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Journal of Materials Processing Technology 117 (2001) 75–83

Journal of Materials Processing Technology

www.elsevier.com/locate/jmatprotec

Intelligent approaches to tolerance allocation and manufacturing operations selection in process planning

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Received 21 June 2000

Abstract

In the modern manufacturing environment, alternative sets of manufacturing operations can normally be generated for machining one feature of a part. Each set of manufacturing operations results in a specific manufacturing cost in terms of the allocated tolerances, and requires a specific set of manufacturing resources, such as machines, fixtures/jigs and cutting tools. In this paper, the problems of allocating tolerances to the manufacturing operations and selecting exactly one representative from the alternative sets of manufacturing operations for machining one feature of the part are formulated. The purpose is to minimize, for all the features to be machined, the sum of the costs of the selected sets of manufacturing operations and the dissimilarities in their manufacturing resource requirements. The techniques of the genetic algorithm and the Hopfield neural network are adopted as possible approaches to solve these problems. The genetic algorithm is utilized to generate the optimal tolerance for each of the manufacturing operations, and the Hopfield neural network is adopted to solve the manufacturing operations selection problem. An illustrative example is given to demonstrate the efficiency of the proposed approaches. Indeed, the proposed approaches show the potential of working towards the optimal solutions to the tolerance allocation problem and the manufacturing operations selection problem in process planning.

Keywords: Computer aided process planning; Hopfield neural network; Genetic algorithm; Tolerance allocation; Manufacturing operations selection

1. Introduction

With the emergence of the global manufacturing era, the manufacturing environment has become increasingly competitive, as markets become more dynamic and customer-driven. As a result, the need for flexibility, efficiency, and quality has imposed a major change on manufacturing industries. Indeed, the product cost has a surging effect on manufacturing performance and competitiveness. The tolerance allocation and the manufacturing operations selection in process planning are two essential factors governing the product cost in manufacturing. In this connection, the development of more efficient approaches has become an impending necessity in solving the tolerance allocation problem and the manufacturing operations selection problem in process planning.

Computer aided process planning (CAPP) has assumed an important role in manufacturing, in particular, to cope with the demands for flexibility, efficiency, and quality in the modern dynamic industrial environment. CAPP can be defined as the use of computers to determine systematically the procedures of manufacturing a product, so that the end product will be functional, economical, and of an acceptable quality [1]. However, most generative CAPP systems normally assume that only one set of sequenced manufacturing operations can be generated to machine one feature. Each set of sequenced manufacturing operations is composed of several manufacturing operations so ordered to machine the feature to meet design requirements. The tolerance of each manufacturing operation is pre-determined and unchangeable. This study proposes a more practical and flexible point of view, where a number of alternative sets of sequenced manufacturing operations are generated for each feature. The tolerance of each operation is not pre-determined, and can be optimized in order to minimize the manufacturing cost to machine each feature. Each alternative set of manufacturing operations results in a specific manufacturing cost, and requires a specific set of manufacturing resources, e.g., machines, fixtures/jigs, and cutting tools. The objective of this research is therefore to: (1) determine the tolerance for each sequenced manufacturing operation, so as to minimize the manufacturing cost for machining a feature; (2) select exactly one representative from the alternative sets of manufacturing operations for each feature, so as to minimize the sum of the manufacturing costs of the selected sets of manufacturing operations, and

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0924-0136/01/$ – see front matter
PII: S0924-0136(01)01154-2

