

설계특징형상으로부터 가공특징형상 추출 (Incremental Feature Recognition from Feature-based Design Model)

이재열 · 김광수
포항공과대학교 산업공학과

ABSTRACT

In this paper, we propose an incremental approach for recognizing a class of machining features from a feature-based design model as a part design proceeds, utilizing various information such as nominal geometry, design intents, and design feature characteristics. The proposed approach can handle complex intersecting features and protrusion features designed on oblique faces. The class of recognized volumetric machining features can be expressed as Material Removal Shape Element Volumes (MRSEVs), a PDES/STEP-based library of machining features.

Keywords : feature-based design, incremental feature recognition, MRSEVs

1. Introduction

Features are tools for linking product or functional information with geometric and topological information, associating them with design intent, and thus they provide a better approach to product modelling, allowing the designer to think of an object in terms of high-level abstractions rather than a set of low-level geometric information such as faces, loops, edges, and vertices[1]. For this reason, considerable attention is focused on feature modelling to realize fully integrated CAD/CAM systems. There are two paradigms to obtain feature models from the design: *feature recognition* and *feature-based design*.

Feature recognition identifies and groups feature entities from a geometric model: *graph pattern matching*[3,4,6], *convex-hull approach*[7], and *hint-*

based approach[13,14,16]. However, these approaches depend on the nominal geometry of a part so that they cannot recover the designer's intents such as tolerances, attributes, and nongeometric information only available at the design stage.

In the feature-based design approach, the designer specifies the initial CAD model in terms of various features which translate directly into the relevant manufacturing features[1,2,15]. However, design features cannot always be mapped into machining features (e.g., protrusion features). In such a case, the model must be transformed into a set of machining features via feature conversion. A hybrid approach which tries to integrate feature-based design and feature recognition approaches in a design stage is proposed[5,10,12]. This approach overcomes the drawbacks of the above two approaches, and seems to be the most promising methodology. Nevertheless, they have not appropriately handled protrusion features that may interact with other features.

In this paper, we propose an incremental approach for recognizing a class of machining features from the feature-based design model by integrating feature-based design and feature-recognition approaches in a single framework. The incremental feature recognition consists of four main modules depending on the type of design features; base, depression, transition, and protrusion features. The main idea is that this approach can handle feature interactions and deal with a variety of protrusion features including those features designed on oblique faces. A class of recognized machinable features can be expressed as Material Removal Shape Element Volumes (MRSEVs), a PDES/STEP-based library of machining

features[8,9,13], so that we can exchange feature data with other CAD/CAM systems.

The remainder of this paper is organized as follows. Section 2 overviews the system architecture, defines design and machining features that we consider in this paper, and introduces the terminology necessary to describe the recognition method. Section 3 describes the proposed methodology of incremental machining feature recognition from the feature-based design model. In the final section, we conclude with some remarks.

2. System overview

2.1 Parametric design features

To combine features, B-rep models, and geometric constraints in a unified structure, we use a hybrid CSG/B-rep model in an object-oriented programming environment (OOP). Design features are represented as C++ classes with geometric constraints, and ACIS™ solid modeller is used as a solid modelling kernel for the B-rep model that is required to produce nominal feature volumes and to extract machining features during the design process.

There are three main types of design features; 1) *Primary features*, 2) *Transition features*, and 3) *Datum features*. The subclasses of the Primary features are *Prismatic features* and *Rotational features*. Most of the basic features such as pockets, bosses, holes, grooves, and pockets with islands are the instances of the Primary feature class or its subclasses. Transition features include *rounding* and *chamfering* features. A primary design feature is defined as a parametric shape that consists of a feature section, attributes, and a set of constraints. Its profile P is defined in a sketching plane which can be a planar face of another feature or a datum plane. The definition of P is based on parametric constraints to be solved when the feature is created. The constraints define the intrinsic shape of P as well as its position relative to the existing geometry. The profile P can be used as the profile for MRSEVs after feature recognition, which will be explained later.

Parametrically designed features allows the designer to efficiently perform design modifications by simply changing specified relationships, that is, the 2D profile

dimensions. Basically, the user can design a part interactively by using existing features in the feature definition library or by parametrically creating new features in terms of instances of the generic design features. These two alternatives give the user the possibility of choosing a more convenient way of designing features[11].

