3D RECONSTRUCTION OF THE HUMAN FOREARM COMPLEX THROUGH EFFICIENT COLOR IMAGE SEGMENTATION

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INTRODUCTION

According to the recent development of the imaging and acquisition devices, the need of efficient 3D reconstruction of a geometric model from image data has frequently emerged for engineering simulation and analysis in many application fields. A particular need of 3D geometric reconstruction exists in biomedical engineering for accurate representation and display of the anatomic structures using various imaging modalities such as CT, PET, and MR images. More recently, photogrammatic cross-sectional images are available from the Visible Human Project® (VHP). In this study, we proposed an efficient boundary detection algorithm for color images and subsequent 3D reconstruction through lofting process with the application to the human forearm complex using the VHP datasets.

METHODS

A total of 214 slices of the color images were used for the segmentation and 3D reconstruction of the forearm complex. Each slice had 2048 by 1216 resolution with a pixel size of 0.3528 mm. The distance between neighbor slices was 1 mm. The presented segmentation method was designed for an object with cross-sectional boundaries, satisfying the following two geometric properties, star-shaped polygons and conforming geometries between the neighboring boundary curves.

(1) *Star-shaped polygon*: A polygon *P* is star-shaped [1] if there exists a point *q* not external to *P* such that for all points *p* of *P* the segment $\overline{qp}$ lies entirely within *P*.
(2) *Geometric conformity*: The two closed curves C_i and C_{i+1}, from the two adjacent slices (Fig. 1) have geometric conformity if the shape differences are sufficiently small in terms of translation, rotation, shear, and scaling transformation. As a result, the two matching points, P_{i+1} and P_i on the curves C_{i+1} and C_i, respectively, satisfy following relationship,

$$d\left(P_i, P_{i+1}\right) < d\left(P_i, \tilde{P}_{i+1}\right) \quad (1)$$

where $d(P_i, P_{i+1})$ is a Euclidean distance between the two points P_i and P_{i+1}. The point $\tilde{P}_{i+1}$ is an intersection in the curve C_{i+1} and the line passing through P_i and P_i^C, where P_i^C is the centroid of the curve C_i (Fig. 1). This property ensures that the correct matching point P_{i+1} can be located instead of $\tilde{P}_{i+1}$, resulting in an efficient points-on-line detection algorithm proposed in this study.

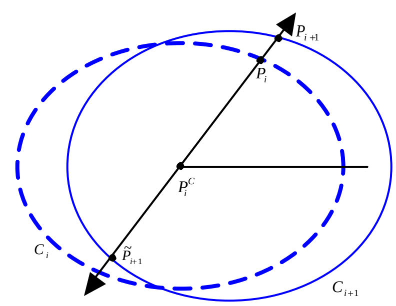

Figure 1. Two closed curves having geometric conformity

Image segmentation involves dividing an image into different regions having homogeneous properties. Each object component (class) can be classified into different categories by means of separating surfaces those are defined by discriminant functions. The minimum distance classifier [2] has been an effective tool in many pattern classification problems and was used in this study. The class centers, representing each class, are obtained through clustering process, where the fuzzy c-means algorithm [3] was used in this study. The fuzzification parameter, controls the sharpness of the decision boundaries, was given as a value of 2. In this study, the average RGB values of the 8-neighbors of the given pixel were used.

In order to detect points on the new boundary curve (solid curve), it is necessary to find point P_{i+1} from the given corresponding point P_i on the previous given contour (dotted curve), shown in Fig. 1. There are three cases to find P_{i+1} associated with the relationship between the two curves. An algorithm to find a new point P_{i+1} from the given point P_i on the boundary of the previous slice and given angle *?* is following:

Calculate next new outward point $P_{n,o}$
Calculate next new inward point $P_{n,i}$
If *diff*($P_{n,o}$, $P_{n,i}$), P_{i+1}=P_i, return // Same Points
Let Dd=increment, $P_{n,i}$=$P_{n,o}$=P_i
While (Dd < d_{max})
    If *diff*($P_{n,o}$, P_i), P_{i+1}=$P_{n,o}$, break // Outward Point
    Elseif *diff*($P_{n,i}$, P_i), P_{i+1}=$P_{n,i}$, break // Inward Point
    Else
        Dd= Dd + increment
        Calculate next outward point $P_{n,o}$ with given *?*, Dd
        Calculate next inward point $P_{n,i}$ with given *?*, Dd
    End If
End While

Subsequently, curve fitting, constructing composite parametric curves from a sequence of data points, is necessary for the boundary points from the boundary tracing algorithm or for digitized curves by the other edge detection techniques. Detected boundary points were fitted to the B-spline curve in this study.

Lofting operation is one of the popular techniques to generate a 3 dimensional model from a series of two dimensional boundary curves. In order to avoid skewed surface during the lofting operation, the angle invariant assumption, a boundary curve generates another adjacent boundary curve by the translation and scaling transformation, was introduced. That is, for two adjacent curves, one curve could be obtained by translation and scaling transforms of the other curve. Due to this angle invariant property between the neighboring boundary curves, the boundary points of each slice could be re-sampled with the given specific angles from their own centroids. So all boundary points in the fitted cross-sectional curves were re-sampled. Then these re-sample points were re-fitted to the B-spline. Using the re-fitted boundary curves, 3D geometric models of the human forearm complex were generated through the lofting operation. An interface program to a commercial CAD system (SolidWorks, Inc, Concord, MA) was developed to reduce manual works for the lofting.

RESULTS

The 3D geometric models of the human forearm complex were reconstructed as a result of the color image segmentation and lofting operations, shown in Fig. 2. Computational implementation of the image segmentation algorithms was done using custom MATLAB programs and the image processing toolbox (MathWorks, Inc, Natick, MA). Lofting operation for the series of the boundary curves was performed in a commercial CAD system (SolidWorks, Inc, Concord, MA) by a custom Visual Basic 6.0 interface program so that geometric models of the forearm complex could be exported in various neutral CAD file formats.

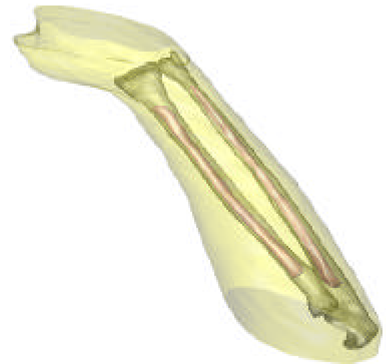

Figure 2. Generated geometric models of the forearm complex in assembly mode

DISCUSSION

In this study, we proposed new methods for color image segmentation and re-sampling method for 3D reconstruction, which were implemented for the forearm complex using the VHP dataset. The RGB color space was chosen in this study since there are no high correlation phenomena in the VHP datasets and it requires smallest computational time compared to the other image spaces. The proposed points-on-line detection method is a one dimensional image segmentation algorithm for the star-shaped polygon with the series of the color images using the minimum distance classifier in the RGB space. Compared to the traditional snakes algorithm [4], it showed significant improvements in the time complexity. Therefore this new segmentation method can be applied to an image analysis system, requiring small processing time such as real time processing.

Appropriate choice of the segmentation parameters is of importance during the segmentation operation. It was reported that choice of segmentation parameters in CT images could cause a substantial variability on architectural measurements up to 20% [5]. The current algorithm required only one parameter for the fuzzy c-means clustering, while traditional snake algorithms [4] need quite a number of segmentation parameters. This would enhance the robustness and stability compared with the snake algorithms. The reconstructed 3D geometric model can be used for visualization as well as further engineering simulations.

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