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Slicing Recognition of Aircraft Integral Panel Generalized Pocket

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Abstract

To automatically obtain a machining area in numerical control (NC) programming, a data model of generalized pocket is established by analyzing aircraft integral panel characteristics, and a feature recognition approach is proposed. First, by reference to the practical slice-machining process of an aircraft integral panel, both the part and the blank are sliced in the *Z*-axis direction; hence a feature profile is created according to the slicing planes and the contours are formed by the intersection of the slicing planes with the part and its blank. Second, the auxiliary features of the generalized pocket are also determined based on the face type and the position, to correct the profile of the pocket. Finally, the generalized pocket feature relationship tree is constructed by matching the vertical relationships among the features. Machining feature information produced by using this method can be directly used to calculate the cutter path. The validity and practicability of the method is verified by NC programming for aircraft panels.

Keywords: numerical control; aircraft integral panel; feature extraction; computer aided manufacturing

1 Introduction

With the development of numerical control (NC) programming technology, computer aided manufacturing (CAM) software has become a powerful tool to process complicated geometries. Simply relying on the technicians' experience to assign the machining areas and parameters in an interactive manner is not enough to meet the requirements in practices, hence it has become a tendency to develop NC programming technology so that CAM software can automatically develop an NC machining program based on the part and blank. This means that the CAM system should be able to automatically obtain the machining area in NC programming. This makes the automatic machining feature recognition act as a base or a key.

Feature recognition has been the object of study for over three decades and a variety of advanced methods has been presented, such as attributed adjacency graph-based (AAG-based) matching[1], convex hull decomposition[2], volume decomposition[3], hint-based approaches[4], hybrid approach[5-6], probabilistic or evidential reasoning[7-8], and artificial neural network-based (ANN-based) method[9]. Numerous recognition algorithms have been suggested to help solve the problem of intersecting features and feature recognition of complicated parts. However, the ambiguousness of feature representation and the diversity of feature interpretation make it difficult for the existing algorithms of

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feature recognition to provide a rational explanation of machining features, which makes the machining features unable to completely satisfy the requirements by machining[10]. Moreover, by mainly fitting the prismatic parts with regular shape, these algorithms are deficient in their practicality and universality.

As an effective method for rough machining, Layer-by-layer[11-12] is very suitable for multisurface parts with complex topology or thin-walled parts. The basic approach is: first, assume that the slicing is done with a set of planes normal to the *Z*-axis; second, compute the contours formed by the intersection of the horizontal plane with the part and the blank, on each layer; finally, define pockets and generate the tool path by arranging these elements. As the closed contour loops formed by the intersections on layers, conforms with some profiles of the machining feature, this method can be applied to machining feature recognition.

As one of the most important aircraft structures, the integral panel is much more complex in shape than any other machine parts. To reduce its weight and meet other requirements, there are usually complex cavities, pits, and curved surfaces on it. This article applies the slicing recognition method to recognize the machining features of aircraft integral panels, that is, the machining features are recognized and extracted with the information about intersections between the part and the blank created by slicing.

2 Generalized Pocket and Model of Representation

2.1 Generalized pocket

Generally, depending on the structural characteristics and different processes in NC machining, the machining features of an aircraft integral panel can be classified into outer profiles, pockets, ribs, bosses, and so on. The details of the feature classification are available for reference in Ref.[13].

Aircraft integral panel machining can be considered as a complex generalized pocket, milling in the view of manufacturing. In part designing, a rib is composed of a top and sides; in NC machining, the top needs to be machined in a special way, whereas, the sides indirectly by pocket milling. If there is a rib inside a pocket, the rib should be machined before the pocket. A fringe is a curved side close to the outer profile. If a fringe is contained in a pocket, it should be machined separately after the pocket. A pit on the wall, which is always located at the outer profile or side of the pocket is machined together with a T-slot cutter after completion. A boss on the bottom of the pocket is generally regarded as an island pocket. Structurally, ribs, fringes, and bosses are pocket-contained geometric structures, which are machined before or after the pocket, according to their types. Geometrically similar as it is to a pocket, an open structure needs to be treated as a special pocket when it undergoes machining. Furthermore, roughing of the outer profile of an aircraft integral panel can also be viewed as layer-by-layer pocket milling.

In summary, a generalized pocket is constructed in a manner where the pocket is taken as the main feature and the pocket-contained ribs, fringes, ribs, pits on wall, and so on, are the auxiliary features.

