Finding Glenoid Surface on Scapula in 3D Medical Images for Shoulder Joint Implant Operation Planning — 3D OCR

Majid Mohammad Sadeghi[a], Emin Faruk Kececi[a,b], Kerem Bilsel, M. D.[c], Ayse Aralasmak, M. D.[c]
[a]Department of Mechatronics Engineering, Istanbul Technical University, Istanbul, Turkey
[b]Department of Mechanical Engineering, Abdullah Gul University, Kayseri, Turkey
[c]Bezmialem Vakif University, Orthopaedics and Traumatology Dept., Fatih, Istanbul, Turkey

ABSTRACT

Medical imaging has great importance in earlier detection, better treatment and follow-up of diseases. 3D Medical image analysis with CT Scan and MRI images has also been used to aid surgeries by enabling patient specific implant fabrication, where having a precise three dimensional model of associated body parts is essential. In this paper, a 3D image processing methodology for finding the plane on which the glenoid surface has a maximum surface area is proposed. Finding this surface is the first step in designing patient specific shoulder joint implant.

Keywords: Medical image processing, patient specific implant design, Glenoid surface.

1. INTRODUCTION

The application of imaging in the medical field is of great importance because of the opportunities it provides in diagnosing diseases without having to cut patients open [1]. Additionally using imaging has helped in the earlier detection of diseases as well as in enabling more effective treatments [2]. Medical imaging has opened its way to areas beyond simple diagnosis, including treatment and follow up of a disease [3]. With the improvement in imaging technologies; being able to create higher quality images and using advanced computer science, medical image processing applications have expanded to different areas of medical treatment. The use of medical image processing has advanced from qualitative to quantitative applications.

Medical image analysis has also expanded to being a part of the surgical simulation and planning. In joint implantation surgeries, for instance, medical image processing can help a surgeon make better decisions based on a specific patient's joint characteristics, and thus use special implants for each particular patient [4]. Using this patient specific implants reduces the risk and increases the success ratio of the operation plus it increases the durability of the implant.

There are different technologies including Computed Tomography (CT) and Magnetic Resonance Imaging (MRI) which create 2 dimensional images of the body. Whereas CT is superior for imaging of bony structures, MRI has proven better at detecting soft tissue, such as cartilage, muscles and tendons. Using any of the acquisition methods and applying image processing techniques, a three dimensional model of the target joint can be extracted for creating patient specific implants. To be able to design a patient specific implant, precise measurement of the 3D model of bones in the joint is necessary. In this paper a shoulder joint implant design is considered. One of the key features to find in a shoulder joint is the glenoid surface of the scapula bone. Since this surface will be supporting the implant, finding exact position and orientation of it are very important to insure success of the operation [5].

In this paper a 3D image processing methodology for finding the plane on which the projection of the glenoid surface has the most area is proposed. Having this plane is the first step in finding the sphere matching the glenoid surface. Methodology of the proposed approach is explained in the following section and considerations about speed, accuracy and repeatability of the algorithm are discussed afterwards.

2. METHODOLOGY DESCRIPTION

The first step in applying the algorithm is to open and read CT scan images covering the complete scapula bone and the top part of the humerus, provided by radiologists. CT scan images are acquired as a set of two dimensional greyscale

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images each of them saved in a three dimensional matrix format including x-y position and grey level value for each point. A sample of 2D CT scan image used in this work is shown in Fig. 1.

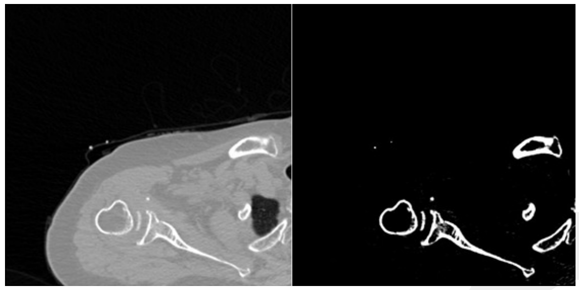

Figure 1. 2D CT Scan image of shoulder (left), and contrast cut of same image to show only bones (right).

These three dimensional matrices must be combined to form of a four dimensional matrix representing a three dimensional image. The resolution of this three dimensional image in z direction, or the direction perpendicular to the plane of each 2D image, depends on the distance between each layer of the acquired CT scan image named as slice thickness. In this study the slice thickness was 1 mm. The General procedure in which the program works is presented in Fig. 2.

1. Loading dataset into the 3D Slicer Software
2. Separating bones from other tissues
3. Separating the scapula from other bones
4. Saving the 3D model
5. Importing the 3D model into MATLAB Software
6. Visualizing the 3D model of Scapula in MATLAB
7. Rotating the model around axes with defined resolution
8. Capturing the projection in current orientation
9. Converting the current projection to grayscale and detecting edges
10. Finding the correlation factor value of the current projection and reference image
11. Keeping only the highest correlation factor and corresponding orientation.
12. Repeating steps 7 to 11 until all orientations are covered

Figure 2. Procedure of the methodology proposed.

