Proceedings of the 28th IEEE
EMBS Annual International Conference
New York City, USA, Aug 30-Sept 3, 2006

Navigation System for Computer Assisted Tumor Ablation using Radio Frequency

C. Alcérreca Alcocer, E. Hazan Lasri, and F. Arámbula Cosío

Abstract— **Currently, physicians are using a new technique based on radiofrequency (RF) induced hyperthermia, to treat tumors in the musculoskeletal system. This method uses a RF probe, which is placed inside the tumor, which in turn is heated within the active volume of the probe, eliminating in this way the tumor cells without affecting healthy cells. For this treatment, the surgeon must know the exact shape and location of the tumor. Usually a Nuclear Magnetic Resonance Imaging (NMRI) study is performed before surgery. Ultrasound imaging is used to locate the tumor intraoperatively. In this work is presented a computer system to build a 3D model of the tumor and adjacent bones based on segmented images from the preoperative NMRI study. Then, during surgery, the model will be registered with the anatomy of the patient, using intraoperative ultrasound images segmented by the surgeon. This work is part of a larger project, which will be a complete Computer Aided Surgery (CAS) system to help train physicians in radiofrequency treatment and to make the procedure more reliable and efficient.**

I. Introduction

TRADITIONALLY, physicians treat tumors in the musculoskeletal system using three different techniques: chemotherapy, radiotherapy, and surgical extraction. All these methods are highly invasive and, therefore, unpleasant to patients. Recently, radiofrequency (RF) induced hyperthermia is being used to treat these tumors. This method uses a RF probe, which is placed inside the tumor, which in turn is heated within the active volume of the probe, eliminating in this way the tumor cells without affecting healthy cells. The procedure is minimally invasive. Usually, a Nuclear Magnetic Resonance Imaging (NMRI) study is performed preoperatively and intraoperative ultrasound (US) is used during treatment. In this way, the physician knows the shape and location of the tumor (through the NMRI study) as well as where he is placing the probe (through the intraoperative US images). The main problem with this approach is that the surgeon is required to construct a mental model of the tumor shape and location which is registered with the anatomy of the patient using the ultrasound images. The surgeon then has to place accurately the active volume of the RF probe within the tumor. This process is prone to localization errors of the active volume, which can produce either, under exposure of the tumor, or damage to adjacent structures. In order to maximize tumor treatment with minimum damage to adjacent structures in the musculoskeletal system, a computer navigation system is being developed. The navigator is based on a preoperative 3D model of the tumor and adjacent anatomy (mainly bones), which is registered to the anatomy of the patient using intraoperative ultrasound images and an optical tracker. The system will display in real time the location of the active volume of the RF probe inside the patient. In the next sections are presented the basics of RF tumor ablation, as well as our preliminary results on the construction of the 3D model of a tumor and its intraoperative registration.

Manuscript received on April 24, 2006.

Claudio Alcérreca is with the Image Analysis and Visualization Lab., CCADET UNAM, México, D.F., 04510 (calcerreca@prodigy.net.mx).

Fernando Arámbula is with the Image Analysis and Visualization Lab., CCADET UNAM, México, D.F., 04510. (phone +52 55 56 22 86 02 ext 1148; fax: +52 55 56 22 86 51; arambula@aleph.cinstrum.unam.mx).

Eric Hazan is with the National Institute of Rehabilitation, Calzada México Xochimilco No. 289, México, D.F., 14389 (ehazan@cnr.gob.mx).

A. Radio Frequency Tumor Ablation

This technique for tumor treatment uses a high power and high frequency generator, as well as one or more probes with electrodes. Electricity flows from these electrodes to a foil pad, usually attached to the patient's back or thighs [4]. High frequency (above 500 kHz) prevents the patient from electrocution, while high power heats the volume near the small electrodes, causing local necrosis. A tumor can be ablated in this way without the need of open surgery or other more invasive techniques.

B. Computer Assisted Surgery

Computer assisted surgery (CAS) and computer assisted therapy (CAT) systems are being developed for all kinds of medical treatments. The main idea behind these systems is to use current information technologies (IT) to help physicians treat patients more effectively and efficiently. These systems help to make better surgical plans and to assist the surgeon during execution as well as improved execution minimizing the invasiveness and increasing the safety of delicate interventions.