2.2 Representation model

Fig.1 shows a structural model of a generalized pocket, where pockets, ribs, pits on wall, and inner/outer convergence surfaces are machining features.

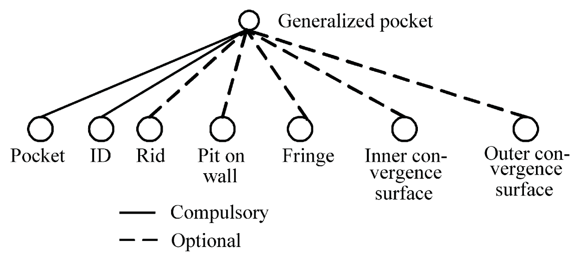

Fig.1 Structural model.

The Backus-Naur form describing the nodes is defined as follows:

<generalized pocket>:: = (<pocket>, <ID>, [rib], [pit on wall], [fringe], [inner convergence surface],

[outer convergence surface])

⟨pocket⟩:: = (⟨center coordinate⟩, ⟨top surface⟩, ⟨bottom surface⟩, ⟨guide profile⟩, [island profile])

⟨guide profile⟩:: = (⟨guide line⟩{, ⟨guide line⟩}, ⟨part face on which guide line locates⟩{, ⟨part face on which guide locates⟩})

⟨ID⟩:: = (⟨pocket identification⟩|⟨open pocket identification ⟩)

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3 Slicing Recognition for Generalized Pockets

3.1 Discussion

The method presented in this article originates from the actual slicing machining process of an aircraft panel. Aircraft integral panel machining is in general regarded as complex generalized pocket milling. Every pocket possesses one outer profile named guide profile (GP) with some nonmachining boundaries named island profiles, maybe inside it (see Fig.2(a)). The removal volume is the area between the guide profile and the island profile.

In Fig.2(b), contours are formed when both the part and the blank are simultaneously sliced by a horizontal plane, and, accordingly, the pocket profile can be extracted by recognizing intersection loops. Fig.2(a) illustrates the outer profile of the pocket and the profile of the pocket with an island. When the part and the blank are sliced by a set of slicing planes normal to the *Z*-axis (see Fig.2(c)), generalized pockets are generated by pocket profiles between two adjacent layers. Meanwhile, the associated profiles are modified depending on whether there are ribs or inner/outer convergence surfaces on the part, where intersectional curve loops exist. By matching the vertical relationships among features, a generalized pocket feature relationship tree is finally constructed (see Fig.2(d)) and complete features are found along the branches of the feature relationship tree (see Fig. 2(e)).

The basic steps of this approach can be described as follows:

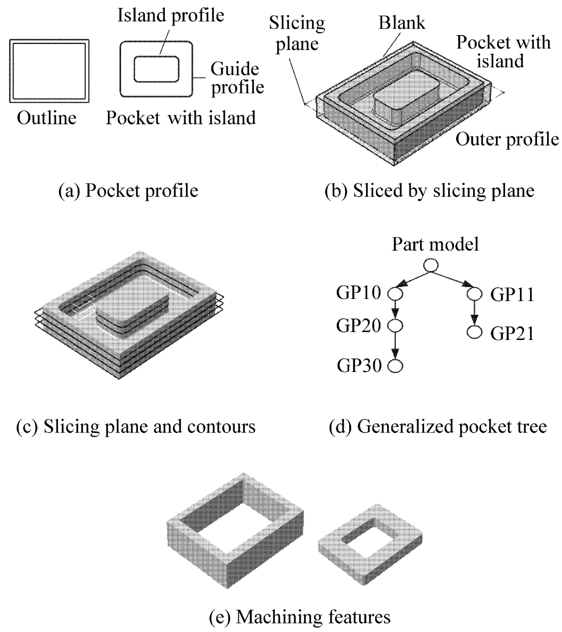


Fig.2 Sketch map of machining feature recognition based on slicing technique.

(1) Slice the part and the blank with a set of planes normal to the cutter axis, and compute the intersectional contours formed by the intersection of the slicing planes with the part and the blank in each layer, to form a closed intersectional curve loop.

(2) Construct generalized pocket profiles by recognizing the intersectional curve loop.

(3) Adjust some pockets' slicing plane locally, according to the horizontal planes between two adjacent parallel layers.

(4) Determine the auxiliary features of the generalized pocket, based on the types and position of the face at which the intersectional curves exist, and correct the pocket profile according to the auxiliary feature.

