CONSIDERING DESIGNER'S INTENTION FOR THE EXTRACTION OF MANUFACTURING FEATURE

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Abstract

A manufacturing feature can be defined simply as a geometric shape and its manufacturing information to create the shape. For the extraction of manufacturing features with their proper manufacturing information from the product design information, it is needed to consider the designer's intention described in the functional data of the face elements that construct the manufacturing features. In this paper, a new manufacturing feature ontology is proposed. New subclasses of manufacturing features are created based on the required manufacturing method to create the shape of the manufacturing features as intended by the designer. By developing a feature library based on the proposed manufacturing feature ontology, the extraction of manufacturing features with their proper manufacturing information is made possible.

Keywords:

Manufacturing feature, manufacturing feature ontology, feature library, designer's intention, process planning

1 INTRODUCTION

Computer Added Process Planning (CAPP) integrates the automation of product design with that of manufacturing by linking the design representation of Computer Aided Design (CAD) system with the manufacturing process representation of Computer Aided Manufacturing (CAM) system. In effort to interface CAD and CAPP, feature technology has emerged as the enabling technology to convert CAD product data to manufacturing information. Many approaches have been developed to extract manufacturing features from the CAD product data [1]. For the CAD product data described as a boundary representation (B-Rep), graph-based feature recognition approach has been a popular method for feature recognition since the B-Rep data structure can be viewed as graph data structure [2]. However in general, the recognition of interacting and overlapping features cannot be handled well with graph-based approach [3].

Responding to this problem, Kao et al proposed Super Relation Graph (SRG) Method to enable the recognition of interacting and overlapping features in several different ways, corresponding with different kind of machining operations [4].

For the development of the manufacturing feature recognizer, the authors implemented the SRG Method and proposed the Extended SRG Method [5]. By modifying the SRG Method, the proposed Extended SRG Method is able to extract not only single depression features, but also protrusion and compound features. Protrusion and compound features can also be extracted by the Extended SRG Method since these features can be represented by the Extended SRG.

To use the Extended SRG Method for the extraction of manufacturing features, it is necessary to develop a feature library that consists of pre-defined features and their corresponding graph representations, and the manufacturing information to create the shape of the features. However, same type of manufacturing features that can be extracted by the Extended SRG may require different manufacturing methods[6]. For example, a thru hole feature may require a cylindrical grinder to create the shape, while the other thru hole feature may require threading to create the shape, depending on why the designer designed the geometrical shape. Thus, it is necessary to consider the designer's intention for the extraction of manufacturing feature with their proper manufacturing information.

In this paper, the authors propose the creation of a manufacturing feature ontology by considering the designer's intention. New subclasses of manufacturing features are created based on the required manufacturing method to create the shape of the manufacturing features as intended by the designer. By developing a feature library based on the proposed manufacturing feature ontology, the extraction of manufacturing features with their proper manufacturing information is made possible. The automatic extraction of manufacturing features with their proper manufacturing information is very useful for the realization of a manufacturing feature-based CAPP System.

The structure of this paper will be as follows. In order to make this paper self-contained, the architecture of the proposed manufacturing feature-based CAPP System and the proposed Extended SRG Method are described in section 2 and 3 respectively. In section 4, creation of the manufacturing feature ontology is described. In section 5, a case study is used to show the validity of the proposed approach for manufacturing feature extraction.

2 INTEGRATED AND FLEXIBLE CAPP SYSTEM

Figure 1 shows the overview of the proposed integrated and flexible CAPP System, which consists of 3 steps:

Step 1: manufacturing feature recognition from the product design data.

Step 2: generation of multiple process plans of a part type based on the recognized manufacturing features.

Step 3: determination of optimal sets of process plans for product mix.

The result of Step 3 is used as the input for the production scheduling of an automated production station. And during the shop floor monitoring, when dynamic changes such as changes in production quantity, changes in parts of existing product, machine breakdown, etc occur, re-scheduling may be done by using a new result of the Step 3 of the CAPP System.

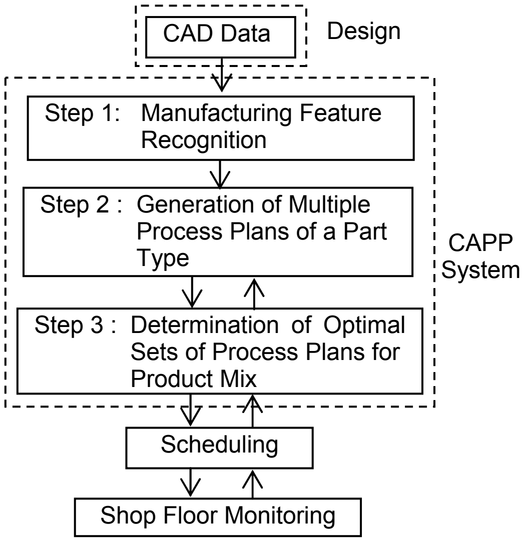


Figure 1: Overview of Flexible and Integrated Computer Added Process Planning System.

