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Modeling of process parameter selection with mathematical logic for process planning

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ABSTRACT

Process planning is the systematic determination of detailed methods by which workpieces or parts can be manufactured economically and competitively from initial stages to finished stages. One of the key problems of computer-aided process planning (CAPP), however, is the complexity of process knowledge representation of process planning and the diversity of manufacturing background. Process knowledge representation and inference mechanism of process parameter selection is one of the most important issues in the research on CAPP. A proper methodology for modeling inference mechanism of process parameter selection, hence, is essential for selection of process parameters in process planning. The paper presents an atomic inference engine model of process parameter selection in process planning using mathematical logic. The methodology of modeling the inference mechanism of process parameter selection is proposed with backward chaining of mathematical logic that is a form of goal-directed reasoning. An illustrative case has been analyzed using the proposed approach to demonstrate its potential application in the real manufacturing environment, by combining with a practical application of a hole-making in a industrially relevant workpiece. The outcomes of this work provide a process reasoning mechanism for process parameter selection in process planning and thus alleviate automated process reasoning problems in process planning.

1. Introduction

Process planning is the systematic determination of detailed methods by which workpieces or parts can be manufactured economically and competitively from initial stages to finished stages [1]. Process planning, as defined by Chang et al., is also an act of preparing detailed operation instructions to transform an engineering design to a final part or processing documentation for the manufacture of a piece part or assembly [2,3]. Computer-aided process planning (CAPP) is an essential component of a computer integrated manufacturing (CIM) system. The purpose of CAPP is to automate process planning tasks so that the process plans are generated consistently [4].

However, a successful automatic machining process planning system relies greatly on a good process reasoning mechanism which is still the basic crux of process planning. One of key problems of CAPP, furthermore, is the complexity of process knowledge representation of process planning and the diversity of manufacturing background. Although increasing researchers and engineers from both academia and industry have also attempted to develop CAPP systems, the application of most CAPP systems relies on the experienced process planners and thus the totally automatic process planning using computers is still far from being realized. An additional complication is due to the fact that process knowledge representation and inference mechanism in process planning are difficult in a changing manufacturing environment and different industries. Hence, we have presented a systematic methodology to address this problem in the previous work [5], which represents process knowledge by the first- and second-order logic of mathematical logic and maps them onto manufacturing resources. It should be noted, however, that process parameter selection in process planning is yet one of the most important subtasks in the research on automated process planning, and also a bottleneck hampering the automation process of CAPP. Therefore, it is of great importance to properly create a systematic approach of process knowledge representation and inference mechanism of process parameter selection in process planning, both qualitatively and quantitatively. In this paper, an atomic inference engine model of process parameter selection in process planning (ML-PPS) is presented using mathematical logic to address this problem. ML-PPS provides a process reasoning mechanism for process parameter selection in process planning and thus alleviates automated process reasoning problems in process planning.

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The first section introduces the background of the research field and the significance of modeling inference mechanism of process parameter selection in process planning. The second section briefly reviews the previous work on selection of machine tools and cutting tools and their parameters. The third section presents a systematic methodology of modeling process parameter selection using mathematical logic. The fourth section analyzes an illustrative case using the proposed approach to demonstrate its potential application in the real manufacturing environment, by combining with a practical application of making a hole in a industrially relevant workpiece. The remainder of this paper discusses the gains achieved by the systematic methodology of modeling of processparameter selection with mathematical logic for process planning.

2. Review of previous work

Since Niebel pioneered the idea of using computers in process planning [6], increased research work has been undertaken in the area of computer-aided manufacturing and process planning. Therein, numerous systems have been developed for selection of machine tools and cutting tools in process planning. Arezoo et al. classify such generative tool selection systems in about 1980s into four levels of automation and sophistication as follows [7]:

- The first-level systems provide graphics with a catalogue of available cutting tools to select the tools from this catalogue [8,9].
- The second-level systems offer all combinations of tool sets to select the best tool set according to the user's experience [10].

