MR Imaging-Guided Needle Biopsies with an Augmented Reality System in a Closed Bore System: A Pilot Study Assessing the Feasibility in Phantoms and a Pig

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Introduction

MR guidance for interventional procedures is receiving increasing attention. Open MR scanners designed in a C-arm or a double doughnut fashion give the physician access to the patient during scanning, thereby enabling real time MR imaging feedback. However, the availability of such scanners is not widespread, and most of the open scanners operate at field strengths below those used routinely in diagnostic applications. In contrast, conventional closed bore MR scanners operate at high-field strength, provide excellent image quality, and are available in many hospitals. Yet, the closed bore magnet design is not conducive to the performance of MR imaging-guided procedures.

Augmented reality (AR) image guidance systems map medical data such as MR images onto the patient's body. The physician can see beyond the surface as the patient's body becomes transparent through the integration of the visual field and imaging data. Augmented reality provides a direct and intuitive way of presenting medical image information for image-guided procedures. The goal of this study is to adapt an AR system to work within an MR environment and to test its use as a navigation tool for MRI-guided needle biopsies using a high-field (1.5T) closed bore MR scanner

Method

System Hardware: The AR system consists of a video-see-through head-mounted display (HMD). Two color video cameras attached to the HMD provide a stereoscopic view; a third head-mounted video camera is added for tracking. The tracking camera measures the viewer's position and orientation in relation to a set of optical markers attached to the MRI table. This fixed reference frame firmly anchors the graphics with respect to the real scene. Another set of optical markers is attached to the needle. The system runs on a single personal computer and achieves real-time performance with 30 frames per second, generating a stable visual augmentation of the real scene. An MR data set of a calibration phantom with 8 multimodality markers is used to establish the relationship between the optical markers of the phantom and the frame coordinate system (fig.1). A homogeneous transformation matrix is computed, which maps any point in the MR coordinate system to the "frame" coordinate system. This transformation matrix allows augmentation of MR slices with any generated computer graphics. In a second step the needle is automatically calibrated to an attached marker cluster. Needle position and orientation can then be computed using the needle marker cluster.

Phantom Experiments: The experiments were performed on a high-field 1.5 Tesla closed bore magnet system (Magnetom Sonata, Siemens Medical Solutions, Erlangen, Germany). The biopsy phantoms consisted of round buckets filled with Natrosol gel (500g of Natrosol in 2000 ml H_2O). To mimic lesions within the phantoms, 6 hollow plastic tubes with 12 mm diameter and 5 mm in height and 18 hollow plastic tubes with 6 mm in diameter and 5mm in height were embedded in the gel. The tubes were placed with their longitudinal axis parallel to that of the round bucket at different spatial locations and levels inside the bucket. The needle used for the simulated biopsy was a 20cm long MR-compatible 18-gauge needle.

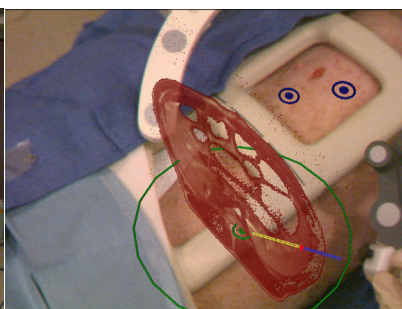**Fig. 1:** Experimental setup showing the pig placed into the augmented reality setup on the MRI table

Fig.2: Augmented Reality view of the pig showing the needle (blue), the needle tip (red dot) and the needle pointer (yellow)

To prepare the augmented reality guided biopsy procedure, MR images of the gel phantom were acquired using an axial gradient echo sequence (FLASH3D, TR,TE: 9, 5 ms; 25dg flip angle; 1mm slice thickness; 256x256 matrix; BW 260 Hz/pixel). The images were transferred to the AR-system computer and a custom interactive image processing tool was used to segment the target and background tissues. The segmented data were used to generate 3D VRML models of each target. For the biopsy experiments, the MR table containing the phantom was moved to a position outside the scanner. Using the HMD, a virtual 3D object of each target was augmented into the optical view of the user. The needle was graphically enhanced with a thin virtual cylinder; in addition, a 7cm long linear extension of a different color was used (fig.2) to allow aiming of the needle to the target while the needle was still outside of the phantom. 24 biopsy experiments using tube targets were completed. Prior to every experiment, the objects of interest were augmented into the physician's HMD view. After the physician completed the AR guided needle insertion, the location of the needle tip was recorded in the augmented reality coordinate system. Gadolinium doped Gel droplets were inserted through the needle and left in place inside the gel phantom at the needle tip. MR control scans were then acquired in order to assess the distance of the marker to the lesion target. The position of the markers in the MR coordinate system was measured.

Animal Experiment: The animal experiment was conducted on a fully anesthetized pig weighing 38 kg positioned in a supine position in the MR scanner. After acquisition of a localizer, axial and coronal 2D HASTE images (TR, TE: 1100, 117 ms, ETL 256, 5-8 mm slice thickness, 490 Hz/pixel) were used to visualize the pancreas and liver of the animal. The images were then transferred to the AR computer; based on these images the pancreatic tail, the gallbladder and the common bile duct were selected and marked in the augmented space. The MR patient table was removed from the bore and the animal prepared for the "biopsy." For the actual puncture (fig.1), the respective target as well as an MR slice containing the target was augmented into the HMD (fig.2). Immediately after the AR-guided puncture outside the magnet, the animal was brought back into the scanner with the biopsy needle still in position and MR images were obtained to verify the position of the needle.

Results

In the phantom experiments the virtual needle extension was very helpful to make sure that the needle path intersected with the center of the virtual lesion target. This allowed subsequent needle insertion in a firm and constant motion along the desired path all the way to the target. In all phantom experiments the needle was correctly placed with the tip inside the tubes in all 24 targets, a 100% success rate. The evaluation of the 3D coordinates of the needle tip position in the AR space in comparison to the actual 3D coordinates of the targets showed a deviation of the needle tip from the center of the target below 2mm in all 24 cases, with a mean error of 0.5mm.

In the animal experiments, the interaction of the virtual needle extension with the augmented MR images provided abundant information and helped to avoid crossing important structures. The total puncture times were 12s, 14s and 18s respectively. In all animal experiments the deviation in needle position between AR and MR confirmation was less than 5mm on the post-procedure image.

Discussion

The AR system presented here has proven to effectively facilitate image guided needle biopsies with a 100% success rate for lesions as small as 6 mm in diameter. MR images acquired shortly before the procedures in a closed magnet are mapped into the patient space after moving the patient outside the magnet. The 3D display enables the physician to visualize these MR images in-situ, and makes hand-eye coordination during puncture very intuitive. This method provides an elegant means to perform percutaneous interventions with a closed bore MR scanner.