2.2 Preliminaries

In order to interface with any CAD/CAM systems which use feature representations, it is crucial to represent features in a general and standard interchange format like STEP. Kramer[8,9] has developed a library of MRSEVs, which represent the shapes of volumes that can be removed by machining operations in a 3-axis machine tool, using general-purpose cutting tools. MRSEVs can be defined by EXPRESS and STEP form features. An MRSEV machining feature F is defined as a solid model object that can be removed by a single machining operation in a single setup. The main types or classes of MRSEVs are *primary_mrsev_volume* and *secondary_mrsev_volume*. The subtypes of the *primary_mrsev_volume* are *linear_sweep*, *groove*, *edge_cut*, and *rotation_pocket*. Especially, the *linear_sweep* can represent most of the machining features such as holes and pockets, and each of them can result from sweeping a *nice_closed_profile* along a straight line perpendicular to the plane of the profile. Islands may be included in some types of the pocket.

Let a set of recognized machining features be $FM = \{F_1, F_2, \dots, F_n\}$, a given part P , and a workpiece W . FM is said a *valid* MRSEVs machining model for the given part P if it has the following properties:

- *Completeness*: P can be fully decomposed when the union of all machinable volumetric features F_i contains the delta volume Δ , i.e., $\Delta \subseteq \bigcup_i F_i$, where $\Delta = W -^* P$, and $-^*$, \bigcup^* , and \bigcap^* denote regularized set difference, union, and intersection[16].
- *Nonintrusion*: $F_i \cap^* P = \emptyset$
- *Presence*: $(\bigcup_i F_i -^* F_j) -^* \Delta \neq \emptyset$ and $F_i \cap P \neq \emptyset$, which means at least one face of F_i should contact with P

- **Accessibility:** To remove each machinable feature, a tool should be moved from outside W into the removal volume without intersecting P .

3. Incremental feature recognition

Given a set of design features $DFM = \{DF_1, DF_2, \dots, DF_n\}$, a set of previously recognized machining features FM , and the intermediate part P , the feature recognition algorithm consists of four main mapping modules depending on the type of design feature DF_n to be added. The proposed recognition approach can handle various realistic parts such as the Gehause and ANC test 101 parts shown in Figure 1. Figure 1b shows an incremental design procedure of the Gehause that consists of various design features including protrusion features. Throughout this paper, the detailed recognition algorithm to be explained is based on both parts in Figure 1a.

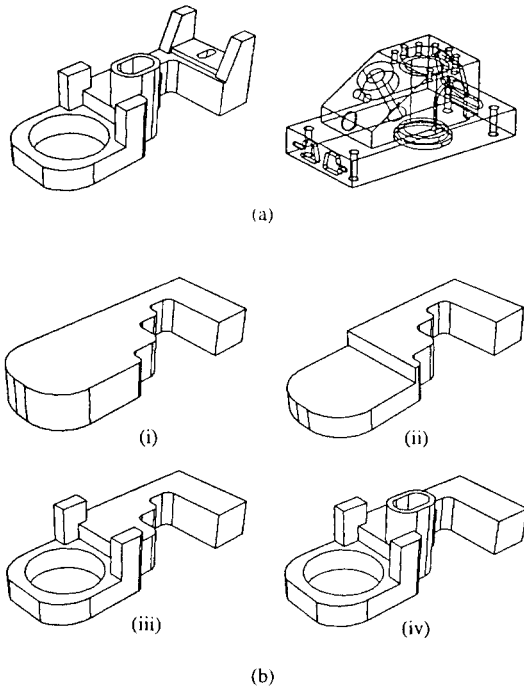


Figure 1. (a) the Gehause and ANC 101 parts, (b) an incremental design procedure of the Gehause

3.1 Finding MRSEVs from Base Feature

A base design feature DF_1 is defined by a parametrically designed 2D section from which its 3D

volume is generated by sweeping. The base design feature created by this approach is typically complex and impossible to be directly mapped onto machining features as shown in Figure 1b(i).

Mapping DF_1 into machining features takes two steps; 1) deriving a raw material W and 2) extracting machining features by differentiating the base design feature from W . The shape of the raw material can be either a minimum enclosing block of the base design feature or a non-block type. However, we assume that the workpiece is a rectangular stock, but its size is variable according to design features and their locations. The machining feature extraction can be formally expressed as finding all F_i such that $F_i \subseteq W - DF_1$. The number of machining features to be derived depends on the shapes of the base design feature and raw material.

Figure 2 shows an extraction example from the base design feature shown in Figure 1b(i). The result shows a workpiece W , a general bottomless pocket F_1 , and another two bottomless pockets (F_2 & F_3). Note that this module generates machining features that can be machined with minimum setups on a 3-axis milling machine. For example, if a feature has several accessibility directions, the feature with the z-axis accessibility direction is preferred. Hence, classifying F_1 as a general bottomless pocket rather than several features is because of this criterion. Similarly, F_2 and F_3 are also recognized as pockets rather than roundings.

