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Manufacturing Feature Extraction for Sculptured Pocket Machining
(Sculptured 포켓 가공을 위한 가공특징형상 추출)

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ABSTRACT

A methodology which supports the life cycle of the feature used from design to manufacturing for sculptured pocket is newly developed and presented. The information contents in a feature can be easily conveyed from one application to another in the manufacturing domain. However, the feature generated in one application may not be directly suitable for another without being modified with more information. The objective of the paper is to present the methodology of decomposing a bulky feature of sculptured pocket to be removed into compact features to be efficiently machined. In particular, the paper focuses on the two tasks: 1) to segment horizontally a bulky feature into intermediate features by determining the adequate depth of cut and cutter size and to generate the temporal precedence graph of the intermediate features and 2) to further decompose each intermediate feature vertically into smaller manufacturing features and to apply the variable feed rate to each small feature. The proposed method will provide better efficiency in machining time and cost than the classical method which uses a long string of NC codes necessary to remove a bulky feature.

Key words: Feature extraction and conversion, Feature-based process planning, Sculptured part, Cutting condition.

1. Introduction

Process Planning known for a vital link between CAD and CAM generates a large amount of processing information related to different aspects of controlling a shop floor (Chang *et al.* 1987). A promising approach to the integration of CAD/CAM is the feature-based process planning which considers the machined part a collection of machinable features, and fills up machining information on how to machine the features. The objective of the paper is to address a methodology necessary to decompose a bulky feature to be removed into compact features to be efficiently machined for the sculptured shape pocket. The detailed objectives of the paper are the two tasks: First, a bulky removal feature of the sculptured pocket is segmented into several thin layers called as intermediate features and the temporal precedence of the segmented features is automatically constructed. Second, a layered feature is further decomposed vertically into smaller features called as manufacturing features which can be machined with variable cutting conditions. It is assumed that the machining operation is performed on a 3-axis machining center and require no re-fixturing. Further, the boundary of pocket is defined using set of line segments and arc segments. it is also assumed that the pocket has no islands and the bottom of pocket is a trimmed sculptured surface.

2. Related Work

There have been many researches for the development of feature-based process planning systems for specific part family like prismatic and rotational parts. A method for extracting machining features from the DSG file and determining processes, resources, cutting parameters for prismatic part has been suggested (Perng and Cheng 1994). Feature modeling concepts are applied to the GT-based variant process planning system in a factory which produces parts that can be grouped into a limited number of part family (Opas *et al.* 1994). A structured approach to integrating CAPP and control using feature concepts has been proposed for rotational components in the three level shop floor control architecture (Cho *et al.* 1994). In the research, manufacturing features are extracted from the DXF file and the generated feature precedence graph is converted into a hierarchical set of process plans.

3. Overview of the Concept

The overall concept of the proposed feature decomposition methodologies is depicted in Figure 1. **First**, the designed part model is interpreted by the system and then a set of *removal features*, the non-part portions from the raw material are extracted. Information contents including boundary of pocket, height of pocket, position vector of the removal feature, and tolerance are embedded in a removal feature.

