33rd Annual International Conference of the IEEE EMBS
Boston, Massachusetts USA, August 30 - September 3, 2011

RECOGNITION-BASED SEGMENTATION AND REGISTRATION METHOD FOR IMAGE GUIDED SHOULDER SURGERY

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ABSTRACT

For any image guided surgery, independently of the technique which is used (navigation, templates, robotics), it is necessary to get a 3D bone surface model from CT or MR images. Such model is used for planning, registration and visualization. We report that graphical representation of patient bony structure and the surgical tools, interconnectively with the tracking device and patient-to-image registration are crucial components in such a system. For Total Shoulder Arthroplasty (TSA), there are many challenges, The most of cases that we are working with are pathological cases such as rheumatoid arthritis, osteoarthritis disease. The CT images of these cases often show a fusion area between the glenoid cavity and the humeral head. They also show severe deformations of the humeral head surface that result in a loss of contours. This fusion area and image quality problems are also amplified by well-known CT-scan artifacts like beam-hardening or partial volume effects. The state of the art shows that several segmentation techniques, applied to CT-Scans of the shoulder, have already been disclosed. Unfortunately, their performances, when used on pathological data, are quite poor [1, 2]. The aim of this paper is to present a new image guided surgery system based on CT scan of the patient and using bony structure recognition, morphological analysis for the operated region and robust image-to-patient registration.

Index Terms— Image guided surgery, shoulder arthroplasty, computed tomography (CT), image segmentation, pattern recognition, registration.

1. INTRODUCTION

The shoulder is a ball-and-socket joint that enables us to raise, twist and bend our arm. It also lets us move our arm forward, to the side and behind us. In a normal shoulder, the rounded end of the upper arm bone "head of the humerus" glides against the small dish-like socket "glenoid" in the shoulder blade "scapula". These joint surfaces are normally covered with smooth cartilage. They allow the shoulder to rotate through a greater range of motion than any other joint in the body. The surrounding muscles and tendons provide stability and support. Unfortunately, many conditions can lead

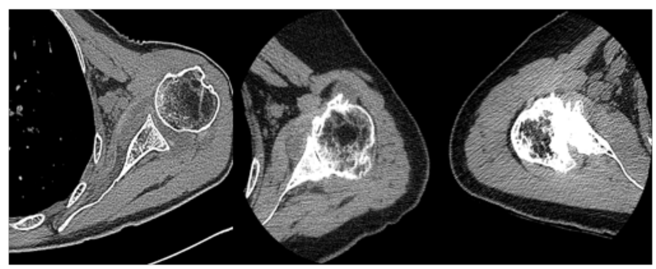

Fig. 1. Two dimensional (2D) computed tomography (CT) scan shows a normal shoulder on the left and two pathologic shoulder on the right. The pathologic cases show a fusion area between the glenoid cavity and the humeral head.

to loss of the cartilage and mechanical deterioration of the shoulder joint. The result could be a lot of pain with a loss of strength and decreased range of motion in the shoulder. In severe cases, bone-on-bone arthritis may lead to erosion of the bone(Fig.1). Shoulder replacement surgery, also called shoulder arthroplasty, is a successful, pain-relieving option for many people. During the procedure, the humeral head and the glenoid bone are replaced with metal and plastic components to alleviate pain and improve function. This surgical procedure is very difficult and limited to expert centers. The two main problems are the minimal surgical incision and limited access to the operated structures. The success of such procedure is related to optimal prosthesis positioning. For Total Shoulder Arthroplasty (TSA), separating the humeral head in the 3D scanner images would allow enhancing the vision field for the surgeon on the glenoid surface. So far, none of

Thanks to the French Research National Agency (ANR-France) for funding.

978-1-4244-4122-8/11/$26.00 ©2011 IEEE

the existing systems or software packages makes it possible to obtain such 3D surface model automatically from CT images and this is probably one of the reasons for very limited success of Computer Assisted Orthopedic Surgery (CAOS) applications for shoulder surgery. This kind of application often has been limited due to CT-image segmentation for severe pathologic cases and patient to image registration.

2. MATERIAL AND METHODS

Volumetric preoperative CT datasets have been used to derive a surface model shape of the shoulder. CT was preferred for clinical trials because of superior bone contrast which provides for the extraction of bony surface of the patient. The proposed navigation system is based on conventional infrared localization device, which locates in 3D and in real time position and orientation for surgical tools using passive markers associated to rigid bodies that will be fixed on the patient bone and on the surgical instruments.

