A Manufacturing Feature Extraction System in Machining Process Planning

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Summary
Manufacturing feature can be applied as an intelligent interface that can understand the meanings of the product design information preserved in CAD (Computer Aided Design) data from the view point of manufacturing technology. Thus, the establishment of a manufacturing feature extraction system that has the ability to extract suitable manufacturing method effectively from the design objects is essential in developing a CAPP (Computer Aided Process Planning) system. Considering the role of manufacturing features in process planning, it is necessary to develop a manufacturing feature extraction system that is able to extract manufacturing feature, which is not only the geometric shape, but also the corresponding manufacturing information to create the intended shape. In this paper, a manufacturing feature extraction system is proposed. A case study is used to show the validity of the proposed system.

Key words:
Manufacturing feature, Manufacturing feature extraction, Feature library, Process planning.

1. Introduction

For the integration of CAD (Computer Aided Design) and CAPP (Computer Aided Process Planning), manufacturing feature can be applied as an intelligent interface that can understand the meanings of the product design information preserved in CAD data from the view point of manufacturing technology [1]. Therefore, the establishment of a manufacturing feature extraction system that has the ability to extract suitable manufacturing method effectively from the design objects is essential in developing a CAPP system.

There are many research reports that describe the development of feature extraction methodologies [2], [3], [4]. However, these reports only focus on the extraction of the geometric shapes, and do not describe the extraction of suitable manufacturing information to create the intended shape. Recognizing shape features from CAD product data is, of course, an important process [5]. However, considering the role of manufacturing feature in process planning, it is necessary to develop a manufacturing feature extraction system that is able to extract manufacturing feature which consists of the geometric shape and the corresponding manufacturing information to create the intended shape.

In this paper, a manufacturing feature extraction system is proposed. The manufacturing feature extraction method used in the manufacturing feature extraction system is the Extended Super Relation Graph (Extended SRG) method [6]. Extended SRG method is an extended version of Super Relation Graph method [7].

The structure of this paper is as follows. Section 2 describes the structure of manufacturing feature extraction system. Section 3 describes the manufacturing feature extraction process. In section 4, a case study is used to show the validity of the system. In the last section, the conclusions of this paper are presented.

2. The Structure of the Manufacturing Feature Extraction System

The overall scheme of the proposed manufacturing feature extraction system is illustrated in Fig.1. First, the system generates Extended SRG representation of the object from the object's CAD data. After the generation of Extended SRG representation of the object, pattern matching is done to extract features, in this sense, the geometric shapes, from the Extended SRG representation of the object. For this purpose, it is necessary to develop a database which consists of pre-defined feature representing extended SRG patterns. For the extraction of corresponding manufacturing information to create the intended shape, the system uses data, such as material data, size, tolerance, and surface roughness to find the appropriate manufacturing information which is stored in the feature library which consists of manufacturing information.

By using the proposed system, manufacturing features, which consist of the geometric shape and the corresponding manufacturing information to create the intended shape, can be extracted. In the next section, the manufacturing feature extraction process is described.

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3. The Manufacturing Feature Extraction Process

3.1 Generation of Extended SRG representation of object's CAD data

The procedure for generation of Extended SRG representation of object's CAD data is as follows.

Step 1: constructing envelope face set. An envelope face is a face of the minimum convex hull of the object for manufacturing feature extraction. Fig.2(b) shows the envelope face of the part shown in Fig.2(a). The constructed envelope face set of the part is ENV={f_5, f_6, f_7, f_8, f_9, f_{10} }.

Step 2: constructing global graph. The neighborhood relationship of the faces that construct the part can be modeled by means of a global graph. A global graph is a graph that shows the adjacency relation of all faces that construct the part. Faces are represented by nodes, and the adjacency relations of two faces are represented by links. Fig.2(c) shows the constructed global graph of the part shown is Fig.2(a).

Step 3: constructing the interacting feature face set (IFFS). IFFS is a set of faces that cover the removal volume of the part. By removing nodes belonging to ENV and the links incident to those nodes from the global graph, Interacting Feature Face Graph (IFFG) can be obtained. An IFFS can be constructed by grouping all the nodes in one IFFG. Fig. 2(d) shows the IFFG obtained from the part shown in Fig.2(a). Thus, IFFS1 ={f_1 , f_2, f_3, f_4} is constructed.

Step 4: generating Extended SRG. For each IFFS constructed in Step 3, Extended SRG with links representing super-concavity relation, face-to-face relation, convexity relation, and edge number and edge types is generated.

