32. Considering Designer's Intention for the Development of Feature Library of a Process Planning System

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In this paper, the creation of ontology of manufacturing features for the development of a feature library is described. The designer's intention described in functional data of the feature constructing face elements is considered for the creation of the ontology. The creation of the manufacturing feature ontology is intended to make the feature library be useful for the extraction of manufacturing information for process plans generation.

1. INTRODUCTION

In the production stage, dynamic changes such as increased production, part type changes, machine breakdowns etc are ordinary occurrences. To deal with these dynamic changes, we presupposed the need to integrate design, manufacturing and scheduling activities. Our research puts its goal in the generation of a CAPP system that can integrate process planning, scheduling and manufacturing activities (Sakurai , 2000). Figure 1 shows the overview of the proposed CAPP system. The system consists of 3 steps.

- Step 1: feature sets creation from the product design data (CAD data).
- Step 2: generation of process plan of a part based on the created feature sets.
- Step 3: determination of optimal set of process plans for product mix.

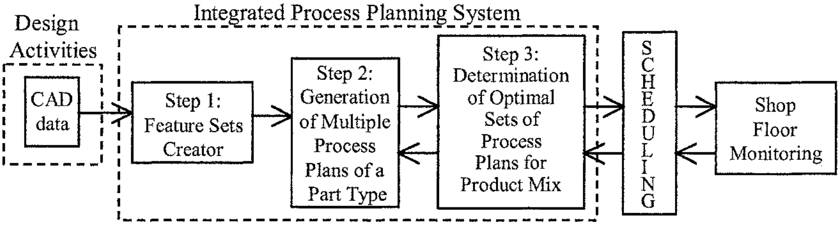


Figure 1: Overview of Integrated Computer-Aided Process Planning System

The optimal set of process plans obtained in Step 3 is used for the shop floor scheduling. During the shop floor monitoring, re-scheduling may occur to handle the dynamic changes in the manufacturing stage. In the re-scheduling stage, we can return to Step 3 to determine the optimal set of process plans for the present shop floor or production planning condition.

In order to bring this integrated process planning system to realization, we have proposed a Feature Sets Creator that can lead to the generation of multiple process plans (Muljadi *et al*, 2005). For the development of the Feature Sets Creator, we implemented Super Relation Graph (SRG) Method (Kao *et al*, 1995). We did some modification to the SRG Method and proposed the Modified SRG Method. The Feature Sets Creator uses the Modified SRG Method to extract manufacturing features from the product design information. We have further modified the Modified SRG Method, and proposed the Extended SRG Method that is able to extract not only single depression features, but also protrusion and compound features (Muljadi *et al*, 2003). Protrusion and compound features can also be extracted by the Extended SRG Method since these features can be represented by the Extended SRG. We store manufacturing features and their Extended SRG representations in a feature library.

For the development of a feature library for the CAPP system, we collect and store manufacturing features, their corresponding Extended SRG representations and the manufacturing information needed to create the shape of the manufacturing features. However, we found that instances of same type of manufacturing features may require different manufacturing methods. For the automated extraction of manufacturing information, the task will become easier if we have instances of a feature class in the feature library refer only to same possible manufacturing methods.

In this paper, for the development of the feature library, we propose the creation of ontology of manufacturing features by considering the designer's intention described in the functional data of the face elements that construct the features. The goal of this ontology creation is to make the feature library be useful for the automated extraction of proper manufacturing information to create the manufacturing features that are extracted by the Extended SRG Method.

The structure of this paper is as follows. In order to make this paper self-content, the Extended SRG Method is described briefly in Section 2. In Section 3, we discuss the creation of ontology of manufacturing features for the feature library. In Section 4, a case study is used to show the validity of the proposed manufacturing feature ontology to enable feature library to extract proper manufacturing information from the extracted manufacturing features.

2. EXTENDED SUPER RELATION GRAPH METHOD

In Extended SRG Method, feature extraction is made possible by using three relations between faces, super-concavity relation, face-to-face relation and convexity relation, and also by using the edge elements which construct the features. Super-concavity relation, face-to-face relation and convexity relation can be defined by Eq.1, Eq.2 and Eq.3 respectively.

