Available online at www.sciencedirect.com
SCIENCE DIRECT

International Journal of Machine Tools & Manufacture 46 (2006) 107–113

INTERNATIONAL JOURNAL OF MACHINE TOOLS & MANUFACTURE DESIGN, RESEARCH AND APPLICATION

www.elsevier.com/locate/ijmactool

Fuzzy similarity-based rough set method for case-based reasoning and its application in tool selection

Ya-jun Jiang, Jun Chen*, Xue-yu Ruan

National Die and Mold CAD Engineering Research Center, Shanghai Jiao Tong University, 1954 Huashan Road, Shanghai 200030, Peoples' Republic of China

Received 14 March 2005; accepted 5 May 2005
Available online 21 June 2005

Abstract

Case-based reasoning (CBR) embodied in die and mold NC machining will extend the application of knowledge-based system by utilizing previous cases and experience. However, redundant features may not only dramatically increase the case memory, but also make the case retrieval algorithm more complicated. Additionally, traditional methods of feature weighting limit the development of CBR methodology. This paper presents a novel methodology to apply fuzzy similarity-based Rough Set algorithm in feature weighting and reduction for CBR system. The algorithm is used in tool selection for die and mold NC machining. The proposed method does not need to discretize continuous or real-valued features included in cases, from which can effectively reduce information loss. The weight of feature a_i is computed based on the difference of its dependency defined as $\gamma_A - \gamma_{A-\{a_i\}}$, which also represents the significance of the corresponding feature. If the difference is equal to 0, the feature is considered to be redundant and should be removed. Finally, a case study is also implemented to prove the proposed method.

Keywords: Case-based reasoning; Tool selection; Feature weighting; Feature reduction; Fuzzy similarity-based rough set

1. Introduction

With the development of modern manufacturing industry, die and mold has been becoming one of main ways to manufacture various products in recent years. Nowadays manufacturing of die and mold is mainly completed on NC machines or machining centers, therefore, the selection of appropriate cutting tools plays an important role in the process planning. It influences not only the surface quality of die and mold cavity, but also affects the machining cost and efficiency. Tool selection usually includes selection of tool materials, tool type and tool parameters. Even with the advance of CAD/CAM software presently, this activity remains an interactive activity in most instances. The main reason is that cutting tool selection is a complicated task which requires considerable experience and knowledge [1]. To realize automation of tool selection, many researchers have attempted to embody such experience and knowledge in knowledge-based system for process planning [2–4]. Knowledge-based rule reasoning systems were developed. The main sources of knowledge for these intelligent systems are machinery and production handbook, tooling engineers or domain experts. Shen [5] investigated the decision making and learning strategies for determining cutting tools, including to select the correct cutting tools, to determine the optimal parameters and number of cuts. Zhao [6] describes a novel concept for the integration of a CAD system and a knowledge based system of cutting tool selection and conditions for turning operations—EXCATS. This system is able to generate the component representation model from CAD data, and a set of rules is established for automatic determination of tools. ANN is another approach to determine optimum cutting tools. Santochi [7] designed neural networks for the automated selection of technological parameters of a cutting tool, such as insert grade, normal clearance angle, normal rake angle, cutting edge inclination angle included angle and etc.

Most of above mentioned knowledge-based systems for tool selection are based on rule reasoning methodology.

* Corresponding author. Tel.: +21 6281 3430 8318.
E-mail address: jun_chen@sjtu.edu.cn (J. Chen).

0890-6955/$ - see front matter
doi:10.1016/j.ijmachtools.2005.05.003

However, in unstructured domain it is not convenient to acquire and represent such kind of knowledge and experience. Furthermore, knowledge acquisition for RBR is the bottleneck which needs close cooperation of domain experts and knowledge engineers. Case-based reasoning (CBR), as another complementary method, has been developed for tool selection. While selecting tools for die and mold machining, engineers have to take into account a large number of factors including properties of die and mold materials, operation requirement and die and mold geometric features. Generally, they will spontaneously recollect similar cases encountered previously, and then revise them for new problems. CBR just simulates such thinking and decision process. Liu [8] and Wang [9] applied CBR in selection of tools and cutting conditions for high speed machining. Zhang [10] established an intelligent design system of NC cutter based on CBR which is composed of a case library and the code machining reasoning mechanism.