Nomenclature

a, b	the indices of alternative sets of manufacturing operations for all features, $\forall a, b \in N^{\mathrm{s}}$
C^{p}	the sum of manufacturing costs and dissimilarities among the selected manufacturing operation sets to machine a part
C_a^{s}	the cost of manufacturing operation set a
C_i^{o}	the manufacturing cost of operation i according to tolerance δ_i
d_{ab}	the weighted hamming distance between manufacturing operation sets S_a and S_b
i	the index of the operation in a set of manufacturing operations
k, l	the indices of the features in a part
N^{f}	the total number of features to be machined in a part
N^{r}	the total number of manufacturing resources requirements, such as machines, fixtures/jigs and cutting tools
N^{s}	the total number of alternative sets of manufacturing operations to machine all the features in a part, where $\bigcup_{k=1}^{N^{\mathrm{f}}} N_k^{\mathrm{s}} = N^{\mathrm{s}}$
N_a^{o}	the number of manufacturing operations in set a
N_k^{s}	the number of alternative sets of manufacturing operations to machine feature k
O_{iak}	the operation i in manufacturing operation set a to machine feature k
q	the index of manufacturing resources used by all features in a part
S_a, S_b	the alternative manufacturing operation sets a and b
S_{ak}	manufacturing operation set a to machine feature k
ΔV_i^{δ}	the allowable variation of stock removal for operation i
w_q	the weighting coefficient of the manufacturing resources
x_a (x_b)	$\begin{cases} 1 & \text{if manufacturing operation set } a\ (b), \text{ is selected} \\ 0 & \text{otherwise} \end{cases}$
y_{ka}	$\begin{cases} 1 & \text{if } a \in N_k^{\mathrm{s}} \text{ for all } k \in \{1, 2, \ldots, N^{\mathrm{f}}\} \\ 0 & \text{otherwise} \end{cases}$

Greek letters

δ_i	the machining tolerance of operation i
δ_i^{ll}	the lower limit of the machining tolerance of operation i
δ_i^{ul}	the upper limit of the machining tolerance of operation i

the dissimilarities in their manufacturing resource requirements, for the total number of features in one part.

The tolerance allocation and manufacturing operations selection problems have received relatively little attention in the literature. Dong [2] proposed a mathematical model to select the optimal set of manufacturing operations for each feature according to the manufacturing costs associated with the tolerances. However, the tolerance levels in Dong's model were pre-determined, and were the same for every set of manufacturing operations. Zhang and Wang [3] suggested a mathematical model to identify the optimal representative from a number of alternative sets of manufacturing operations by minimizing the manufacturing cost in terms of tolerances. At the same time, the tolerance and the intermediate manufacturing dimension are decided. Zhang and Wang [4] also used the same mathematical model to determine the optimal tolerance for a given set of manufacturing operations by using simulated annealing. However, simulated annealing often takes a long time to obtain the optimal solution to the problem. Knapp and Wang [5] utilized the back-propagation neural network to select one set of manufacturing operations for each feature. However, none of the approaches discussed above has attempted to solve both the tolerance allocation problem and the manufacturing operations selection problem simultaneously, for minimizing the sum of the manufacturing costs of the selected sets of manufacturing operations in terms of the allocated tolerances, and the dissimilarities in their manufacturing resource requirements for machining all the features in a part.

In this study, two mathematical models are constructed to represent the behavior of the tolerance allocation problem and the manufacturing operations selection problem. A genetic algorithm is introduced to solve the optimal tolerance allocation problem. By using the results from the tolerance allocation procedure, a Hopfield neural network is proposed to select the optimal sets of manufacturing operations for all the features of the part. The detailed energy function of the Hopfield neural network specially constructed for solving such a problem is established. An illustrative example is presented to demonstrate the efficiency of the approaches developed in this paper. Indeed, the results show that the approaches proposed in this paper are powerful but simple means to provide high quality solutions to the tolerance allocation problem and the manufacturing operations selection problem in process planning.

2. Problem statement

In generative CAPP systems, several sets of alternative manufacturing operations can be generated to machine one feature. This is done so because a number of manufacturing operations can be used to machine the same feature to reach the identical design requirements by utilizing the intelligent inference method (Fig. 1). For instance, in order to machine a hole in a prismatic part, the operations can be drilling, rough-boring, semi-finish-boring, finish-boring, rough-reaming, semi-finish-reaming, and finish-reaming. Hence, the search tree can be constructed according to the precision requirements of the operations for machining a hole in the