In this set of CT scan images, bones must be separated from the other tissues. For the next step the scapula bone needs to be separated from the other bones. In this work, the separation of the bones and the scapula is performed using 3D Slicer software [6, 7]. The separation of bones from other tissues is performed by using thresholding. The separation of the scapula from other bones is performed using labeling. Fig. 3 shows the separated bones and separated scapula in the 3D Slicer software.

Figure 3. Bones separated from other tissues (left), and Scapula separated from other bones (right) in 3D Slicer Software.

The scapula bone 3D model is then saved and imported into MATLAB software environment. After the scapula is separated from the rest of the image, a surface rendering algorithm is used to visualize the three dimensional model of the scapula as shown in Fig. 4.

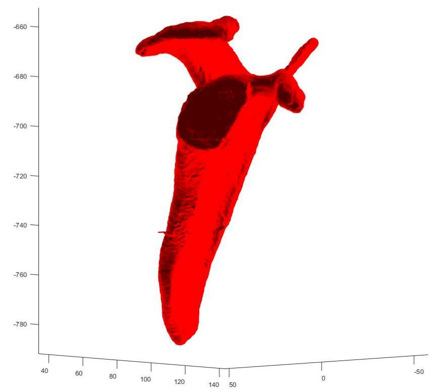

Figure 4. 3D model of the scapula visualized in MATLAB using surface rendering.

This 3D model of the scapula is used to create two dimensional projections from different orientations. It is done by rotating the 3D model in small angles and taking 2D projection images in each step. The rotation is performed around all three axes so that the scapula is viewed thoroughly from all angles. In Fig. 5 the scapula is shown being rotated around one axis with large angles to present the procedure.

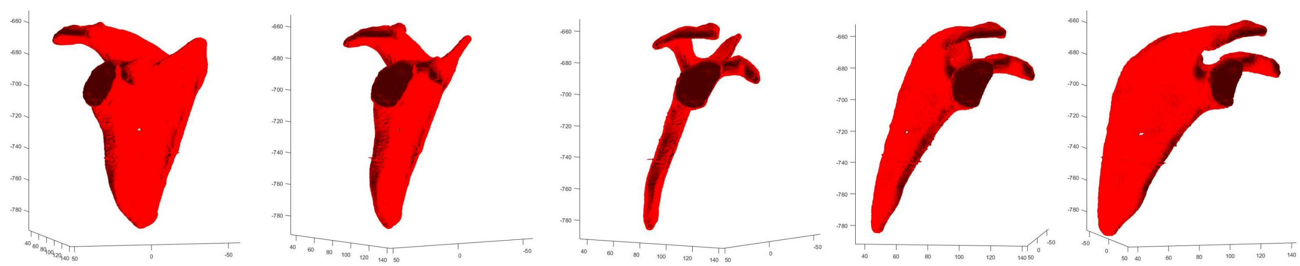

Figure 5. Five steps of rotating the scapula 3D model around one axis and capturing 2D projections.

In the next step, Canny edge detection method is applied to two dimensional projections to detect the edges. The edges in the projected images show the periphery of the bone. Fig. 6 shows the detected edges in projections from Fig. 5.

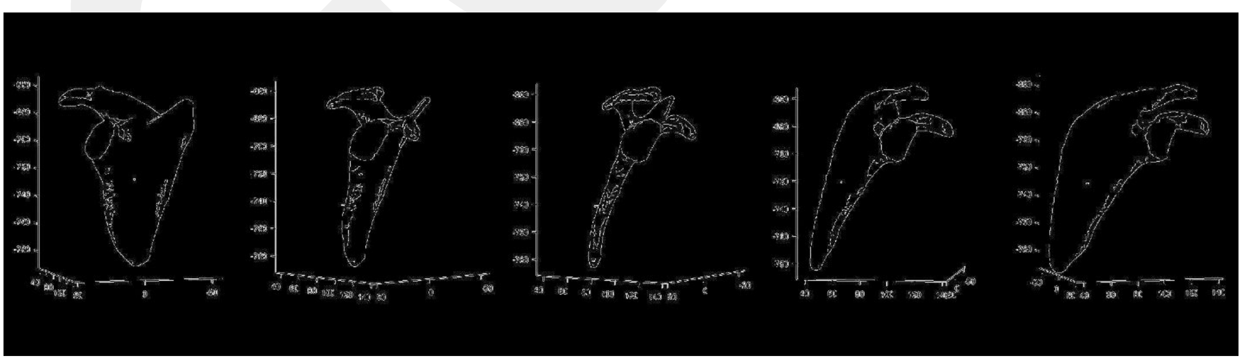

Figure 6. Results of Canny edge detection on 2D projections in Fig. 5.

The edge patterns resulting from the previous operation are compared to a reference image containing the edge pattern of the general shape of the glenoid. Reference image is shown in Fig. 7.

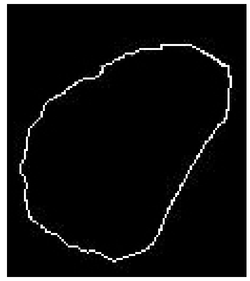

Figure 7. Reference image containing the general shape of the glenoid edge.