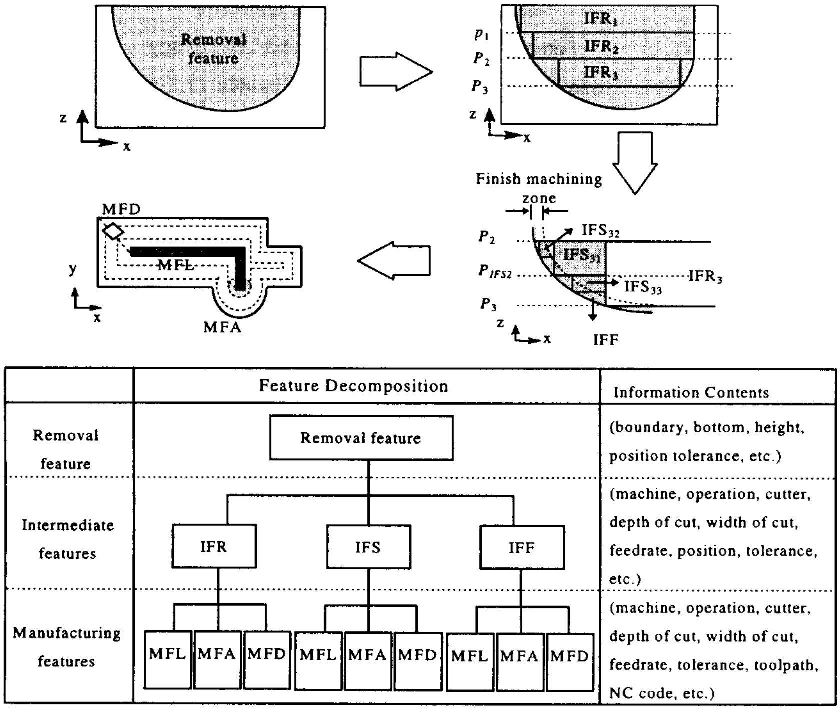

Figure 1. Overall concept of feature decomposition

Second, a bulky removal feature is decomposed into several thin and layered features by considering the depth of cut which is determined according to the shape of removal feature, cutter specification, material type of stock, etc. The pieces of pocket volume with uniform depth are called ***Intermediate Features for Rough machining*** (Hereafter it is called ***IFRs***). If the protruding distance of a remaining layer is so large that the protrusion cannot be removed by a finishing pass, for somehow efficient machining, the protrusion had better be removed by a semi-rough machining once , which are called ***IFSs*** (***Intermediate Features for Semi-rough machining***). If the protrusion can be removed by a finishing cutter pass without changing offset distance for a finishing cutting plane, it is called ***IFFs*** (***Intermediate Features for Finish machining***). A protrusion continue to be decomposed until all the segments become either ***IFFs*** or ***IFSs***. Each intermediate feature is filled with specified cutter and cutting method, but does not have the associated tool path and NC code. The temporal precedence graph of intermediate features is easily constructed by the x and z value of basic coordinate of each feature.

Third, the intermediate feature is further decomposed into the compact manufacturing features according to the cutting conditions of each segmented part. A ***manufacturing feature*** is the one that can be removed by a single cutting movement with the same depth of cut but without changing the feed rate. Manufacturing features are classified into three manufacturing feature class: ***MFLs*** (***Manufacturing Features of Line elements***), ***MFAs*** (***Manufacturing Features of Arc elements***), and ***MFDs*** (***Manufacturing Features of Diagonal elements***). By the above definition, the adjusted feed rate can be embedded into the manufacturing feature, through which efficient process planning can be performed. The temporal precedence of manufacturing features is also easily determined according to the above tool paths.

4. Extraction of Intermediate Features

In extracting intermediate features from a removal feature, the depth of cut represents the height of each intermediate feature. Since an adequate depth of cut depends on the shape of removal feature, the cutter specifications, and the material type of stock, which therefore must be considered in extracting intermediate features.

4.1. Selection of Cutters

The removal feature is horizontally segmented into a few sub-volumes, which are called **tool group volumes (TGVs)**, for the purpose of determining an appropriate cutter size for each sub-volume. In order to evaluate the shape of removal feature, the moving average of cross-sectional area of each hunting plane is calculated. Then the removal feature is decomposed into tool group volumes(TGVs) at the corresponding hunting planes. An adequate cutter for each TGV is select by adopting the biggest cutter selection methodology (Bala and Chang 1991) for the lowest z-valued hunting planes for each TGV.

Procedure: Selection of Cutters
Input: A removal feature
Output: Cutter for each TGV
Step1: Decompose the removal feature into a series of hunting planes h_i ($1 < i <$ n-1)
Step2: Obtain the cross sectional area a_i of each hunting plane h_i
Step3: Calculate the moving average $(a_{i-1} + a_i)/2$ for each cross section.
Step4: Decompose the removal feature into a few tool group volumes(TGVs)
Step5: Select an adequate cutter for each TGV.

4.2. Determination of Cutting Parameters

Once a cutter is determined for each TGV of the removal feature, the cutting parameters, including depth of cut, width of cut, and feed rate are determined. In the paper, machining time is minimized as objective function and cutting force is considered as constraint function. An experimental design is devised for determining the efficient cutting parameters due to the complexity of the cutting force equation.

4.2.1. Objective function: Machining Time

Machining time can be regarded as the summation of the actual cutting time and cutter changing time. If the removal feature is segmented into n-slices of IFRs, the machining time can be formulated as Equation (1).

$$T = \frac{h_{TGV}}{D_c} \cdot \{ \frac{V_{est}}{D_c \cdot W \cdot F} + TD + 2 \cdot t_c \} - t_c \qquad (1)$$

where TD_i implies actual cutting time of the i-th IFR for a drilling operation, t_c implies the cutter change time, V_{est} implies the estimated removal volume (mm^3), D_c implies the depth of cut (mm) and W implies the width of cut (mm) and F implies the feed rate (mm/min), and h_{TGV} implies the height of the TGV.