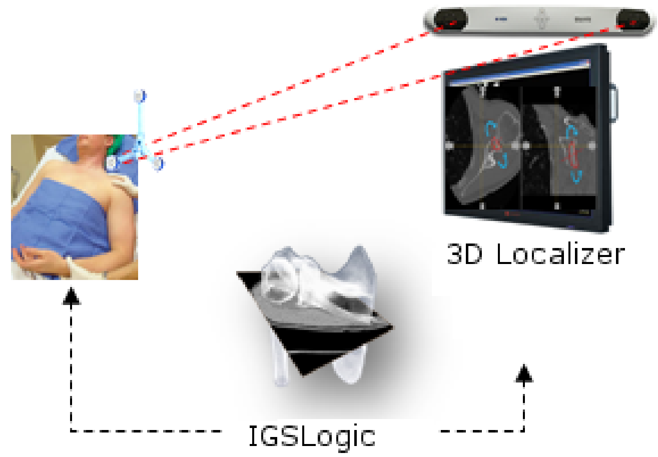

Fig. 2. The navigation system is based on a conventional infrared localization device, markers fixed on the bony structure of the patient and innovative software (IGSLogic - Telecom Bretagne) for segmentation and registration.

2.1. Automatic recognition-based segmentation to extracting the bony structure of the shoulder

Segmentation is an important step in medical imaging for classification and visualization of similar tissues and their registration over time. Segmentation of bone from CT images has been shown to be very useful for procedures such as joints cinematic analysis, surgical planning and navigation for total hip and/or knee replacement [2] and other clinical applications [3, 4]. However, automated segmentation of bone is a challenging task, due to several distinct difficulties such as non-uniformity of bone tissue, diffused and weak edges, narrow inter-bone regions, inherent blur of CT images, and partial volume effect [5, 6]. Automatic segmentation of the humerus and the scapula from three-dimensional (3-D) CT images is crucial for computer assisted surgical planning and intra-operative navigation (Fig.2). CT scan of the shoulder joint usually reveals a narrow space between the humerus and the glenoid because of the very low density of cartilage on X-ray CT. However, clinical complications such as osteoarthritis, congenital deformities, technical limitations of CT imaging like inherent blurring and partial volume effect and the narrow inter-bone regions often result in fused regions, as well as weak and diffused boundaries in glenoid and humerus images. CT exam of pathologic shoulder would show:

- Loss of the normal cartilage joint space.
- Flattening or irregularity in the shape of the bone.
- Bone spurs.
- Loose pieces of bone and cartilage floating inside the joint.

In our study, we used "IGSLogic" software (Telecom Bretagne-France)[1], for the segmentation and patient-to-image registration. 10 CT-scans for patients aged from 58 years to 91 years (mean age of 78.4 years) were analyzed. The expected result is the list of all voxels labeled as belonging to the scapula or to the humerus. The first step of this procedure is fully automatic segmentation method based on mathematical morphology filtering. This step is followed by 3D shape recognition algorithms applied to each object found in the volume. The third step is a specific processing that only treats the region between the humerus and the glenoid surface in order to separate possible contact areas [7]. The main idea is based on an original technique of pattern recognition for shoulder bone structures in the CT scan. It is a new technique that takes into account the topological and morphological attributes of various parts of shoulder joint with a contour-model acquired using Fourier Descriptors (Fig.3). This pattern recognition system is robust to inter-individual variability and pathological changes. This method is particularly autonomous, this means it automatically detects and separates areas of fusion between scapula and the humerus without user interaction. This ability of auto-correction is based on a signature-based method which has been developed in our laboratory for this issue. In order to assess the performance of this method, we have performed a comparison as follows. A "Bronze Standard" was defined as result of manual segmentation performed by two experts. These manual segmentation results are then compared to those obtained by our software. Qualitatively, the recognition based algorithm could be performed successfully on images with no specific similarities, high level deforma-

[1] filed by the French Agency of Software Protection (FR001.510013.000.R.P.2009.000.21000)