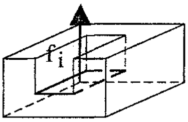
$$n^{+}_{f_i} . n^{+}_{f_j} \neq -1;\ f_i \cap S(f_j)^{|+|} \neq \emptyset \text{ and } f_j \cap S(f_i)^{|+|} \neq \emptyset \tag{1}$$

$$n^{+}_{f_i} . n^{+}_{f_j} = -1;\ f_i \subset S(f_j)^{|+|} \text{ and } f_j \subset S(f_i)^{|+|} \tag{2}$$

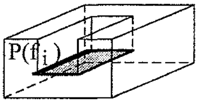
$$n^{+}_{f_i} \cdot n^{+}_{f_j} \neq 1; n^{+}_{f_i} \cdot n^{+}_{f_j} \neq -1; f_i \cap S(f_j)^{|+|} = \emptyset;$$

$$f_j \cap S(f_i)^{|+|} = \emptyset; E_{f_i} \cap E_{f_j} \neq \emptyset \tag{3}$$

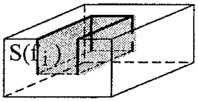
where $n^{+}_{f_i}$ is the positive face normal of face f_i (Figure 2(a)), and the strict positive half space of face f_i, $S(f_i)^{|+|} = \{ x \mid {n^{+}_{f_i}}^{T} x > k \}$ is the positive half space which exclude the embedding plane of face f_i, $P(f_i) = \{ x \mid {n^{+}_{f_i}}^{T} x = k \}$ (Figure 2(b),(c)), E_{f_i} is the set of edges of face f_i. $n^{+}_{f_j}$, $S(f_j)^{|+|}$ and E_{f_j} are defined similarly as above.



(a) Positive Face Normal of Face f_i



(b) The Embedding Plane of f_i



(c) Strict Positive Half Space of f_i

Figure 2: Explanation of terms used in Extended SRG Method

Figure 3 shows the Extended SRG representation of a stepped-hole feature. A node with one circle in the Extended SRG corresponds to a plain face of the feature. A double circle node corresponds to a curve face. Dotted links are used to represent face-to-face relations. Solid links are used to represent super-concavity relations and face-to-face relations. To distinguish these two relations, 0 is used as the attribute of the solid links to represent super-concavity relations and 1 to represent convexity relations. Solid links with no attribute are used to represent the face-edge relations. Plain edges are represented by e_n and curve edges are represented by e^{+}_{n}. The Extended SRG Method has the ability to extract not only single depression features, but also protrusion and compound features, since protrusion and compound features can have their Extended SRG representations too.

In the development of feature library, a collection of manufacturing feature types, their corresponding Extended SRG representations and the possible manufacturing information to create the manufacturing features is stored. In the next section, we discuss the creation of manufacturing feature ontology to make the feature library be useful for the extraction of proper manufacturing information of manufacturing features extracted by Extended SRG Method.

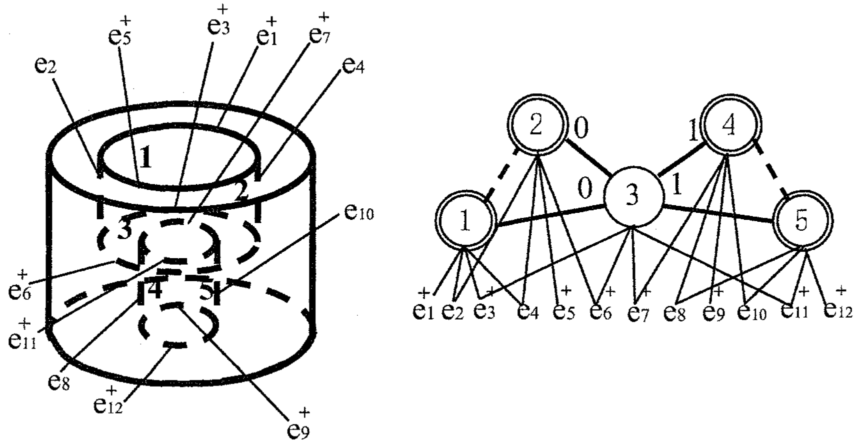


Figure 3: Stepped-hole feature and its Extended SRG representation

3. FEATURE LIBRARY

3.1 Feature Library for the Generation of Process Plans

A manufacturing feature can be defined simply as a geometric shape that has its manufacturing information to create the shape. This definition means that when a manufacturing feature is extracted from the product design information, the possible manufacturing information to create the shape is also extractable at the same time (Kanamaru *et al*, 2004). The linkage between manufacturing features and their corresponding possible manufacturing information is stored in the database, which we call as a feature library. Thus, a feature library plays a big role for the generation of process plans based on the recognized manufacturing features. As manufacturing features are extracted, the manufacturing information can also be extracted from the feature library.

3.2 Representation of Designer's Intention

Manufacturing features are extracted from the product design information. However, in order to extract proper manufacturing information to create the manufacturing features, we need to recognize the functions of the manufacturing features. To do so, we have to know why the designer designs the geometrical shapes, or in other words, we have to understand the designer's intention. So, we can say that understanding the designer's intention is very important to extract the proper manufacturing information to create the manufacturing features. However, since normally designer does not design a part using manufacturing features, we suppose that it is better to understand the designer's intention by considering the functions of the face elements that construct the manufacturing features.