Usually, the link between the patient and the CAS system is a 3D navigator. Navigators can be classified in three main groups, depending on the activities performed by them: passive, active and semi-active. Passive systems display relevant information according to the planning, active systems realize part of the intervention, and semi-active systems involve a combined action with the human operator, such as constrain movement in one or more degrees of freedom. [5]

The system we are developing will be a passive one, since it will only display images and 3D models, which will help the surgeon to locate the RF probe and place it in the exact position to ablate the tumor effectively and to cause the least possible damage to healthy cells.

II. PREOPERATIVE 3D TUMOR MODEL

The 3D model of the tumor will be constructed from an annotated preoperative NMRI study. This imaging modality was chosen because it is able to show the tumor and adjacent structures (mainly bones) with clarity. Software tools will be developed to assist the surgeon in the manual annotation of the tumor and bones on each image. Usually, a NMRI study shows a series of slices with an approximate separation of 1 mm. Each slice has high pixel resolution (at least 256x256), but a small bone may appear in only two or three images (cross sections). To build a 3D model, we may need to interpolate a few more slices from the annotated original data. The method proposed is spline interpolation.

Once we have enough cross sections to represent the tumor and adjacent bones, a 3D triangular mesh will be constructed using the marching cubes algorithm [1]. Working with a mesh instead of directly with the volume helps to make a smoother model and helps the computer to display it correctly and efficiently. Since we want a real time navigation system to be used during surgery, the performance of the graphics system is an important issue. Fig. 1 shows an example of a 3D model built from segmented NMR images. The next section describes the registration of the 3D model with the anatomy of the patient using intraoperative US images.

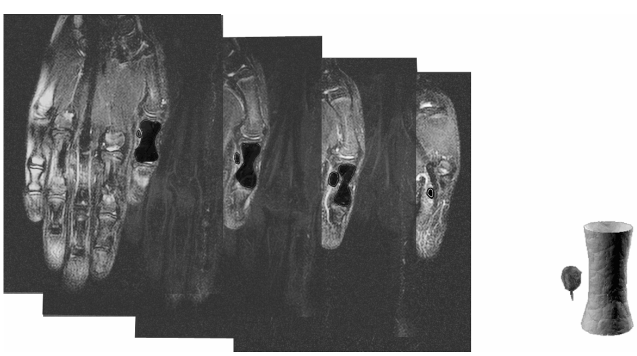

Fig. 1. Segmented NMR images and final 3D model obtained after interpolation and meshing.

III. INTRAOPERATIVE MODEL REGISTRATION

The simplest and most accurate approach to register a preoperative model with the anatomy of the patient is based on fiducial markers which are rigidly fixed to the patient during the preoperative imaging studies, and are later used during surgery to register the preoperative 3D model. Fiducial markers however can cause postoperative pain to the patient. This is why we have chosen intraoperative US to register the preoperative model with the anatomy of the patient. Model registration will be based on the anatomical features identified in the 3D model as well as in the intraoperative US images (semiautomatic ultrasound image annotation software is being developed in a parallel project [3]). This approach has been used previously with very accurate results. [6]

A. Ultrasound Image Acquisition and Processing

During surgery, the physician uses an US probe to watch the bones and tumor of the patient in real time. Then when the probe is introduced, it also appears in the US images. An optical tracking system (POLARIS from Northern Digital) will be used to track the 3D position and orientation of the US probe as shown in Fig. 3. Relevant anatomical features, such as bone edges and tumor boundaries will be annotated semi-automatically on each US image as ilustrated in Fig. 2. The registration of the high definition preoperative model constructed from the NMRI study with the anatomy of the patient can then be performed using the intraoperative landmarks annotated on the US images and an appropriate registration algorithm as described below.

