Title:
An Automatic Modeling Method for Three-Axis Machining Process Parts Based on Slicing Recognition

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Introduction:
Process part model can accurately reflect the geometric shape, machining quality and their changes during the machining process, and drive NC automatic programming. The automatic modeling of process part is an essential step in the multi-station machining of complex parts, and the process cutting volume is the basic data required to perform the corresponding process machining at each station [1]. As so far, feature recognition method [2] and process information method [3,4] are the main methods for the construction of process part model. In Kim and Wang's research [5], they proposed a hybrid machining feature recognition method for cast-then-machined parts. They lifted machined faces to obtain offset volumes, and combined the half-spaces induced by the connected sets of machined faces, which resulted in the starting workpiece. However, it is difficult to recognize complex interacting features. In Park's research [6], they proposed a method for generating the target machining volumes and intermediate models from a rough model, a finished model and a sequence of machining operation, and verified the effectiveness of this method by comparing with the cutter swept volume. The above methods have high requirements for the information standardization of the input model, so they lack generality.

In this paper, an automatic geometric modeling method for 3-axis machining part is proposed to improve modeling efficiency, reduce model data complexity, and provide an accurate sequence of process part models for CAPP. The proposed method uses a process part model after finishing a machining process, which is called the back-part model, as a direct input. Secondly, the topological elements which coincide with cutting volume contours can be extracted by identifying and calculating the intersecting data. Then, all cutting volume models machined at the current station are constructed. The machinability of the automatically generated cutting volume model is determined by current station, instead of process planning or equipment performance parameters. Finally, the cutting volume model corresponding to the current process is selected interactively to build the blank of the process, which is called the pre-part model.

Main Idea:
General working flow of the modeling method based on slicing recognition
The general working flow of the proposed modeling method is shown in Fig. 1. The entire process can be divided into five steps. Among these steps, the type recognition of layer element contours and the matching of contour correspondences between layering intersections are the key to determining the accuracy of the pre-part model. The data model structure and data calculation relationships in the modeling process can be summarized as shown in Fig. 2. The detailed techniques used in each step will be thoroughly discussed below.

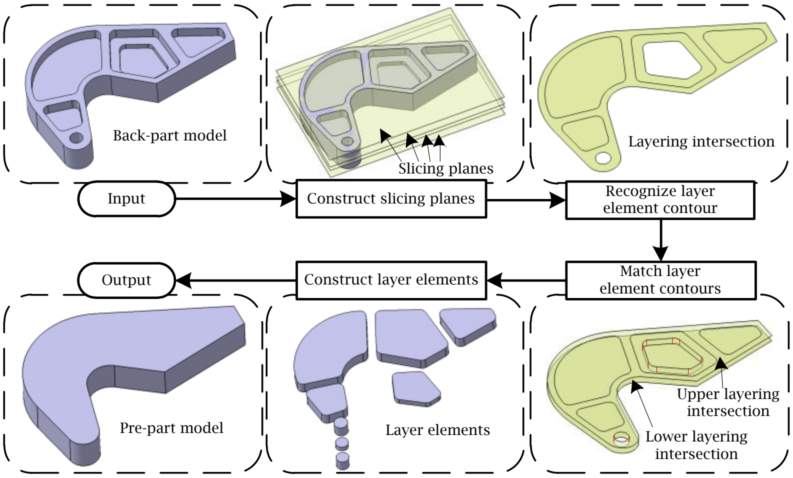

Fig. 1: General working flow of the proposed modeling method.

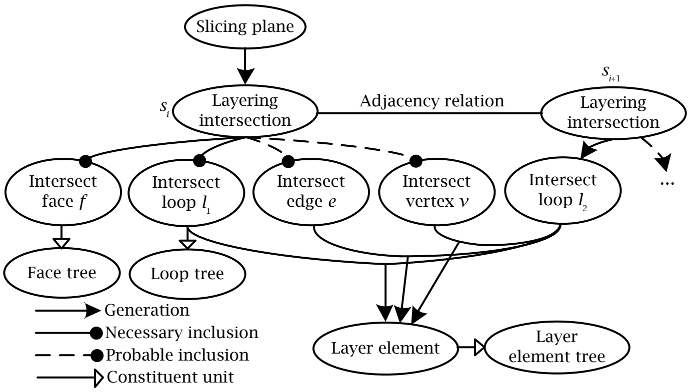

Fig. 2: Data model structure of the proposed method.

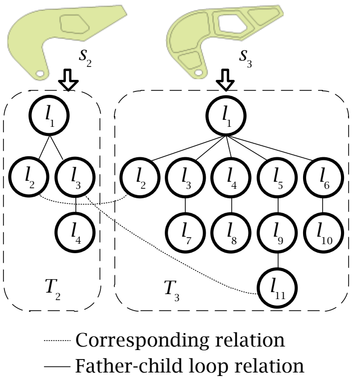

Fig. 3: Intersect loop tree.