The method to perform this comparison is to compute the correlation coefficient between the two images. The correlation coefficient is a quantitative similarity measure between the two images. The higher the correlation coefficient, the more the two images match each other.

This operation is repeated for all of the two dimensional projections and the highest correlation factor value decides the closest projection to the reference image. This projection defines the orientation of the plane parallel to the glenoid surface. A picture of a detected 2D projection is shown in Fig. 8.

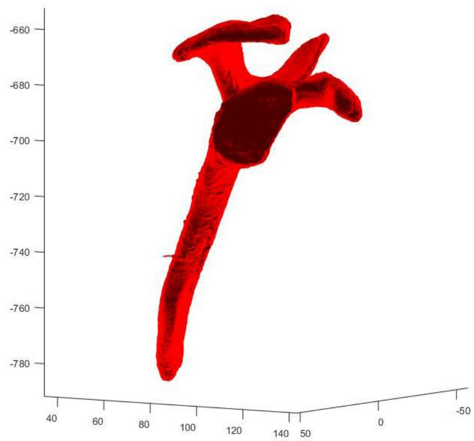

Figure 8. The detected projection with the highest correlation value.

3. CONSIDERATIONS

In this section the speed, accuracy and repeatability of the method are considered and approaches to improve them are applied.

3.1 Speed

The speed of the operation is affected by different parameters including the hardware used, the resolution of the input images and the algorithm itself.

CT scan images' resolution affects the time required to complete the algorithm. There are two types of resolution in three dimensional images. The first one is in plane resolution or the resolution of each two dimensional image in x and y direction. The other type is defined by the slice distance in CT scan images. The higher the number of slices in each millimeter, the higher the resolution of the 3D image in z direction will be. The resolution concept has a twofold effect on the algorithm. If the resolution is higher, the algorithm takes a longer time to complete, but at the same time it can improve the accuracy of the algorithm by including more accurate input data.

In the algorithm proposed, the resolution of rotation angles in between each two dimensional projections, is a factor affecting the speed of algorithm. The higher the resolution, the more 2D projections are created. As a result, keeping the rotation resolution low, increases the speed of the algorithm. However, this can have a negative effect on the accuracy of the method which will be discussed in the following sections.

Furthermore, regardless of the exact number of 2D projection images recorded which form the 3D image, data transfer from random access memory (RAM) to data storage or hard drive and reverse is slower than working only on RAM. As a result, instead of saving images to the hard drive which increases the time of operation greatly, an algorithm for the RAM was modified to apply edge detection and correlation factor finding on each 2D projection, so that speed of the algorithm increases. In this method the correlation factor in each step is compared with previous highest value and only the orientation which gives maximum correlation is saved.

3.2 Accuracy

Accuracy of the method presented depends on the resolution of the rotation angles in between each two dimensional projection acquisitions. When the resolution is increased or the angle in each rotation is decreased, more projections are created which provides a better chance to detect the most precise orientation. As it is mentioned before, increasing the resolution of rotation also has a negative effect on the speed of the algorithm. The solution proposed to this issue is to apply a fine tuning step after the initial result is found. In this way, using a small rotational angle resolution with higher speed, the algorithm will find an initial orientation close to the desired one. In the next step the algorithm is run again to create 2D projections and analyze them to find the highest correlation, but this time projections are made only around a close angle of initial orientation. In this step the resolution can be much higher than the first step. Using this method the algorithm will perform a fast and precise operation. To implement this method, steps 7 to 12 of Fig. 8. are repeated with a higher resolution around the detected orientation.

3.3 Repeatability

Since the algorithm performs analysis on 2D images taken in discrete angle distances, the initial orientation of the scapula bone in the three dimensional space can affect the orientation detected as the initial orientation in the algorithm. This effect can be minimized through the fine tuning section of the algorithm. A higher rotational resolution in the fine tuning step will result in minimizing this effect.

4. DISCUSSION

Another method currently used to find glenoid surface is explained in [8]. For this method acquisition of CT Scan images are performed in a predefined standard so that the initial position and orientation of bones are roughly known. In this method initial steps and separation of scapula bone are performed with a similar approach to the method presented in this papers. Later, scapula plane is found using weighted least square method by calculating the minimum quadratic distances of all voxels on the scapula to a mean plane passing through it. Having scapula plane and knowing the initial orientation of it in the 3d image, watershed method is used to detect glenoid surface voxels. After that, least square method is used again on the glenoid surface voxels to find glenoid plane.

One disadvantage of this method compared to this paper's method is the necessity of acquisition of CT Scan Images with a predefined standard and Images already captured with are not valid to be processed with this method. Another disadvantage is that glenoid and scapula planes are not guaranteed to have a certain accuracy, while in this paper's method the accuracy of glenoid plane can be increased as much as necessary with adjusting the fine tuning step.

5. CONCLUSION

In this work, a three dimensional medical image processing methodology is proposed to find the plane in which the glenoid surface has a maximum area. The proposed method is capable of fast and precise operation by performing an initial step in which a less accurate result is found, and a following fine tuning step in which the initial result is improved.

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