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Application of genetic algorithm to computer-aided process planning in preliminary and detailed planning

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ABSTRACT

Computer-aided process planning (CAPP) is an important interface between computer-aided design (CAD) and computer-aided manufacturing (CAM) in the computer integrated manufacturing (CIM) environment. A good process plan of a part is built up based on two elements: (1) optimized sequence of the operations of the part; and (2) optimized selection of the machine, cutting tool and tool access direction (TAD) for each operation. On the other hand, two levels of planning in the process planning is suggested: (1) preliminary and (2) secondary and detailed planning. In this paper for the preliminary stage, the feasible sequences of operations are generated based on the analysis of constraints and using a genetic algorithm (GA). Then in the detailed planning stage, using a genetic algorithm again which prunes the initial feasible sequences, the optimized operations sequence and the optimized selection of the machine, cutting tool, and TAD for each operation are obtained. By applying the proposed GA in two levels of planning, the CAPP system can generate optimal or near-optimal process plans based on a selected criterion. A number of case studies are carried out to demonstrate the feasibility and robustness of the proposed algorithm. This algorithm performs well on all the test problems, exceeding or matching the solution quality of the results reported in the literature for most problems. The main contribution of this work is to emerge the preliminary and detailed planning, implementation of compulsive and additive constraints, optimization sequence of the operations of the part, and optimization selection of machine, cutting tool and TAD for each operation using the proposed GA, simultaneously.

1. Introduction

Computer-aided process planning (CAPP) is considered the key technology for computer-aided design/manufacturing (CAD/CAM) integration. It consists of the determination of processes and parameters required to convert a block into a finished product. The process planning activity includes interpretation of design data, selection and sequencing of operation to manufacture the part, selection of machines and cutting tools, determination of cutting parameters, choice of jigs and fixtures, and calculation of machining times and costs. To clarify the process planning, parts are represented by manufacturing features. Fig. 1 shows a part composed of m features, in which each feature can be manufactured by one or more machining operations (n operations in total for the part). Each operation can be executed by several alternative plans if different machines, cutting tools, or setup plans are chosen for this operation (Case and Harun Wan, 2000; Maropoulos and Baker, 2000). A process plan for a part consists of all operations needed to process the part and their relevant machines, cutting tools, tool access directions (TADs), and operation sequences.

Two major tasks are involved within the process planning, namely, operation selection and operation sequencing. The operation selection is based on the form-feature geometry, its technological requirements and mapping these specifications to the appropriate operation or series of operations (Weill et al., 1982). Operation sequencing is concerned with selection of machining operations in steps that can produce each form feature of the part by satisfying relevant technological constraints specified in part drawing, while minimizing the number of setups, maximizing the machines utilization, minimizing the number of tool changes, etc. In other words, the operation sequencing problem in the process planning is considered to produce a part with the objective of minimizing the sum of machine, setup, and tool change costs. In general, the problem has combinatorial characteristics and complex precedence relations, which makes the problem difficult to solve. A good process plan for a part is built up based on two elements: (1) the optimized sequence of the

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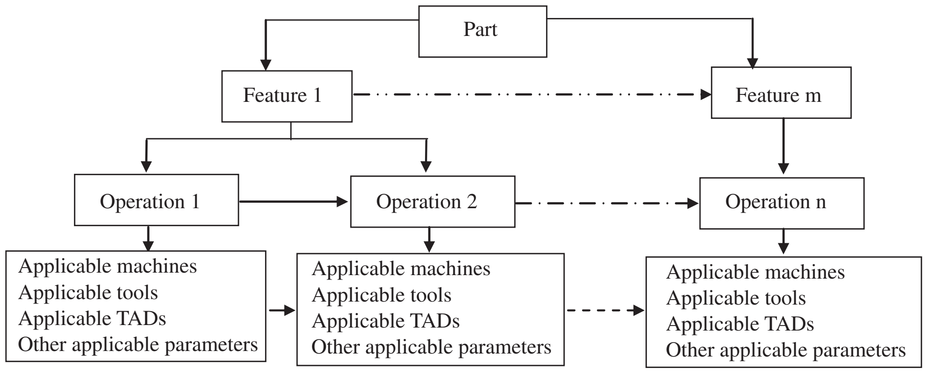

Fig. 1. Representation of a process plan.

operations of the part and (2) the optimized selection of machine, cutting tool, and TAD for each operation. Although many CAPP systems have been reported in literature, only few of them have considered the optimization of the sequence of operations, and suggested alternative sequence of operations or process plans. Operation sequencing is a complex task exhibiting the combinatorial nature. As the operations sequencing problem involves various interdependent constraints, it is very difficult to formulate and solve this problem using integer programming and dynamic programming methods alone.