4.2.2. Constraint Function: Cutting Force

The variation of cutting force can be obtained from the following instantaneous force model. At every instance, the cutting force of the cutter is the sum of infinitesimal forces along the cutter flutes. The equations that represent the total force acting along X and Y directions at the jth angular position of the cutter are shown below.

$$F_X(j) = \sum_{i=1}^{D/D}\sum_{k=1}^{N}\{K_T \cdot D \cdot ({}^{F}\!/\!_{{}^{S}\!/\!_{N}})[\sin\alpha(i,j,k)\cos\alpha(i,j,k) - K_R \cdot \sin^2\alpha(i,j,k)]\} \qquad (2)$$

$$F_Y(j) = \sum_{i=1}^{D/D}\sum_{k=1}^{N}\{K_T \cdot D \cdot ({}^{F}\!/\!_{{}^{S}\!/\!_{N}})[\sin^2\alpha(i,j,k) - K_R \cdot \sin\alpha(i,j,k)\cos\alpha(i,j,k)]\} \qquad (3)$$

where K_T and K_R are the cutting coefficients which vary with feed rate, width of cut, and depth of cut, which are determined by experiment. From Equations (2) and (3), the factors affecting the cutting force include depth of cut D_c, feed rate F, spindle speed S, number of flute N_f, width of cut W, cutter helix angle α_h, and cutter radius R.

4.2.3. Computation

In order to obtain the appropriate cutting parameters from the objective and constraint functions, an simulation-based experimental design is used due to the complexity of the mathematical equations. Among several factors affect the objective and constraint functions, the three cutting parameters, depth of cut (D_c), width of cut (W), feed rate (F) are selected as control factors whose values are determined. On the other hand, the cutter radius (R), the cutter helix angle (α_h), and the number of cutter flutes (N_f) can be fixed since a cutter was chosen in the previous stage. Once, the experimental design has been completed, the simulation is started by computing the machining time and the cutting force for each experiment. The results are then analyzed, and a set of cutting parameters can be determined. Although the determined set of cutting parameters are sub-optimal, the feed rate will be adjusted to further improve machining productivity by considering the actual width of cut (W_a) in the next stage. If there is another TGV in that removal feature, the same procedure should be repeated for the TGV.

```
Procedure: Determination of Cutting Parameters
Input: Removal feature, Selected cutter
Output: Depth of cut, Width of cut, Feed rate
While ( $TGV_i$ is not null, i=1, 2, ..n )
    Step1: Determine the levels of each cutting parameter
    Step2: Design the experimental plan
    Step3: Simulate the machining time and cutting force for each experiment
    Step4: Analyze the resulting data and determine the best cutting parameter
End While
```

4.3. Extraction of IFRs

The IFRs can be extracted based on the previously determined depth of cuts. In order to determine the actual cutting planes of the adjacent TGVs, some merging operation should be performed. The volume of IFRs is obtained by sweeping the cross sections, which are generated by intersection of the actual cutting planes and the removal feature, to the plus z direction with the depth of cuts.

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Procedure: Extraction of IFRs
Input: Removal feature, Cutters, Cutting Parameters
Output: IFRs
Step1: Generate actual cutting planes for the removal feature by merging the last and the first cutting plane of $TGV_{i+1}$
While (actual cutting plane $acp_i$ is not NULL, $i$=1,2,3,...)
    Step2: Obtain each cross-sectional profile $p_i$ of each actual cutting plane $acp_i$.
    Step3: Generate an $IFR_i$ by sweeping each $p_i$ to the plus z direction with the distance of depth of cut $Dc_i$
    Step4: Assign the depth of cut($D_c$), width of cut($W_c$), feed rate($F$), cutter, and position vector to $IFR_i$ and go to Step1
End While
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4.4. Extraction of IFSs

Some uncut side volume remaining after extracting IFRs can continue to be decomposed until all the segments become either IFSs and IFF in order to reduce the volume removed by finish machining.