The above two levels consider the geometric aspects of the component during machining and consider no cutting technology.

- The third-level systems incorporate some 'tool preference criteria' into tool selection [11,12]. These systems do not only find all combinations of tool sets geometrically capable of machining the component, but also automatically select the best set in terms of cost.
- The fourth-level systems [13] are more flexible not only to seek the cheapest way of machining a component but also to take the experience of the end user into account. This level of automation has the advantages of the third-level systems while avoiding their rigid system design.

In the past years, most automatic tool selection systems have been developed to select the optimum tools for a specific operation or a set of operations from the standpoint of specific machining processes, such as milling, turning [14–22]. Maropoulos et al. present an intelligent tool selection system (ITS-KBS) with a knowledge-based module to be used for turning and boring operations on a cylindrical component [18,23,24]. Edalew et al. develop a dynamic programming-based system that utilizes mathematical modules and heuristic data to determine and calculate cutting parameters and total component cost [19]. Pande et al. report a computer-assisted process planning system (PC-CAPP) for prismatic components, which incorporates various modules including component feature representation, automatic selection of machine tools and process parameter, etc. [25]. Many of these systems are generally knowledge-based with a simplified technology module, which can be applied for calculation of cutting conditions, selection of tools in operations of specific machining processes.

Recent advances in computer hardware and software technology have led to several methods in calculation of efficient cutting parameters and selection of a tool or combination of tools for a specific operation or set of operations [26]. In this regard, these methods mainly involve various techniques: fuzzy set theory, expert system, object-oriented technology, artificial neural networks (ANNs), etc. One of these techniques or hybrid of the two of these techniques are used to select machine tools, cutting tools and their process parameters. For instance, fuzzy models are built for metal cutting data selection or environmental benign process planning selection using the fuzzy set theory [27,28]. Hashmi et al. apply fuzzy logic principles to intelligent selection of machining parameters in process planning [29–31]. Chang et al. utilize a self-organizing fuzzy-nets optimization (FNO) system for the machining conditions: cutting speed, feed, and depth of cut, with respect to various combinations of the criteria, minimum unit production cost, minimum unit production time and minimum number of passes [32]. Arezoo et al. use an expert system for selection of cutting tools and conditions of turning operations [7]. Chen et al. present hybrid of fuzzy logic and expert system for selection of cutters and cutting conditions based on partial and imprecise information [33]. Fernandes et al. propose an object-oriented methodology for selecting the tooling parameters for parts in a CIM environment [34]. Santochi et al. employ ANNs in automated selection of technological parameters of cutting tools in turning [35]. However, although many systems have been developed for selection of machine tools and cutting tools using various and numerous methods, the effective methodology of process parameters selection in process planning is still troubled by process inference logic representation, inference information complexity and diversity, and unreasonable structure of inference mechanism. In this work, we have made an attempt in the direction of building a systematic approach to address this problem using mathematical logic and mapping process knowledge into the manufacturing resources [5], but the problem is still far from being solved completely.

Therefore, there is a significant dearth of similar systematic work for modeling of process parameter selection. A more systematic study in the paper has been carried out and an inference engine model of process parameter selection using mathematical logic is then presented. The methodology of modeling the inference mechanism of process parameter selection is proposed with backward chaining of mathematical logic that is a form of goal-directed reasoning.

3. Modeling of process parameter selection with mathematical logic

3.1. Process parameter selection

Process parameter selection, as a sub-function of process planning, is a complex task which requires considerable experience and knowledge, where these process parameters form the basis of metal cutting operations. Traditionally process parameter selection is manually done by experienced operators and engineers, sometimes by means of various and numerous machining data handbooks. In this method, on the one hand, since tool selection mainly depends on practical experience, numerous errors and inconsistencies are often the result. Selection of the wrong process parameters of the tools generally leads to infeasible or inconsistent process plans. Incorrect process plans had to be scrapped on the shop floor. Selection of the process parameters is thus one of the primary concerns of process planning. Furthermore, the right tool along with the right process parameters must be selected in order to guarantee that full use of