The CAPP System is called flexible since it has the following meanings.

1. The generation of multiple process plans of a part type allows the CAPP System to consider process flexibility, workstation flexibility and sequence flexibility for the determination of optimal sets of process plans for product mix [7].
2. The CAPP System may handle the dynamic changes occur in the manufacturing stage by providing alternative process plans to the scheduling stage[8].

Automatic extraction of manufacturing features and their proper manufacturing information plays a critical role in the development of the integrated and flexible CAPP System since it will become a bridge to link CAD and CAPP and also enable the generation of multiple process plans of a part type in the Step 2 of the CAPP System.

3 EXTENDED SRG METHOD

In Extended SRG Method, feature recognition 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 Equation (1), Equation (2) and Equation (3) respectively.

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

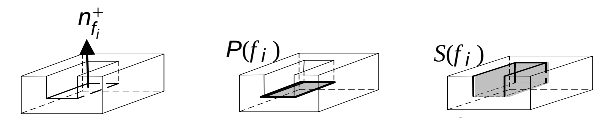
$$n^+_{f_i} \cdot n^+_{f_j} = -1;\ f_i \subset S(f_j)^{|+|} \text{ and } f_j \subset S(f_i)^{|+|} \qquad (2)$$

$$n^+_{f_i} \cdot n^+_{f_j} \neq -1;\ n^+_{f_i} \cdot n^+_{f_j} \neq 1;\ f_i \cap S(f_j)^{|+|} = \emptyset;$$
$$f_j \cap S(f_i)^{|+|} = \emptyset;\ E_{f_i} \cap E_{f_j} \neq \emptyset \qquad (3)$$

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, $S(f_i)^{|+|} = \{x \mid n^{+T}_{f_i} x > k\}$ is the positive half space which exclude the embedding plane of face f_i, $P(f_i) = \{x \mid n^{+T}_{f_i} x = k\}$ (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.

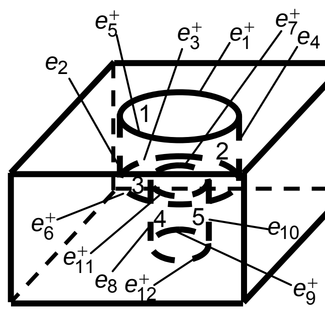
Figure 3 shows the Extended SRG representation of a stepped-hole feature. A node with one circle in the Extended SRG corresponds to a plain face of the feature. A double circle node corresponds to a curve face. Dotted links are used to represent face-to-face relations. Solid links are used to represent super-concavity relations and convexity 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.

For the development of a 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, creation of a manufacturing feature ontology for the development of the feature library that can be useful for the extraction of manufacturing features and their proper manufacturing information is described.

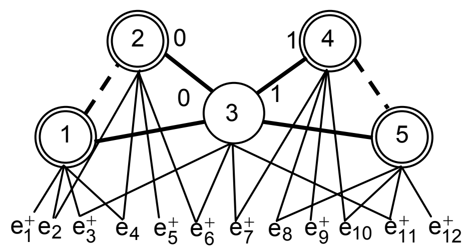


(a)Positive Face Normal of Face f_i (b)The Embedding Plane of Face f_i (c)Strict Positive Half Space of Face f_i

Figure 2: Explanation of Terms Used in SRG.



(a) Stepped-Hole Feature



(b) Extended SRG Representation of Feature in (a)

Figure 3: Stepped-Hole Feature and Its Extended SRG Representation.

4 MANUFACTURING FEATURE ONTOLOGY

4.1 Representation of Designer's Intention

In order to extract proper manufacturing information to create the shape of manufacturing features, it is important to understand the designer's intention. In this research, the designer's intention is represented by the functions of the face elements that construct the features. The face element is defined as a geometrical entity that is bounded by a set of edges.

In this research, the functional data of the 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 elements is given in other reports [9][10]. Table 1 shows the contents of functional properties of face elements that are used for the creation of the manufacturing feature ontology.

4.2 Creation of Manufacturing Feature Ontology

Figure 4 shows the ontology of manufacturing features and function features. Two steps for the creation of the manufacturing feature ontology are as follows.

(1) Creating a function feature ontology. A function feature is defined here as a geometric shape and its functions as intended by the designer. For the creation of a function feature ontology, features that can be represented by Extended SRG are listed up, and then sub-classes of these features are created by describing the required functions of the face elements that construct the features.