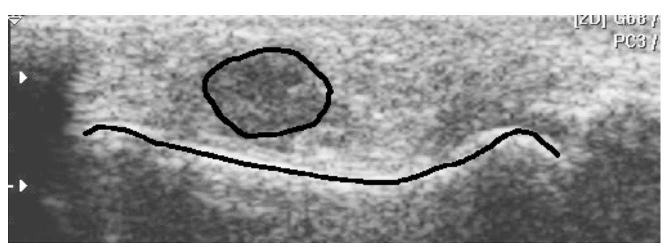

Fig. 2. Segmented US image showing the bone and tumor in the 3D model.

B. Tracking System

The POLARIS optical tracking system is able to locate a series of markers attached to the US and RF probe in 3D space. Combining this information with the 3D model and US images, the system will be able to display the exact position of the RF probe with respect to the patient's tumor. Then, the surgeon will be able to place the probe in the right position to make the treatment as accurate as possible. After the registration, all the information will be displayed in the coordinate reference of the tracking system.

C. Registration Algorithm

A key aspect of our system is the accurate registration of the preoperative 3D model with the anatomy of the patient. Basically, the idea is to find an adequate geometric transformation for the points in one model to be in the reference system of the other model. The first (moving) model is called data model. The second (reference) model is called shape model. In our CAS system, the shape model is the preoperative, NMRI based, model, and the data model is the intraoperative, less reliable, US model.

Since we know the size of both models, the scale factor is computed directly, without the need of a special algorithm. Therefore, we only need an algorithm to compute a rigid transformation (only rotations and translations). Another characteristic of our particular problem is the lack of known point correspondance. Finally, since we need the system to run in real time, the registration algorithm has to be very efficient and reliable. This is why we chose the Iterative Closest Point (ICP) algorithm [2], which consists mainly of four steps:

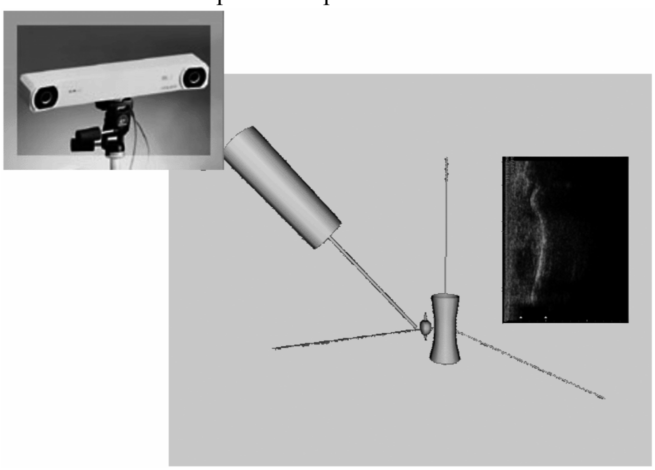

Fig. 3. Intraoperatory registration using US images, 3D model and tracking system.

a. Compute the closest points. The algorithm assumes the matching point in the shape model to each point in the data model is the closest one after each iteration.

b. Compute the registration (transformation). This is the most important step. Usually, the registration is represented by a vector containing information about the rotations and translations. This can be done with different methods, we chose to use a 7 real values vector formed by a quaternion for the rotations and 3 values for the translations in 3D space.

c. Apply the registration. Form a rotation matrix R and a translation vector T, then, for each point in the data model, premultiply by R and add T.

d. Repeat until the change in mean square error falls below a present threshold. The algorithm admits the use of other convergence factors and also includes a maximum number of cycles.

This algorithm is proved to converge to the local minimum and has a fair computation complexity of $O(N_pN_x)$ per iteration, in the worst case, where N_p is the number of points in the data (US) model and N_x the number of points in the shape (NMRI) model.

Currently we are working with an implementation of ICP in the Insight Segmentation and Registration Toolkit (ITK) (www.itk.org), which has shown good results. We also worked with another implementation in MatLab, mostly for testing purposes. We are using quaternion based transformations, which have proven to be more stable than Euler angles in most of our early experiments. Our tests have shown that this algorithm is very efficient and stable when we provide a good initial approximation. This should be no problem if the procedure for obtaining images is followed correctly. In this case, the basic transformation will