Super-concavity relation, face-to-face relation, and convexity relation can be defined by Eq.(1), Eq.(2) and Eq.(3) respectively.

$$n_{f_i}^{+} \cdot n_{f_j}^{+} \neq -1;\ f_i \cap S(f_j)^{|+|} \neq \varnothing \text{ and } f_j \cap S(f_i)^{|+|} \neq \varnothing \quad (1)$$

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

$$n_{f_i}^{+} \cdot n_{f_j}^{+} \neq -1;\ n_{f_i}^{+} \cdot n_{f_j}^{+} \neq 1;\ f_i \cap S(f_j)^{|+|} = \varnothing;$$
$$f_j \cap S(f_i)^{|+|} = \varnothing;\ E_{f_i} \cap E_{f_j} \neq \varnothing \quad (3)$$

where $n_{f_i}^{+}$ is the positive face normal of face f_i (Fig.3(a)), and the strict positive half space of face f_i, $S(f_i)^{|+|} = \left\{ x \mid {n_{f_i}^{+}}^{T} x > k \right\}$ is the positive half space which excludes the embedding plane of face f_i, $P(f_i) = \left\{ x \mid {n_{f_i}^{+}}^{T} x = k \right\}$ (Fig.3(b),(c)). $n_{f_j}^{+}$ and $S(f_j)^{|+|}$ are defined similarly as above. Here, normal vector $n_{f_2}^{+}$ has an opposite direction

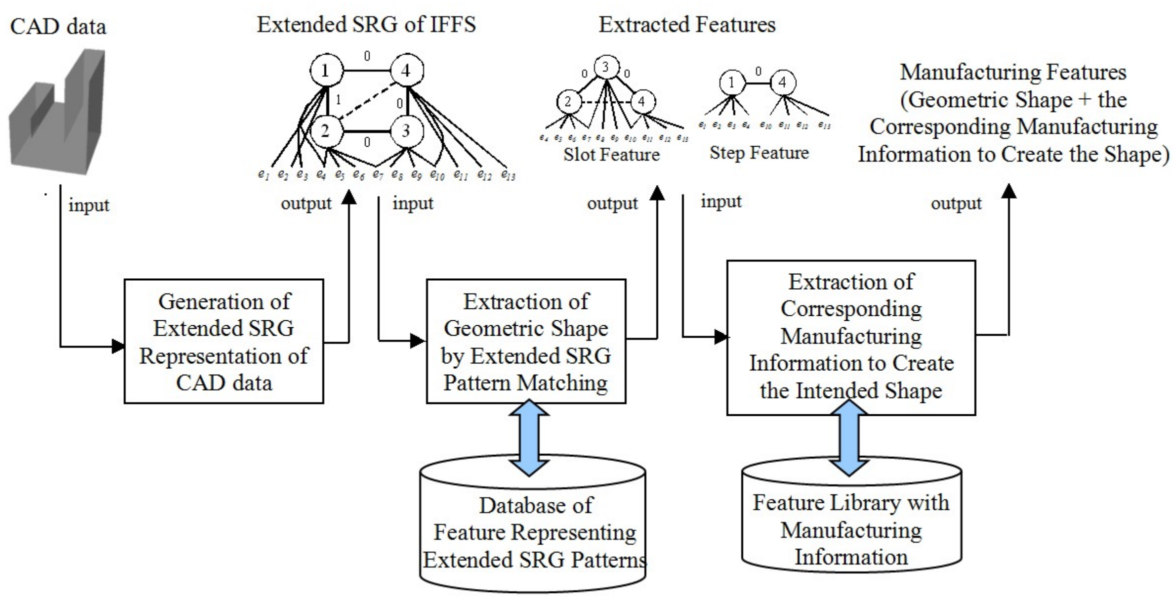


Fig. 1 Overall scheme of the manufacturing feature extraction system.

to normal vector $n^{+}_{f_4}$. Also, face f_2 is the element of strict positive half space $S(f_4)^{|+|}$, and face f_4 is the element of strict positive half space $S(f_2)^{|+|}$. Since face f_2 and face f_4 satisfy Eq.(2), they have a face-to-face relation with each other. Face-to-face relation is represented by dotted link. Also, since face f_2 and face f_4 are interacted with strict positive half space $S(f_3)^{|+|}$ and satisfy Eq.(1), face f_2 and face f_4 have super-concavity relations with face f_3. Super-concavity relations are represented by solid links with attribute 0. Face f_1 and face f_2 satisfy Eq.(3), and have convexity relation with each other. Convexity relation is represented by solid link with attribute 1. Solid links with no attribute are used to represent the face-edge relations. It is also needed to be noted that a node with one circle corresponds to a plain face, while a double circle node corresponds to a curve face, and plain edge is represented by e_n, while curve edge is represented by e^{+}_{n}. Fig.2(e) shows the generated Extended SRG representation of the sample object.

3.2 Development of a database of feature representing Extended SRG patterns

As shown in Fig.1, it is necessary to develop a database of feature representing Extended SRG patterns. The structure of the database is shown in Fig.4. The database is developed based on the following lightweight feature ontology.

