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3D Reconstruction from Orthographic Image and Optimization Processing of NC Machining for Reconstructed Part

J.P. Liu[1,a], B.Y. Ye[1,b] and J.X. Peng[2,c]

[1]School of Mechanical Engineering, South China Univ. of Tech., Guangzhou, 510640, China

[2]Foshan Polytechnic College, Foshan, Guangdong, 528237, China

[a]ljp68@tom.com, [b]byye@scut.edu.cn, [c]nhpjx@163.com

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Abstract. For inverse constructing object from its orthographic image, a new method of 3D reconstruction based on image vectorization and bi-arc approximation of cubic B-spline is investigated. A 3D CAD model is automatically acquired from 2D views by means of 2D primitive recognition, 3D reconstruction of primitive and combination of 3D primitive bodies. With the help of CimatronE8.0 software, reasonable procedure design and optimization toolpath planning are applied to increase machining accuracy and productivity during automatic programming for reconstructed 3D solid. Reconstructed parts are machined on the VMC-600 type machine center with FANUC system. The results of application indicate that this method has many advantages, such as quickly obtaining the CAD model of part, getting smooth machined surface, efficient machining without invalid or reduplicate feed and so on. As a result, it can be applied widely in NC machining field.

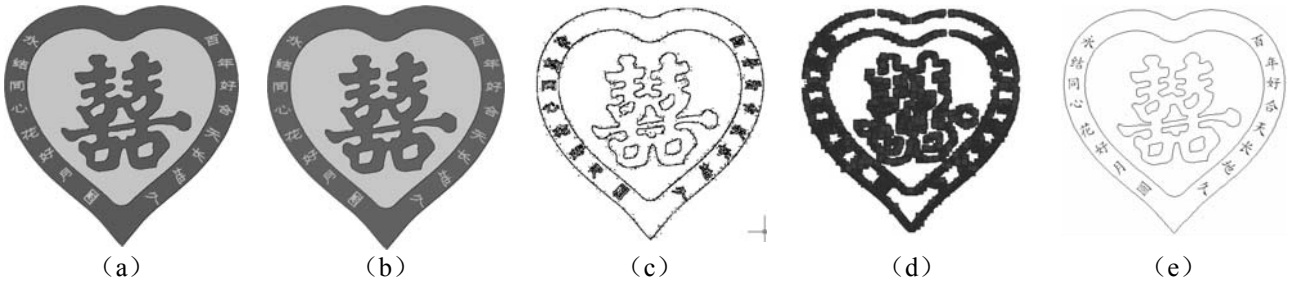
Introduction

3D CAD model of a complex part should be firstly established before automatic programming and NC machining. Usually, there are two methods to obtain a 3D model: ① Manual drawing by computer with CAD software; ② Inverse constructing 3D model from its part object. In the case of without engineering blueprint or that of with part objects but lacking measure equipment for inverse constructing, it is hard to get a 3D model of part in general. For solving this problem, a new method is investigated to achieve 3D CAD model of part object from its orthographic projection image (this method is also suitable for 2D Engineering drawings). Firstly, cubic B-spline outlines are obtained after part contour is extracted from orthographic image and vectorization processing is made. For common NC machine tools, the non-circular outline can not be processed by direct interpolation and can only be done by arc or line interpolation. In order to approximate the B-spline by using less number of tangent arcs or lines and obtain smooth machined surface for B-spline contour machining, an algorithm of arc approximation of B-spline is put forward and realized at the VC++ 6.0 software platform. A 3D CAD model is automatically acquired from 2D views by means of 2D primitive recognition, 3D reconstruction of primitive and combination of 3D primitive bodies. Then optimal NC machining strategy and knowledge machining based on remaining stock are applied to process the reconstructed part by using CimatronE8.0 software. This NC machining process, which reversely constructs part from its orthographic image, integrates many technical achievements coming from computer graphics, artificial intelligence, graphic and image processing, CAD/CAM and NC technology, etc. It can greatly enhance production efficiency and machining quality, thus it can be applied especially to the fields of NC turning, milling, wire electrical discharge machining.

