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Rapid Creation of Tailor-made Products with Complicated Shapes by 3D Printer and Multi-axis Control Multi-tasking Machine

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In recent years, tailor-made products such as artificial joints and bone, etc. are drawing wide attention as well as sport goods in terms of meeting a variety of requirements of customers. However, it is usually very difficult to fabricate tailor-made products with high efficiency since they consist of different shapes for each product. Thus, a new CAM system is developed to generate NC data of tailor-made products to create by use of 3D printer and multi-axis control multi-tasking machine. In the study, complex shapes of tailor-made products are formed by means of STL data taken by 3D-scanner, MRI, X ray-CT, etc. The CAM system generates STL data for 3D printer and CL data and finally NC data for multi-axis control multi-tasking machines. From several machining experiments, it is found that the CAM system has the potential of creating tailor-made products easily and efficiently.

Keywords: *Tailor-made product, STL data, Multi-axis control multi-tasking machine, CAM*

1. Introduction

In recent years, attention is drawn to tailor-made products with complex shapes as well as aircraft parts and automobile products [1]. Here, tailor-made products stand for biofunctional parts such as artificial bones and joints for medical use [2, 3], and shoes or golf club fitting to costumer’s requirement. The fabrication of tailor-made products requests complex shape creation technology with high efficiency due to complex different shape for each product.

The fabrication and assembly of such tailor-made products need highly advanced technology. Thus, it is difficult to create them without costing much labor.

Complex shape products have currently been created by means of 5-axis control machining centers or 5-axis control multi-tasking machines, based on their 3D-CAD data [4, 5, 6]. It is because the reduction in lead time and high efficient machining can easily be performed by their use.

Thus, the study deals with the rapid fabrication system of tailor-made products with complex shapes by making use of multi-axis control multi-tasking machines. As tailor-made products generally consist of complex shapes, it is difficult to design them by 3D-CAD. Accordingly, the system utilizes STL data taken by 3D-scanner, MRI, X-ray CT and so on [7].

In the study, a human thighbone model is fabricated by a 3D-printer and a multi-axis control multi-tasking machine, as an example of tailor-made products.

2. Outline of System

The outline of the system is shown in Fig. 1. STL data obtained by 3D-Scanner, MRI, X-ray CT and so on has two possibilities; the direct processing by 3D-printer to form the same shape by plaster and the mechanical machining of metallic material by means of 5-axis control multi-tasking machine. The study mainly handles the latter, that is, the fabrication of metallic tailor-made product. In addition, a scanner having resolutions of 0.25 mm/px in the depth direction and 0.75 mm/px in the perpendicular plane is used to get STL data of an object as a tailor-made product.

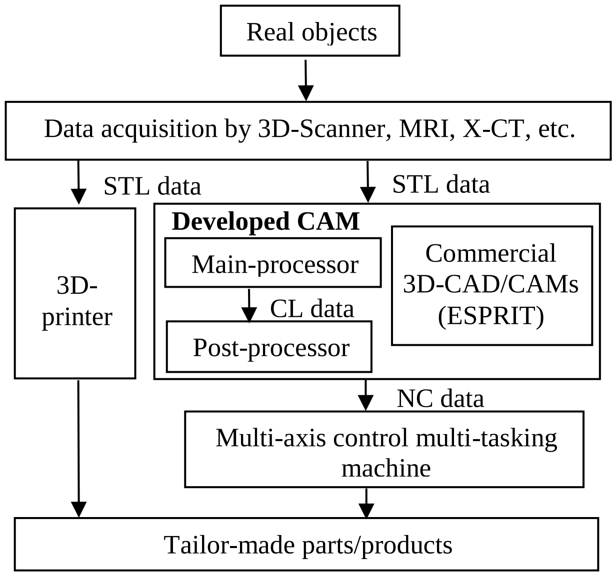

Fig. 1 Outline of system

STL data consists of a large amount of small triangles covering the whole surface of a 3D-object, as illustrated in Fig. 2(a). Each triangle is defined by three points and its normal vector. When the system reads the generated STL data, the vertices of triangles are overlapped, as shown in the same figure. To solve the problem, the system extracts a vertex from overlapped points. As a result, the surface of the object is correctly covered by a large amount of small triangles with their normal vector.

