A Hybrid Feature Recognizer for Machining Process Planning Systems

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Abstract

We describe a hybrid feature recognition method for machining features that integrates three distinct feature recognition methods: graph matching, cell-based maximal volume decomposition, and negative feature decomposition using convex decomposition. Each of these methods has strengths and limitations, which are evaluated separately. We integrate these methods in a sequential workflow, such that each method recognizes features according to its strengths, and successively simplifies the part model for the following methods. We identify two anomalous cases in the application of maximal volume decomposition, and their cure by introducing limiting halfspaces. Feature volumes recognized by all three methods are then combined into a unified hierarchical feature representation, which captures feature interaction information, including geometry-based machining precedence relations.

Keywords:

CAPP, CAM, Feature

1 INTRODUCTION

Process planning systems should be capable of dealing with industrial demands of versatility, flexibility, and agility for product manufacturing. Feature recognition has been considered as a key technology to link design information and manufacturing information, and the development of process planning and cost evaluation systems heavily depends on it. For machining applications, a part must be described in terms of machining features such as slots, steps, and pockets to facilitate downstream applications.

Over the past decade, the technology for machining feature recognition has steadily advanced, but presently there is no satisfactory feature recognizer that relies on a single approach to feature recognition. Each feature recognition method has its own strengths and weaknesses, and superiorities and limitations. Therefore, to develop a more robust and practically complete feature recognition system, multiple feature recognition methods need to be incorporated into the system so that they mutually complement each others' capabilities. This paper presents a hybrid feature recognition system that is being developed as part of the Feature-Based Automatic Process Planning System (FAPPS) [1].

2 PREVIOUS FEATURE RECOGNITION METHODS

There have been attempts to develop hybrid feature recognition algorithms [2]. Laakko and Mäntylä developed a machining feature recognition algorithm that combines a graph-matching method with a rule- and constraint-based system [3]. Gao and Shah proposed a hybrid method that combines graph-matching method with hint-based feature recognition [4]. These previous methods are viewed as enhancements of graph-matching method, not as real combinations of distinctive feature recognition techniques.

This paper considers three distinct feature recognition methods that are to be combined into a hybrid feature recognition system: graph matching (GRP), maximal volume decomposition (MVD), and negative feature decomposition (NFD) using convex decomposition.

2.1 Graph-Matching Method (GRP)

The graph matching method has been very popular in the feature recognition research community [5][6]. In this approach, the B-Rep of a part is represented by a graph whose nodes represent faces and whose arcs represent edges. Features are defined as subgraphs, and the part model is searched for occurrences of each feature subgraph. This approach is efficient and robust at recognizing non-interacting features. However, when features interact, the topological and geometric patterns of the features are destroyed by the interaction. The main problem with the graph matching method is its inability to recognize such interacting features.

2.2 Maximal Volume Decomposition (MVD)

Given a part and its stock material, the delta volume is defined as the set difference between the part and the stock material. The stock material may be specified by the user, or generated from the bounding box of the part. The delta volume is the sum of volume to be removed by machining. The maximal volume decomposition method takes the delta volume of a part as input and decomposes it into large and simple subvolumes called maximal volumes [7]. It has been demonstrated that most maximal volumes correspond to machining features. The half-spaces of a maximal volume are the half-spaces of the model, and it does not have any concave edges.

Maximal volume decomposition method can recognize intersecting features. However, as the number of cells increases, it may suffer from a combinatorial complexity.

2.3 Negative Feature Decomposition (NFD)

Alternating Sum of Volumes with Partitioning (ASVP) is a convex volume decomposition using convex hull, set difference, and cutting operations [8]. It organizes the boundary faces of a part in an outside-in hierarchy, while associating volumetric components with these faces. By systematically combining components according to the hierarchical structure of the decomposition and the face dependency information obtained during decomposition, the ASVP decomposition is converted into the form feature decomposition (FFD). For machining applications,

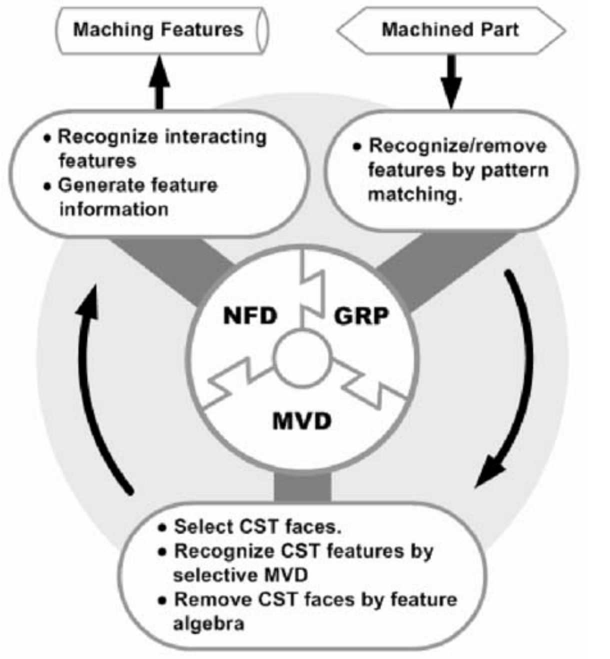

Figure 1: Hybrid feature recognition system.

positive-to-negative conversion is applied to all positive form features, which converts the FFD into a Negative Feature Decomposition (NFD) consisting of a positive base component and negative removal volumes. These negative removal volumes are classified as machining features according to their original face information [9]. This method is able to recognize interacting features.