3D Reconstruction from Orthographic Image

Orthographic Image Vectorization of Part. 2D contours information should be extracted before 3D reconstruction of part. This requires that part contours be extracted from vector graphics and so that it can be expressed by mathematical method. But part image is constructed by pixels. Therefore

image vectorization is the first need to do for 3D reconstruction. Here, vectorization process for orthographic image is illustrated by an example of heart-shaped part.



（a） （b） （c） （d） （e）

Fig. 1 Vectorization process from orthographic image of heart-shaped part

First noise smoothing and geometric correction of calibrated original image (Fig.1 a) are processed. And then binarization treatment of gray image is made (Fig.1 b). After edge of binary-conversion image is detected and extracted, vectorization graphic of contour is obtained and can be saved as dxf-typed or dwg-typed CAD file.(Fig.1 c). In AutoCAD 2008 environment, the non-circular outline is fit as B-spline (Fig.1 d). And finally, 2D contour with accurate dimension is obtained after editing (Fig.1 e).

Arc and Line Approximation of B-spline. Cubic B-spline function is second order differentiable continuous on every spline node and this makes the whole spline curve smooth. Due to the limits of NC machining, B-spline contour can not be processed by direct interpolation for common machining tools and so that it must be approximated by arc or line before NC machining. In this paper, an algorithm of arc spline approximation is applied to ensure machined surface of B-spline contour smooth by connecting every spline node with tangent arc or line.

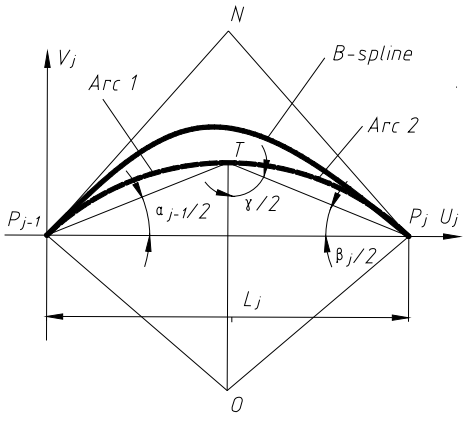


Fig. 2 Arc spline approximation

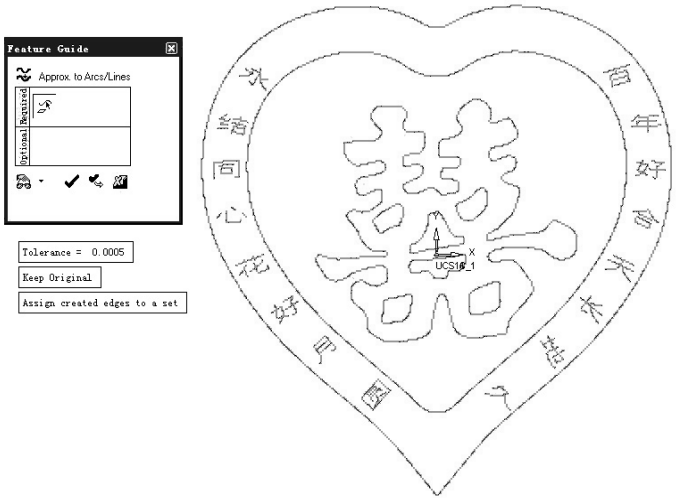


Fig. 3 Approximation result of heart-shaped part

As shown in Fig.2, establish a local coordinate system ($U_jP_{j-1}V_j$) in which the origin of coordinate is at point P_{j-1} and the vector direction of line $\overline{P_jP_{j-1}}$ represents positive direction of X coordinate axis. First, make two tangent lines ($\overline{P_{j-1}N}$, $\overline{NP_j}$) pass by any two adjacent B-spline nodes [$P_{j-1}(x_{j-1}, y_{j-1}), P_j(x_j, y_j)$] and intersect at point N. Arc $P_{j-1}N$ is tangent to arc TP_j at point T (tangent point should be in the perpendicular bisector between two adjacent spline nodes). And arc $P_{j-1}T$ is tangent to line $\overline{P_{j-1}N}$ at node P_{j-1}. Similarly, arc TP_j is tangent to line $\overline{NP_j}$ at node P_j. The coordinate value of tangent point T is calculated as follow:

