Recognition of Multi-Intersecting Features of Boundary Representation CAD Model

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Abstract—This research aims to solve technical problem of automatic feature recognition in a Computer Aided Process Planning system. This feature recognition method was developed to represent a 3D model as classes of manufacturing features based on graph theory. In addition, “accessibility” was proposed to recognize intersecting features with complicated graph structure which cannot be predefined by users. The experimental result shown in case study proofed that this proposed method is effective in multi-intersecting feature recognition.

1. INTRODUCTION
With the increasing of manufacturing demand, a high-efficient Computer Aided Process Planning system becomes a key technology in intelligent manufacturing field. Currently, CAM programmers recognize features in CAD model and plan the machining sequence based on experience. This process is manual work. An automatic CAPP system which plays a role as an information bridge between CAD and CAM replaces this work with efficient algorithm without manual error.

1.1. Literature Review
For decades, one of the most popular ideas in CAPP research is the idea that divides the system into two parts, feature recognition and process planning. Feature recognition aims to reinterpret different manufacturing features involved in the input CAD model and process planning aims to give a machining priority sequence of those manufacturing features.

There are rule-based feature recognition methods. Narabe, et al [1] and Mutou, et al [2] proposed a method to judge features in triangle mesh grids from STL (Standard Tessellation Language) file and developed a solution give a priority of those recognized manufacturing features depending on the time cost. Dwuyanti, et al [3] came up with “delta volume decomposition” method to generate tool path based on the delta volume which will be removed in the machining process. Jaider, et al [4] gave a method for rotational parts from STEP AP203 (Standard for the Exchange of Product, Application Protocol 203), proposed geometry and topology rules to define rotational features.

Defining freeform feature is complicated because shape of freeform feature is different to be represented by formulas. Sonthi, et al [5] calculated principle curvatures. Pernot [6] classified freeform feature into two main levels and furtherly developed a hierarchical freeform features taxonomy. Na, et al [7] proposed a freeform machining feature recognition method with both curved-based segmentation and manufacturability analysis-based segmentation consideration.

Joshi, et al [8] proposed a graph-based method to store 3D model. It represents models in a topology way. Zhu and Kato [9] applied graph structure in feature recognition to show features in graph
representation. Necessary geometry entities were stored in graph attributes. Bendjebla [10] proposed differential geometry to finish freeform machining feature classification also based on graph theory. STL recognition, volume decomposition and STEP rule-based methods have large computation cost. Graph-based method greatly reduces the calculation amount instead.

1.2. Objective
To automatically recognized manufacturing features involved in 3D CAD models, a feature recognition system based on graph theory was developed in this research. A multi-intersecting feature recognition method based on “accessibility” was proposed to decompose the relatively complicated regions into the pre-defined manufacturing features.

2. DATA CONVERSION

2.1. Boundary Representation
Boundary representation (B-rep) is applied to represent a 3D CAD model. For example, a cube shell is bounded by 6 faces, every face is bounded by four edges. For a B-rep model, the geometry and topology attribute are two basic components.

| Topologic Attributes |
|----------------------|
| Solid → Shell → Face → Loop → Edge → Vertex |
| Surface               |
| Plane                 |
| Line                  |
| Point                 |
| Curve                 |

Figure 1. Relationship between typical topology and geometry attributes

2.2. Graph Representation – Attributed Adjacency Graph
Graph is a structure including nodes and arcs. Nodes in graph represent faces. Arcs between two nodes represent edges. Nodes and arcs with geometry attributes are named as Attributed Adjacency Graph (AAG for short). The objective of AAG is to store the topology entities of B-rep model into graph structure.

There are two kinds of arcs in graph structure, convex arcs are defined as edges whose adjacent faces forming angle larger than 180°. While the two faces of concave arc are forming angle smaller than 180°. In AAG node graph, convex arcs are in black while concave arcs are in red.
2.3. AAG Decomposition
The objective of feature recognition module is to identify the manufacturing feature by matching the stored model with the predefined database. The first procedure is AAG decomposition. Deleting all convex arcs and extracting the concave graph in which there are only concave connection. Then the concave graph can be classified into certain class which contains typical manufacturing features as shown in Figure 3. The concave graph involved in Figure 2(b) can be classified into the Multi-node class, then identified as feature named “Closed Pocket”.

2.4. Accessibility – Intersected feature recognition
In some cases, there will be “unrecognized” feature whose concave graph has not been predefined as shown below in Figure 4.

To deal with this feature, “Accessibility” was defined. In this research, the planar faces which are completely accessible from its normal direction with no obstacles are defined as “Accessible Faces”. In other word, milling tool is accessible to process these accessible faces directly. An example for demonstration is shown below in Figure 5.
3. CASE STUDY

The model in Figure 6 involves Face, Step, Slot, Open Pocket, Closed Pocket, etc. The model was conversed into an AAG model at first, then AAG decomposition process extracted 18 concave graphs from the model. The displayable result is shown at last in Figure 6(c). It includes an “Unrecognized” manufacturing feature whose concave graph was shown in Figure 6(c) in gray frame and not predefined.

After “Accessibility” detection, the “Unrecognized” feature mentioned above in the case study has three accessible faces as shown in Figure 7: Face 5 - “F5”, Face 21 - “F21” and Face 48 - “F48”. By applying breadth-first search for first level to go through all the adjacent nodes surrounding to the accessible nodes, new concave graphs can be generated.
For example, doing the breadth first search of “Face 5” for first level means to find the nearest nodes of “F5”. The search output is: “F7, F9, F42”. They form a concave graph containing “F5, F7, F9, F42”. It belongs to multi-node class “Open Pocket” type.

Figure 7. Accessible nodes in the “Unrecognized” concave graph

Figure 8. “Accessibility” detection and “Unrecognized” feature decomposition
As shown in Figure 8, in this case three concave graphs “F5, F7, F9, F21”, “F4, F7, F21, F42, F43” and “F7, F15, F42, F48” which are recognized as one “closed pocket” and two “open pocket” can be generated. As a result, the unrecognized concave graph involved in this AAG model can be decomposed into three sub-concave graphs.

Figure 9. “Unrecognized” region recognition result
4. CONCLUSION
This research aims to automatically recognize the manufacturing features of input model based on graph
theory. The main contribution of this work can be summarized as below:
1. An AAG structure was proposed to store an object 3D model. Concave graphs were classified
into different manufacturing feature to reduce the computation complexity.
2. “Accessibility” of a face was defined and detected to recognize features with complicated concave
graph.

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