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CREATION OF FEATURE SETS FOR DEVELOPING INTEGRATED PROCESS PLANNING SYSTEM

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Abstract: Our research puts its goal in the generation of a computer-aided process planning system for machining process in the dynamic manufacturing stage. For this goal, we develop a Feature Sets Creator that can lead to the generation of multiple process plans. The generation of multiple process plans of a part is intended to provide alternative plans in the determination of optimal sets of process plans for all the part types in the shop, and to provide flexibility in the shop floor scheduling. The Feature Sets Creator is divided into 2 phases. First, by using Modified Super Relation Graph Method, we recognize interacting and overlapping features in several different ways, corresponding with different kind of machining operations. The second phase is feature organization phase. Here, we organize recognized features into multiple feature sets. In the paper, we will present a case study to confirm the validity of the feature set creator.

Key words: Feature Recognition, Feature Organization, Process Planning System.

1. INTRODUCTION

Dynamic changes such as increased production, machine breakdowns etc are ordinary occurrence in the manufacturing stage. Skilled workers deal with these dynamic changes by changing the manufacturing schedules, or even by changing the process plans. Thus, we presupposed the need to integrate process planning, scheduling and manufacturing activities. Our research puts its goal in the generation of a CAPP system that can integrate process planning, scheduling and manufacturing activities [1]. Figure 1 shows the overview of our proposed process planning 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.

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 be occurred to handle the dynamic changes in the manufacturing stage. In the re-scheduling stage, we can return to Step 3 to determine of the optimal set of process plans for the present shop floor or production planning condition.

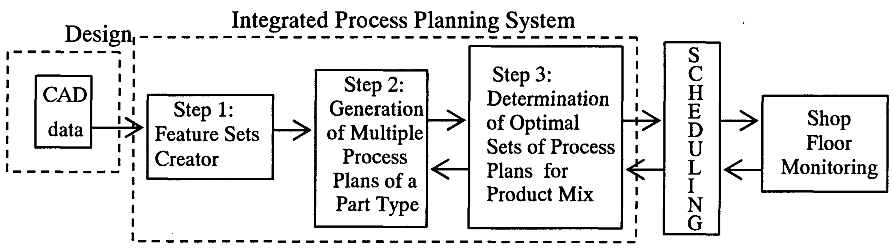


Figure 1. Overview of Integrated Computer-Aided Process Planning System

In order to bring this integrated process planning system to realization, we develop a Feature Sets Creator that can lead to the generation of multiple process plans. The Feature Sets Creator consists of 2 phases: Feature Recognition Phase and Feature Organization Phase. For the Feature Recognition Phase, we implemented Super Relation Graph method [2]. In SRG method, B-Rep product data structure is converted into graph structures, and by extracting feature representing graph patterns from the graph structures, features are extracted. In general, the recognition of interacting and overlapping features cannot be handled well with graph-based approach [3], but the SRG method is capable of recognizing interacting or overlapping features in several different ways, corresponding with different kind of machining operations. However, the proposed SRG method was developed only to deal with features constructed by plane faces. We proposed Modified SRG method to deal with curve faces. We will describe the Modified SRG in section 2. After features have been recognized by the Modified SRG method, features are organized into one or more features sets. The idea of organizing features into feature sets came from the fact that there are interacting features which are automatically machined by machining the other features. For this Feature Organization phase, we use our proposed Feature Spatial Relation Method. We will describe the Feature Organization phase in section 3. In section 4, we will use a case study to show the validity of our Feature Sets Creator.

2. MODIFIED SRG METHOD

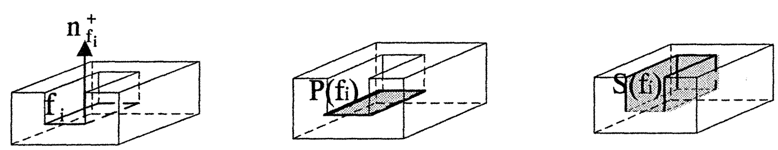
2.1 Modifying the Super Relation Graph Method

In SRG Method [2], feature recognition is made possible by using two relations between faces, super-concavity relation and face-to-face relation. Super-concavity relation and face-to-face relation can be defined by Equation (1) and Equation (2) respectively.

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

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

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)). $n^+_{f_j}$ and $S(f_j)^{|+|}$ are defined similarly as above.