(1) Level 0: Ontology name

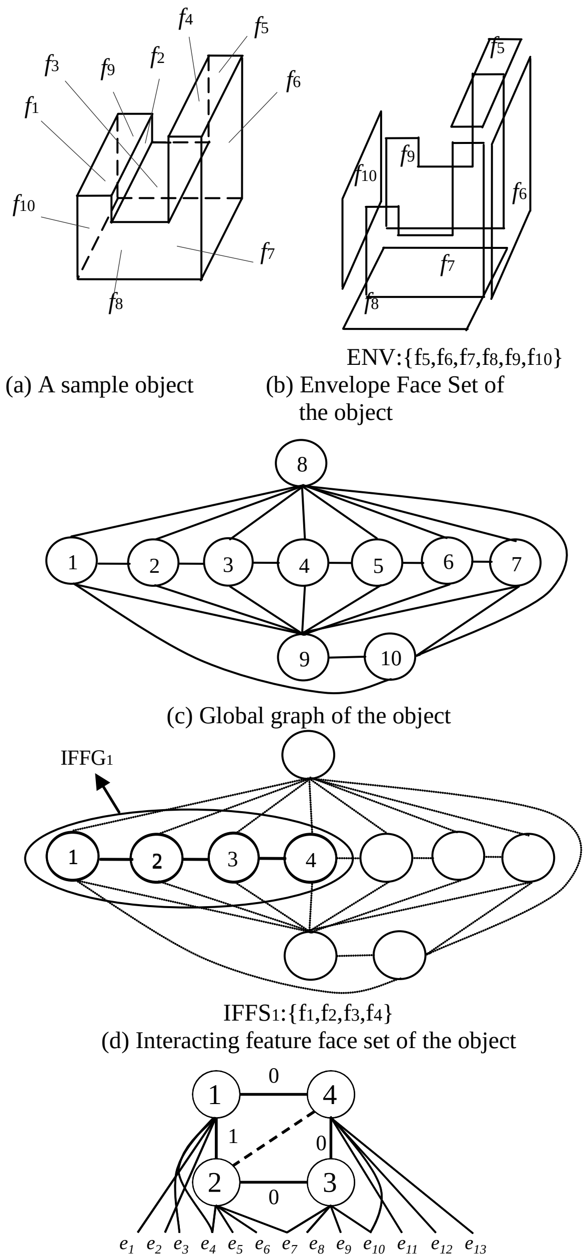
(2) Level 1: Manufacturing feature classes are created based on the face numbers, such as MF with two faces, MF with three faces, etc.

(3) Level 2: Sub-classes of the manufacturing feature classes in level 1 are created by describing the face types of the parent classes. Thus, the sub-classes of the MF with two faces are MF with two plain faces, MF with two curve faces, and MF with one plain face and one curve face.

(4) Level 3: Sub-classes of the manufacturing feature classes in level 2 are created by describing the relations between faces. For example, MF with 3 plain faces can have MF with 3 plain faces with one face-to-face and two super-concavity relations, etc.

(5) Instances of the lowest level of the manufacturing feature classes are created based on manufacturing features that fit the relations between faces shown by the name of the lowest level manufacturing feature classes. For example, MF with 3 plain faces with one face-to-face and two super-concavity relations has slot feature as its instance. The instance has the Extended SRG pattern as its metadata.

The feature ontology is used to support the pattern matching algorithm described in the following section.