(5) Construct a generalized pocket feature relationship tree by matching vertical relationships among generalized pockets.

(6) Unite information about generalized pockets along the same branch of the relationship tree, to obtain all the features.

3.2 Construction and local modification of slicing plane

In the process of generalized pocket recognition based on slicing technology, the orientation of setup, namely, the direction of feature recognition should be determined initially, otherwise different directions or different types of recognized features could result from the unsuccessful recognition. According to the structural properties of the aircraft integral panel, this article takes the part height as the *Z*-axis and a set of slicing planes perpendicular to the *Z*-axis are established.

According to the actual machining, the plane that coincides with the bottom of the cutter in layer-by-layer machining is named slicing plane, which is established by taking the cutting depth during roughing as the criteria. However, for some pockets shown in Fig.3, the slicing plane is not just at the bottom of the pocket, thus they need local modification of the slicing plane for this pocket in this layer. The rule of local modification can be described as follows:

IF $((d<\delta)\ \&\ (z_1>z))\ ||\ (z_1<z)$, THEN the slicing plane for this pocket, in this layer, should be locally adjusted to the bottom of this pocket.

In this expression, d represents the distance between the slicing plane and the pocket bottom (see Fig.3(a)); δ the deviation of the cutting depth; z_1 the *Z*-coordinate of the slicing plane; z the *Z*-coordinate of the pocket bottom. $z_1>z$, means the slicing plane is above the pocket bottom (see Fig.3(a)), whereas, $z_1<z$, implies the opposite (see Fig.3(b)).

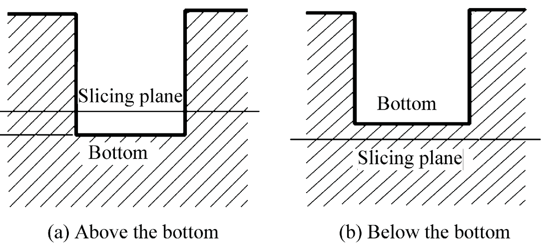


Fig.3 Local adjustment.

3.3 Recognition of intersectional curve loop

As a base to constitute a generalized pocket profile, the recognition of the intersectional curve loop involves two aspects: one is to determine the inner loop and outer loop, and the other is to judge the loop relationship.

(1) Judgment of loop's character

The judgment of loop's character is to judge whether a loop is an inner one or an outer one. Fig.4 shows the relationship among the geometric objects and topological objects in computer aided three-dimensional interface application (CATIA) system. The topological objects of the solid model in CATIA include bodies, lumps, volumes, shells, faces, loops, and so on (see Fig.4). A body is composed of a lump made of volumes. Each lump is a set of volumes connected by faces. A shell is made of faces, and the boundary of the face is named loop.

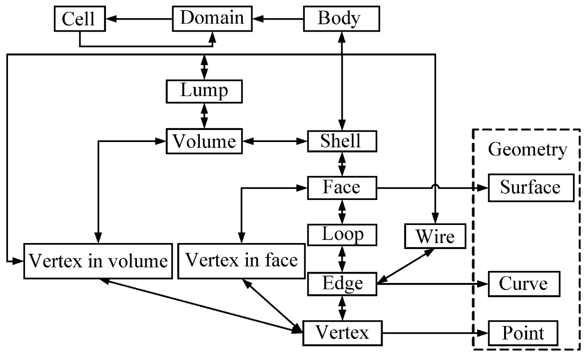


Fig.4 Geometric and topological objects diagram.

The relationship r_{LF} between a loop and a face includes the external boundary ($r_{LF}=1$), internal boundary ($r_{LF}=-1$), and immersion into the face ($r_{LF}=0$). Bodies, faces, and wires coexist in a solid model. Moreover, an intersectional contour and an intersection can interconvert. Therefore, an intersectional contour with multiple "loops" can be converted into an intersectional "face" and an intersectional curve loop, whether outer or inner, can be determined by querying the relationship r_{LF} between the loop and the face. Hence, the rules to govern a loop's character are described as follows:

Rule 1 IF the relationship between a loop and a face is $r_{LF}=1$, THEN the loop is an inner loop, OR ELSE IF $r_{LF}=-1$, THEN the loop is an outer loop.

Rule 2 IF the loop is formed by the intersection of the slicing plane with the blank, THEN the loop is defined as an inner loop.

