Three-dimensional solid reconstruction of femoral CT images based on reverse engineering

B X Yang, M D Duan, Z Y Zhang and J B Liu

School of Mechatronics Engineering, Henan University of Science & Technology, Luoyang, Henan 471003. China

*Corresponding author’s e-mail: duan_mingde@163.com

Abstract. In order to solve the problems of edge blurs and surface roughness in the 3D model generated by CT image, a reconstruction method of femur 3D model based on reverse engineering is proposed. The 3D skinned data of the femur were obtained by threshold segmentation, region growth and repaired layer-by-layer CT images. Through the reconstruction of the patch and the transition surface, the 3D model of the femur was finally obtained. The femur model obtained by the 3D reconstruction method based on reverse engineering had a clear profile and can meet the requirements.

1. Introduction
In the process of medical diagnosis, the diagnostic doctor often reviews the relevant information provided by two-dimensional CT tomographic images, and makes a judgement on the skeletal diseases and defects according to working experience. Using this method to diagnose the skeletal diseases, the diagnostic results are inaccurate and inefficient, while three-dimensional reconstruction of the CT images processed by medical image processing is often used in computer-aided surgery and structural analysis, so it can observe the lesions more intuitively and provide technical guidance for related operations [1-2]. For the problems of blurred edges, low precision and rough surface of the three-dimensional model that are directly generated by medical CT image processing, this paper presents a design method of the three-dimensional model of femur based on the reverse engineering principle and CT image processing technology. According to the principle of surface partitioning, the three-dimensional skin data obtained from image processing are fitted to the surface, and the free-form surface model of the femoral external contour is established. Finally, the three-dimensional solid model of femur is reconstructed through the reconstruction of the surface and the transition surface, which lays the foundation for the subsequent finite element analysis.

2. Modeling methods and processes
The modeling process mainly includes image processing, information extraction, surface reconstruction and entity reconstruction. Firstly, the original information of femur is obtained from the gray-scale image of CT image through the processing of CT image acquisition, threshold segmentation, region growth and mask editing, and triangular mesh surface is obtained by rapid pre-modeling. If there are no noise points, the surface is reconstructed by reverse engineering, and the data in reverse engineering modeling are divided into blocks. The three-dimensional solid model of femur is completed by surface fitting and entity generation. The design procedure of the three-dimensional
solid model of femur is shown in Figure 1.

![Entity modeling flow chart](image)

**Figure 1. Entity modeling flow chart**

### 3. The Image acquisition and processing of CT

After CT image in the DICOM format is imported into Mimics, the image information with different gray characteristics, including bone tissue, muscle, cartilage and so on, is obtained. When acquiring CT scanned image, it will be obtained due to interference of external factors. Image are affected by noise, resulting in local blurring and ambiguity of the image. These interference factors will have a great impact on subsequent image processing and analysis. Therefore, the imported image must be processed by threshold segmentation, region growth and mask editing. As shown in Figure 2, the import of the CT image shows that the untreated CT image information of femur is highly integrated with surrounding tissues and other structures, and can not directly extract the image information of femur.

![CT image import](image)

**Figure 2. CT image import**

#### 3.1 Threshold segmentation

In the practical application, in order to divide the femur tissue information and surrounding tissue information in the gray image according to the level, the threshold selection method of gray histogram
is often used to binarize the gray image \cite{4-5}. As shown in Figure 3, the binary method can extract the femur from the tissue better.

![The original image](image1) ![binarization](image2)  
**Figure 3.** Image grayscale processing of CT

3.2 Preliminary modeling

After the above processing, all the features of the femur have been selected, and then the selected femoral mask is pre-modeled \cite{6}, and the three-dimensional skin model calculated from the femoral tomography image is generated. If there are noise points in the generated three-dimensional skin, the mask edition is refined again, and if there are no noise points, the edition begins. The comparison of mask editing before and after repair is shown in Fig. 4. It can be seen from Fig. 4 that the noise points after mask editing are significantly reduced.

![a) Before mask editing](image3) ![b) The mask is edited](image4)  
**Figure 4.** Skin model

4. (3D) solid model building

The reconstructed models are only triangular meshes enveloped on the surface of the model, not entities \cite{9}. However, these triangular meshes can be reconstructed by the reverse engineering method, and femoral entity can be generated, which lays the foundation for subsequent mechanical analysis. Because of the complexity of the femoral contour surface, and CATIA has powerful function of surface modeling design and powerful ability of surface comprehensive analysis, this paper reconstructs the femoral surface based on the CATIA platform. The flow chart of surface modeling is shown in Figure 5.

![Flow chart of surface modeling](chart)

**Figure 5.** Flow chart of surface modeling
4.1 data segmentation
Because the external contour of femur is a complex surface and the change of curvature is large, triangular meshes need to be regionalized according to the change of curvature, and different facet elements need to be constructed accordingly. As shown in Figure 6, the femur is divided into three segments according to its convexity and concavity, and the upper and lower segments are reconstructed in turn.