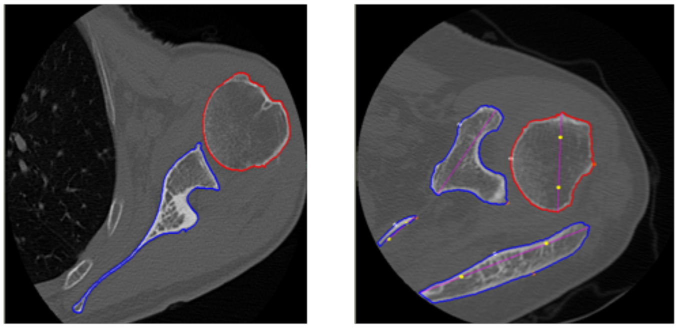

Fig. 3. Results of two CT scan images after the recognition-based segmentation. Scapula parts (in blue) are segmented and recognized, the humeral head (in red) is also segmented and detected.

tion, different orientation and placement for the bony structure. The system could isolate the bony region of scapula from the fusion region in all cases (Fig.4). The experimental results indicate that this method yields excellent performances in short time processing for the 3D volume, especially, when it is compared to manual segmentation done by radiologists. Table 1 defines the classification results using a confusion matrix in order to assess the performance of this recognition system.

	System predictions %			
Class	**Humerus**	**Scapula**	**Fusion**	**Rejected**
Humerus	96	0	0	4
Scapula	0	88.89	0	10.08
Fusion	0	7.02	91.31	0
Rejected	0	0	0.70	97.50

Table 1. Confusion Matrix of the classifier.

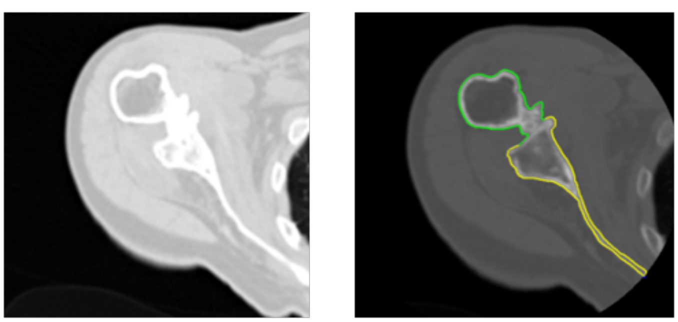

Fig. 4. Pathologic cases with fusion area between the glenoid and the humerus have specific processing in order to separate possible contact areas. On the left we have an example of a "fusion object" that will be segmented (right image) and recognized automatically as a pathologic case, and then a correction algorithm will be applied to separate the two objects.

2.2. Genetic Algorithms-based registration method

One of the fundamental challenges for any image guided system is to accurately register the pre-operative 3D data to the intra-operative 3D bone surface of patient. An ideal surface registration algorithm should be robust, accurate and should have the following properties:

- Not dependent on a good initial estimate of the parameters.
- Insensitive to noise, outliers and data occlusion.

Registration is a universal problem which must be addressed in almost all computer assisted or image-guided surgical systems. It is equally important in orthopedics, neurosurgery, cranio-facial surgery, or any specialty in which computer assisted surgical techniques are employed. The need for intra-operative registration arises due to the fact that there is an unknown spatial relationship between the pre-operative data (i.e., medical images, surgical plans) and the physical patient on the operating room table. The role of registration is to establish this relationship (referred to as the spatial transformation), thus allowing 3-dimensional (3D) locations within the pre-operative data to be unambiguously associated with the corresponding anatomical locations on the actual patient in the operating room, and vice-versa. During the last decades, image acquisition devices have undergone rapid development and growing amount and diversity of obtained images invoked the research on automatic image registration [8]. According to the database of the Institute of Scientific Information (ISI), in the last 10 years more than 1000 papers were published on the topic of image registration. We do not contemplate to go into details of particular algorithms, rather we want to describe results of comparative experiments between a basic traditional registration method using a modified Levenberg-Marquadt algorithm compared to our results using Genetic Algorithms (GAs) approach and point out interesting parts of our technique for a shoulder augmented surgery system. The IGSLogic uses genetic-algorithm-based method for CT-based navigated shoulder surgery. In the surgical environment, the main difficulty is the small anatomical exposed area of scapula. This small area provides us with a small number of digitized points which will be registered to a large scapula surface. Generally, that leads to an important risk of local minimal convergence and not a global minimal solution. Genetic Algorithms (GAs) provide a powerful and domain independent search method for complex, poorly understood search spaces, a good technique to avoiding the local minima solution. The process starts by encoding the transformation parameters into binary strings and then combining them with other binary strings to create better "guesses" to the solution. The method eventually converges to the global solution. GAs are often more attractive than gradient search methods because they do not require complicated differential equations or a smoothed search space. The genetic algorithm needs only a single measure of how good a single individual is compared to the other individuals. The objective function provides this measure. Our new objective function is computed using a 3D distance map between the 3D points and the surface model. An initial population of chromosomes is randomly generated. We chose as chromosome an array of 6 parameters: the three translations and the three Euler angles representing rotations. We used human CT dataset for 20 patients with pathologies as omarthrosis, osteonecrosis and rheumatoid arthritis. The shoulder bony structure for each patient was segmented then extracted using IGSLogic. The 3D surface extracted was rendered for visualization as a 3D surface model. The 3D points data set was collected from 4 regions: glenoid posterior and anterior contours, the superior tip of the coracoids and the anterior tip of the acromion. A known geometrical transformation was applied to these points, and then a Gaussian noise was added to the 3D points in the data set. The performance has been compared to a traditional matching algorithm "Levenberg-Marquardt (LM) algorithm" which directly minimizes the model-data fitting error via nonlinear minimization. Series of 20 tests were performed with each dataset using different geometrical transformations with an important range for translation from -10 mm to +10 mm and for rotation from -0.3 rad to +0.3 rad. Results of all tests were visually checked and the root mean squares (RMS) error for each point was calculated to examine differences between the two techniques. The RMS error for transformed points is more significant than minimization residual error to assessing the accuracy. The experiments were intended to show that the GA-based technique, reported here, offered much better results, than the conventional matching. The numerical results of the experiments are presented in Table 2. Registration error was lowest for the GA technique, with an RMS of 3.81 mm in translation and an RMS of 0.19 rad in rotation for the new method. These results are compared with an RMS of 9.09 mm in translation and 0.23 rad in rotation for the classic matching.