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Procedure: Extraction of IFSs
Input: Removal feature, Cutter, and Depth of cuts for IFRs
Output: IFSs
While ($IFR_i$ is not NULL, $i$ = 1, 2, 3 ...n-1)
    Step1: If the horizontal length of side uncut volume of $IFR_i$ is greater than the predetermined threshold, generate an $IFS_{ij}$ by sweeping the cross-sectional profile to the plus z direction with the distance of depth of cut for $IFS_{ij}$ which is 0.5 × the depth of cut for $IFR_i$.
    Step2: If the horizontal length of new side uncut volumes are greater than the predetermined threshold, continue to generate $IFS_{ij-1}$, $IFS_{ij-2}$ as Step1
End While
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4.5. Intermediate Feature Precedence Graph

Once all the intermediate features are extracted, their precedence can be determined. In order to represent a set of intermediate features, their attributes, and precedence relationship among the features, the AND/OR graph is adopted. In the IFPG, there may be so many alternatives by which intermediate features can be removed.

5. Extraction of Manufacturing Features

5.1. Feed Rate Adjustment along Tool Paths

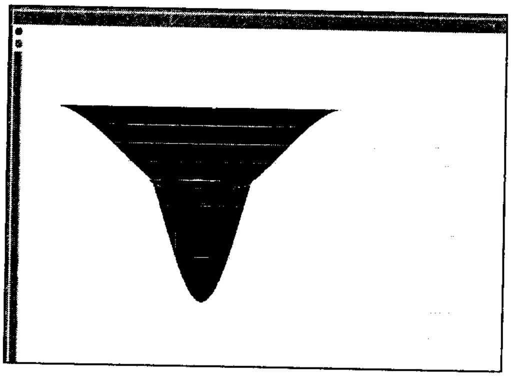
Since an actual width of cut varies according to the shape of tool path element, the cutting force also varies. It is possible to predict the cutting force along the tool path (Altintas *et al.* 1991). The actual width of cut can be generated from nominal width of cut and arc angle data. With the known depth of cut, actual width of cut and the allowed maximum cutting force, an acceptable feed rate can be derived from Equations (2) and (3) for each tool path element. The type and geometry of each tool path element is read, classified and assigned to each manufacturing features. If the type of tool path element is arc or diagonal, the actual width of cut should be calculated and assigned to the attribute AW_c of manufacturing features.

5.2. Manufacturing Feature Precedence Graph

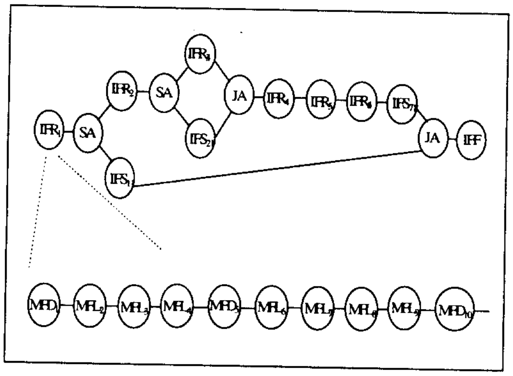
Once manufacturing features are extracted from an intermediate feature, the temporal precedence of manufacturing features can be determined. A manufacturing feature precedence graph(MFPG) which is also an AND/OR graph is an extended intermediate feature precedence graph(IFPG). The precedence is easily constructed from the manufacturing feature data which is extracted from the tool path information in the previous stage.

6. Examples

This chapter represents an example for the life cycle of a feature from design to manufacturing. The shape of removal feature considered is a pocket that is represented as trimmed sculptured surface. The following example is prepared according to the proposed methodologies of the paper using UniGraphics under IRIS Workstation environment.



(a) intermediate features



(b)feature precedence graph

Figure 2. Example of feature decomposition

7. Conclusion

An efficient methodology of decomposing a bulky removal feature into compact manufacturing features was proposed for process planning of sculptured pocket parts. The characteristics of the methodology are to use feature-based process planning in machining the sculptured pocket part, and to append the machining and geometric information to the manufacturing features. The proposed methodology can increase the productivity by determining the better cutting conditions and by applying the variable machining parameter to entire machining of a given feature. The methodology proposed here can be easily adaptable to general shaped prismatic parts machining. The information contents in a manufacturing feature must be stored in such a that way they can be modified in real-time, since process planning is usually performed without the dynamic shop floor status. Therefore, an intelligent process planning system is required to generate a process plan which can be rapidly modified in the SFCS according to the changed tool status. It could be resolved by representing a process plan intelligently using neural network or expert system.

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