The functional data of face elements can be described as basic function, mechanism utilized for realization of the basic function, and condition and direction of the motion. The detail explanation of the functional data of face elements is given in another report (Ando *et al*, 1989). Table 1 shows the contents of functional properties of face elements that are used for the creation of manufacturing feature ontology. The scope of the functional properties of face elements shown in Table 1 is limited to machined products.

Table 1 - Contents of Functional Properties

Basic Function	Mechanism utilized for realization of the basic function	Condition and direction of the motion
Transmission of motion	1: friction-mech. 2: gear-mech. 3: link-mech. 4: cam-mech.	1: liner 2: smooth-liner 3: very-smooth-liner 4: round 5: smooth round 6: very smooth round
Constraint of motion	1: rigidity-mech. 2: ball-bearing-mech. 3: sliding-mech.	1: liner 2: weak-radial 3: strong-radial 4: weak-thrust 5: strong-thrust
Fixation of motion	1: bolt-and-nut 2: bolt-only 3: friction-mech. 4: bearing-fit 5: key-fit 6: river-fit 7: shrinkage-fit	1: stationary-object 2: revolutionary-object

3.3 Creation of Manufacturing Feature Ontology

Figure 4 shows the manufacturing feature ontology and the functional data ontology. New classes for manufacturing feature ontology are created to have their relation with the functional data ontology. The relation between the class of the manufacturing feature ontology and the functional data ontology represents how the manufacturing features should be manufactured to fulfill the required functions. Each new class of the manufacturing feature ontology will refer to a collection of possible manufacturing information that can be used to create the shape of the instances of the feature class.

In Figure 4, a "precise drilled thru hole" class is created to relate the thru hole feature type in the manufacturing feature ontology with the "transmission by friction in liner motion" class of the functional data ontology. This is done since the "precise drilled thru hole" can fulfill the required mentioned functions. And for the "precise drilled thru hole" feature class, a collection of possible manufacturing information for the instances of the "precise drilled thru hole" feature class should be prepared so that when a manufacturing feature extracted by the Extended SRG Method falls to this class to fulfill the required functional data as intended by the designer, a proper manufacturing information can be extracted automatically

Thus, by creating the manufacturing feature ontology, we can collect and manage the knowledge of process planners to create manufacturing features, and also that the manufacturing feature ontology will make the feature library be useful for the extraction of proper manufacturing information that can lead to the generation of process plans of a part.

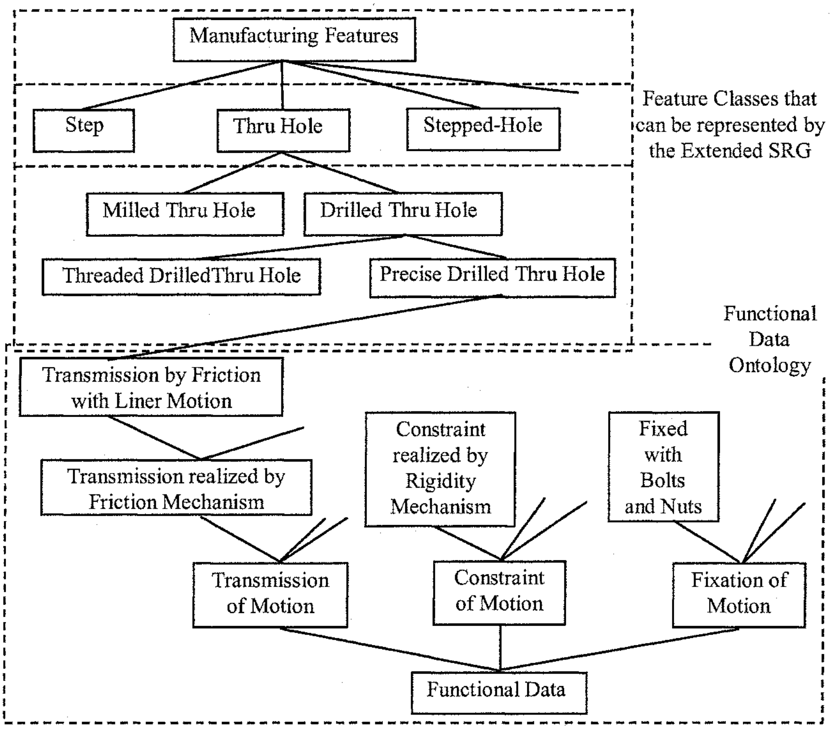


Figure 4 Ontology of manufacturing features and functional data

4. CASE STUDY

Using a sample part shown in Figure 5, we confirm the effectiveness of the proposed manufacturing feature ontology to allow the extraction of manufacturing information from the feature library. Figure 5 shows a sample part with the required functions of the face elements of the part.