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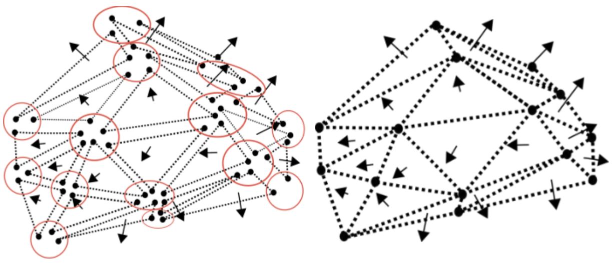
The number of triangles is dependent on the accuracy of approximating the object by triangles.



(a) STL data of object (b) Extracted triangles

Fig. 2 Extraction of triangles from STL data

3. Fabrication of Object by 3D-Printer

As an example of tailor-made products, let us consider a human thighbone. A model of human thighbone is shown in Fig. 3.

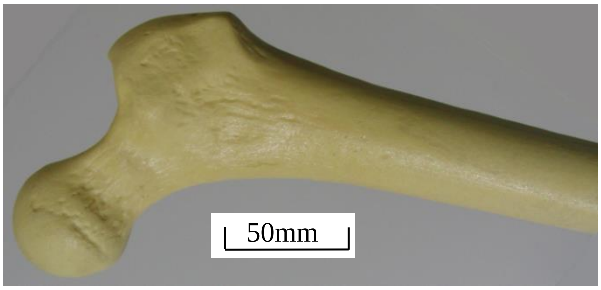


Fig. 3 Example of human thighbone

The model is converted to STL model by means of a scanner (Kinect), as shown in Fig. 4, which consists of a large amount of small triangles. The enlarged triangles can be clearly seen in Fig. 5.

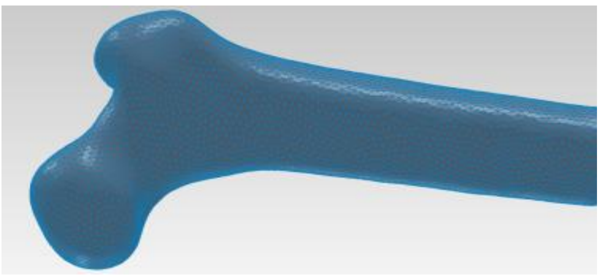


Fig. 4 STL model of human thighbone

By use of STL data of the human thighbone model, 3D-printer (Dimension BST768, Stratasys) fabricates it immediately. Figure 6 shows the fabricated plaster model of the human thighbone.

4. Fabrication of Object by 5-axis Control Multi-tasking Machine

4.1 CAD/CAM system

STL data of the object to be fabricated is transferred to

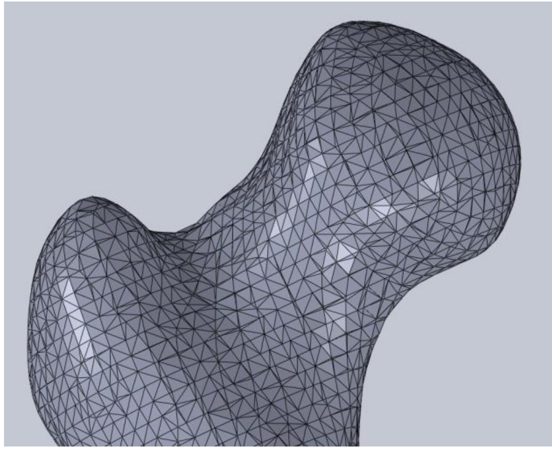


Fig. 5 Enlarged part of STL model

Fig. 6 Fabricated plaster thighbone model

CAD/CAM system, as seen in Fig. 1. Two CAD/CAM systems are available in the study, that is, a commercial 3D-CAD/CAM (ESPRIT, DT-Technology) and our developed CAD/CAM.

ESPRIT system [8] is used to generate CL (Cutter Location) data of rough machining tool path, as illustrated in Fig. 7. CL data stands for the cutting tool movement in 3D-CAD coordinate system.