(2) Judgment of loops' relationship

It can be seen from Fig.5 that the relationship of loops can be divided into: separation, direct inclusion, and indirect inclusion (Loop1 and Loop3).

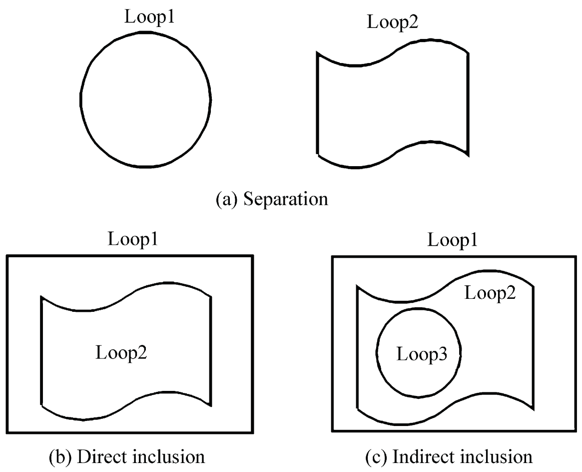


Fig.5 Relationship of loops.

The following rule can be applied to constitute a pocket profile.

Rule 3 IF a loop is an inner one, THEN the loop is defined as a guide profile, OR ELSE IF an outer loop is contained directly in an inner loop, THEN the outer loop is viewed as an island profile.

With the help of the recognition method of the intersectional curve loop mentioned earlier, the generalized pocket profile can be set up based on the loops' relationship, after a successful judgment of the loop's character has been made.

3.4 Judgment of machining face types and topological position

(1) Recognition of machining face types

Machining face types and topological position decide the machining feature types, and the manufacturing method in NC also serves as a base to judge if there are auxiliary machining features in the generalized pocket. Fig.6 shows the machining face types and the position of the machining feature of an aircraft integral panel.

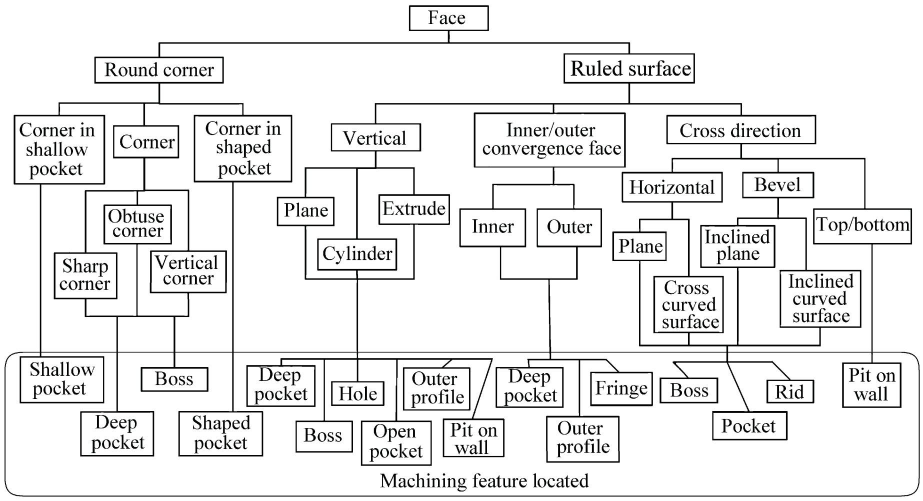


Fig.6 Face types and machining feature.

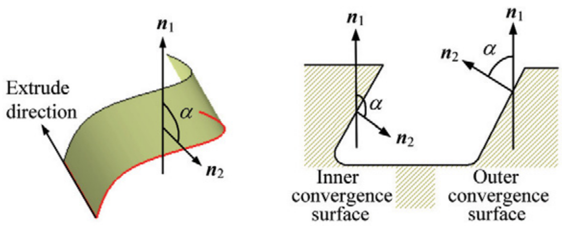
In an aircraft integral panel, there are very few shaped surfaces or other curved surfaces could be seen, so ruled surfaces predominate. This limits the analysis to the recognition method of the ruled ones. The judgment of the ruled surface types is to first, judge the face shape formed in CATIA, such as, plane, cylinder, and tabulated cylinder (see Fig.7), which is formed by extruding the spline curves, then calculate the angle α included between the normal line direction of the surface and the Z-axis by using