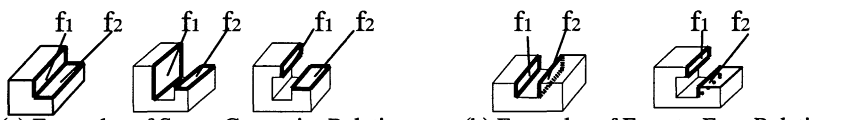


(a) Positive Face Normal of Face f_i (b) The Embedding Plane of Face f_i (c) Strict Positive Half Space of Face f_i

Figure 2. Explanation of terms used in SRG

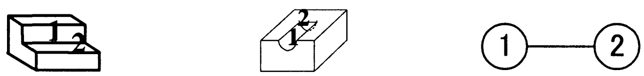
Figure 3 shows the example of the super-concavity relation and face-to-face relation. In general, the above two relations between faces are called super relations. Using these two relations, features can be defined using super relation graphs (SRGs). A SRG is an undirected graph, where the node in the SRG corresponds to a face in the feature, and two types of links are used to represent relations between two faces. Solid links are used to represent super-concavity relations and dotted links to represent face-to-face relations. But a problem with the SRG method is that geometrically and topologically different kind of features may have one same SRG, if the node is used to correspond to both plane and curve faces. Figure 4 shows that a step feature and a partial round notch feature are represented by same SRG.

In our research, we modified this SRG method. We divide the usage of node for plane faces and curve faces. In the Modified SRG method, a circle node in the SRG corresponds to a plane face in the feature, and a double circle node corresponds to a curve faces. Figure 5 shows the SRG of Partial Round Feature using the Modified SRG method.



(a) Examples of Super-Concavity Relation (b) Examples of Face-to-Face Relations

Figure 3. Example of Super Relations



Step Feature Partial Round Feature (b) SRG of features in (a)

(a) Features

Figure 4. Example of features represented by same SRG

Figure 5. Partial Round Feature and its SRG in the Modified SRG Method

2.2 Procedure for Feature Recognition

The procedure for feature recognition using the Modified SRG method is as follows.

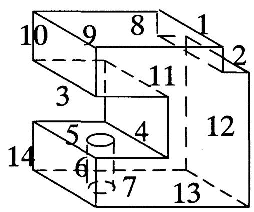
Step 1: Obtaining the Envelope Face Set. Envelope face set is the set of faces on the envelope of the object. An envelope is defined as the convex hull of an object and it should consist of primitive shapes such as cubes, parallelepipeds, cylinders, cones or prism. Figure 6(b) shows the envelope faces of the sample part in figure 6(a). Thus, the envelope face set is ENV= $\{f_8,f_9,f_{10},f_{11},f_{12},f_{13},f_{14}\}$.

Step 2: Constructing the Global Graph. A global graph is a face adjacency graph that shows the neighbourhood relationship of the faces of the part. Nodes of the graph represent the faces, and arcs between the nodes represent the neighbourhood relationship between the faces. Figure 6(c) shows the global graph of the part in figure 6(a).

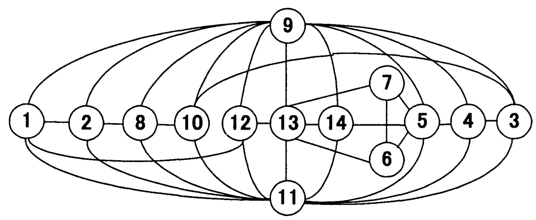
Step 3: Obtaining Interacting Feature Face Set (IFFS). IFFS is a set of faces that surround the removal volume of the part. IFFS is obtained by constructing interacting feature face graphs, which are constructed by removing the nodes belonging to the ENV and the links incident to those nodes from the global graph. An IFFS can be obtained by grouping all the nodes in one IFFG. Figure 6(d) shows the IFFGs of the part in figure 6(a). Thus, the IFFSs of the part are $IFFS_1=\{f_1, f_2\}$ and $IFFS_2=\{f_3, f_4, f_5, f_6, f_7\}$.

Step 4: Generating SRGs. For each IFFS obtained in Step 3, its SRG consists of the nodes corresponding to the elements of the IFFS, and the links representing either super-concavity relations or face-to-face relations. Figure 7 shows the SRGs generated from each IFFS.

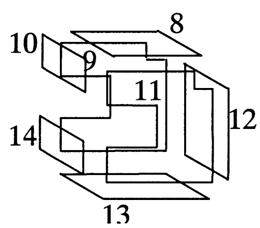
Step 5: Extracting Features. Feature extraction is done by extracting the feature representing SRG from SRG of each IFFS. Figure 8(a) shows that step feature representing SRG is extracted from SRG of IFFS$_1$. Extracted feature representing SRGs from SRG of IFFS$_2$ are shown in figure 8.



