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Integrating multi-granularity model and similarity measurement for transforming process data into different granularity knowledge

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ABSTRACT

The core of intelligent manufacturing is to incorporate the expert knowledge in manufacturing process, and knowledge transformation is the key to knowledge accumulation and application. In this paper, the research carried on transformation for different granularity knowledge from the cases of sheet metal parts in process planning. First of all, this paper analyzes the difference of organization structure between process data and knowledge in the base. The multi-granularity model of process knowledge is established in the form of tuple, which helps to clarify the hierarchy structure and internal relations. Thereafter, the concrete process is presented to transform single granularity process data into multi-granularity process knowledge, i.e., process data extraction, state determination and knowledge construction. With respect to state determination, similarity measure methods for different granularity knowledge are established to reduce the redundancy in the transformation process. As a novel approach, sequence alignment based on edit distance is proposed to calculate similarity exactly between two process flows. Finally, the knowledge transformation tool for different granularity knowledge is developed to enhance knowledge acquisition and improve the strength of knowledge reuse in fabrication order design for sheet metal parts through application of the above method. Also an example is given to illustrate the usefulness of the proposed method.

1. Introduction

Intelligent manufacturing technology increasingly becomes the key technology for knowledge-driven, automation and flexibility in manufacturing process to satisfying rapidly varying market requirements [1,2]. Since intelligence is the ability to make use of knowledge to solve practical problems [3], knowledge is the foundation and kernel of intelligence. Most traditional manufacturing process depended upon professional engineers of specific knowledge area to seek specific solution [4]. Consequently, the intelligent system in supporting manufacturing process is urgently needed to allow the design of new and inventive solutions with non-experiential domain background using the knowledge base [4,5]. That is to say, the core of intelligent manufacturing is how to incorporate the expert knowledge into manufacturing processes for realizing intelligence, which is reflected in knowledge acquisition [6,7], storage and application of the knowledge base. As the pivotal link between design and manufacturing [8], process planning is an extremely complex activity with high comprehensiveness and creativeness, and the whole procedure of process planning cannot do without effective support of process knowledge. As a consequence, process knowledge is the core and key element in realizing the intelligence for the process planning information system in manufacturing industries. With the development of manufacturing informatization, Computer Aided Process Planning system has been widely used in aircraft manufacturing industries, which has accumulated a large quantity of process data. As the crystallization of proficient engineers, process data contains a vast of process knowledge. For instance, with a great variety of parts and forming process methods, fabrication order design for aircraft sheet metal parts is a knowledge-intensive process. The fabrication order of each part contains knowledge of process flow design, process resource selection, part description, process method description and so on. How to acquire the implied process knowledge from process data is urgent to solve for improving the intelligence of CAPP system.

Owing to the diversity, complexity and experience of process knowledge, the solutions of many problems come from existing successful cases. CBR(Case-Based Reasoning) is an approach to problem solving and sustained learning based on the specific knowledge of previously experienced, concrete problem situations [9]. Since it avoids starting from a scratch, CBR has been successfully applied in process planning [10,11] to allow a process planner to retrieve, reuse, revise, and retain existing solutions to similar past problems [12,13]. CBR

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provides a powerful learning ability to use past experiences as a basis for dealing with new problems, and facilitates the knowledge acquisition process by reducing the time required to elicit solutions from experts [14]. Moreover, as the system continues to grow, its ability to deal with the problems increases [15].

A case is usually represented by a problem statement and an associated solution. The typical representation of the case could roughly be divided into two categories: feature vector and hierarchical tree structures. For the former, a case is described in a set of attributes, while a case is composed a number of classification modules at different levels of the database-tree for the latter. A large case-base requires a complex and efficient indexing mechanism and techniques to eliminate redundant or contradictory cases [16]. In the last decades, most of the research developments are more focus on the stage of retrieval and similarity of problem pairs. As a consequence, many different methods have been developed such as feature-based similarity measure [10,17,18], improved cosine similarity measure [19], combining case indexing and similarity matrix based on the constructed ontology [20], part similarity measurement using ontology and multi-criteria decision making technique [21], similarity evaluation based on the fuzzy rules [22,23], the nearest neighbor retrieval [24] and artificial bee colony [25]. In addition, some cases can only be described by hierarchical tree structures [14]. Therefore, similarity measures for hierarchical cases have been provided in many researches [14,26–28]. Both the tree structures and node labels' concept should be compared for similarity evaluation between tree structured cases.