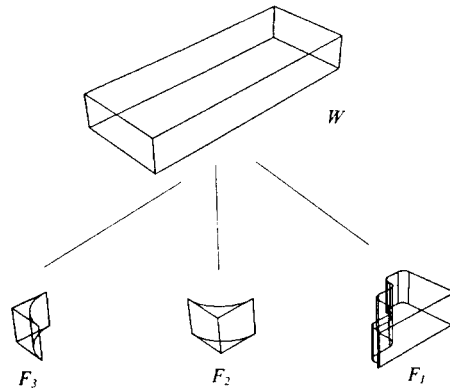


Figure 2. Extraction example from a base design feature

3.2 Mapping Depression Features as MRSEVs

This mapping can be simply done if a depression feature DF_i does not interact with previously recognized machining features since the depression features such as pockets, slots, or holes can be directly mapped into MRSEVs in which each feature section serves the profile of an MRSEV. When interactions occur, the mapping procedure takes the following steps:

- *merging test*: for intersecting features F_i and F_j , test whether they can be merged into a more appropriate feature than using the initial features separately.
- *Feature reduction test*: test whether machining F_i before F_j would make it possible to machine F_j using the smallest feature f of the same class of F_j . That is, if there is a feature f in class (F_j) such that $\text{erv}(f) \subset \text{erv}(F_j)$ and $\Delta -^* \text{erv}(F_i) -^* \text{erv}(F_j) = \Delta -^* \text{erv}(F_i) -^* \text{erv}(f)$, then modify F_j as f , e.g., $f = F_j -^* F_i$ and vice versa.
- *Slicing test*: If above two steps are not satisfied, merge all the intersecting features as Δ_n , and slice Δ_n into *above* and *below* solids along their common accessibility direction. Then, map the above solid into MRSEVs. Continue the same slicing test for the below until below = \emptyset .

Figure 3 shows a recognition example when a depression DF_2 intersects F_2 and F_3 in Figure 2. Note

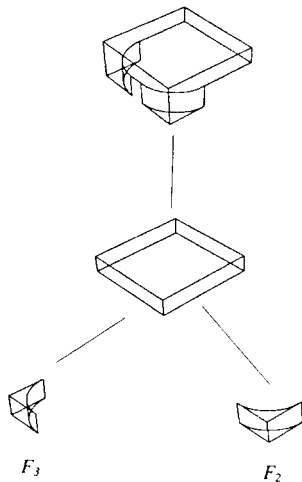


Figure 3. Extraction example from a depression feature

that F_2 and F_3 have shorter depth than previously recognized ones since machining F_4 can remove the volume shared with F_2 and F_3 .

3.3 Mapping Transition Features as MRSEVs

Transition features such as chamfering and rounding can be directly mapped into MRSEVs. If a transition feature is a convex feature, it is a machining feature. Otherwise, if concave, it is considered as the blending of the bottom profile of a feature, which is used to select an appropriate machining tool such as a fillet-ended mill. Figure 4 shows an example of transition feature mapping when concave or convex transitions are added.

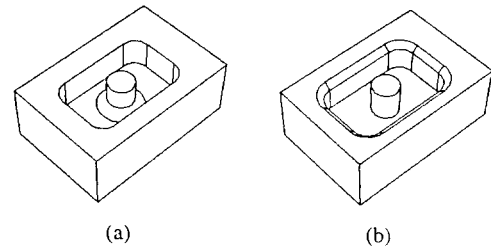


Figure 4. Transition feature: (a) concave, (b) convex

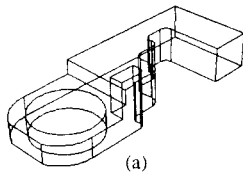
3.4 Mapping Protrusion Features as MRSEVs

In handling a protrusion DF_n , volumes surrounding DF_n have to be extracted and converted to machining features. Thus, the workpiece needs to be increased to compensate for the protrusion feature, if necessary. First, DF_n is divided into *In* and *Out* solids where $In = DF_n \cap^* W$ and $Out = DF_n -^* W$. For $In \neq \emptyset$, intersecting features IF_i are searched for, and then they are modified and reclassified as new MRSEVs according to the location and orientation of DF_n . For $Out \neq \emptyset$, the system enlarges the workpiece W to compensate for *Out* and converts the surrounding volume of W as new features F_i .

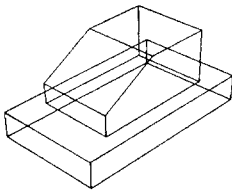
There are three types of protrusion features depending on the relations between their growing directions and accessibility directions of intersecting features (see Figure 5). A type1 protrusion has a growing direction that is same or opposite to the accessibility direction of intersecting features F_k . In this case, the volume of each F_k is modified as $F_k = F_k -^* In$ and redefined as a new MRSEV.