(2) Creating the manufacturing feature ontology. First, manufacturing features that have their Extended SRG Representation are listed up. Sub-classes of these manufacturing features are created by describing general manufacturing methods to create the parent classes. Sub-classes of these sub-classes are created to have their relation with the function feature ontology. The relation between the classes in the lowest level of the manufacturing feature ontology and the function feature ontology represents how the manufacturing features should be manufactured to fulfill the required functions of the face elements that construct the manufacturing features.

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

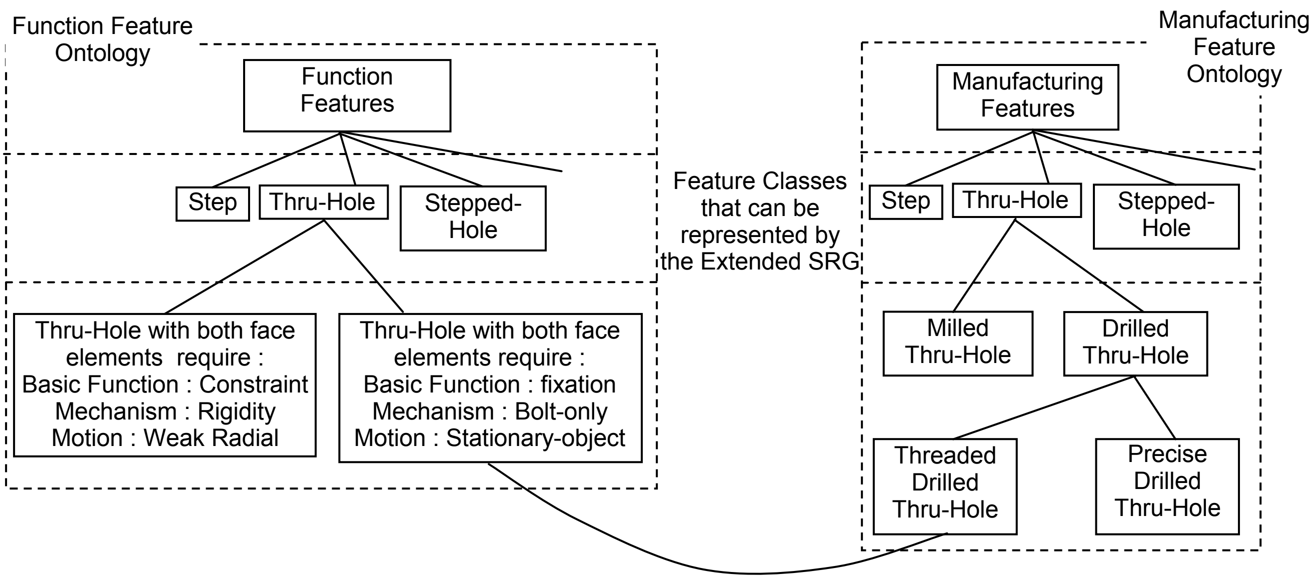


Figure 4: Ontology of Manufacturing Features and Function Features.

In Figure 4, a “threaded drilled thru hole” class is created to relate the thru hole feature type in the manufacturing feature ontology with the “thru-hole with both face elements require: Basic Function: fixation, Mechanism: Bolt-only, Motion: Stationary-Object” class of the function feature ontology. This is done since a threaded drilled thru hole can fulfill the required mentioned functions. Then, in the development of the feature library, a collection of possible manufacturing information for the instances of the “threaded drilled thru-hole” manufacturing 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 of the face elements as intended by the designer, a proper manufacturing information can be extracted automatically. Thus the creation of manufacturing features ontology will make the feature library be useful for the extraction of manufacturing features that can lead to the generation of process plans of a part.

5 CASE STUDY

Figure 6 shows a part of a flywheel shown in Figure 5 that is used for the case study here. As shown in Figure 6, a bearing will be fixed in the hole and a shaft will rotate inside the hole smoothly. Table 2 shows the functional data properties of each face elements.

Using the Extended SRG Method, 3 manufacturing features are extracted : a thru hole feature (f_4 , f_5) (Figure 7(a)), a blind hole feature (f_1 , f_2 , f_3) (Figure 7(b)), and a stepped-thru hole (f_1 , f_2 , f_3 , f_4 , f_5) (Figure 7(c)).

Then, using the functional data shown in Table 2, the extracted features find the matched manufacturing feature classes from the feature library. Thru hole feature (f_4 , f_5) matches the “rough internal turning thru hole” feature class, since the faces of the thru hole have no basic function., but are needed by other functional faces. Blind hole feature (f_1 , f_2 , f_3) matches the “internal turning and milled blind hole” feature class, where internal turning process is used to machine face f_1 and face f_2 , and milling process to machine face f_3 . Stepped-hole feature (f_1 , f_2 , f_3 , f_4 , f_5) matches the “rough internal turning and internal step turning stepped-hole” feature class, where rough internal turning and internal step turning process are required to manufacture the shape.

