Computer Assisted Ablation of Tumors using Radio Frequency
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Abstract
A computer assisted system for treatment of tumors in the musculoskeletal system is being developed at the Image Analysis and Visualization Lab. of CCADET, UNAM. The system is designed to assist the surgeon, during radiofrequency (RF) ablation of the tumors, through real time computer graphics models of the tumor, the adjacent structures (bones), and the active volume of the RF probe. The three dimensional model of the tumor and adjacent bones will be constructed from a preoperative MRI study and then registered intraoperatively to the patient using an optically tracked ultrasound probe. In this work are reported the current advances in the development of the system application using the framework CAMPAR, and our current results of semi-automatic segmentation of tumors and bones in ultrasound images.

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 needle, 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. In order to make this process minimally invasive, accurate placement of the probe inside the tumor is needed. Usually, a Magnetic Resonance Imaging (MRI) 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 MRI 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 following sections is described the framework used (CAMPAR) to develop our software application which includes: A graphical user interface, as well as registration and model interaction algorithms. We also present our current results of semiautomatic segmentation of bones and tumors in ultrasound images.

CAMPAR

Is a framework programmed in C++, which allows synchronized access and display of data coming from different devices, such as: medical imaging, optical trackers, and video cameras. CAMPAR is designed and optimized for real time applications in computer assisted surgery systems, it was developed by the group Computer Aided Medical Procedures at the Technical University of Munich (http://campar.in.tum.de).

In our system we use real time 3D position data provided by an optical tracker (POLARIS from Northern Digital Inc.) to calculate and display in CAMPAR the position of the RF probe with respect to the preoperative 3D model of the tumor. In Fig.1 is shown an screen shot of CAMPAR with a window showing the position of the probe.

Fig.1. CAMPAR proyect opened with VC 5.0. In the window is shown the 3D position of a tool.
PREOPERATIVE GRAPHICS MODEL

The 3D model of the tumor is constructed from an annotated preoperative MRI study. This imaging modality was chosen because it is able to show the tumor and adjacent structures (mainly bones) with clarity. Software tools are used to assist the surgeon in the manual annotation of the tumor and bones on each image. Once we have enough cross-sections to represent the tumor and adjacent bones, a 3D triangular mesh is constructed using the marching cubes algorithm [Lorensen y Cline, 1987]. 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. In Fig. 2 is shown an MRI study of the hand of a child which shows an small tumor next to the proximal phalanx. The 3D model of the phalanx and the tumor is illustrated at the right of Fig. 2.

Fig. 2. MRI study of a hand with a small tumor and the 3D model of the tumor and the adjacent bone (phalanx).

INTRAOPERATIVE MODEL REGISTRATION

A 2D ultrasound probe is used during RF ablation to localize the tumor inside the patient. A POLARIS optical tracker will be used to measure the position and orientation of the US probe in order to acquire sets of ultrasound images of the tumor where we can measure its total 3D size and shape. Relevant image features (such as bone edges) will be annotated semiautomatically on each image as described below.

Transoperative registration of the preoperative 3D model with the anatomy of the patient can be accomplished using the image features and a registration algorithm such as iterative closest points (ICP) [Besl y McKay, 1992]. In this work we used the implementation provided in the insight toolkit (ITK: www.itk.org). In Fig. 3 is illustrated the registration of our 3D model of tumor and bone.
SEMIAUTOMATIC SEGMENTATION OF ULTRASOUND IMAGES

The method reported by Van Ginneken et al., [2002] was used to segment the tumor and bones in an US image. The method is based in the identification of optimal features for bone/tumor classification with a k-nearest neighbours classifier. A large set of features is constructed with the 1st and 2nd moments of the histograms of bone and tumor regions, taken from US image derivatives up to 2nd order (Dx, Dy, Dxx, Dyy, Dxy) and filtered at 5 different scales (σ). In Fig. 4 is illustrated the calculation of 60 features per image pixel (D_0 is the original filtered image).

Fig. 3, Results of 3D registration using iterative closest points: (top) preoperative and intraoperative models misaligned; (bottom) models aligned with ICP.

Fig. 4. Calculation of 60 features per pixel of bone or tumor
Three training samples were constructed with 600 vectors of 60 features each, of the classes, tumor, bone and background. A genetic algorithm (GA) [Goldberg, 1989] was used to select an optimum subset of features for the classification of each pixel using a k-nn classifier (k=11). Our objective function was the sum of classification errors on a validation sample. In table 1 are shown the optimal features found with the GA for the classification of tumor, bone and background pixels.

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Table 1. The GA produced the following optimal features: 2nd moment of Dx at $\sigma=0.5$; 2nd moment of Dy at $\sigma=0.5$; etc.

In Fig. 5 are shown the results of the segmentation of an US image using the 27 optimal features found with the GA and a k-nn classifier (k=11). To optimize the classification time and accuracy the segmentation was implemented with a region growing strategy starting from manual seed points.

![Fig. 5. a) Original image with manually annotated seed points; b) Segmentation of bone (white) and tumor (grey) using 27 features (table 1) and a 11-nn classifier.](image)

**CONCLUSIONS**

The framework CAMPAR allows for a rapid and effective implementation of computer assisted surgery systems. Currently we have a preliminary prototype of our system which can show the position of different tools inside the working volume of a POLARIS optical tracker. A semi-automatic image segmentation method has been implemented, to facilitate the intraoperative registration of the 3D graphics model with the intraoperative US images of the patient. The main disadvantage of the method used is that processing times are too long for surgical applications. A
possible alternative for intraoperative registration is the use of original MRI and US images without segmentation as described in Penney et al., [2004].

References