(a) A Sample Part

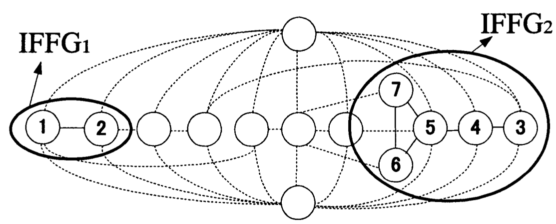


(c) Global Graph of the Part



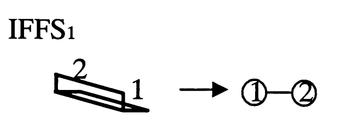
ENV: {f$_8$,f$_9$,f$_{10}$,f$_{11}$,f$_{12}$,f$_{13}$,f$_{14}$}

(b) Envelope Face Set of the Part

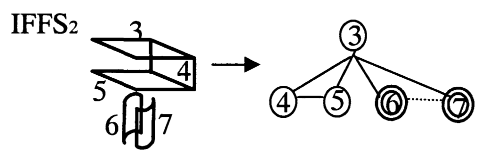


(d) the interacting feature face graphs of the part, IFFG$_1$ and IFFG$_2$, obtained from Global Graph by deleting the nodes of Envelope Face Set and links incident to those nodes

Figure 6. Example of Global Graph, Envelope Face Set and Interacting Feature Face Graph of a Part

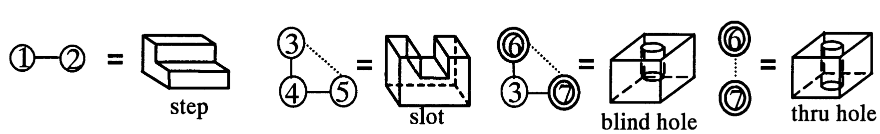


(a) Super Relation Graph of IFFS$_1$



(b) Super Relation Graph of IFFS$_2$

Figure 7. Super Relation Graphs of the Sample Part using Modified SRG Method



(a) Step feature representing SRG extracted from SRG of IFFS$_1$

(b) Feature (slot, blind hole, thru hole) representing SRGs extracted from SRG of IFFS$_2$

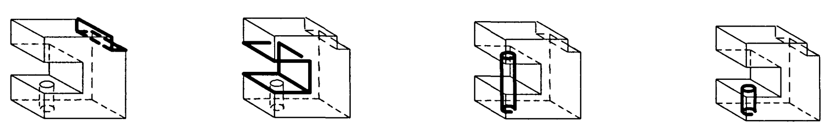
Figure 8. Extracted feature representing SRG from SRG of each IFFS of the part

3. FEATURE ORGANIZATION

3.1 Machining Feature

As we consider the interaction relation of features recognized by the Modified SRG method, there are 3 types of interaction need to be considered.
1. Features that have no interaction with other feature(s). Step feature shown in figure 9(a) has no interaction relation with other features. This feature can be called independent feature.
2. Features that interact other feature(s) partially. Slot feature shown in figure 9(b) and blind hole feature shown in figure 9(c) are interacting with each other partially. Both features can be called interacting features.
3. Features that are covered by other feature(s) completely. This type of interaction shows the existence of overlapped feature. Thru hole feature shown in figure 9(d) is covered by blind hole feature in figure 9(c). Also, blind hole feature in figure 9(c) is covered by slot feature in figure 9(b) and thru hole feature in figure 9(d). In each cases, thru hole feature and blind hole feature can be called overlapped feature.

In the machining point of view, when features that cover an overlapped feature being machined, the overlapped feature will be automatically machined. It means that overlapped feature should not be considered as a machining feature. Thus, only independent and interacting features that can be called machining features. We proposed Feature Spatial Relation (FSR) method to organize machining features into feature sets that have no overlapped features.



(a) Step Feature (b) Slot Feature (c) Blind Hole Feature (d) Thru Hole Feature

Figure 9. Extracted Feature of the Part in figure 6(a)

3.2 Feature Spatial Relation Method

The FSR method can be represented as follows. Let $t_i \in T_x(IFFS)$, where $T_x(IFFS)$ denotes the feature set in IFFS, t_i be the element of T. Let $S(t_i)$be the space for feature t_i to occupy. Feature set $T_x(IFFS)$ is derived from the equation below.

$$T_x(IFFS)=\{t_i \mid \bigcup_{i\in N} S(t_i) \supseteq S(IFFS),\ \bigcup_{i\in N} S(t_i) \cup S(t_{i+1}) \not\subset \bigcup_{i\in N} S(t_i),\ \bigcup_{i\in N} S(t_i) \cup S(t_{i+1}) \not\subset S(t_{i+1})\} \quad (3)$$

where N={1,⋯, n}, and n is the total number of features in IFFS.

