Research on Intelligent Design of Machine Tool Guide Rail Based on Case-based Reasoning

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Abstract. In order to solve the problem of low efficiency of machine tool guide rail design, reduce design cost and shorten design cycle, a guide rail design method based on case-based reasoning is proposed. First, the framework of the intelligent design system for machine tool guide rails is constructed; based on the water injection principle WFT in the communication field, by establishing the rationality index of weight distribution, the Lagrangian function is constructed to optimize the weights, and the convergent water injection distribution algorithm is obtained. Similarity calculation performs case retrieval, and makes corresponding parameterized modifications to similar cases. The research results show that the intelligent design method of the machine tool guide rail can quickly and automatically retrieve similar cases, so as to realize the intelligence and automation of the machine tool guide rail design, speed up the product design process, and improve the design efficiency.

1. Introduction

Case-based reasoning (CBR) is a relatively new reasoning technology and machine learning method in the field of artificial intelligence. At present, scholars at domestic and international have carried out extensive and in-depth research on CBR implementation methods. Jun Wang et al. studied the knowledge-based intelligent design system knowledge base construction method[1]. Guofu Yin et al. studied the modern design theory and method of mechanical products facing the information age[2]. Wang P et al. proposed a new case retrieval method based on self-organizing mapping and fuzzy similarity priority ratio[3]. Yanwei Zhao et al. proposed a method for case retrieval based on the extension distance theory[4]. Analysis of the above-mentioned literature shows that the key to the realization of the CBR method is to express the knowledge according to the characteristics of the design domain knowledge, and to use the corresponding retrieval method to quickly and accurately find the required case.

This paper draws on the principle of water injection WFT in the field of communication, by establishing the rationality index of weight distribution, constructing Lagrangian function to optimize the weights, and obtaining a convergent water injection distribution algorithm. And through the similarity meter for case retrieval, a CBR-based guideway design method is proposed, and the framework of the machine tool guideway intelligent design system is constructed.

2. Research on key technologies of intelligent design of machine tool guide rails

2.1 Knowledge expression of machine tool guide rail parameters

Using ontology theory to uniformly express product design requirements knowledge and abstract
descriptions according to certain rules is an effective way to solve the problem of requirement description, which can fundamentally solve the consistent understanding of demand information and realize the sharing and reuse of product demand knowledge.

![Knowledge expression of guide rail parameters](image)

In the process of expressing the product design requirement knowledge ontology, people always process the requirement knowledge according to a certain level of information granularity. The acquired requirement knowledge must be decomposed at multiple granularities to better establish the requirement knowledge base and guide the subsequent intelligent product design.

2.2. Research on the method of weight distribution of guide rail attribute nodes

Drawing lessons from the water injection principle WFT in the communication field, the optimal distribution mechanism of channel power is applied to the distribution of attribute weights, and a WFT-based distribution method is obtained (WFA)\(^5\). The descriptive formula of attribute weight allocation according to WFT is:

\[
R = \sum_{i=1}^{n} \log_2(1 + \alpha_i^2 \omega_i), \sum_{i=1}^{n} \omega_i = 1
\]  

(1)

In the formula, \(R\) is the rationality index of weight distribution (corresponding to the capacity maximization index of channel power allocation in WFT). \(\alpha\) represents the importance of the \(i\)-th attribute, that is, the case library. The degree of correlation between the \(i\)-th attribute in the output and the output can be determined by calculating its correlation coefficient, that is:

\[
\alpha_i = \frac{\sum_{k=1}^{n} (x_{i,k} - \bar{x}_i)(y_k - \bar{y})}{\sqrt{\sum_{k=1}^{n} (x_{i,k} - \bar{x}_i)^2} \sqrt{\sum_{k=1}^{n} (y_k - \bar{y})^2}}
\]

(2)

Among them, \(\bar{x}_i\) represents the mean value of the characteristic value of the \(i\)-th attribute, and \(\bar{y}\) represents the mean value of all cases in the case library. In order to calculate the attribute weight, the Lagrangian function needs to be constructed according to the WFT solution idea. Combining equation (1), the Lagrangian function is obtained as follows:

\[
L(\omega, \lambda) = \sum_{i=1}^{n} \log_2(1 + \alpha_i^2 \omega_i) + \lambda(1 - \sum_{i=1}^{n} \omega_i)
\]

(3)

Among them, \(\lambda\) is the Lagrangian operator. The meaning of \(L(\omega, \lambda)\) is that the weight assignment is reasonable under the constraint condition of formula (1). After obtaining the partial derivative of \(\omega_i\) in
equation (3), we get:

$$\frac{\partial L}{\partial \omega_i} = \frac{1}{\ln 2} \frac{\alpha_i^2}{(1 + \alpha_i^2 \omega_i)} - \lambda = 0, i = 1, 1, \ldots, n$$  \hspace{1cm} (4)$$