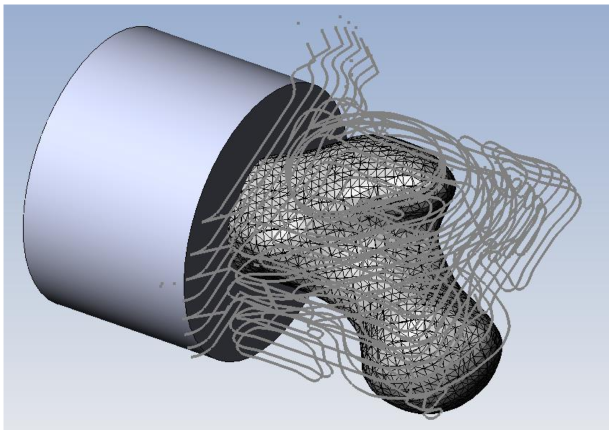


Fig. 7 Rough machining tool path generated by ESPRIT

With regard to finishing operation, our system is used, which consists of two processors; main-processor and post-processor.

The role of the main-processor is to generate CL data for cutting tools. In the study, the system generates CL data for three kinds of finishing tool path, taking account of the structure of 5-axis control multi-tasking machine.

Here, a general structure of 5-axis control multi-tasking machine is illustrated in Fig. 8. A cylindrical workpiece is mounted by a main spindle (C-axis). A rotational tool like mill or drill is clamped by a milling head (B-axis). The rotational tool allows for 5 degrees of freedom of movement; X, Y, Z, B and C. This means 5-axis control.

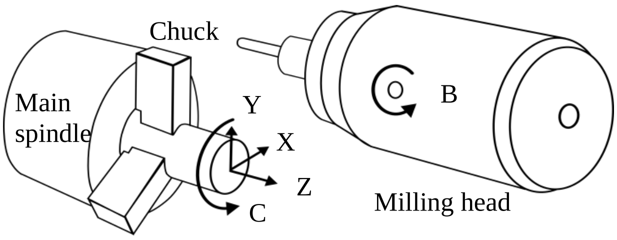
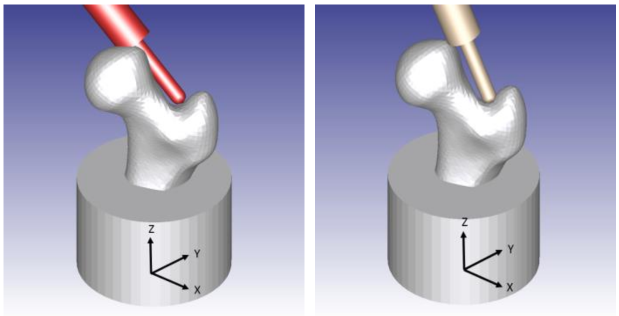


Fig. 8 Structure of 5-axis control multi-tasking machine

The important thing to consider in 5-axis control machining is the collision avoidance between the cutting tool and the workpiece. When the collision takes place on the tool path, the system changes the tool axis vector to avoid it by rotating B-axis and C-axis simultaneously.

The collision avoidance at a point on the tool path is shown in Fig. 9, where the collision takes place in the left figure and is avoided by rotation of the tool vector in the right figure.

The tool path is prepared by calculating the cross-sectional curved line between STL model and the plane perpendicular to X-axis, Y-axis and Z-axis respectively, as shown in Fig. 10. The distance between planes is equal to the depth of cut. As a result, three kinds of tool path are generated as CL data in the study.



(a) With collision (b) Without collision

Fig. 9 Collision avoidance

CL data generated by the main-processor is transferred to the post-processor in order to convert to NC data, taking account of 5-axis control machine tools. In the study, the structure of 5-axis control multi-tasking machine is as same as Fig. 8.

