Tagungsband der 6. Jahrestagung der Deutschen Gesellschaft für Computer- und Robotergestützte Chirurgie (CURAC) 11.-13.10.2007 in Karlsruhe, pp. 79-81

Ultrasound-based Registration of Preoperative CT or MRI Data for Navigation in Brain Surgery

S. Winter[1], C. Hansen[2], C. Dekomien[1], I. Pechlivanis[3], M. Engelhardt[3], H. Ermert[2], K. Schmieder[3]

[1]Institut für Neuroinformatik, [2]Lehrstuhl für Hochfrequenztechnik, [3]Neurochirurgische Universitätsklinik, Ruhr-Universität Bochum, Deutschland

Ansprechpartner: Susanne.Winter@neuroinformatik.rub.de

Abstract:
Image-based navigation is a well established method in brain surgery. The main problem is the registration of the preoperative image data within the coordinate system of the head in the operating theatre. We developed a system where intraoperatively acquired three-dimensional ultrasound data serves as a basis for a multimodal image registration. The main advantages of the ultrasound-based registration are the independence of landmarks or fiducial markers and the ability to repeat the registration quickly and easily without additional radiation exposure.

Keywords: Navigation, Ultrasound, Multimodal Image Registration, Brain Surgery

1. Objective and Motivation

Intracranial surgeries are routinely planned and conducted by means of preoperatively acquired CT or MRI volume data sets of the patient's head [1-3]. For this, a registration between these data sets and the position and orientation of the head in the operating theatre has to be performed. In neurosurgery, a point-based registration incorporating fiducial markers as landmarks is usually used – the use of anatomic landmarks is not feasible due to greater inaccuracy. These fiducial markers are attached to the patient's head prior to the preoperative CT or MRI scan, and must remain until the intraoperative registration is completed (i.e. potentially over night). For the registration, the positions of the markers must be pinpointed in the preoperative 3D data set and, intraoperatively, on the head of the patient using a pointer and a visual navigation tracking system. For the latter, the position of the head is tracked using a reference base, mounted on the Mayfield clamp in which the head is fixed. The accuracy of this method varies and strongly depends on the precision of the localization of the markers in the data set and, in particular, on the patient's head. Furthermore, a registration is only possible while the markers are in place. If the markers are lost prior to surgery, a completely new preoperative data set has to be acquired. Moreover, an intraoperative re-registration (e.g. after an unscheduled but necessary rearrangement of the head or after a system crash) is usually not possible, as the markers are removed for the surgery or are not accessible during surgery.

As an alternative, we developed a system for an ultrasound-based registration [4,5]. Here, an intraoperatively-acquired ultrasound volume data set is used for an image-based registration. This method is repeatable at any time, non-invasive and non-ionizing. It also combines high accuracy with fast and flexible handling. While the accuracy was previously proven *in-vitro* on a spine phantom [6], the applicability of the method was evaluated *in-vivo* at the lumbar spine and at the knee [7,8]. In this paper, we present results of the ultrasound-based registration of the head with MRI-data.

2. Methods

Our algorithm performs a surface-to-volume registration of bone structures between intraoperatively-acquired ultrasound volume data set and preoperatively acquired MRI data. As a first step, voxels that are imagable with ultrasound according to the physical properties of ultrasound wave propagation (i.e. beampath, shadowing, specular reflections) are segmented. The segmentation is done semi-automatically in the MRI data by the use of a threshold based method, in which the location of the ultrasound scan and the direction of the sound propagation are considered. Next, this surface is registered within the