(a) A sample object (b) Envelope Face Set of the object

(c) Global graph of the object

(d) Interacting feature face set of the object

(e) Extended SRG of IFFS1

Fig.2 Generation of Extended SRG representation of an object

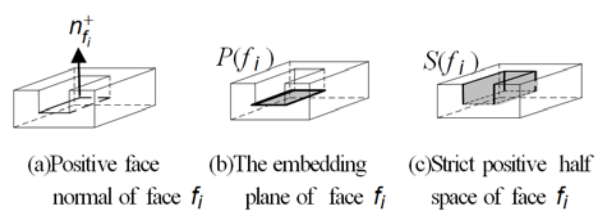


Fig.3 Explanation of terms used in Extended SRG

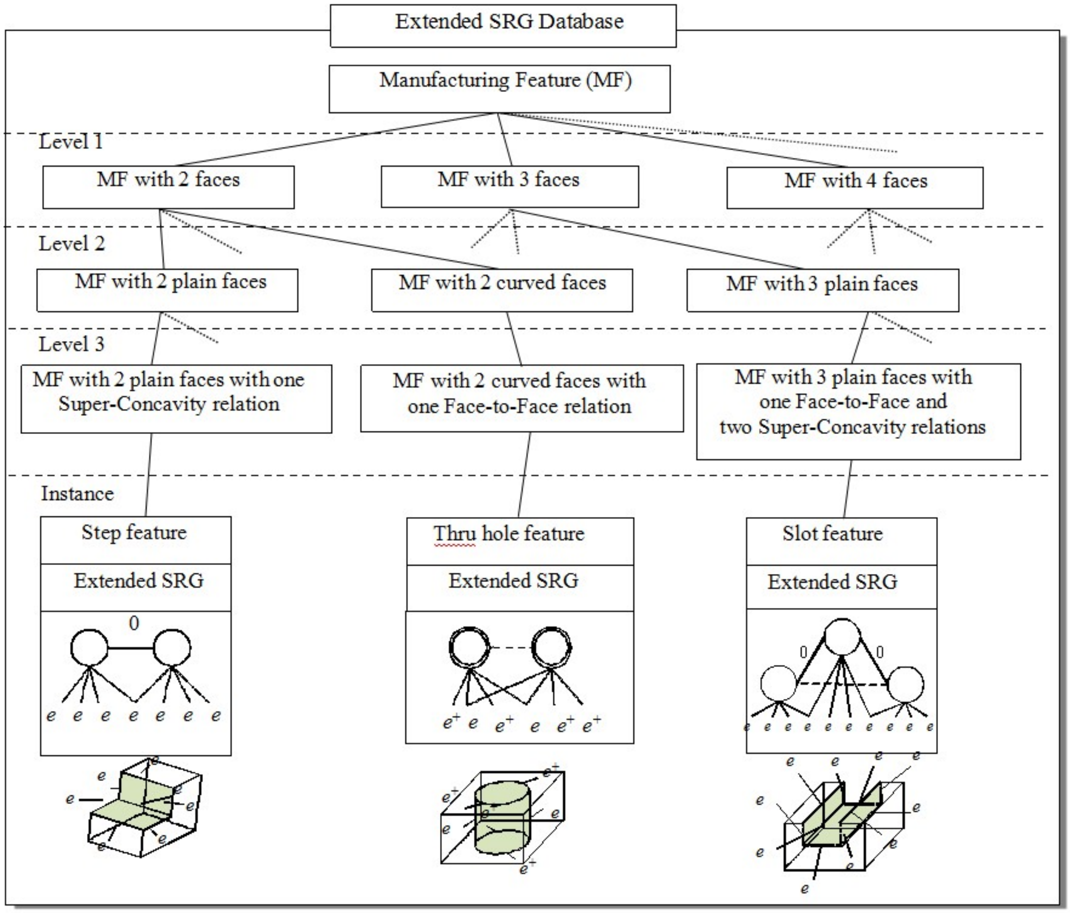


Fig. 4 Structure of the database of feature representing Extended SRG patterns

3.3 Pattern matching algorithm

Fig.5 shows the Extended SRG pattern matching to extract features, in this sense, the geometric shapes from the Extended SRG of the object. Each step of the algorithm will be explained using the sample object shown in Fig.2(a). The pattern matching algorithm is applied to the generated Extended SRG shown in Fig.2(e).

In Step 1, the number of faces which construct the IFFG, x is determined. Fig.2(d) shows that there are 4 faces which construct the IFFG of the sample object. Thus, x = 4.

In Step 2, A_{41} $\{f_1, f_2, f_3, f_4\}$ is created from the Extended SRG of the sample object, since there are features constructed by 4 faces in the feature library shown in Fig.4.

In Step 3, pattern matching is done by searching manufacturing feature with 4 faces that has the same number of plain face p, curve face c, face-to-face relation q, super-concavity relation w, convexity relation e as the Extended SRG of A_{41}. Since there is no matching result, the process will be continued with x=3 and return to Step 2.

In Step 2, when x=3, A_{31}, A_{32}, A_{33}, A_{34} are created (see Fig.6). In Step 3, no match result is found for A_{31}, A_{32}, and A_{33}. However, since Extended SRG of pre-defined slot feature in the feature library has the same number of plain face p, curve face c, face-to-face relation q, super-concavity relation e, convexity relation w as the Extended SRG of A_{34}, A_{34} is extracted as slot feature.

In Step 4, the validity of the extracted feature is verified. The extracted feature is valid if

$$|V(A_{xk})| \cap \text{IFFS} = \varnothing \qquad (4)$$

$|V(A_{34})| = S(f_2)^{|+|} \cap S(f_3)^{|+|} \cap S(f_4)^{|+|}$ is the strict volume enclosed by the intersection of the strict positive half space of f_2, f_3, f_4 which construct A_{34}. As illustrates in Fig.8, $|V(A_{34})|$ does not intersect $\text{IFFS}_1 = \{f_1, f_2, f_3, f_4\}$. Thus, A_{34} is a valid slot feature, and is added to the EFL (Extracted Feature List) in Step 4 of the algorithm.