Nevertheless, CBR has suffered from some major drawbacks such as case adaptation and knowledge elicitation in recent years [12,29]. Hence, adaptation knowledge acquisition derived from the cases has been paid more and more attention. To conquer the problem, case-based mining [30,31] have been developed to mine a quality case base from a raw case set automatically. By incorporating the dependency parser with rule-based chunking, Zhao et al. [32] achieved extracting the dependencies of the noun phrases and verb phrases from sentences to generate relation triples. Crawa et al. [33] developed an approach that assembles adaptation training data from the case-base itself, and learns adaptation knowledge that refines initial CBR solutions retrieved from the case-base. To acquire adaptation knowledge from a case-base, Assali and Lenne [34] presented a semi-automatic approach based on Formal Concept Analysis techniques. Castro-Schez and Murillo [35] proposed a new fuzzy learning algorithm to generate the If-Then rules for case classification to facilitate knowledge acquisition. By using neural network to implement the dynamic classification and indexing of cases, Huang et al. [36] set up the case-based knowledge acquisition model for process planning. Although the application of CBR methods has fully exploited process route planning knowledge, other fine-grained knowledge implied in process data has not been exploited such as selection of machine tool and tooling, determination of process parameters, and process terminology.

After acquiring adaptation knowledge, the newly solved problem would be added as new case knowledge at retain stage. These researches provided very useful guidelines for adaptation knowledge acquisition. However, the granularity of knowledge is coarse since the knowledge acquired is usually the whole case. In fact, it requires different levels and different granularity process knowledge in the process of problem-solving. In other words, users often deal with data having hierarchical structures measured at different levels of granulations [37]. Also, except adaptation knowledge, it causes that the rest part of case would be stored repeatedly. Upon current time, very few efforts have been done on the research on the fine-granularity knowledge acquisition from the case. In the same time, before storing adaptation knowledge into knowledge base, it is also necessary to evaluate similarity with the historical cases. As the solution part of the process planning case, process flow is the most important adaptation knowledge. The similarity measurement model for process flow is indispensable to develop in case retain stage. Liu et al. [38] combined operation encoding and Euclidean distance to calculate the similarity between two process routes. To avoid the disadvantage caused by local dissimilarity, the largest subset of similar sequences is applied to evaluate the similarity among process routes [39]. With the largest subset of similar sequences as measurement factor, Zhang et al. [40] proposed a multi-level comprehensive method for the similarity calculation between two process routes. In addition, Zhou and Dai [41] employed sequence alignment technology in bioinformatics to establish the best alignment between two process routes, based on which their similarity is calculated. However, the above methods for process route similarity based on operation encoding still suffer from their disadvantages: since operation encoding is classified according to the machining method, two operations have the same code that can't guarantee they are exactly the same in fact. That is to say, simplifying the process routes, to a certain extent, brings the adverse impact on the accuracy of similarity calculation among the process routes. Aiming at these shortcomings, a novel approach for process flow similarity is proposed in this paper.

The purpose of this paper is to establish task-oriented multi-granularity process knowledge model in order to realize transformation from the process data to various process knowledge in fabrication order design, including process route planning, machine tool selection, tooling selection, process parameters design, etc. At the same time, a similarity calculation model is proposed to eliminate duplicate data to ensure the uniqueness of knowledge. The rest of this paper is organized as follows. The next section makes a comparative analysis between process knowledge and process data, and gives the multi-granularity knowledge model. In Section 3, we present the state definition and determination for process data, and put forward the different transformation process in line with the state. In Section 4, taking into account both structures and values, we establish the similarity computation model for different granularity knowledge to reduce the generation of redundant knowledge. An example of fabrication order design is conducted to explain the feasibility about the above method in Section 5. At last Section 6 draws conclusions and points out future work.

2. Comparative analysis between process knowledge and process data

2.1. The structure analysis for process knowledge and process data

As can be seen in Fig. 1, the case of process planning can be decomposed into two aspects: the information for the design part and process flow. For the former, it consists of many features as following: function class, material type, material specification, primary process method and so on. For the latter, it deals with processes that convert raw materials into more useful and valuable products. More specifically, a process flow can be regarded as a set of working procedures arranged in the order. The working procedure is composed of following attributes: applied process method, type of work, process description, machine tool and tooling.

The concept of granularity embodies refined division of objects. Thereby, the way granularity is described reflects the organization form of process knowledge to a certain extent in the knowledge base. Using a single granularity description for process planning only can obtain a coarse representation on case or process flow, so that it is difficult to fully understand varieties of comprehensive knowledge required in process planning. Furthermore, it is unable to satisfy the requirements on flexible use during the each step in process planning for process planners. Multi-granularity structure is used to organize manufacturing knowledge, which reflects the internal relations among them. Knowledge granularity is proposed to measure the different levels of knowledge refinement. The multi-granularity description of process knowledge is not only conducive to standardization and normalization of process knowledge, but also better for flexible reuse in process planning. The appropriate process knowledge granule can avoid