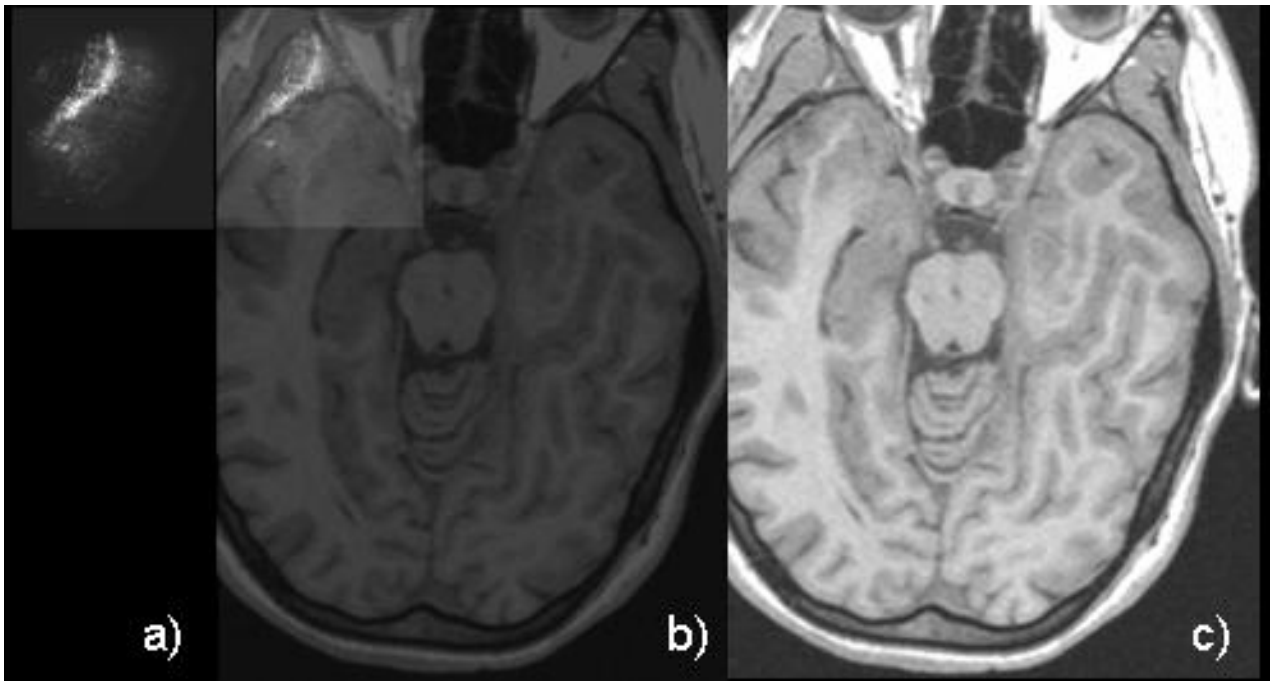

Fig. 1: (a) Axial ultrasound image of the temporal region; (b) superimposed axial ultrasound and registered MR image; (c) corresponding axial MR slices

ultrasound volume by means of an evolutionary optimization [9]. To obtain an initial estimate for this optimization, a rough pre-registration is conducted using three anatomic landmarks: chin, naseon and tragus. For a successful registration, a good spatial distribution of the segmented surface points is essential. For the registration of the head, the anatomy of the region defined by the temporal, the zygomatic and the sphenoid bones turned out to be suitable for this purpose and easily imagable with ultrasound.

Ultrasound volume data sets were acquired using the video output signal of a Siemens Acuson Antares system and a P10-4 phased array that was manually moved and swayed in the elevational direction. The positions of the transducer and the head were tracked with an NDI Polaris Optical Tracking System and two passive reference bases (rigid bodies). Both volume data sets (MRI and ultrasound) were converted to volumes with an isotropic voxel edge length of 0.5 mm. Using these data sets and the aforementioned pre-registration, the ultrasound-based registration was computed.

3. Results

To evaluate the applicability of the presented approach, individuals were scanned with T1-weighted MRI and ultrasound as described above. After the ultrasound-based registration, bone structures show a good geometrical match in superimposed images of ultrasound and MRI. Figure 1 and 2 show the result of the ultrasound-MRI image registration. The visually assessed deviation was less than 1 mm. In addition, soft tissue on the skull was imaged in current position with ultrasound. Here, a slight shift of these structures was noticeable, resulting from the contact pressure of the ultrasound probe. Both the point-based pre-registration and the ultrasound volume scan require less than one minute. Computational time for the ultrasound-based registration was dependent on the dimension of the scanned region, but was in the range of 10-20 seconds.

4. Conclusion and Outlook

We introduced a replicable method for a repeatable registration of preoperative MRI data of the head using ultrasound volume data sets and evaluated the applicability on test persons. Based on the reliability of our results, this approach appears to be suitable for an intraoperative application in neurosurgery, where

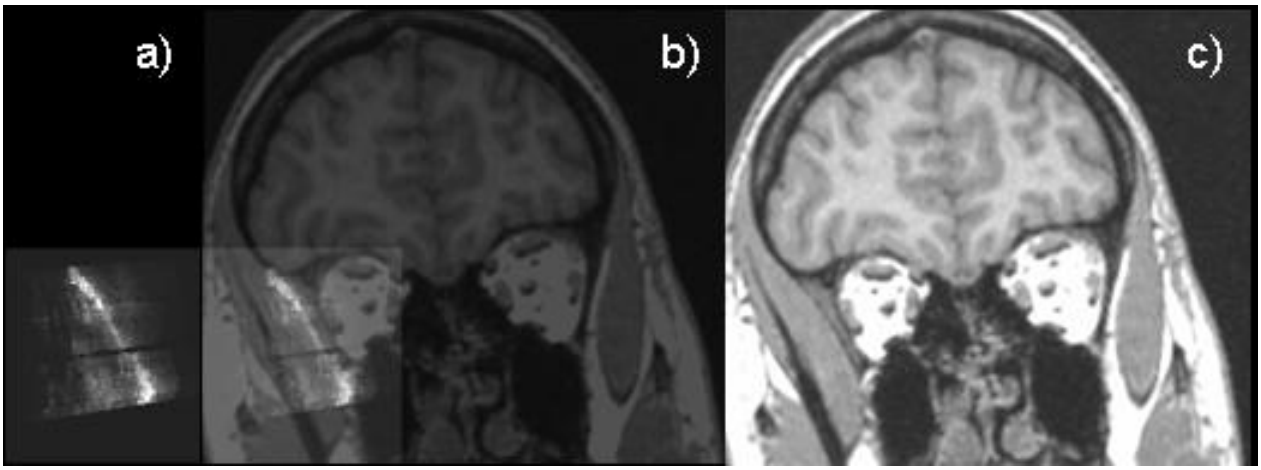

Fig. 2: (a) Frontal reconstruction of the three dimensional ultrasound data; (b) superimposed ultrasound and registered MR image; (c) corresponding frontal MR slices

ultrasound is often used routinely as an online imaging tool. Ultrasound-based registration thus seems to be capable of replacing the conventional point-based registration, which suffers from the dependence on fiducial markers. Although our novel ultrasound-based registration require nearly same time as the conventional point-based approach, it is considerably more flexible. After the registration, ultrasound can be used for further navigational purposes, to update the preoperative data set or to visualize brain shift.

Acknowledgment This project is conducted in cooperation with the Ruhr Center of Excellence for Medical Engineering (KMR), Bochum, Germany, and funded in part by the Federal Ministry of Education and Research, Germany (BMBF, grant: OrthoMIT, 01EQ0424). We would like to thank Siemens Medical Solutions for additional support.

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