Step1. Let x = the number of faces which construct the IFFG;
Go to step 2;

Step2. While x >1{
If the manufacturing feature library has any feature constructed by x faces{
Let A = a set of all face patterns with any super relation with each other and
j = the number of the face patterns in A_x;
k =1;
Go to step3;}
Else x = x-1;}
End

Step3. While k <= j {
Let p = the number of plain faces in A_{xk}, c = the number of curved faces in A_{xk},
q = the number of face-to-face relations in A_{xk}, w = the number of super-concavity relations in A_{xk},
e = the number of convexity relations in A_{xk},
If there is an Extended SRG pattern in the feature library that has the same number of plain face p,
curve face c, face-to-face relation q, super-concavity relation w, convexity relation e as
the Extended SRG of A_{xk} , go to Step4;
Else k = k+1;}
x = x-1;
Go to step 2;

Step4. If Extended SRG pattern of A_{xk} = Extended SRG pattern of pre-defined feature in the feature library{
Let $|V(A_{xk})|$= the strict volume enclosed by A_{xk};
If $|V(A_{xk})| \cap IFFG = \varphi$, then add A_{xk} in EFL as an extracted manufacturing feature;
}
Else k = k +1;
Go to step 3;

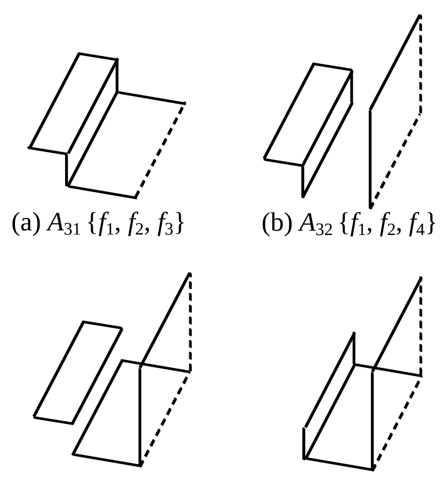
Fig.5 Manufacturing feature extraction algorithm

The process continues with x=2. As shown in Fig.9, A_{21} {f_1, f_2}, A_{22} {f_1, f_4}, A_{23}{ f_2, f_3}, A_{24} { f_2, f_4}, A_{25} { f_3, f_4}are constructed. The extended SRG pattern of pre-defined step feature matches the extended SRG pattern of A_{22}, A_{23}, A_{25}. A_{22} fulfills Eq.4 and is a valid step feature. However, $|V(A_{23})|$ and $|V(A_{25})|$ intersect IFFS1, so A_{23} and A_{25} are not valid features.

Thus, by applying the manufacturing feature extraction algorithm, one slot feature and one step feature are extracted from the sample object.

3.4 Extraction of corresponding manufacturing information

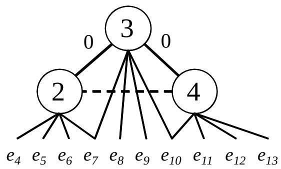
In order to extract the corresponding manufacturing information of the extracted manufacturing features, it is necessary to develop a database which consists of manufacturing features and their corresponding manufacturing information. For such purpose, the feature library which is developed as process planners' knowledge management system is used [8]. Fig.10 illustrates the structure of the feature library.



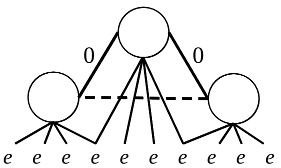
(a) A_{31} {f_1, f_2, f_3} (b) A_{32} {f_1, f_2, f_4}

(c) A_{33} {f_1, f_3, f_4} (d) A_{34} {f_2, f_3, f_4}

Fig.6 All face patterns that are generated when x = 3



(a) Extended SRG of the pattern, $\{f_2, f_3, f_4\}$



(b) Extended SRG of pre-defined slot feature

Fig.7 Extended SRG pattern matching

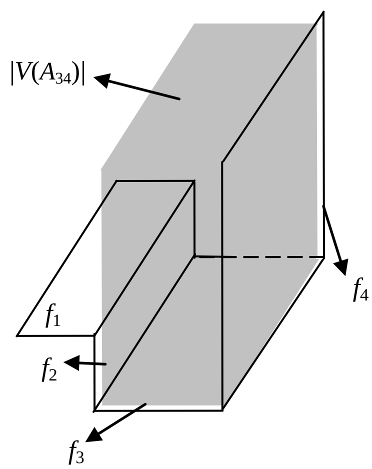
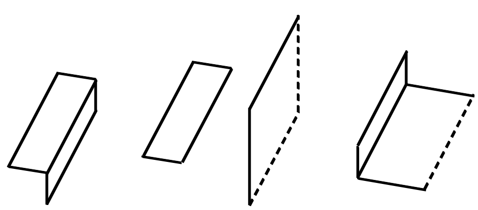
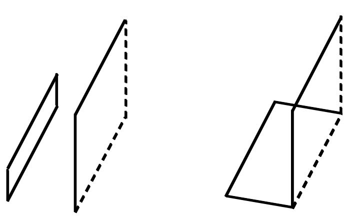