From this, the weight assigned to each attribute can be solved. Taking into account the constraint condition of $\omega_i \geq 0$ in formula (1), the weight calculation formula is

$$\omega_i = \left[ \frac{1}{n} \left( 1 + \sum_{i=1}^{n} 1/\alpha_i^2 \right) - \frac{1}{\alpha_i^2} \right]^{+}$$  \hspace{1cm} (5)$$

2.3 Calculation method of similarity of rail case

Case retrieval is the core of CBR. Its purpose is to retrieve similar cases to solve the current case problem from a large number of cases with as few references as possible, as the basis for solving the current problem [6]. In order to improve the efficiency and accuracy of case retrieval, the calculation of attribute similarity requires comprehensive consideration of both object-type and numerical-type attribute similarities. The similarity of numerical attributes is expressed:

$$Sim(J_1, J_2) = 1 - \frac{\max \left( Depth(Lcs(j_1, j_2)) \right)}{\max \left( Depth(C_i) \right)}, C_i \in C_N$$  \hspace{1cm} (6)$$

In the formula, $Depth(Lcs(j_1, j_2))$ represents the common parent concept with the closest distance between two given concepts, $C_1$ is the current concept that needs to be calculated, $C_N$ is all concepts, and $Depth(C_i)$ represents a concept in the concept tree. The similarity of numerical attributes is expressed:

$$Sim_{n}(C_1, C_2) = 1 - \frac{|a - b|}{a}$$  \hspace{1cm} (7)$$

In the formula, $a$, $b$ are the specific attribute values of certain types of attributes of concepts $C_1$, $C_2$. The weighted attribute similarity is expressed:

$$Sim_{w}(C_1, C_2) = Sim_{n}(C_1, C_2) \times \left( \sum_{i=1}^{n} \omega_i \times Sim_{n} \right)$$  \hspace{1cm} (8)$$

2.4. Case modification

In order to further filter the case collection, it is necessary to sort the extracted similar cases. Set a threshold $\delta$, such as $\delta = 0.90$, when the overall similarity $S \geq \delta$, it can be considered that the similar case basically meets the design requirements, and this case can be used directly. When $0.6 \leq S < 0.9$, you need to modify the similar cases before selecting. When $S < 0.6$, the retrieved case cannot be regarded as a similar case, and a brand-new design is required according to the requirements.

3. Examples of intelligent design system for machine tool guide rails

3.1 The framework of the intelligent design system for machine tool guide rails

This paper uses the VB.NET programming language and Visual Studio 2015 as the development platform to propose a case-based reasoning-based intelligent design system framework for machine tool guide rails, as shown in Figure 2.
3.2 Example of Intelligent Design System for Machine Tool Guide

In this paper, by calling the similar cases in the case library, then modifying the similar cases, and finally saving the results in the relevant database and knowledge base, the method realizes the efficient and rapid design of the machine tool guide rail. The main interface of the system is shown in Figure 3. Enter the user name and password in Figure 3, and click the login button. We can enter the relevant parameters in the guide rail design in Figure 4, and then click the OK button, the system will pop up the machine tool guide rail case retrieval result interface as shown in Figure 5.
Figure 4 System input parameter interface

Figure 5 Case search result interface

Figure 5 shows the instance similarity based on the example retrieval results. The maximum instance similarity of the retrieval results in this example is 0.67, which is less than the threshold and cannot fully meet the needs of customers. The use needs to modify the retrieved examples.

4. Conclusion
This article first classifies machine tool guide rail knowledge based on the characteristics of design knowledge and experience, and then constructs a case-based reasoning-based intelligent design system framework. Finally, it discusses the attribute weight assignment method of case-based reasoning in machine tool guide rail design and case retrieval based on attribute similarity. Algorithms and other key technical issues have been studied, and an intelligent design system for machine tool guide rails under the VB environment has been developed to assist the rapid design of machine tool guide rails. It can be seen from the application analysis that this paper constructs the framework of the intelligent design system for machine tool guide rails, uses the water injection distribution algorithm to assign attribute weights, and uses attribute similarity-based knowledge retrieval and reasoning methods to assist mechanical product design, which can effectively improve design efficiency and degree of intelligence.

Acknowledgments
This research was funded by General Project of Beijing Municipal Education Commission Science...
and Technology Plan(KM202011232012), Beijing Municipal Science and Technology Project (Z191100002019004).

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