3.3 Algorithm of FSR Method

The algorithm of FSR method to obtain T_x(IFFS) is as follows:

Step 1. Form a list of features in a IFFS;
Let n = number of features in a IFFS; x =1;
If n > 2, then go to step 2; Else T_x(IFFS) = {features}; End
Step 2. Initialize k = 2
Step 3 Initialize T_x(IFFS) = {t_1}, i = 1
Step 4. While i + 1 < n {
For $S(t_i) \cap S(t_{i+1}) = \varnothing$ {
$S(t_i) \leftarrow S(t_i) \cup S(t_{i+1})$; Add t_{i+1} into T_x(IFFS); i + 1 ← i + 2; }
For $S(t_i) \cap S(t_{i+1}) \subset S(t_i)$ { i + 1 ← i + 2; }
For $S(t_i) \cap S(t_{i+1}) \subset S(t_{i+1})$ {
T_x(IFFS) ={t_{i+1}}; $S(t_i) \leftarrow S(t_{i+1})$; i + 1 ← i + 2; } }
Step 5: List all features in T_x(IFFS);
let y = number of features in T_x(IFFS); G ←T_x(IFFS); j =1;
While j < y {
For $S(t_j) \cap S(t_{j+1}) \subset S(t_{j+1})$ { Delete t_j from G; j ← j + 1 }
For $S(t_j) \cap S(t_{j+1}) \subset S(t_j)$ { Delete t_{j+1} from G;
If j + 1 < y , j + 1← j + 2; Else j ← j + 1 }
For $S(t_j) \cap S(t_{j+1}) = \varnothing$ {If j + 1 < y , j + 1← j + 2; Else j ← j + 1 } }
T_x(IFFS) ← G;
Step 6: If k = n, End;
Else {for i = 1 , do i←n+1; i←i-1; k=k+1; x=x+1; Repeat Step 3;}

As we apply the above algorithm to the recognized features in figure 9, two feature sets obtained from the IFFS: T_1(IFFS)={slot, blind hole} and T_2(IFFS)={slot, thru hole}. And as each feature set will lead to a different process plan, it shows that the combination of Modified SRG method and FSR method is useful for the generation of multiple process plans of a part.

4 CASE STUDY

Using another sample part, as shown in figure 10(a), we confirm the effectiveness of our feature set creator. Figure 10(b) shows the IFFS of the sample part. Using the Modified SRG method, 9 features are recognized: t_1 is open pocket feature. t_2, t_3 are blind holes. t_4, t_5, t_6, t_7 are thru-holes (see figure 10(c)). And using the Feature Spatial Relation Method, 5 feature sets are constructed: Feature Set T_1={t_1, t_2, t_3}, Feature Set T_2={t_1, t_3, t_4}, Feature

Set $T_3=\{t_1, t_5\}$, Feature Set $T_4=\{t_1, t_6\}$ and Feature Set $T_5 = \{t_1, t_2, t_7\}$. Each feature set will require a different kind of process plans. Thus, it shows that our Feature Set Creator is effective for making multiple process plans.

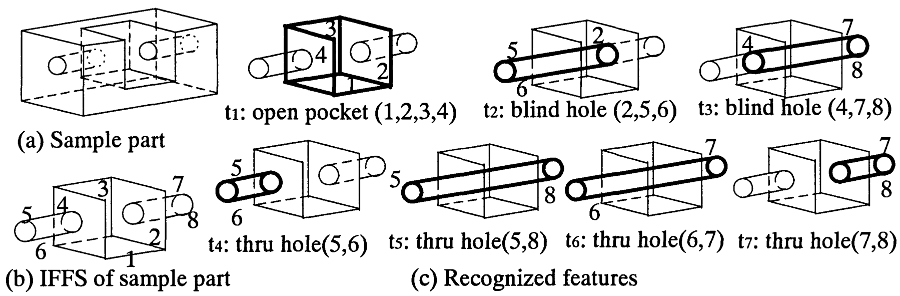


Figure 10. Sample Part, its IFFS and the recognized features

5 CONCLUSION

In this paper, we presented our Feature Sets Creator which consists of 2 phases: Feature Recognition Phase and Feature Organization Phase. In the Feature Recognition Phase, our proposed Modified SRG Method is effective to recognize interacting or overlapping features constructed by plane and curve faces from the boundary data in several different ways. In the Feature Organization Phase, our proposed Feature Spatial Relation Method is effective to organize features into one or more feature sets, which correspond to different kind of process plans. Thus it shows that our Feature Sets Creator is a useful basis for our aim integrated CAPP system.

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