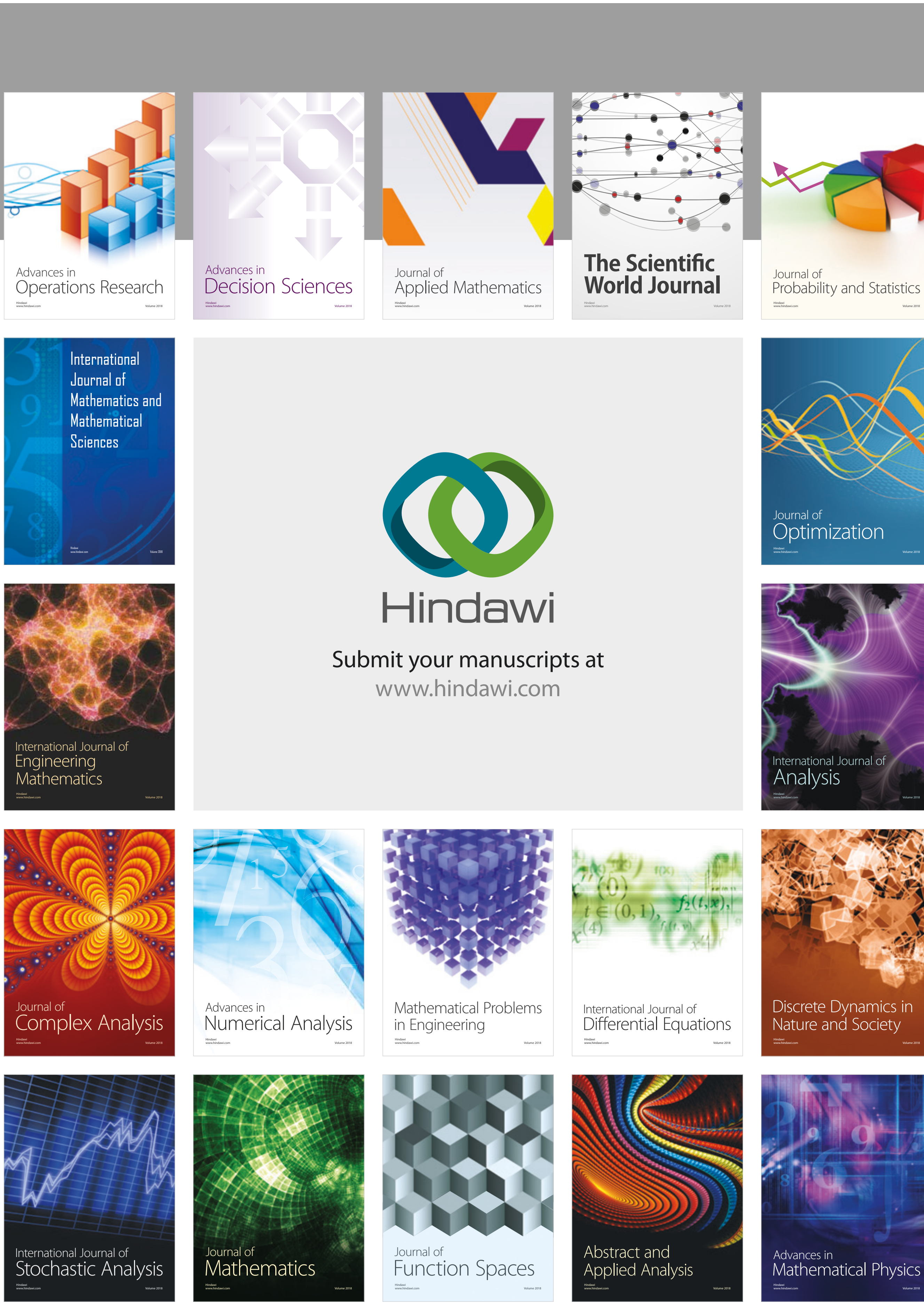
[28] C. Numthong and S. Butdee, "The knowledge based system for forging process design based on case-based reasoning and finite element method," *American International Journal of Research in Science, Technology, Engineering & Mathematics*, vol. 5, no. 2, pp. 45–54, 2012.

[29] T. Xu, N. S. Wade, E. M. Davidson, P. C. Taylor, S. D. J. McArthur, and W. G. Garlick, "Case-based reasoning for coordinated voltage control on distribution networks," *Electric Power Systems Research*, vol. 81, no. 12, pp. 2088–2098, 2011.

[30] L. H. GAN, *Experimental Research and Numerical Analysis on the Intersection Line of Pinehole Ultrasonic Deburring*, Taiyuan University of Technology, Taiyuan, China, 2015.

[31] J. J. Wang, *Research on Case-Based Reasoning in Decision Support System*, Hefei University of Technology, Hefei, China, 2010.

[32] R. Cai, W. B. Rowe, J. L. Moruzzi, and M. N. Morgan, "Intelligent grinding assistant (IGA(©))—system development part I intelligent grinding database," *International Journal of Advanced Manufacturing Technology*, vol. 35, no. 1-2, pp. 75–85, 2007.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