	Translation Error(mm)		*Rotation Error(rad)*	
	GAs	Classic Match.	GAs	Classic Match.
Mean	3.81	9.09	0.19	0.23
SD	1.50	9.98	0.10	0.14
Min	0.64	2.24	0.02	0.02
Max	5.80	35.50	0.32	0.51

Table 2. Results Of Registration Using Classic Matching (LM) And GA-based Method.

3. CONCLUSION

In summary, preoperative planning, 3D CT modeling and intraoperative tracking produced improved accuracy of glenoid implantation. The current paper has presented a new protocol with a novel concept in the world of image guided surgery focused on shoulder arthroplasty. Within our approach, we propose, for the first time, to use pattern recognition instead of manual picking of landmarks to avoid user intervention, in addition to potentially reducing the procedure time. A very important role is played by 3D data sets to visualize specific anatomical structures of the patient. The automatic segmentation of arthritic joints with bone recognition is intended to form a solid basis for the registration. The results of this methodology were tested on arthritic patients to prove that it is not just easy and fast to perform but also very accurate so it realizes all conditions for the clinical use in OR.

4. REFERENCES

[1] C. Chow, H Tsui, and T Lee, “Surface registration using a dynamic genetic algorithm,” *Pattern Recognition*, vol. 37, pp. 105–117, 2004.

[2] O. Cordon, S. Damas, and J. Santamaria, “A chc evolutionary algorithm for 3d image registration,” *LNAI*, vol. 2715 Springer, pp. 404–411, 2004.

[3] J. Chaoui, C. Hamitouche, and E. Stindel, “Recognition-based segmentation technique for shoudler arthroplasty,” Tech. Rep., Telecom Bretagne, 2009.

[4] Y. Kang, K. Engelke, and W. A. Kalender, “A new accurate and precise 3-d segmentation method for skeletal structures in volumetric ct data,” *IEEE TRANSACTIONS ON MEDICAL IMAGING*, vol. 22, pp. 586–598, May 2003.

[5] Charl Botha, *Techniques and Software Architectures for Medical Visualisation and Image Processing*, Ph.D. thesis, Technische Universiteit Delft, September 2005.

[6] W. Yao, P. Abolmaesumi, M. Greenspan, and R. Ellis, “An estimation/correction algorithm for detecting bone edges in ct images,” *IEEE Transactions on Medical Imaging*, vol. 24, pp. No 8, 2005.

[7] J. Chaoui, G. Moineau, E. Stindel, and C. Hamitouche, “Evaluation of recognition-based segmentation method for shoulder augmented surgery,” in *10 Annual Meeting of CAOS-International*, 2010.

[8] Jean Michel Rouet, Jean-José Jacq, and Christian Roux, “Genetic algorithms for a robust 3-D MR-CT registration,” *IEEE transactions on information technology in biomedicine*, vol. 4, no. 2, pp. 126 – 136, 2000.