CBR systems solve problems by reusing the solutions to similar problems stored as cases in a case base [11]. CBR systems for tool selection exert the use of previous machining data in new process problems and extend the application of process planning systems. But there are several key issues which should be further considered in CBR system. The traditional CBR approach usually includes case retrieval, case reuse, case revise and case retain—so-called '4R process'. Case retrieval is one of the most important issues for CBR. Usually, a similarity function based on K-NN is used for case retrieval, however, if the case includes noisy and inconsistent features it will become sensitive. Another problem to case retrieval is how to determine feature weights which are used for case similarity analysis and identify irrelevant and redundant features of the case. In order to make the case more compact and increase the efficiency of retrieval, those redundant features should be removed. Recently, many researchers have conducted their research on fuzzy set and rough set application in feature weighting and reduction. Salamó [12, 13] analyzed and justified the relationship between weighting and case reduction methods based on rough set approach and presented two reduction techniques. Cao [14] proposed a fuzzy-rough method for feature weighting and case reduction. Above mentioned algorithms have been successfully used in case retrieval. In die and mold manufacturing, a CBR system usually involves continuous features, and how to deal with them is another important issue. Several researchers [15,16] discretized the real-valued data set beforehand and produced a new data set with crisp values. Yet whatever discretization methods are, they may lead to information loss of the system. Therefore, in this paper a novel method of feature weighting and reduction is proposed by applying fuzzy similarity based rough set for the CBR system, and the proposed method is used in tool selection for die and mold machining operation. Both continuous and noisy features of cases are considered in this method.

2. Fuzzy similarity-based rough set

Classical rough set theory, proposed by Pawlak [17] in 1982, is a mathematical tool to deal with inexact, uncertain or vague knowledge. It formed upper and lower approximation defined on the indiscernibility relation. Compared with other theories, rough set theory which does not require transcendental knowledge and other related information has been widely applied in artificial intelligence, knowledge discovery, mode recognition and system analysis during the last decade. Classical rough set can only deal with discrete or symbolic attributes in the decision table, however, in reality it is most often the case that the values of attributes may be both crisp and real-valued, and this is where classical rough set theory encounters a problem [18]. One method to deal with those real-valued data (also called continuous values in this paper) is to discretize the data set, but it may lead to lose some information, which will greatly influence the quality of classification results. In recent years it is an interesting subject for many researchers to extend the concept of classical rough set on the base of a similarity or tolerance relation [19,20]. These relations express weaker forms of indiscernibility and, usually, are not equivalence relations. In fact, Refs. [21,22] have also pointed out that the classical rough set theory built on a partition induced by equivalence relations may not provide a realistic view of relationships between elements in the real-world applications.

2.1. Upper and lower approximation of fuzzy similarity-based rough set

Suppose $I=\langle U,A\cup D,V,f\rangle$ is a decision table, where U called universe is a finite non-empty set of objects, $U\neq\emptyset$; $A\cup D$ is the set of attributes. For $a\in A\cup D, f{:}U\rightarrow V_a$, where V_a is the value set of attribute a; and f is the information function.

For any subset of attributes $B\subseteq A$, the fuzzy relation R_B defined on U can be written as:

$$R_B=\{(x,y)\in U\times U:\mu_{R_B}(x,y)\}. \tag{1}$$

where $R_B\in F(U\times U)$, $\mu_{R_B}(x,y)$ is membership degree of (x,y), $\mu_{R_B}(x,y)\in[0,1]$. And its magnitude reflects the extent of (x,y) in possession of relation R_B. If R_B has following properties, we called it fuzzy similarity relation.

(1) Symmetry: $\mu_{R_B}(x,y)=\mu_{R_B}(y,x),\ \forall x,y\in U$,
(2) Reflexivity: $\mu_{R_B}(x,x)=1,\ \forall x\in U$.

Therefore, given a non-empty set of finite objects U, for any object $x\in U$, we define the similarity classes on fuzzy similarity relation R_B denoted as $R_B^{\lambda}(x)$ under threshold λ. $R_B^{\lambda}(x)$ means the set of objects which are similar to object x