The growing direction of a type2 protrusion feature is

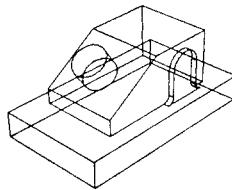
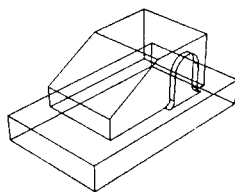
perpendicular to the accessibility direction of an interacting feature or the enlarging direction of W . A type3 protrusion is either type1 or type2 protrusion designed on a oblique face, which has both *In* and *Out* solids. Figure 6 and Figure 7 show the extraction results of type2 and type3 protrusions in Figure 5. Figure 8 shows some of the extracted machining features from the Gehause part.



(a)



(b)



(c)

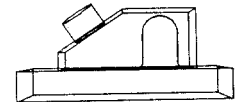


Figure 5. Three types of protrusion features: (a) type1, (b) type2, (c) type3

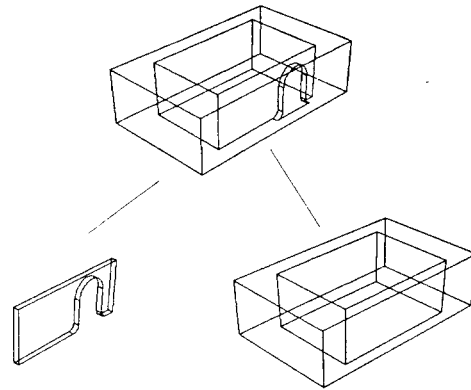


Figure 6. Extraction from a type2 protrusion feature

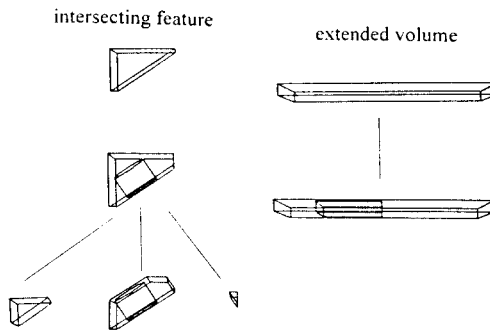


Figure 7. Extraction from a type3 protrusion feature

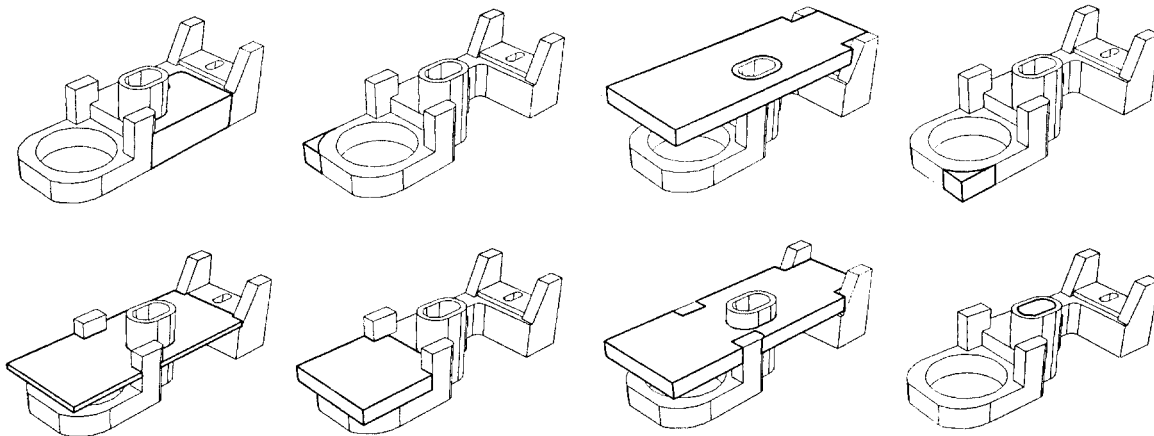


Figure 8. Some of the extracted MRSEVs features from the Gehause part

4. Conclusion

In this paper, we have presented an incremental approach for recognizing a class of machining features from the feature-based design model. In our approach, the feature recognition algorithm is working well for our class of machining features including intersecting features and protrusion features. This paper shows how to combine feature-based design and feature recognition approaches in a single framework for the potential integration of CAD/CAM. The proposed approach has been implemented as a module of the feature-based parametric design system developed by the authors[11]. The module has been written in C++ on an IRIS Indigo R4000 workstation.

We have not yet completed the module for generating alternative sets of machining features. We are currently working for selecting several sets of feasible machining features and finding an optimal feature set through manufacturability evaluation and cost estimation.

Acknowledgments

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