Sequencing of interacting prismatic machining features for process planning

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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.

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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
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 atten-
tions 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.

Owing 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 program-
ming [7], genetic algorithms [6,8], branch and fanthomming
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 interacting 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.

Chen [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
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