Journal of Manufacturing Systems
Vol. 19/No. 1
2000

Modeling of Manufacturing Feature Interactions for Automated Process Planning

Dusan N. Sormaz, Dept. of Industrial and Manufacturing Systems Engineering, Ohio University, Athens, Ohio. *E-mail:* sormaz@bobcat.ent.ohiou.edu
Behrokh Khoshnevis, Dept. of Industrial and Systems Engineering, University of Southern California, Los Angeles, California. *E-mail:* khoshnev@rcf.usc.edu

Abstract

This paper analyzes manufacturing feature interactions and presents algorithms for handling feature interactions in manufacturing process planning. A feature precedence network, which specifies the constraints for the machining sequence, and an AND-OR graph, which describes alternative representations, are built. Application of required/optional volumes, the AND-OR graph, and the feature precedence network in manufacturing process sequencing is then explained.

Required and optional volumes are defined and their use for analysis of interactions of various machining feature types is explained. Case studies are presented to explain volumetric interactions of holes, slots, and pockets with various dimensions, positions, and orientation in the part geometry. The analysis provides insight into which process-sequencing constraints may be resolved before actual process planning and which have to be postponed to be resolved in final process sequencing.

A three-phase algorithm for incorporating of volumetric feature interactions into manufacturing process planning is proposed. The first phase is creation of an AND-OR graph of alternative feature representations. The second phase is building a feature precedence network for a given part as a set of machining sequence constraints. The third phase is analysis of feature interactions for performing geometric updates of machining features during the process sequencing stage.

Keywords: *Automated Process Planning, Feature Interactions, Manufacturing Features*

Introduction

One of the basic process planning tasks is process sequencing. This task is usually performed after selection of processes for all features in the given design. There are two basic criteria for process sequencing. First, a sequence should fully satisfy design requirements, which may include various tolerance specifications, surface quality, material hardness, and so on. Second, within sequences that satisfy design requirements, one with minimal or near-minimal cost should be selected. Therefore, the process sequence is limited by feature precedence constraints that can be represented by a network structure on the basis of the aforementioned design requirements. The feature precedence network should be built before actual process sequencing starts. To build the feature precedence constraint network, knowledge of particular machining processes, knowledge of design specifications in the given domain (such as metal parts), and both geometric and nongeometric design data must be available. The usual approach is to consider machining features on the part, consider possible interactions between these features, and then build a feature precedence constraint network based on these interactions.

Geometric relationships, *technological* relationships, and *economical* factors have to be considered when building a feature precedence constraint network and, subsequently, determining a sequence in which the specified features should be machined.[1,2] Geometric relationships include possible volumetric interactions between features, and dimensional and geometric tolerances. Technological relationships include constraints imposed by the physics of the machining process and/or availability of resources that are necessary to achieve the tolerances specified by the designer. The economical factors introduce notions of machining time and cost for each feature and the cost associated with the entire process plan. An economical process sequence is the one that yields the minimal overall fabrication time and/or cost.

The issue of feature interactions has received attention by many researchers in the fields of feature recognition and process planning. Early efforts in process planning relied on human reasoning, and the user-specified feature relations were presented in the form of predicate relationships between features. This representation served as the basis for process sequencing. For example, in GARI,[3] if a hole, **h1**, intersects a slot, **s1**, then the symbolic predicate **(intersect h1 s1)** is used to indicate that the hole must be machined before the slot. There is an extended set of similar predicates (for example, **open-from, open-into, perpendicular,** and so on) that are parts of user input to the process planning system. A similar approach has been used in HiMapp[4] and RTCAPP[5] to create partial preconditional trees for feature sequencing.

The geometric nature of feature interactions has led to the introduction of a systematic linkage between process planning and geometric modeling (and design) systems with the aim of automatically generating the predicates directly from the solid model of the design. There are several research systems that have used this approach. The main characteristic of these attempts is that they analyze face patterns for feature recognition and face neighborhoods for derivation of feature interactions. This approach was used in the process planning systems described in Joshi, Vissa, and Chang,[6] in AMPS,[4] and in XCUT.[7] For example, if a cylinder belongs to hole h1 and its neighboring planar face belongs to slot s1, then the relationship **(opens-into h1 s1)** is established between the hole and the slot with the implication that the hole be machined after the slot. Hummel[7] recognizes that classification of features based on precedence relations has far-reaching consequences in process planning procedures.

When features interact, the recognition of machining features and building of the feature precedence network become difficult. Vandenbrande[8] and Vandenbrande and Requicha[9] considered machining features as surface features. They proposed a novel approach to feature recognition that solves virtually all feature interactions and facilitates building of the feature precedence network. Their system, OOFF, defines machining features as both solid volumes and as sets of faces and then performs a series of checks so that the machinability of these features is assured.

This paper discusses volumetric feature interactions that impact the process sequencing task and suggests some guidelines for building suitable feature precedence constraint networks based on these interactions.

Manufacturing Features

In this section, manufacturing features and interactions between them are described. The explanation is based on geometric modeling concepts as they relate to solid objects and solid models. The symbols used in this section correspond to the mathematical set theory ($\subseteq$ = subset, $\subset$ = proper subset, $\varnothing$ = empty set, ∂ = boundary) and Boolean operations on regular 3D sets ($\cap^*$ = intersection, $\cup^*$ = union, $/^*$ = set difference, where the superscript * denotes regular operations). The interested reader should consult the literature in geometric modeling for details.

Feature Definitions

In this paper, it is assumed that manufacturing features are defined by their parameters, as explained in Vandenbrande,[8] chapters 4 and 5. To facilitate the understanding of this paper, a brief explanation of the basic feature definitions as given in Vandenbrande is provided. According to the reference, machining features are machinable in a single machining operation. A machining feature is defined as a volumetric feature (that is, a connected solid entity, see Vandenbrande[8] and Requicha[10]) that is a subset of the volume swept by the cutter in the machining operation. This volume corresponds to the material that is removed in the machining operation. The union of all volumetric features (or delta volume) is equivalent to the volume of total material removed from the stock to obtain the finished part.

Each volumetric feature has a surface feature associated with it. The surface feature is a subset of the volumetric feature boundary that contributes to the part boundary. For a volumetric feature to be present in a given part, its boundary has to contribute to the part boundary (that is, the corresponding surface feature has to be a non-null 2D entity). An example of a volumetric feature and corresponding surface feature is shown in *Figure 1*.

Each machining feature is validated by a set of rules that relate to either of the following groups: Non-intrusion, Presence, Accessibility, and Dimensionality. Non-intrusion rules ensure that there is no volumetric interference between the feature and the part's solid (that is, $V \cap^*$ Part = $\varnothing$). Feature presence rules are used to ensure that the corresponding surface feature exists as a subset of the part's boundary (that is, $\partial V \cap^* \partial$Part $\neq \varnothing$). Accessibility rules perform an analysis of the feature's accessibility for a cutter (and part of the machine spindle) and ensure that neither the cutter nor the spindle intrudes the part while a machining operation is being performed. Dimensionality rules limit the feature parameters (for example, the hole diameter and/or depth of a hole) by the constraints