First, Extended SRG Method is applied to extract manufacturing features from the sample part. As illustrated in Figure 6, there are 5 thru hole features extracted. Then using the functional data shown in Figure 5 as the input, the extracted features find the matched feature class from the feature library. As illustrated in Figure 7, one thru hole feature falls to the "grinded thru hole" feature class, and four thru hole features fall to the "threaded drill thru hole" feature class. Then, manufacturing information for each thru hole features are extracted by referring the instances of the feature classes. The thru hole feature that falls to the "grinded thru hole" feature class extracts a manufacturing method where cylindrical grinder is required to manufacture the shape. The four thru hole features that fall to the "threaded drill thru hole" feature class extract a manufacturing method where threading is required to manufacture the shape. Thus it shows that the manufacturing feature ontology is effective to make the feature library be useful for the automated extraction of proper manufacturing information to create the manufacturing features that are extracted by the Extended SRG Method.

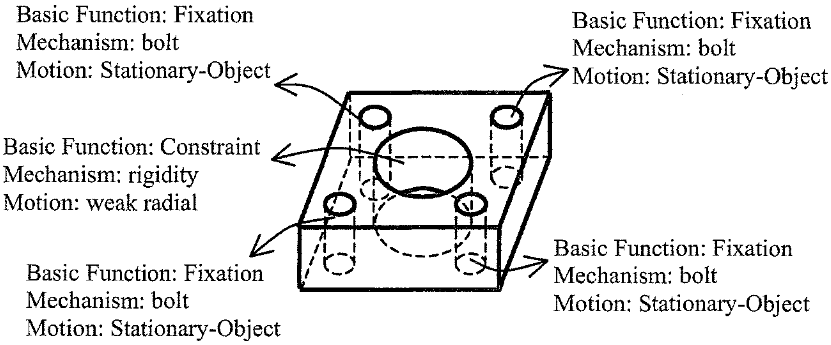


Figure 5: A sample part and the functions of the face elements

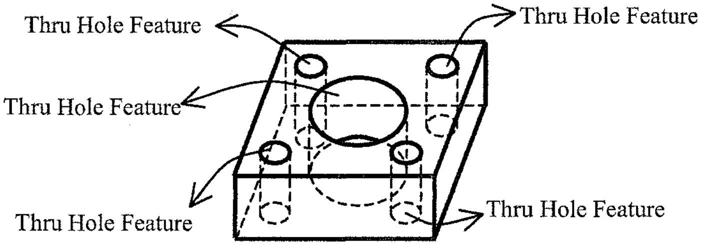


Figure 6: Extracted Manufacturing Features

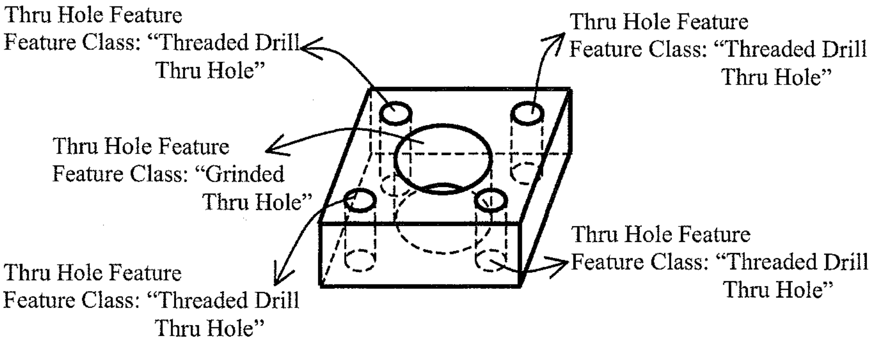


Figure 7: Extracted Manufacturing Features and Their Proper Feature Classes

5. CONCLUSION

In this paper, we presented the creation of ontology of manufacturing features for the development of a feature library by considering the designer's intention described in the functional data of the feature constructing face elements. New classes for manufacturing feature ontology are created to have their relation with the functional data ontology. Each new class of the manufacturing feature ontology will refer to a collection of possible manufacturing information that can be used to create the shape of the instances of the feature class. As shown in the case study, the creation of manufacturing feature ontology will make the feature library be useful for the automated extraction of proper manufacturing information for the generation of process plans.

For the automated generation of process plans, further works need to be done on how the extracted manufacturing information to create manufacturing features can be used for lower stream of process planning activities, such as setup generation, process sequencing etc.

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