$$\left.\begin{array}{ll} \alpha = 0^\circ & (F \text{ is horizontal ruled surface}) \\ \alpha = 90^\circ & (F \text{ is vertical ruled surface}) \\ 90^\circ < \alpha < 90^\circ + \beta & (F \text{ is inner convergence surface}) \\ 90^\circ - \beta < \alpha < 90^\circ & (F \text{ is outer convergence surface}) \\ 0^\circ < \alpha \le 90^\circ - \beta & (F \text{ is cross ruled surface}) \end{array}\right\} \quad (1)$$

where α represents the angle included between the normal direction $\boldsymbol{n}_2$ of a face and Z-axis $\boldsymbol{n}_1$ (see Fig.7), and

$$\alpha = \arccos(\frac{\boldsymbol{n}_1 \cdot \boldsymbol{n}_2}{|\boldsymbol{n}_1||\boldsymbol{n}_2|})$$

β is the largest inclined angle of the inner/outer convergence face.



(a) Extruded face   (b) Inner/outer convergence face

Fig.7 Face recognition.

(2) Rules for judgment of generalized pocket machining features

The rules to determine generalized pocket machining features can be summarized as follows:

Rule 4 IF $\forall e \in L$, $F_{\rm vp}(e) \wedge F_0$, THEN add pocket identification to generalized pocket.

Rule 5 IF $\forall e \in L$, $F_{\rm vp}(e) \wedge (\sim F_0)$, THEN add open pocket identification to generalized pocket.

Rule 6 IF $\exists e \in L$, $F_{\rm vp}(e) \wedge F_{\rm hp}(\rm co)$, THEN correct the pocket profile according to the pit on wall shape, add pit on wall to generalized pocket, and store its pointer.

Rule 7 IF $\exists e \in L$, $F_{\rm tp}(e)$, THEN correct the pocket profile according to the sharp/obtuse angle surface shape, add sharp/obtuse angle surface to generalized pocket, and store its pointer.

Rule 8 IF $\exists e \in L$, $F_{\rm ts}(e)$, THEN correct the pocket profile according to the fringe shape, add fringe to generalized pocket, and store its pointer.

Rule 9 IF $\exists e \in L$, $F_{\rm lo}(e)$, THEN add rib to generalized pocket, and store its pointer.

In the above-mentioned rules, L represents the intersectional curve loop; e the intersectional curve; $F_{\rm vp}(e)$ the vertical ruled face where e is located; F_0 the horizontal plane; $F_{\rm hp}(\rm co)$ the horizontal plane having a common edge with $F_{\rm vp}(e)$, co the common edge; $F_{\rm ts}(e)$ the inclined vertical ruled curved surface where e is located; $F_{\rm lo}(e)$ the cross direction ruled face where e is located; $\wedge$ the logic "and"; $\sim$ the logic "not".

In order to store and organize the recognition results, generalized pocket feature relationship tree can be constructed by using the aircraft integral panel as the root and generalized pocket as the mid node and leaf (see Fig.8).

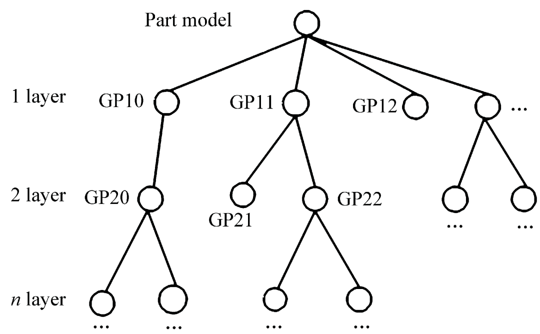


Fig.8 Tree model of generalized pocket.

4 Algorithm and Implementation

4.1 Algorithm design

Fig.9 shows the algorithm on the base of the generalized pocket data model and slicing recognition method mentioned earlier. The slicing plane