Fig. 8 $|V(A_{34})|$ does not intersect IFFS1$\{f_1, f_2, f_3, f_4\}$



(a) $A_{21}\ \{f_1, f_2\}$ (b) $A_{22}\ \{f_1, f_4\}$ (c) $A_{23}\ \{f_2, f_3\}$



(d) $A_{24}\ \{f_2, f_4\}$ (e) $A_{25}\ \{f_3, f_4\}$

Fig. 9 All face patterns that are generated when x = 2

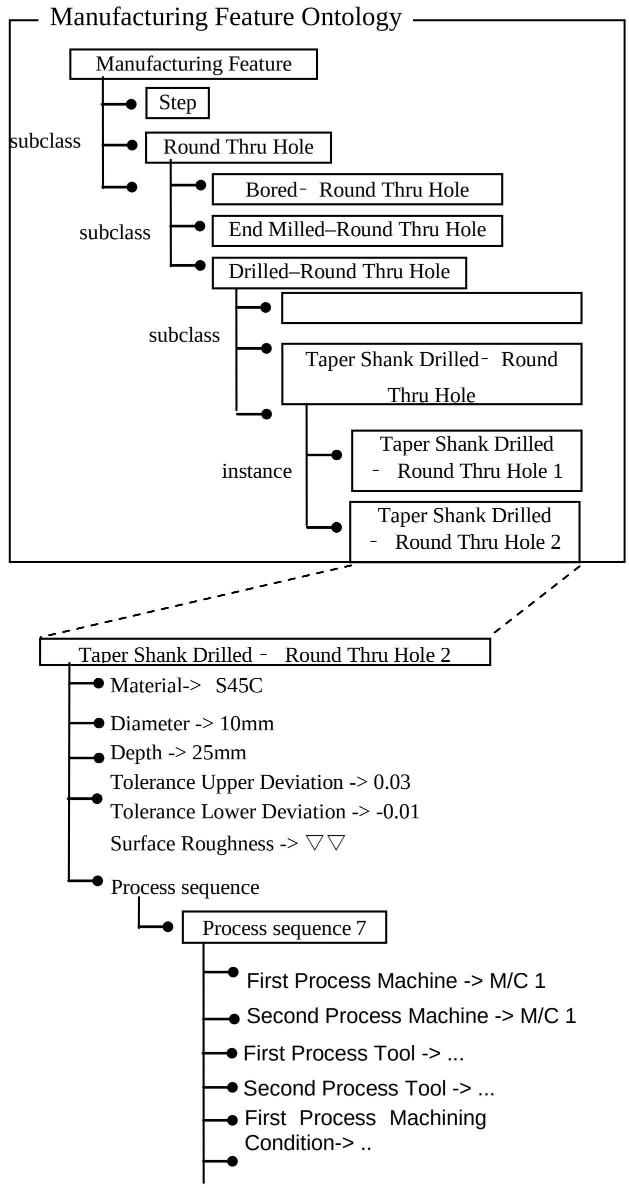


Fig. 10 Structure of manufacturing feature library with manufacturing information

In the feature library, instances of manufacturing feature classes are linked directly with the manufacturing process sequences to create the shape of the features. The process sequences are associated with manufacturing resources, such as machines, tools, and also with other manufacturing information, such as machining conditions, NC programs, etc.

The extracted feature names and data such as size, and surface roughness are used as input data. The system will search for feature instances that have the same data, and deliver the process sequence data which consists of machine data, tool data, machining condition data, etc. to create the extracted features as the output.

Thus, using the proposed manufacturing feature extraction system, the extraction of manufacturing features consisting of the geometric shapes and their corresponding manufacturing information can be done.

4. Case Study

Fig.11 shows the sample part for the case study. The input data used is the xml file of the B-Rep data of the sample part. There are 2 IFFGs generated from the sample part, as shown in Fig. 12 and Fig.13, respectively. IFFG1 consists of six faces: f_4, f_5, f_6, f_7, f_8, and f_9. IFFG2 consists of four faces: f_{11}, f_{12}, f_{13}, and f_{14}. Then the pattern matching algorithm is applied to each IFFGs.