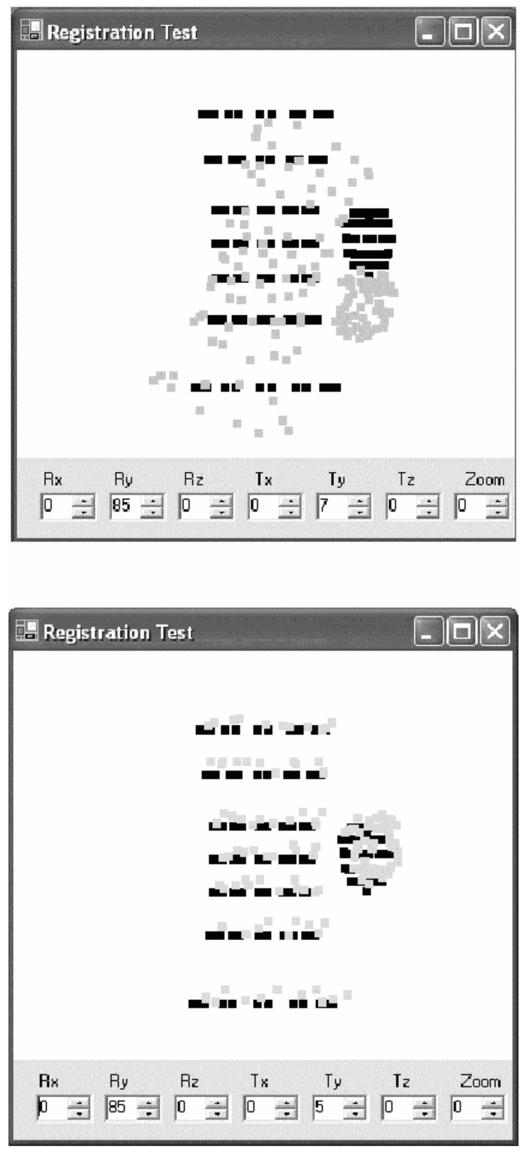

Fig. 4. Graphic interface showing a bad registration (top) and a good registration (bottom). Black points represent the shape model and gray points, the data model.

always be the same and should be a good one. If the protocol is changed (i.e. the images are taken from another angle or are inverted), a new initial approximation would have to be made for the algorithm to perform correctly.

We compare results using a simple graphic interface as shown in Fig. 4. This program is only preliminary and will change significantly as the project advances.

IV. Conclusions

Our CAS system will help physicians to treat tumors in the musculoskeletal system more safely and effectively. It will also help to train students in this surgical procedure. There is still much work to be done, especially in the application of ICP and the real time visualization of the RF probe location. The semiautomatic segmentation of US images is being developed in parallel [3].

References

[1] Lorensen, W.E. and Cline, H.E., "Marching Cubes: a high resolution 3D surface reconstruction algorithm," *Computer Graphics*, vol. 21, No. 4, pp 163-169 (Proc. of SIGGRAPH), 1987

[2] P. J. Besl and N. D. McKay, “A Method for Registration of 3-D Shapes” in *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 14, No. 2, IEEE, February 1992, pp. 239-256.

[3] Luis R. Gutiérrez Medina and F. Arámbula Cosío, “Segmentation of ultrasound images for tumor surgery”, *IX Mexican Symposium on Medical Physics*, Guadalajara, México, 2006

[4] S. N. Goldberg, G. S. Gazelle, P. R. Mueller, “Thermal Ablation Therapy for Focal Malignancy: A Unified Approach to Underlying Principles, Techniques, and Diagnostic Imaging Guidance” in AJR:174, February 2000, pp. 323-331

[5] J. Troccaz, M. Peshkin and B. Davies, “Guiding systems for computer-assisted surgery: introducing synergistic devices and discussing the different approaches” *Medical Image Analysis,* vol. 2, No. 2, Oxford University Press, 1998, pp. 101-119

[6] D. C. Baratt, G. P. Penney, C. S. K. Chan, M. Slomczykowski, T. J. Carter, P. J. Edwards and D. J. Hawkes, “Self-Calibrating 3D-Ultrasound-Based Bone Registration for Minimally Invasive Orthopedic Surgery”, in *IEEE Transactions on Medical Imaging,* vol. 25, March 2006, pp. 312-323