Figure 6. The data block

4.2 Curve reconstruction
Taking the middle femur as an example, different datum planes are selected to form intersecting lines with triangular meshes, and the intersecting lines are reconstructed on the datum planes. The intersecting lines between the grid planes and the datum planes are shown in Fig. 7-a and Fig. 7-b respectively. Because the intersections on the reference plane are reconstructed by B-spline lines, and the three-point collocation method is used to reconstruct the curves in this paper, the sawtooth edge of the periphery is effectively avoided, and the quality of the whole curve is reduced due to the excessive local curvature.

Figure 7. Curve reconstruction

4.3 surface reconstruction
In the process of surface reverse design, Bezier, B-Spline and NURBS surfaces are mainly used. Because NURBS method has good surface quality, relatively fast speed, stable algorithm, and can accurately represent quadratic regular curves and surfaces, this paper mainly uses NURBS surface method to fit femoral surface. The principle is as follows:

Using NURBS surface method, the initial surface of surface reconstruction, i.e. the basic surface, is constructed by extracting the curves with the same convexity and concavity on different reference surfaces. The basic surface constitutes the main part of the whole surface and provides the basis for the subsequent creation of transition surface. Figure 8-A shows the curve used to construct the initial surface, and Figure 8-B completes the creation of the initial surface.
4.4 Transition curved surface

After the initial surface is completed, the adjacent boundary is the curve generated in the process of the plane, which will interfere with the creation of the following transition surface. The boundary is trimmed by stretching plane, which provides a basis for the successful creation of the transition surface. Fig. 9-a and 9-b are before and after basic surface trimming respectively. After pruning, the two adjacent initial surfaces are basically in a parallel state, so that the transition surfaces between the two surfaces can be reconstructed smoothly and the quality of the surface can be improved, thus effectively avoiding the sharp corner phenomenon in the creation of the transition surface.

5. 3D entity model

After the transition between pavement and adjacent surfaces is completed, some closed polygonal holes will be produced, which can be filled with appropriate curved surfaces and be continuous with the surrounding curvature or tangent. After the above process, although the external contour of femur has been formed and there is a continuous relationship between them, it is not a whole. Surface stitching should be used to merge them into one. Firstly, the middle femur is designed, then the upper femur is designed, and finally the lower femur is modeled, and the three parts are connected by the
above transition surface and filling surface. As shown in Fig. 11, for the process of creating the whole femoral surface, Fig. 12 is a comparison between the effect of the three-dimensional model of the whole femoral entity and the triangular mesh surface introduced. From the 12 drawings, it can be seen that the reconstructed three-dimensional entity model has a high coincidence with the triangular mesh surface.

![Figure 11. The reconstruction of the femoral surface](image)

![Figure 12. The reconstruction surface is compared to the mesh face](image)

The errors of reconstructed surface mostly come from the discrete errors of points cloud and the errors in the process of reconstructing reverse surface. The distance between the original points cloud and the reconstructed surface is analyzed by the method of distance measurement. If the maximum distance error between the reconstructed surface and the original point cloud is less than 0.5mm, it can meet the design requirements.

![Figure 13. The error analysis](image)

6. Conclusion
There will be some defects on the surface of the three-dimensional model derived by Mimics, such as uneven surface of the model, blurred edges of the bad surface and other noise points. By using the NURBS surface method in CATIA, the triangular mesh data obtained from the pre-modelling are fitted to the surface through curve reconstruction, surface reconstruction, transition surface, filling surface and surface stitching, so as to reconstruct a more accurate and close to its true shape model, and to further analyze the biomechanical properties of femur.
References

[1] Lalone E A, Willing R T, Shannon H L, et al. Accuracy assessment of 3D bone reconstructions using CT: an intro comparison [J]. Medical Engineering & Physics, 2015, 37(8):729-738.

[2] Li Hong, Sun Hang, Liu Shengnan, Pan Shinong. Intelligent quantitative diagnosis of hip dislocation based on 3d-ct image [J]. Journal of Northeastern University (natural science edition), 2008, 39(02): 190-194.

[3] Wu Li, Li Heng, Xue Yujun. CT image fracture localization of incomplete fractures based on morphology [J]. Optical technology, 2017, 43(04): 359-363+368.

[4] Xue Wendong, Shui Wen, Zhang Shuangyan. Method for tracking femoral CT image contour [J]. Biomedical engineering and clinical, 2004(01): 31-32.

[5] Xue Wendong, Shui Wen, Zhang Shuangyan. Edge extraction of femoral CT image [J]. Shanghai biomedical engineering, 2004(01): 27-28.

[6] Yu Tao, Liu Wentao, Zhu Shuliang, Liu Weiming. Three-dimensional solid reconstruction and finite element analysis based on dental CT images [J]. Journal of wuhan university of technology, 2015, 37(03): 117-123.

[7] Chen Haiyan, Pepper, Peng Aviation. Fracture three-dimensional simulation entity model of reverse create experiment [J]. Chinese joint surg (electronic version), 2016, 10 (5): 520-524.