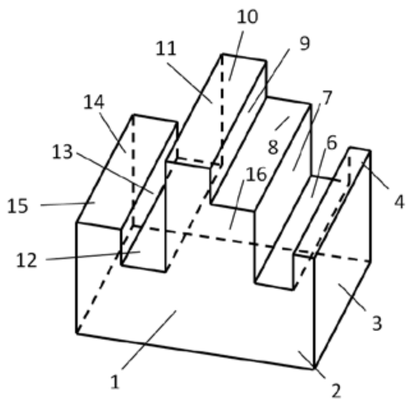


Fig. 11 Sample part

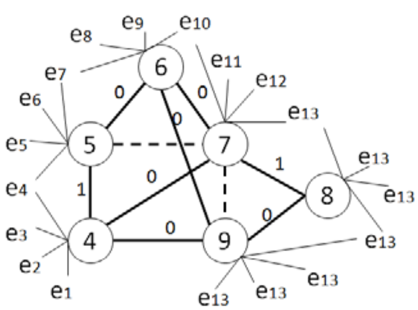


Fig. 12 IFFG1 of the sample part

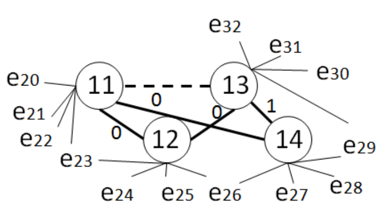
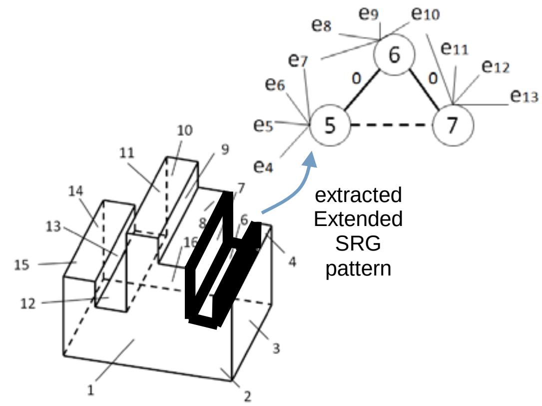
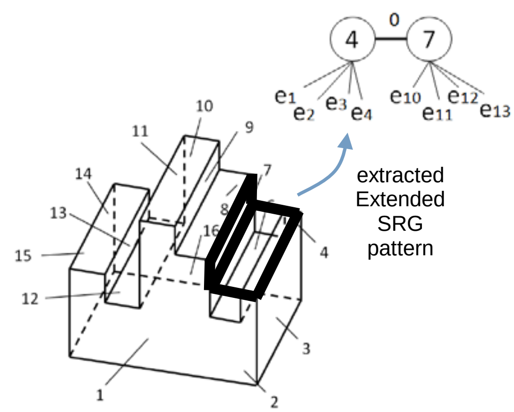


Fig. 13 IFFG2 of the sample part

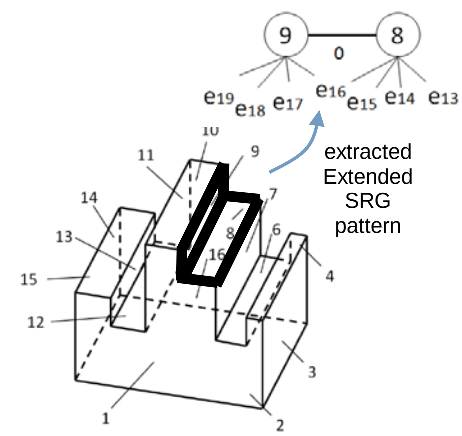
From IFFG1, no feature constructed by 6 faces, 5 faces, or 4 faces is extracted. One feature constructed by 3 faces is extracted, and two features constructed by 2 faces are extracted. Fig.14 shows the extracted features and the extended SRG of each features from IFFG1. One thru slot feature $\{f_5, f_6, f_7\}$, and two step features $\{f_4, f_7\}$ and $\{f_8, f_9\}$ are extracted from IFFG1.



(a)Thru slot feature$\{f_5, f_6, f_7\}$



(b)Step feature $\{f_4, f_7\}$

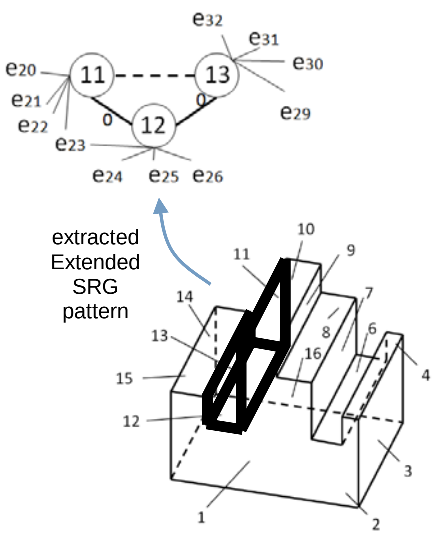


(c) Step feature $\{f_8, f_9\}$

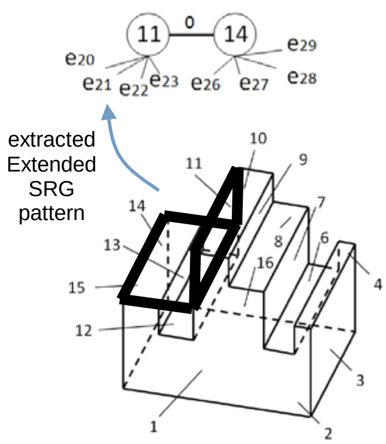
Fig. 14 Manufacturing features extracted from IFFG1

From IFFG2, no feature constructed by 4 faces is extracted. One feature constructed by 3 faces is extracted, and one feature constructed by 2 faces is extracted. Fig.15 shows the extracted features and the extended SRG of each features from IFFG2. One thru slot feature $\{f_{11}, f_{12}, f_{13}\}$, and one step feature $\{f_{11}\ f_{14}\}$ are extracted from IFFG2.