The NFD approach generates rich feature information, including a hierarchical organization of the features, and feature interactions, including geometry-based machining precedence relations. However, its geometric domain restriction of planar faces, and cylindrical faces that interact with planar faces along circular edges, is a limitation.

3 HYBRID FEATURE RECOGNITION SYSTEM

A key consideration in the development of a hybrid feature recognition system is to combine the different methods effectively so that they mutually complement each others' capabilities, without compromising performance and completeness. Our insight is that each individual feature recognition method can be characterized along an efficiency-versus-richness axis, representing a tradeoff between being fast, or being thorough and robust. This leads us to adopt a sequential workflow, roughly in increasing complexity of the feature recognition methods, in which each method handles what it's good at, and successively simplifies the part model for the following methods. This necessitates a post-processing step to combine all three methods' recognized features into a unified feature representation. An overview of our hybrid feature recognition system is shown in Figure 1.

3.1 Recognition of non-interacting features by GRP

The graph matching approach (GRP) is efficient in recognizing non-interacting features. We apply this method first, primarily to simplify the part model before applying NFD. This obtains the set of non-interacting features. For each set of faces recognized as a feature, the corresponding feature volume is instantiated, and is removed from the part using Boolean operations, obtaining the filtered part with all non-interacting features removed. For Part A shown in Figure 2(a), graph matching recognizes two blind hole features.

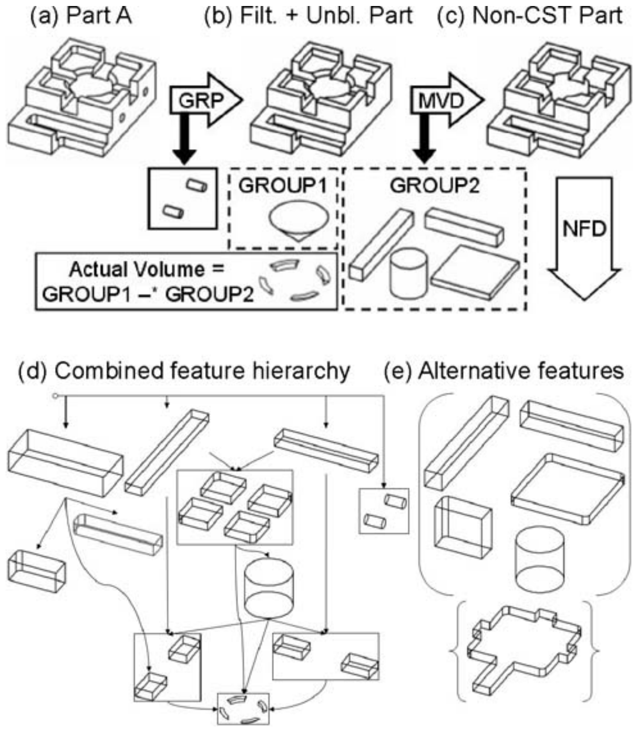

Figure 2: Example of hybrid feature recognition.

As a separate pre-processing step, blends are identified as cylindrical or toroidal faces with straight or circular edges that are tangent-continuous along two non-adjacent edges, and non-planar faces that are adjacent only to other blends. These faces are removed from the part by unblending, which obtains the filtered and unblended part, shown in Figure 2(b). This is the input to the MVD method.

3.2 Selective Maximal Volume Decomposition

Maximal volume decomposition can handle any analytic surfaces, including conical, spherical, and toroidal (CST) faces. However, its cell-based approach may suffer from combinatorial explosion. Selective MVD addresses the combinatorial issue by restricting MVD to a set of faces selected interactively by the user [10].

Recognition of features with CST faces

The selective MVD method has been further developed into a capability to recognize all volumes with CST faces, as follows.

1. Select all CST faces, and all faces adjacent to CST faces, in the delta volume, automatically.
2. Apply selective MVD using the selected faces to obtain subvolumes.
   - Extend all selected faces that have concave edges.
   - Intersect the extended faces with the delta volume, obtaining cells.
   - Compose adjacent cells into maximal volumes if they satisfy the conditions for maximal volumes. (Some subvolumes may fail these conditions.)

Then the subvolumes containing CST faces of the delta volume are the features with CST faces. One restriction in selecting CST faces is that only faces with concave edges are selected, since MVD requires concave edges.

Removal of CST faces

Given the subvolumes generated by the selected MVD, a method has been devised to remove the CST faces from the part, using feature algebra.