Real-Time Image Guided Targeting of MRI Compatible Robotic Assisted Breast Biopsy & Therapeutic System

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Introduction: The ability of a conventional high-field MR scanner to function as a dynamic, flexible real-time interventional imaging tool is appealing as closed-bore systems become more open and accessible. While available MRI techniques can rapidly acquire images, there is currently no reliable way to accurately position and control a robotic system to perform biopsies within an MRI scanner. We present here results from a newly developed robotic system that operates within a closed-bore MRI scanner, and provides real time positioning information and image guidance using a passive magnet field sensor (PMFS).

Methods: The PMFS system, called the EndoScout (Robin Medical Inc., Baltimore, USA), uses specialized gradient pulses that are embedded within an imaging pulse sequence to induce currents in a sensor assembly containing three orthogonal sets of coils. System calibration is performed once per scanner using a grid of sensors that spans the entire diameter and length of the bore of the magnet. During calibration, the sequence with the embedded tracking gradients is run and the currents in the sensors are digitized and used to create a map of the field space, which can be used to determine the location and orientation of the sensors[1-3]. During normal tracking operation using a single sensor and running the special gradient sequence, the EndoScout system digitizes the currents induced across the sensor's coils at a rate of 20 Hz. The induced currents are then compared by an optimization algorithm to the values in the previously stored map of the field space to determine the position and orientation of the sensor.

The robotic system consists of a slave and master robot. The slave robot (left of Figure 1) is positioned within the MRI scanner, and is comprised of a 6-DOF platform controlled by five pneumatic cylinders with associated linear position transducers, a piezoelectric motor mechanism used to insert and retract a biopsy needle, and a 3-axis fiber-optic force sensor integrated with the biopsy needle drive. The PMFS was mounted on the head of the robot, and was used to provide the real-time position and orientation of the needle assembly within the magnet. The master robot (right of Figure 1) is located in the MRI control room, and allows the operator to control the position and orientation of the slave robot, as well as receive haptic feedback from the force sensors as the biopsy needle is inserted or withdrawn.

Experiments were performed using a chicken breast sample that fit between the top and bottom part of a 4-channel breast coil. Six 4" plastic screws were placed into the sample at various locations to be used as markers. The leading tip of the plastic screw was considered as the target, and these targets were approached through robotic intervention from different angles. To perform robotic assisted biopsy under image guidance, a series of high resolution anatomical images were acquired and used to identify a target location in three orthogonal planes (FLASH sequence, TE=2.46ms, TR=440ms, flip angle = 87º, 256x192x35 matrix, slice thickness 3mm, 0.78 mm in-plane resolution). Along with identifying the target location, the images were also used to identify the point of insertion for the biopsy needle. Once the MR coordinates for the target and point of insertion were determined, the master robot was used to direct the slave robot to a location such that the trajectory of the robotic needle was collinear with the point of insertion and the target within the image. Throughout the targeting process, the location and orientation of the slave robot head was continuously monitored by overlaying the tracking information obtained from the Endoscout sensor in real time on the targeting images (Figure 2). Once the robot was in place, additional imaging was performed to confirm the plane of traversal for the needle towards the target using the same high-resolution imaging as described above. After confirmation, the master robot was used to insert the biopsy needle. During needle insertion, tracking was performed using a rapid gradient echo sequence with 1-3 slices (FLASH sequence, TE=1.5ms, TR=4.1-8ms, flip angle = 10º, 129x192 matrix, slice thickness 3mm, 1.56 mm in-plane resolution) to ensure that the needle reached its target, and haptic feedback from the force sensors on the slave robot was relayed in real time to the operator through the master robot.

Results and Discussion: The robotic system was completely compatible with the MR, with no measureable loss in SNR when the robot was actuated. During 6 trials, the robot came within 1-2mm of the target location 5 times, with the targeting being perfect one time as shown in Figure 3. During one of the trials, the target was missed by about 8mm. This error was later attributed to the tissue deformation and movement during the robotic manipulation. The average time from initial imaging to hitting the target (not including the missed trial) was 20.6 +/- 3.5 minutes. Future improvements will include filtering the PMFS data to enhance reliability, and performing the initial image-based robot positioning autonomously.

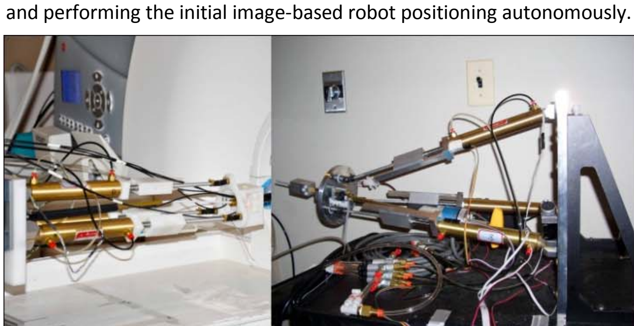

Figure 1 - MRI Compatible Breast Biopsy Slave Robot (L) and Master Robot (R)

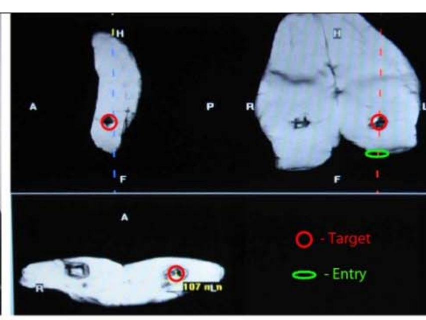

Figure 2 - Real Time PMFS GUI

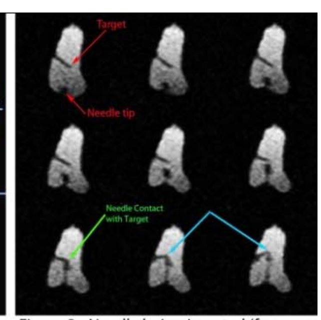

Figure 3 - Needle being inserted (from bottom) and hitting the target. Blue arrows show target being displaced by biopsy needle

References:

1. Hong et al., Surgical endoscopy, 2008. 22(2): p. 552-6.
2. Kurumi et al., , 2007. 12(2): p. 85-93.
3. Tang et al., IEEE Transactions on Medical Imaging, 2008. 27(2): p. 247-54.

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