$$\begin{cases} U_r = \dfrac{L_j}{2} \\ V_r = \dfrac{L_j}{2}\tan\dfrac{\alpha_{j-1}+\beta_j}{4} \end{cases}. \quad (1)$$

where α_{j-1} is the angle of tangent chord at node P_{j-1}, β_j is the angle of tangent chord at node P_j and L_j is chord length between node P_{j-1} and node P_j.

In order to distinguish left or right arc at a spline node, subscript (+) expresses right arc and subscript (-) expresses left arc. So, calculation of left arc at node P_j is given as follows:

$$\begin{cases} U_{cj(-)} = L_j - R_{j(-)}\cdot\sin\beta_j \\ V_{cj(-)} = -R_{j(-)}\cdot\cos\beta_j \\ R_{j(-)} = (\dfrac{4}{L_j}\cos\dfrac{\alpha_{j-1}+\beta_j}{4}\sin\dfrac{3\beta_j-\alpha_{j-1}}{4})^{-1} \end{cases}. \quad (2)$$

where $R_{j(-)}$ is radius of left approximation arc, $U_{Cj(-)}$ is X coordinate of circle center of left approximation arc, and $V_{Cj(-)}$ is the Y coordinate one. Calculation of right arc at node P_{j-1} is similar to the left one, it is given as follows:

$$\begin{cases} U_{cj-1(+)} = R_{j-1(+)}\cdot\sin\alpha_{j-1} \\ V_{cj-1(+)} = -R_{j-1(+)}\cdot\cos\alpha_{j-1} \\ R_{j-1(+)} = (\dfrac{4}{L_j}\cos\dfrac{\alpha_{j-1}+\beta_j}{4}\sin\dfrac{3\cdot\alpha_{j-1}-\beta_j}{4})^{-1} \end{cases}. \quad (3)$$

where $R_{j-1(+)}$ is radius of left approximation arc, $U_{j-1(+)}$ is X coordinate of circle center of right approximation and $V_{j-1(+)}$ is X coordinate one.

According to analysis above, B-spline between any two adjacent nodes can be approximated by bi-arc, thus whole spline will become a ployline which consists of some tangent arcs and lines after arc approximation. On the other hand, approximated B-spline is first order continuous and has equal curvature for single piecewise spline. From Fig.3, we can see that this application program of arc spline approximation has friendly user interface. Users can input arbitrary given approximation tolerance in the tolerance window.

3D Reconstruction from 2D Views. Generally, boundary representations (B-rep), constructive solid geometry (CSG) and approach-based algorithm are the typical algorithms of 3D reconstruction [1]. This paper simulates the method of shape analysis and presents a new method for 3D reconstruction based on engineering semantics understanding. The main ideas of algorithm are as follows: First, multiple views are separated from graphic data, primitive loops of are searched and then dimension information related to 3D feature modeling is extracted. Second, divided primitives and the combined relation between primitives are recognized by engineering semantics understanding [2]. Third, sweeping representation is used for components reconstruction. If unsuccessful, the approach algorithm is then arranged for 3D reconstruction. Provided that the two methods are not fit for this component, the component can be reconstructed based on primitives decomposition. Fourth, each of decomposed primitives is supposed to be among of elementary feature, sweeping feature, volume-cutting feature and boundary feature. And it is reconstructed by using a corresponding algorithm in order of precedence, i.e. CSG→Sweeping representation→the approach algorithm→B-Rep. Every reconstructed 3D component or primitive is validated by its projective views. Finally, all reconstructed components and primitives are assembled into a goal object by Boolean operation and 3D editing operations [3].

