Generation of Alternative Feature-Based Models and Precedence Orderings for Machining Applications*

Satyandra K. Gupta† and Dana S. Nau‡

University of Maryland
College Park, MD 20742 USA

Overview

Increasing global competition is challenging the U.S. manufacturing industry to bring competitively-priced, well-designed and well-manufactured products to market in a timely fashion. Since decisions made during the design stage can have significant effects on product cost, quality, and lead time, increasing research attention is being given to integrating engineering design and manufacturing, with a focus on design for manufacturability.

Consider the task of designing and manufacturing machined parts. Often there can be several different ways to machine a part. Which way is best depends on several factors, including dimensions, tolerances, surface finishes, availability of machine tools and cutting tools, fixturability, and optimization criteria. Thus, to evaluate the manufacturability of the proposed design, we may need to consider more than one way to machine it.

This paper outlines our approach for generating and evaluating alternative ways to machine a part. For additional details, see [1]; for other related work, see [2, 3].

Approach

For generating and evaluating the machining alternatives for machined parts, we have developed a generate-and-test methodology to systematically generate and evaluate alternative operation sequences, to see which ones best balance quality against cost. Our approach is illustrated in Fig. 1. Some of the steps shown in Fig. 1 are discussed below.

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†Institute for Systems Research and Department of Mechanical Engineering. Email: skgupta@cs.umd.edu

‡Institute for Systems Research, Department of Computer Science, and Institute for Advanced Computer Studies. Email: nau@cs.umd.edu

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Step 1. For our purposes, a *machining feature* f is the volume swept by the cutting tool during machining. This includes both the *removal volume* (i.e., the portion of f that is capable of cutting), and the *accessibility volume* (i.e., the remaining portion of f). This generalizes the concept of a machining feature used by researchers such as [4]. An FBM (or *feature-based model*) is collection of machinable features, each of which can be created by one or more machining operations.

If we are given an initial FBM F for some part, other FBM's for that part can be produced by manipulating the features in F; and these alternative FBM's will correspond to different sets of machining operations, with different precedence constraints. To generate these alternative FBM's, we use feature manipulation operators for reorienting, enlarging, reducing, splitting or combining the features in F. The basic idea is somewhat similar to the feature algebra described in [4], but the specific operators are different.

We use a variety of pruning strategies to discard unpromising FBM's. For example, we will consider F to be unpromising if it contains features whose dimensions and tolerances appear unreasonable, or if its estimated number of required setups or relative machining time are too large.

Step 2. Due to accessibility and other machining constraints, the set of features that describes a part cannot necessarily be machined in any arbitrary sequence. Instead, these constraints will require that some features be machined before or after other features. However, for a given set of features, usually there will be more than one order in which the features can be machined.

Given an FBM F, we can determine the precedence constraints for F by examining the features in F. For example, if f and g are features for which there is a nonempty intersection between f's accessibility volume, g's removal volume, and the workpiece, then g needs to be made before f. Once we have found the precedence constraints, we can represent them in a graphical structure called the *time-order graph* for F.

loop:

1. Generate an FBM for the part, using heuristic techniques to discard unpromising FBMs.
2. Identify precedence constraints on the FBM.
3. **loop:**
   (a) Use the precedence constraints to generate an operation sequence capable of producing the FBM, using heuristic techniques to discard unpromising operation sequences.
   (b) Estimate the machining accuracy achievable by each of the machining operations in the operation sequence. If the sequence cannot produce the required tolerances and surface finishes, then discard it and go to Step (a).
   (c) Estimate the production cost and time associated with the operation sequence. If the process sequence satisfies the quality and cost optimization criteria, then include it in the list of candidate operation sequences.
   (d) If every promising operation sequence for the FBM has been examined, then exit Step 3.

   repeat
4. If every promising FBM has been examined, then exit, returning the best process sequences that were found.

repeat

Figure 1: Approach for generating and evaluating operation sequences.

Step 3. Once the time-order graph has been constructed, a topological sorting procedure can be used to generate operation sequences that satisfy the precedence constraints; the next task is to select the one that is most preferable. Depending on the particular optimization objectives, we may wish to find the sequence that produces the highest machining accuracy achievable, the lowest machining cost, the lowest production time, or some combination of these measures. We use various empirical and mathematical models to estimate the achievable tolerances and manufacturing costs [5].

Impact

Some of the benefits of our approach are listed below:

1. *Pushing process engineering upstream:* By using domain-specific features, we will be incorporating process-related information in the features themselves. This allows an easy mapping of machining features to machining operations.
2. *A sound theoretical basis:* As opposed to existing rule based approaches, our approach is based on theoretical foundations, which we hope will enable us to make rigorous statements about the soundness, completeness, efficiency, and robustness of the approach.
3. *Focus on alternatives:* The information provided by this research will enable us to provide the necessary information to a manufacturing engineer or a process planning system about the alternative ways in which the part might be machined. Depending upon machine tool availability and/or other constraints specific to plant facilities, one can choose a appropriate process plan.

We anticipate that the results of this research work will be useful in providing a way to speed up the evaluation of new product designs in order to decide how or whether to manufacture them. Such a capability will be especially useful in flexible manufacturing systems, which need to respond quickly to changing demands and opportunities in the marketplace.

References

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