Available online at www.sciencedirect.com
ScienceDirect
Computers in Industry 58 (2007) 295–303
COMPUTERS IN INDUSTRY
www.elsevier.com/locate/compind

Sequencing of interacting prismatic machining features for process planning

Zhenkai Liu [a], Lihui Wang [b,*]

[a] Institute for Information Technology, National Research Council of Canada, Ottawa, Ontario K1A 0R6, Canada
[b] Integrated Manufacturing Technologies Institute, National Research Council of Canada, London, Ontario N6G 4X8, Canada

Received 17 September 2004; accepted 3 July 2006
Available online 1 September 2006

Abstract

Today, feature-based process planning has been popular in academia and industry with its ability to rigorously integrate design and manufacturing. To date, research on feature sequencing is mainly focused on using expert systems or knowledge-based systems, geometric based approaches, unsupervised-learning or artificial neural network, and genetic algorithms. The approach presented in this paper, however, is a hybrid one using both knowledge-based rules and geometric reasoning rules. In addition to feature sequencing rules formulation, our research contributions consist of: (1) determining machining precedence constraints by a set of defined knowledge-based rules, (2) grouping machining features into setups based on tool approaching directions, and (3) sequencing features within each setup through geometric reasoning. The sequence of materials (features) to be removed depends on two types of interactions: adjacent interaction and volumetric interaction. A set of rules for geometric reasoning is therefore developed to generate feature sequence. The developed approach has been implemented as the *Sequence Generator* module in a *Distributed Process Planning* system and is validated through a case study.

Keywords: Process planning; Machining features; Feature interaction; Feature sequencing; Geometric reasoning

1. Introduction

Modern manufacturing today is constantly challenged by stiff global competition, low-volume large-variety production, requirements for high productivity and product quality, as well as short lead-time from design to manufacturing. During the last two decades, CAD/CAM technologies have been extensively developed to automate and integrate various activities in the design and manufacturing cycle. Despite these efforts, difficulties remain in the integration of CAD and CAM domains, mainly due to their diverse informational needs. CAD focuses on part specific geometry and technology while CAM concerns more on process-specific features and their accuracies. Integration efforts thus attempt to augment or translate information across the two domains.

Feature-based process planning plays a crucial role in such an integration effort. In feature-based process planning, machining features are recognized from the part CAD model, and machining processes and their sequences are determined based on the features and other machining-relevant technological information. Features are considered as a main factor in the CAD and CAM integration because various design, engineering and manufacturing data can be associated with a feature. As a part may contain many features, proper sequencing of machining these features is crucial in achieving efficient and high-quality manufacture of the part [1]. All corresponding actions (tool selection, setup planning, etc.) in process planning can be chained with features during feature sequencing.

In order to machine a single part with several machining features, a number of different setups may be required. Machining features within a setup may or may not be intersecting, which further complicates the sequencing of features [2]. Within a setup, one feature may require several tools to make. The sequencing of features within one setup that requires only a minimum number of tool changes is important in reducing part machining time. To address the above problems, we developed an approach for feature sequencing in process planning. In our approach, machining features are analyzed with a set of knowledge-based (KB) rules to determine the machining precedence constraints. These machining features are grouped together based on defined tool approaching directions. Feature sequencing in each group is partially dependent on the geometric interactions between

* Corresponding author. Tel.: +1 519 430 7084; fax: +1 519 430 7090.
E-mail address: lihui.wang@nrc.gc.ca (L. Wang).

0166-3615/$ – see front matter
doi:10.1016/j.compind.2006.07.003

features. A set of rules for geometric reasoning (GR) is also developed to generate feature sequence.

This paper is organized into five sections. Section 2 gives a literature review on related research work. Section 3 depicts our approach to determining feature sequence for prismatic parts with interacting features. System implementation and a case study are presented in Section 4. Finally, conclusions and future work are summarized in Section 5.

