**8th. World Congress on Computational Mechanics (WCCM8)**
**5th. European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)**
**June 30 – July 5, 2008**
**Venice, Italy**

# Image-Based Shape Modeling of the Human Body via Free-Form Deformation and Numerical Optimization

***Kenji Shimada[1], Murat Gunay[2] and Mun-bo Shim[3]**

[1] Carnegie Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213, USA
shimada@cmu.edu
http://www.andrew.cmu.edu/user/shimada/

[2] Sensata Technologies, Inc.
529 Pleasant St.
Attleboro, MA 02703, USA
m-gunay@sensata.com

[3] Samsung Electronics
munbo.shim@samsung.com

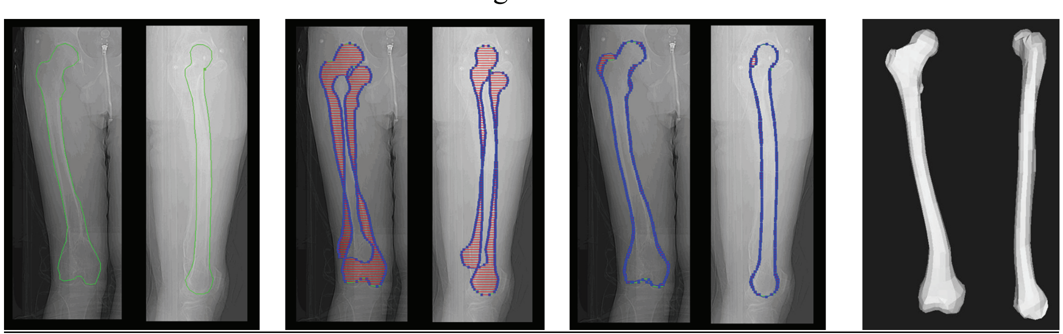
**Key Words:** *Shape Reconstruction, Geometric Modeling, CT, MRI, Anatomy, Organ.*

## ABSTRACT

Many medical and engineering applications require a three-dimensional (3D) shape of a human organ. In medicine 3D shapes are required in computational simulation-based medical diagnosis, pre-surgical planning, and robotic surgery. In engineering 3D shapes are required for product development including safety analysis and ergonomic design.

The conventional method of image-based 3D shape modeling consists of two steps: image segmentation and shape generation. Although there are effective algorithms available for the second step [1], the first step of image segmentation usually requires manual intervention and thus is time and labor intensive.

This paper presents an efficient computational method for reconstructing a 3D shape of a human organ from a limited number of x-ray images or computed tomography (CT) images. The three-dimensional template geometry of a healthy human organ is used as a priori knowledge, and the template geometry is deformed by free-form deformation (FFD) [2] to generate a patient-specific geometry. A numerical optimization scheme, sequential quadratic programming, is employed to find the optimal set of FFD parameters that match the contour or cross-section of a deformed template with the contour or cross-section shown in an image.

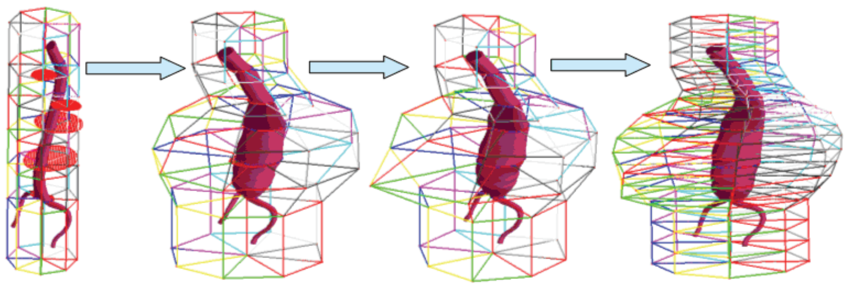


(a) Input X-ray images — (b) Initial errors between template and images — (c) Minimized error by deforming the template — (d) Automatically generated 3D shape

Figure 1: 3D femur shape reconstruction from two x-ray images.

Figures 1 and 2 demonstrate the results of applying the proposed shape reconstruction method to a femur and an abdominal aortic aneurysm (AAA). The 3D model of a femur shown in Figure 1 was generated from only two x-ray images, front and side images [3, 4]. The reconstruction took less than a minute on a standard personal computer. This femur model was created for the pre-surgical planning of an osteotomy surgery. Figure 2 illustrates how the proposed method can be applied to the shape modeling of AAA [5, 6]. This geometry was used for a FEM stress analysis and blood-flow CFD analysis. In the CFD analysis the geometric continuity of a deformed model is critical. Such continuity is maintained by raising the order of the polynomial function used in FFD. The experimental results show that 10-15 cross-sectional images are sufficient to create a detailed AAA shape for structural and flow analyses.

The proposed image-based 3D modeling method provides medical and engineering professionals with a time and labor-efficient alternative for generating a 3D shape of a human body part by using a small number of x-ray or CT images.



(a) 3D shape template is deformed by the optimization of the control parameters of extended free-form deformation.

(b) Rapid-prototyped 3D model

Figure 2: 3D shape modeling of abdominal aortic aneurysm.

## REFERENCES


[1] Bajaj, C.L., E.J. Coyle, K-N. Lin, "Arbitrary topology shape reconstruction from planar cross sections," Graphics Models and Image Processing, 58(6):524–43, 1996.

[2] Coquillart, S., "Extended free-form deformation: A sculpturing tool for 3D geometric modeling," ACM SIGGRAPH 24(4):187–96, 1990.

[3] Gunay, M., "Three-dimensional bone geometry reconstruction from x-ray images using hierarchical free-form deformation and non-linear optimization," Ph.D. thesis. Carnegie Mellon University; 2003.

[4] Shimada, K., K. Krause K, R. Mendicino, L. Weiss, and T. Kanade, "Computer-aided bone distraction," US Patent, US6.701.174. 2004.

[5] Shim, M., M. Gunay, and K. Shimada, "Three-dimensional shape reconstruction of an abdominal aortic aneurysm form computer tomography images using extended free-form deformation," Computer-Aided Design, 10.1016/j.cad. 2007.10.006, 2007.

[6] Gasbarro, M.D., K. Shimada, and E.S. DiMartino, "Explicit Finite Element Method for In-vivo Mechanics of Abdominal Aortic Aneurysm," European Journal of Computational Mechanics, 2006.