Fig.4 illustrates the reconstruction process of a heart-shaped part. The combination of Object ARX 2008 and Visual C# 2.0 is used to implement the new method in AutoCAD 2008 environment.

According to algorithms ideas above, heart-shaped part is successfully reconstructed. Fig.5 shows the reconstruction of heart-shaped part and the user interface of application module of 3D reconstruction. The encircled part at left of Fig.5 shows the menu of 3D reconstruction module.

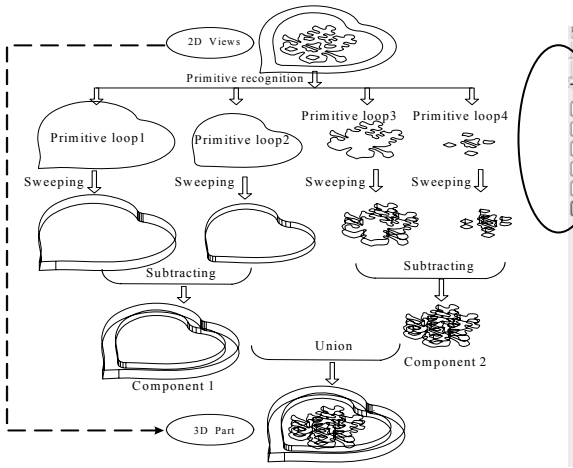


Fig. 4 3D reconstruction of heart-shaped part

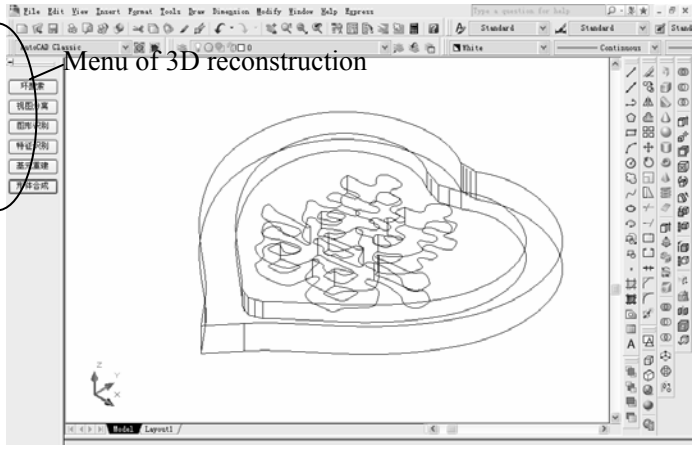
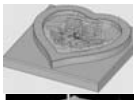
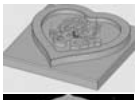
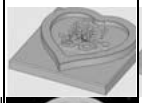
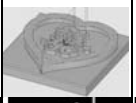
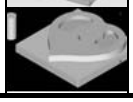
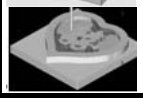
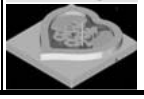


Fig. 5 Reconstruction result of heart-shaped part

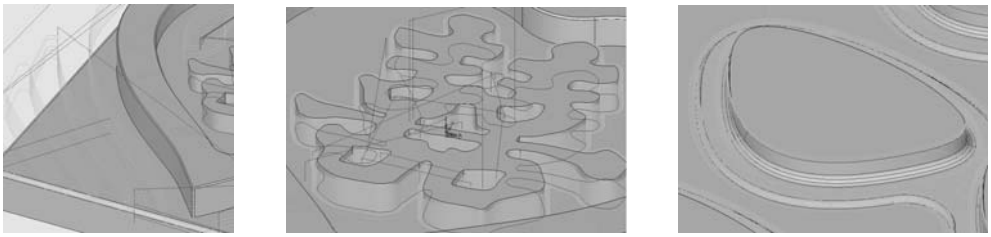
Automatic Programming and NC Machining of Reconstructed Parts