Fig. 16 shows the window that shows the list of the extracted manufacturing features. The same window is used to input data such as size and surface roughness of each extracted features to extract the corresponding manufacturing information.



(a) Thru slot feature$\{f_{11}, f_{12}, f_{13}\}$



(b) Step feature $\{f_{11}, f_{14}\}$

Fig. 15 Manufacturing features extracted from IFFG2

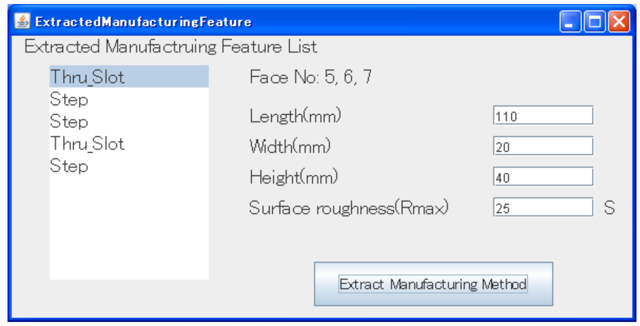


Fig. 16 The window showing the extracted manufacturing features. The same window is used to input data of the extracted manufacturing features to extract the corresponding manufacturing information

Fig.17 shows the window with the list of the extracted manufacturing features and the corresponding manufacturing information. The detail of the corresponding manufacturing information can be opened by selecting the process sequence that the user wants to open. Fig.18 shows a sample of the corresponding manufacturing information.

Based on the above result, the proposed manufacturing feature extraction system can be used to extract manufacturing features and their corresponding manufacturing information that can lead to the generation of machining process plans of a part.

5. Conclusions

The results from this research can be summarized as follows.

(1) This paper proposed the manufacturing feature extraction system where manufacturing features consisting of the geometric shapes and their corresponding manufacturing information can be extracted.

(2) The manufacturing feature extraction method used in the manufacturing feature extraction system is the Extended Super Relation Graph (Extended SRG) method. By matching the Extended SRG patterns of the object with Extended SRG patterns of pre-defined features stored in the database, manufacturing features, in this sense, the geometric shapes, can be extracted.

(3) The corresponding manufacturing information to create the shape of extracted features can be done by using feature library which is developed as the process planners' knowledge management system. The manufacturing process sequences which are associated with other manufacturing information to create the shape of features can be extracted.

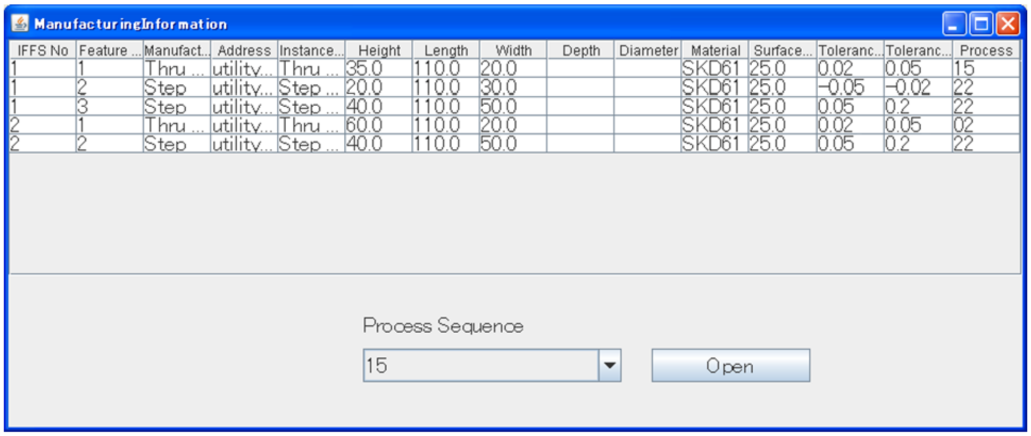


Fig. 17 The window that shows the extracted manufacturing features and the corresponding manufacturing information

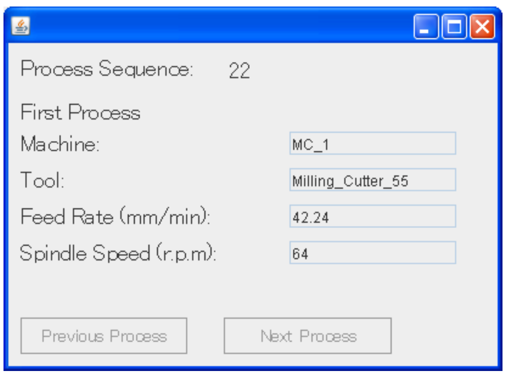


Fig. 18 A sample of manufacturing information

(4) By extracting manufacturing features consisting of geometric shapes and the corresponding manufacturing information to create the intended shape, the proposed manufacturing feature extraction system can be useful to support the generation of machining process plans.

Acknowledgments

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