Evolutionary algorithms, which mimic living organisms in achieving optimal survival solutions, can often outperform conventional optimization methods. In the past two decades, GA has been widely applied for solving complex manufacturing problems, e.g. job shop scheduling and process planning. In this paper, a genetic algorithm (GA) is chosen for solving this optimization problem. The process planning is divided into preliminary planning and secondary/detailed planning. In the preliminary stage, feasible sequences of operations is carried out considering compulsive constraints of operations using the proposed GA and during the secondary and detailed level of planning, the optimized sequence of the operations of the part, and the optimized selection of the machine, cutting tool, and TAD for each operation is acquired using a genetic algorithm considering additive constraints as well. It means during the secondary of planning, relevant manufacturing information, such as, machine tools, cutting tools, and TADs for the operations of the part is determined.

This paper is organized into five sections. Section 2 gives a literature review on the related research work. Section 3 illustrates our approach for determining the optimized operations sequence and determines a machine, cutting tool, and TAD for each operation. System implementation and a case study are presented in Section 4. Finally, conclusions are summarized in Section 5.

2. Related research work

Computer-aided process planning, being a part of manufacturing automation solutions, has received much attention in both academia and industry during the last three decades (Cay and Chassapis, 1997). CAPP systems can be categorized into variant or generative types or their combinations. In a variant system, a set of standard plans is established and maintained for each part family. The plans are then retrieved using a classification and coding scheme as used for group technology. In a generative system, a process plan for a new part is automatically created, synthesizing the process information. For this purpose, the decision logic is built into the computer system as decision tree, decision table, knowledge-based expert system and the like.

Feature sequencing and operation sequencing are two different levels of process sequencing in the literature. Feature sequencing is concerned with high-level process planning activities, e.g. setup planning (Chen and LeClair, 1994). As a part may contain many features, a proper sequence for machining these features is vital in achieving efficient and high-quality manufacture of the part. Here, a setup refers to a group of features that can be machined in a certain fixturing configuration. Feature sequencing is also relevant to minimization of the number of setup and tool changes. On the other hand, operation sequencing deals with the problem of determining in what order to perform a set of selected operations such that the resulting sequence satisfies the precedence constraints established by both parts and operations (Lee et al., 2001). The nature of operation sequence generation is to develop a feasible and optimal sequence of operations for a part based upon the technical requirements, including part specifications in the design, the given manufacturing resources, and certain goals, such as cost or time target. The operation sequence generation problem can usually be modeled as large-scale and combinational optimization problems (Qiao et al., 2000). Integer programming, genetic algorithms, search heuristics, hybrid genetic algorithm, and simulated annealing approaches have been applied to operation sequencing.

Lin and Wang (1993) proposed a two-phase problem solving structure. In phase I, they focused on the selection of process plans for a group of parts to be machined for the next planning cycle. It was formulated and solved as a dynamic programming problem. In phase II, two 0–1 integer programming models are formulated and solved for selection and sequencing operations and tools for those process plans. But regarding a single sequence of operations may not be the best for all the situations in a changing production environment with multiple objectives, such as minimizing number of setups, maximizing machine utilization, and minimizing number of tool changes. Reddy et al. (1999) applied a genetic algorithm as a global search technique for a quick identification of optimal or near-optimal operation sequences in a dynamic planning environment. Since sequences can be obtained quickly, this algorithm can actually be used by the process planner to generate alternative feasible sequences for the prevailing operating environment. Qiao et al. (2000) used a GA-based approach to machining operation sequencing for prismatic parts. Four types of process planning rules including precedence rules, clustering rules, adjacent order rules and optimization rules were considered and encompassed quantitatively in the fitness calculations for alternative operation sequences. The proposed GA proves effective for machining operation sequencing of prismatic parts, by incorporating various production environment considerations into process planning. Lee et al. (2001) developed six local search