Image-Guided Interventional Device for 3D Access and Localization of Breast Lesions

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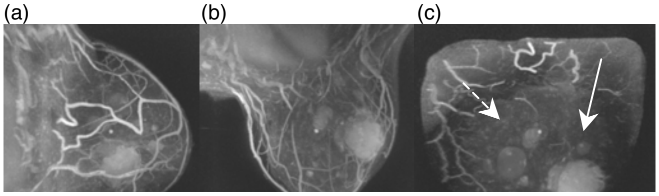
Introduction: Real-Time Image guidance for breast biopsy is routinely performed with ultrasound (US) but the margins of the lesion are not always well seen [1]. Breast MRI has exceptional sensitivity for lesion detection and 3D high resolution capabilities for depiction of the tumor margins with high confidence [2]. Although, MRI-guided breast biopsy with a core needle or vacuum-assisted system has proven to be feasible [3,4,5], the process is time consuming as the patient needs to be moved out of the magnet bore for the biopsy procedure, making real-time image guided interventions (IGI) impossible. In this research, we explore the feasibility of automated trajectory planning using 3D isotropic resolution planning images with an MR compatible biopsy device that uses a cylindrical coordinate system. The device is integrated into a commercial RF-coil and can be used with real-time MRI technology and remote control to perform the procedure without removing the patient from the magnet bore.

Methods and Results:

3D MR Planning Sequence: The VIPR-SSFP [6] sequence uses two half-echoes sampled along two adjacent radial lines during each TR that inherently refocuses the transverse magnetization. Fat suppression is achieved by separating fat and water signal into separate image volumes using the LC-SSFP technique [7]. An example of a fat suppressed reconstruction acquired with isotropic resolution (.78 x .78 x .78 mm^3) using a 4-channel breast coil (MRI Devices Corp., Waukesha, WI) in a total scan time of 5 minutes is shown in Figure 1. This was a patient with a hematoma associated with a tumor (arrow) and several visible cysts (dotted arrow).

Figure 1. 3D Planning Images: Fat suppressed images demonstrating the 3D isotropic capabilities of VIPR SSFP (a) Sagittal MIP (b) Axial MIP (c) coronal MIP, thinned to demonstrate distinction of cyst (dotted arrow) and hematoma associated with the tumor (solid arrow).

(a) (b) (c)



Device Design: A novel robotic apparatus (Figure 2) for image-guided intervention of breast lesions in 3 dimensions. The device was designed based on a cylindrical coordinate system for improved localization and control. Use of 3D coordinate system allows direct access to breast lesions during real-time MR-IG interventions. The apparatus has three fiducial markers evenly distributed on its rotation base (arrows). Another marker is placed on the needle support/holder. The 3D planning image contains these MR visible markers within the field of view. After the image is loaded into the GUI, it is projected in the coronal plane to show the apparatus' base plane (figure 3a). Algorithms to translate the lesion location information within the cylindrical coordinate system into robotic positioning movements have been developed and integrated into a 3-D Graphical User Interface (GUI) with network connection to the MR scanner system (Figure 3b).

Figure 2. Robotic apparatus: Two base markers are visible. The third one is located under the black fixture. Needle support marker is on back.

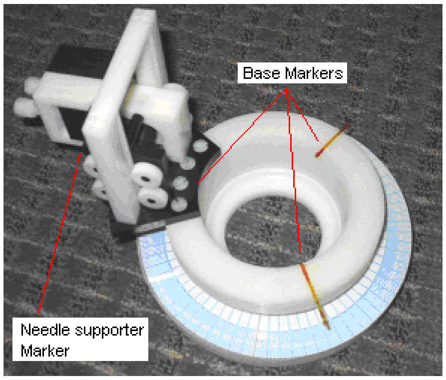
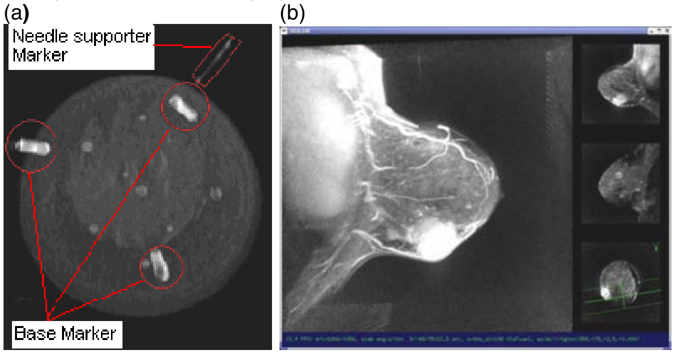


Figure 3. Trajectory planning and GUI Layout: (a) Image on left is taken with the breast phantom and robotic apparatus. The markers are circled. (b) Image on right shows the 3D interface GUI layout (without apparatus) for a patient. The current plane is shown in the main window, while orthogonal slices are along right column.

(a) (b)



Graphic Interface and Planning: The GUI calibrates the device coordinates using reference pixels selected by mouse clicks on the inner tips of the markers. Since the markers are distributed evenly in the circle, the center coordinates are the average of the three markers. This is also the center of the cylindrical coordinate system. From any desired plane, a fourth click on the lesion of interest allows determination of the rotation angle. Next, the image is projected to the plane that contains the lesion and axis of the cylindrical coordinate. The needle guide will also be in this plane after the rotation is completed. The displacement and tilt angle of the needle guide are then calculated by placement of the fifth reference marker. The rotation angle, displacement and tilt angle are all required before the device will activate its motor and position/orient the needle.

Discussion and Conclusions: A practical and easy system for localization and trajectory planning for MRI image guided breast biopsy in three dimensions has been designed and partially implemented. The use of 3D MR information for planning takes full advantage of the 3D nature of MR data, allows more direct access to the suspect lesion and integration of functional images into the planning process. The simplicity of the planning and localization procedure presented in this work is directed at making robotic controlled intervention more robust, safe, and practical. Validation experiments in phantom studies will be performed to further refine the design and quantify performance of the system.

References:

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