In the first step, the slicing planes intersected with the input back-part model are generated first. According to the z-coordinate values of vertices on the back-part model, a group of parallel horizontal planes are created, which are called the slicing planes. Each slicing plane intersects with the back-part model to generate the geometric topological data set on the layer.

In the second step, we compute the contours formed by the intersection of the slicing plane with the back-part model on each layer. The geometric topological information obtained from the intersection of slicing planes is called the layering intersection, which is represented by s. The layering intersection can be formally defined as $s\ F,L,E,V$, where F, L, E and V are the set of intersect faces, intersect loops, intersect edges and intersect vertices respectively. The intersect faces and intersect loops can define the contours of machining features such as groove, hole and boss, etc. The intersect edges and intersect vertices can define the contours of wedge machining features, such as V-groove, and the contours of conical machining features, such as conical hole, respectively. The topological elements mentioned above are collectively called as intersect topological elements, or intersect elements for short, represented by φ.

In the third step, the upper and lower contour of layer elements are matched between two adjacent layering intersections. The recognition process of each layering intersection takes its adjacent upper layering intersection as the calculation reference. The corresponding relationship is determined based on the correlation surface of two intersect elements on adjacent layering intersections, and the upper and lower contour of layer elements can be defined by the corresponding intersect elements, and then the types of layer elements can be represented.

In the fourth step, layer element solid model is constructed by the basic modeling operations of CAD system, such as stretching and trimming, based on its upper and lower contours identified in the previous step. Layer element trees are constructed according to the overlap relation of upper and lower end faces to represent the longitudinal position relation between layer elements. For any two adjacent layer elements on the tree, the upper one is called the father layer element and the lower one is called the child layer element. A father element may have no or several children, but a child element has only one father element.

In the fifth step, the cutting volume and the back-part model perform Boolean union operation to generate the pre-part model. According to the process planning, the cutting volume actually machined by the current process is selected interactively, which makes the process part sequence easy to modify.

Computation of the Layering Intersection

In order to extract the contour of layer elements and judge the type of layer elements, the attributes of layer elements are analyzed and the corresponding relations between the adjacent layer intersections are calculated in this subsection.

1) Attribute analysis of intersect elements on a single laying intersection

Let s be a laying intersection, and its intersect loop set is L. The intersect loop tree shown in Fig. 3 can be used to represent the inclusion relationships between intersect loops[7].

Let l be an intersect loop of f, which can be divided into the outer intersect loop and the inner intersect loop according to its relative position with f, represented by $l = l^o$ and $l = l^i$ respectively.

Let e be an intersect edge on s. If e is not a constituent edge of any intersect loop, it is called an isolated intersect edge, or isolated edge for short, represented by $e \in E_s$. Let $E = \{ e_i \mid i = 1,2,\cdots,n \}$ be a set of intersect edges on s. If $\forall e_i \in E$, $\exists e_j \in E$, $i \neq j$, so that e_i and e_j are adjacent, then E is called an isolated intersect edge chain, or isolated edge chain for short, represented by $E \subseteq E_s$.

Similarly, if the intersect vertex v on s is not the endpoint of any intersect edge, it is called an isolated intersect vertex, or isolated vertex for short, represented by $v \in V_s$.

2) Corresponding relationship analysis between adjacent layering intersections

The corresponding relation of layer topological elements is judged by the same associated faces. Let s_1 and s_2 be two adjacent layering intersections and s_1 is above s_2, and let l_1 be an intersect loop on s_1.

(1) Loop-loop corresponding relationship

Let l_2 be an intersect loop on s_2, if the following conditions are both met:

a. $l_1 = l^o \wedge l_2 = l^o \ \vee \ l_1 = l^i \wedge l_2 = l^i$;

b. $\forall e_i \in E_2$, $\exists e_j \in E_1$, where E_2 and E_2 are the edge sets of l_1 and l_2 respectively, so that e_i and e_j have common associated faces on the back-part model. Then l_1 is called the corresponding loop of l_2, represented by $l_2 \mapsto l_1$.

(2) Edge-loop corresponding relationship

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Let $E=\{e_i \mid i=1,2,\cdots,n\}$ be an isolated edge chain on s_2. If $\forall e_i \in E$, $\exists e_j \in E_1$, so that e_i and e_j have common associated faces, then l_1 is called the corresponding loop of E, represented by $E \mapsto l_1$.

(3) Vertex-loop corresponding relationship

Let v be an isolated vertex on s_2. If $\forall e_i \in E$, v and e_i have common associated faces, then l_1 is called the corresponding loop of v, represented by $v \mapsto l_1$.