In general, a complex part is machined on the NC machining tool by automatic programming. Maybe different people choose various machining method and different process parameters at the time of toolpath planning, but basic principles such as good quality, high productivity, security machining and toolpath optimization should be considered. For enhancing machining accuracy, we should remain uniform distribution of allowance for the next procedure during current procedure and make machining shape similar to the final machined shape as far as possible. Making full use of the powerful function of CimatronE8.0 software, we can realize the required goals above.

Table 1 Toolpath planning and toolpath simulation of heart-shaped part

No.	1	2	3	4	5	6	7	8
Procedure	Rough Spiral	Re-rough	Re-rough	Horizontal areas	Horizontal areas	3D step	Flow line	Open contour
Tool path								
Simulation								

Due to general process thinking of procedure planning, that is to say, rough machining→re rough machining→finishing horizontal planar areas→re rough machining again→semi finishing →finishing→cleaning up, toolpath planning and simulation verifying of heart-shaped part are shown in table 1 To sum up, application strategies of heart-shaped part at the aspects of toolpath optimization and intelligent machining are as follows (Fig.6): ①by updating remaining stock, efficient machining comes true without invalid or reduplicate feed during the procedure of rough machining, re rough machining and finishing. ② keep uniform depth of processing and even contour distance by stock spiral processing. ③ make the corner toolpath fillet. ④ choose the method of cutting tool lift according to incremental coordinate or safety lift of cutting tool inside of part cavity to reduce times of raising cutting tool and to save processing time. ⑤ keep even step and constant load by using 3D step to obtain good ruled surface. ⑥ by using automatic slope analysis, intelligently distinguish flat or steep site of part and then reasonably select different toolpath planning aiming at different sites to realize smooth cutting when cleaning up.



（a）filet toolpath （b）3D step （c）automatic slope analysis

Fig. 6 Toolpath optimization strategy

Application

To verify the effect above, a copper block (100 mm×100 mm×30mm) is machined on the VMC-600 type machine center with FANUC system by using Seco tool system. Fig.7 shows the machined object of heart-shaped part. Another application example is shown as Fig.8.

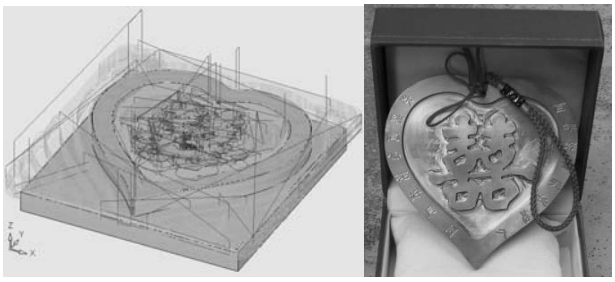


Fig. 7 machined object of heart-shaped part

Fig. 8 Another application example

Conclusion

(1)By inverse constructing object from its orthographic image, 3D modeling of part can conveniently obtained.
(2)Reconstructed part with cubic B-spline contour has smooth surface of NC machining after bi-arc approximation.
(3)Optimization toolpath planning is beneficial to increase NC machining quality and production efficiency of reconstructed part.

Acknowledgment

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Reference

[1] S.H. Joseph and T.P. Pridmore: IEEE Trans Pattern Analysis & Machine Intelligence, Vol. 14 (2000) No.3, pp. 928-940.

[2] G.D. Lu and Q.S. Peng: Computer Aided Design and Computer Graphics, Vol. 12 (2000) No.9, pp. 700-704 (in Chinese).

[3] J.P. Liu, B.Y. Ye, and X.H. Wu: *PROLAMAT Conference on Knowledge Enterprise* (Shanghai, China, June 15-17, 2006), Vol. 1, pp. 704-709.