2. Related research work

Computer-aided process planning (CAPP), being a part of manufacturing automation solutions, has received many attentions in both academia and industry during the past 30 years [3]. There are mainly two approaches to the automation of process planning: variant and generative. The variant approach is based on the assumption that for a given part design there may be some similar parts that have been produced in the past. The logical way to produce a new process plan is to look for a similar one and modify it to satisfy the new design requirements. The generative approach, however, is different. It produces an entirely new process plan for the new part based on the design data and the available process planning knowledge.

Owning to various advantages, a feature-based approach has been adopted to many process planning systems. This is because that the feature-based approach is widely used for part modelling in CAD as it can facilitate the representation of various types of part data in a meaningful form needed to drive the automated CAPP [4].

Machining process sequencing is a crucial part in process planning. Feature sequencing and operation sequencing are two differently levels of process sequencing. Feature sequence is concerned with high-level process planning activities such as setup planning [2]. 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 minimizing 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 [5]. 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 problems can usually be modelled as large-scale and combinational optimization problems [6]. Integer programming [7], genetic algorithms [6,8], branch and fanthoming algorithms [5], search heuristics [9], as well as hybrid genetic algorithm and simulated annealing [10] approaches have been applied to operation sequencing.

During feature sequencing, handling feature interactions becomes the critical issue for achieving a satisfactory result. An interaction between features occurs when the cutting of one feature affects the subsequent machining of another feature. Sometime, the machining of certain features may accidentally destroy the necessary entities such as fixturing surfaces, locating surfaces, and supporting surfaces required for machining other features. Interactions have long been an important topic in both feature recognition literature and process planning literature because of the difficulties they present. Interactions make it hard to identify features and hard to sequence them properly in process planning. Faheem et al. [11] made a distinction between feature interactions and manufacturing interaction. Sormaz [12] proposed a three-phase algorithm for incorporating volumetric feature interactions into process planning. Allada and Agarwal [13] presented a formalization of feature interactions to determine sequencing of machining operations based on a classification schema for the intersecting and non-physical intersecting feature relationships.

Hayes [14] defined an interaction graph that identifies possible feature interactions and resultant sequences to process these features from the pre-defined rules acquired from machinists. By finding the commonality between squaring and the interaction graph, setup and feature sequences can be roughly determined. The system did not discuss the important issue of how the features are collected together in one particular setup.

Chang [15] grouped features into clusters based on the tool-approach direction. He then defined an order of precedence among different features and feed directions used for setup generation. As a result, two levels of sequencing can be determined: (a) the global or part level sequencing determines the final feature clusters and their sequence and (b) the setup level sequencing decides the feasibility of the features to be made in a particular setup. The former finds the feature clusters based on the tool-approach direction. Each feature can only appear in one cluster. On the basis of the pre-defined precedence constraint, a cluster can be refined. The latter refines the clusters, again on the basis of the commonality of the tools. Clusters are reordered if there is any conflict in the pre-defined precedence.

Chen and LeClair [2] proposed an unsupervised-learning approach to cluster features into setups for machining and a memory associative approach to discover the feature sequence within a setup. In their approaches, intersecting and non-intersecting features within a setup are identified and classified. A discover-and-merge algorithm can merge tool graphs of features into a new tool graph. An optimal-tool-sequence algorithm is introduced to find the best sequence across the features in a setup.

Hwang and Miller [16,17] used forward chaining to produce a list of feasible feature sequences in a hybrid blackboard model. Their algorithm has four steps: (1) define the important information for features and feature-related concerns; (2) prioritize the given features according to the given constraints and sorting guidelines; (3) sequence the features; (4) attach the needed operations to the features.

Chen et al. [18] sequenced all the features of a workpiece according to geometric and technological constraints. The task of feature sequencing is converted to a constraint optimization problem which is similar to the traveling salesman problem (TSP). The Hopfield neural net approach for TSP is adopted and