Figure 8 and Figure 9 illustrate two different kind of process plans that can be generated to manufacture the area of the flywheel shown in Figure 6 based on the extracted manufacturing features and their manufacturing information.

In the first process plan, this stepped-hole will be manufactured by three different manufacturing processes, internal turning, milling and rough internal turning. In the second process plan, the stepped-hole will be manufactured by two different manufacturing processes, rough internal turning and internal step turning. Thus the creation of manufacturing features ontology will make the feature library be useful for the extraction of manufacturing features and their manufacturing information that can lead to the generation of process plans of a part.

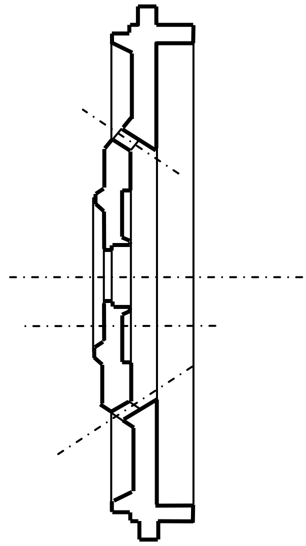


Figure 5: A Sketch of a Flywheel.

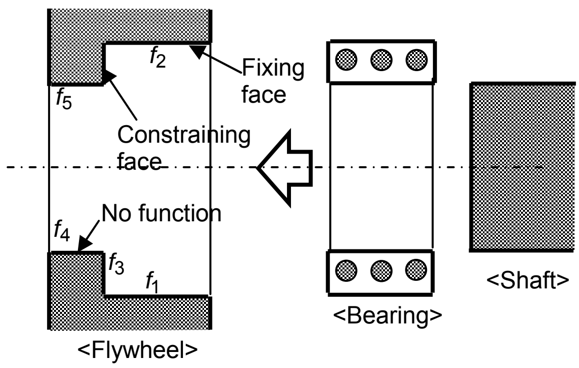
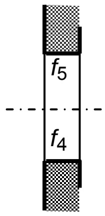


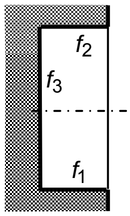
Figure 6: The Area of the Flywheel Used for the Case Study and Its Connection with Other Parts.

Table 2: Functional Data of Face Elements.

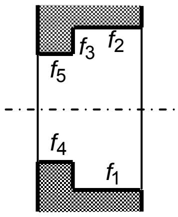
Face Elements	Basic Function	Mechanism utilized for realization of the basic function	Condition and direction of the motion
f_1	Fixation	Bearing Fit	Stationary-Object
f_2	Fixation	Bearing Fit	Stationary-Object
f_3	Constraint	Ball-Bearing	Strong-thrust
f_4	No function	-	-
f_5	No function	-	-



(a) Thru Hole

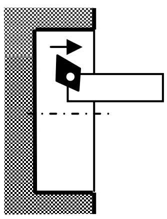


(b) Blind Hole

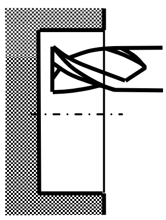


(c)Stepped-Hole

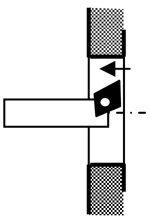
Figure 7: Features Extracted by Extended SRG Method



(a) Internal Turning

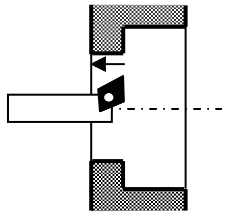


(b) Milling

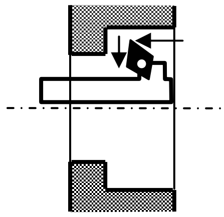


(c) Rough Internal Turning

Figure 8: Processes in Process Plan 1.



(a) Rough Internal Turning



(b) Internal Step Turning

Figure 9: Processes in Process Plan 2.

6 CONCLUSION

This paper described the creation of manufacturing feature ontology for the development of the feature library that can be useful for the extraction of manufacturing features and their proper manufacturing information. By considering the designer's intention described in the functional data of the face elements that construct manufacturing features, new classes for manufacturing feature ontology are created. Each classes in the lowest level of the manufacturing feature ontology represents how the manufacturing feature should be manufactured to fulfill the required functions of the face elements that construct the manufacturing feature. Based on the proposed manufacturing feature ontology, a feature library is developed. In the feature library, a collection of possible manufacturing information for the instances of each classes in the lowest level of the manufacturing feature ontology should be prepared so that when a manufacturing feature extracted by the Extended SRG Method falls to its lowest level sub-class to fulfill the required functional data of the face elements as intended by the designer, a proper manufacturing information can be extracted automatically. As shown in the case study, the creation of manufacturing feature ontology will make the feature library be useful for the automated extraction of manufacturing features and their proper manufacturing information for the generation of process plans of a part.

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