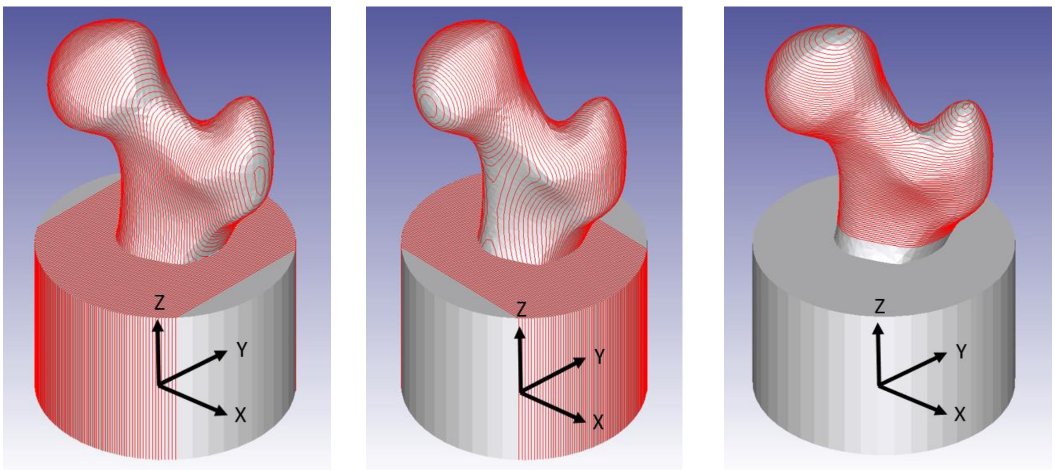
4.2 5-axis Control Machining

Metallic tailor-made products can be fabricated by use of machine tools. In the study, 5-axis control multi-tasking machine is applied to fabricate a human thighbone model of aluminum alloy.

At first, a cylindrical aluminum workpiece is roughly machined, as shown in Fig. 7. Then, the finishing is performed by three kinds of tool path, as explained in Fig. 10. The finishing condition is shown in Table 1.

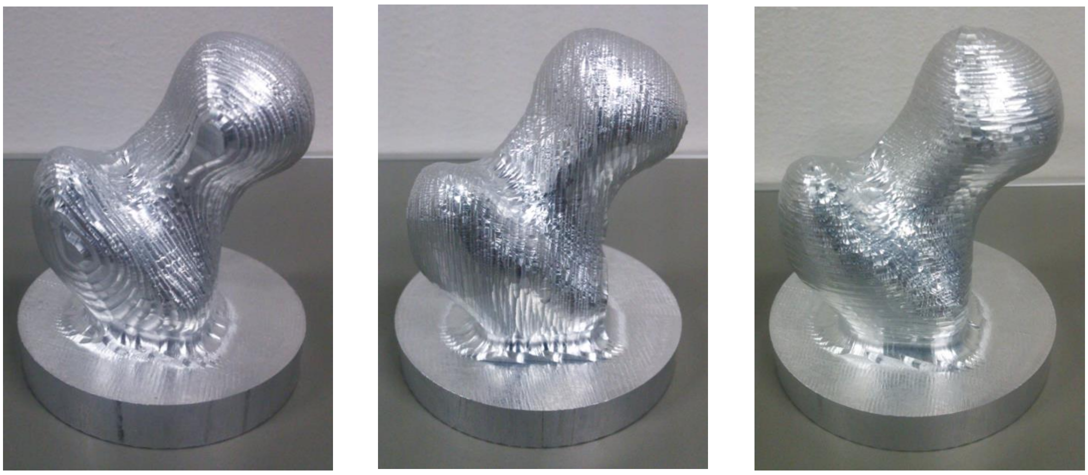
Table 1 Finishing condition

Material	Aluminum KS21
Tool	Ball End Mill R3×6
Spindle speed	4300 rpm
Feed rate	500 mm/min
Depth of cut	0.6 mm
Pick feed	0.3 mm
Cutting fluid	Dry cut



(a) YX-plane (b) XZ-plane (c) XY-plane

Fig. 10 Three ways of tool path generation with regard to each plane



(a) YX-plane (b) XZ-plane (c) XY-plane

Fig. 11 Machined results by different tool path

The machined results are shown in Fig. 11, which correspond to the tool path shown in Fig. 10. As seen from figures, it is found that the thighbones are well fabricated, although the profile accuracy is difficult to measure due to the curved surface. However, their surface accuracy is not satisfactory because the finishing condition is not necessarily suitable. The theoretical surface roughness is expected to be 4 μm Rmax, however the actual one is about 50 μm Rmax on relatively flat surface.

5. Conclusion

To meet the requirement of fabricating metallic tailor-made parts/products in the rational manner, the system was developed to fabricate them by means of 5-axis control multi-tasking machine, based on STL data obtained by 3D-scanner. From the machining results of human thighbone model, it is found that the developed system has the potential of fabricating metallic tailor-made parts/products rationally.

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