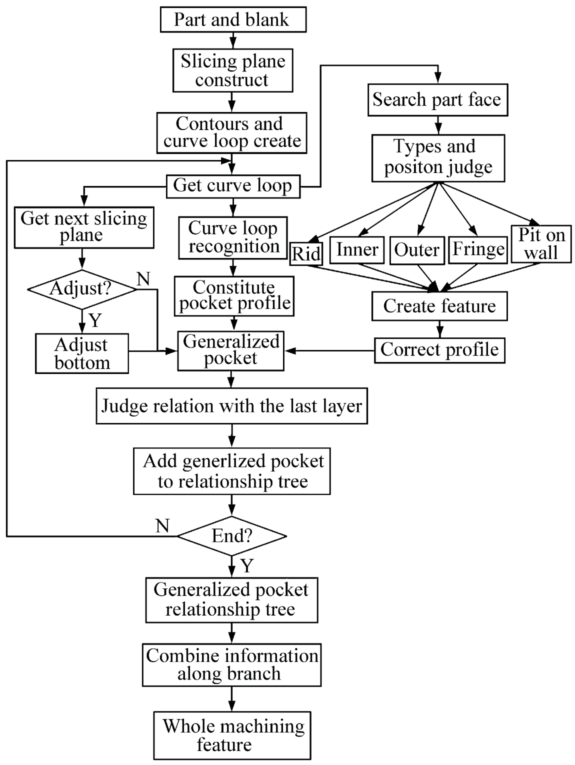
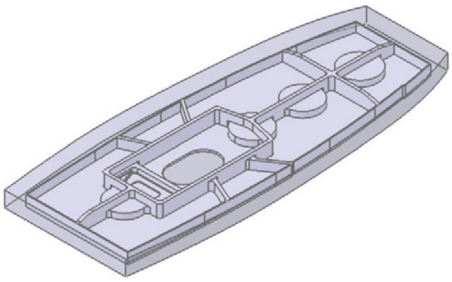


Fig.9 Flow chart of automatic feature recognition.

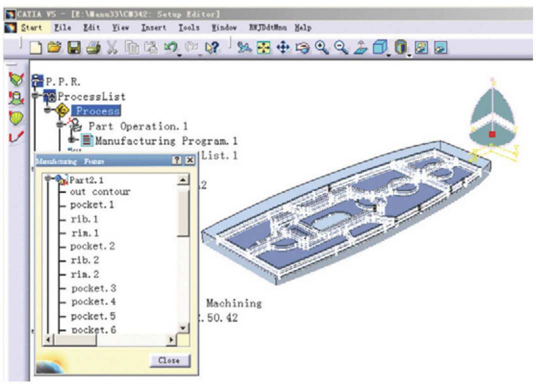
construction and adjustment, intersectional curve loop recognition, and face types and position judgment constitute the core of the algorithm.

4.2 Implementation and verification

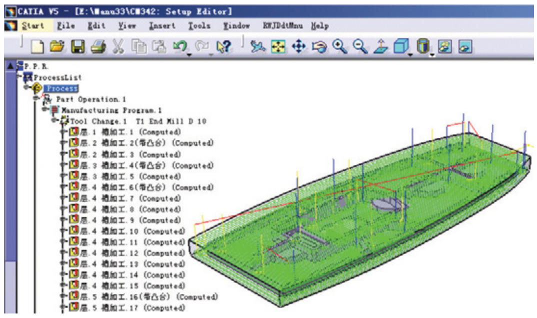
The proposed slicing recognition method was implemented using Visual C++ 6.0 in CATIA component application architecture (CAA), an application development platform of computer aided design (CAD) system CATIA V5R14. The workpiece in Fig.10(a) is taken as an example. It is composed of an outer profile, thirteen pockets, eight ribs, and one open pocket. After recognition, by using this approach, the machining features and intersectional curve loops are formed as shown in Fig.10(b). By applying the machining feature information directly to the NC programming system of the aircraft integral panel, the machining geometry can be set automatically, and the tool path computed so as to generate the cutter trajectories during roughing and finishing (see Fig.10(c)). The recognition results meet the requirements needed by NC machining and can be effectively applied to the aircraft integral panel NC programming.



(a) Part and blank



(b) Machining features and intersectional curve loops



(c) Tool path of roughing and finishing

Fig.10 Example of automatic machining feature recognition.

5 Conclusions

This article introduces an improved machining feature recognition approach for NC machining aircraft integral panels based on the generalized pocket data model and the slicing recognition method of the generalized pocket, with a successfully developed recognition algorithm and an “automatic machining feature recognition” module. The module has been verified on aircraft integral panels with satisfactory results. Conclusions can be drawn as follows:

(1) The presented method provides an applicable, efficient tool for aircraft integral panel recognition.

(2) Information about machining features such as tops, bottoms, guides, and so on, can be directly used to compute a tool path, well solving the problem of automatic setting machining geometry in NC programming.

Successful as it is in extracting the machining features for aircraft integral panels, the proposed method should be improved in the following aspects in the future: its application should be expanded to spherical and other curved surfaces; serious consideration should be given to the recognition of compound ribs.

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