Construction of the Layer Element

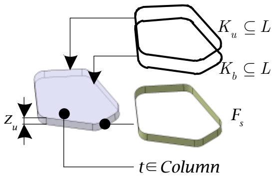

Fig. 4: Layer element modeling parameters.

Layer element is the basic component unit of cutting volumes. As shown in Fig. 4, the layer element is defined as $u\ t,K_u,K_b,F_s,z_u$, where K_u and K_b are the upper and lower end contours of the layer element respectively, and t, F_s and z_u are the type, the set of associated faces on the back-part and the height of the layer element respectively. The type of K_b can be intersect loop, intersect edge, or intersect vertex, and can be expressed as $K_b \subseteq L$, $K_b \subseteq E$ and $K_b \subseteq V$. Determined by the type of K_b, the type of layer element can be column, wedge and cone, and can be expressed as $t \in Column$, $t \in Wedge$ and $t \in Cone$ respectively. According to whether the upper end contour can be completely extracted from the upper laying intersection, the layer element can be further divided into several subtypes (Tab. 1).

Type	*Subtype*	*Contour conditions*
$t \in Column$	$t \in ClosePocket$	$K_b \subseteq L \wedge l_b^o = l^i$, $K_u \subseteq L \wedge l_b^o \mapsto l_u^o \wedge l_b^{i,j} \mapsto l_u^{i,j}, j=0,1,\cdots,n$
	$t \in OpenPocket$	$K_b \subseteq L \wedge l_b^o = l^o$, $K_u \subseteq L \wedge l_u^o = E \cup E_s$
	$t \in Boss$	$K_b \subseteq L \wedge l_b^o = l^o$, $K_u \subseteq L \wedge l_u^o = E_p$
$t \in Wedge$	$t \in CloseWedge$	$K_b \subseteq E \wedge E_b \subseteq E_s$, $K_u \subseteq L \wedge E_b \mapsto l_u^o \wedge l_u^o = l^i, l_b^i = \varnothing$
	$t \in OpenWedge$	$K_b \subseteq E \wedge E_b \subseteq E_s$, $K_u \subseteq L \wedge E_b \mapsto l_u^o \wedge l_u^o = E \cup E_s, l_b^i = \varnothing$
$t \in Cone$	$t \in CloseCone$	$K_b \subseteq V \wedge v_b \in V_s$, $K_u \subseteq L \wedge v_b \mapsto l_u^o \wedge l_u^o = l^i, l_b^i = \varnothing$
	$t \in OpenCone$	$K_b \subseteq V \wedge v_b \in V_s$, $K_u \subseteq L \wedge v_b \mapsto l_u^o \wedge l_u^o = E \cup E_s, l_b^i = \varnothing$

Tab. 1: Contour conditions of layer elements.

In particular, if K_u is not enclosed, sealing edges should be successively created according to the right-hand rule, denoted as e_s. As shown in Tab. 1, the outer intersect loop containing sealing edges is denoted as $l_u^o = E \cup E_s$,where E and E_s are the intersect edge set and the sealing edge set respectively. If $t \in Boss$, all edges of the lower contour are projected onto the upper layer intersection, which is called the projection edge and denoted as e_p . The outer intersect loop formed by projection edges is denoted as $l_u^o = E_p$, where E_p is the set of projection edges.

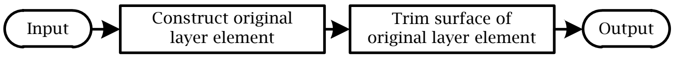

Fig. 5: General modeling flow of the layer element.

The modeling process of the layer element is shown in Fig. 5. Firstly, the negative direction of Z axis in the processing coordinate system is taken as the stretching direction and the height z_u is taken as the stretching value to create the original layer element, represented by u_b . Then, trim the surface of original layer element with associated faces, reserving the material domain pointed by the normal vector outside the face. Finally, the layer element model with precise geometry is output. The process is repeated to construct all layer elements and the layer element tree. The cutting volume model is constructed by combing all layer elements. The pre-part model can be generated by Boolean union operation between back-part model and cutting volume model.

Taking the aircraft structural component afterpiece model shown in Fig. 1 as an example, the proposed method saves more than 90% of modeling time compared with the manual modeling method, and the more complex the back-part model is, the more the efficiency is improved.

Conclusions:

In this paper, the reverse modeling method of process part is proposed based on slicing recognition, which can accomplish the accurate identification of 3-axis machining features including boss, hole, and protrusion, and the rapid construction of the corresponding cutting volume model. Compared with the manual modeling process, the validity of proposed method is verified. Besides, the proposed method provides a theoretical basis for further research on the construction of 5-axis machining parts.

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