Phase Only Cross-Correlation Tracking of a Passive Marker for MR-guided Interventions

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Introduction

MRI is a non-invasive, non-ionizing imaging modality providing unparalleled soft tissue contrast for guidance of percutaneous interventional procedures such as biopsy and ablation. Recently, higher field MR scanners with patient access akin to CT along with compatible/safe equipment have become available, making real-time MR-guidance of physician guided needle trajectories more feasible [1]. Problems associated with efficiency and workflow in real-time execution of such procedures is the ability to consistently coordinate the scan prescription with the needle trajectory as it changes (such as when slightly obliques or aiming for a moving target). Additionally, in instances where the lesion is superficially located or where several applicators must be placed in close proximity, such as cryotherapy, the MR visualization of the trajectory can become obscured with respect to the target. In these cases, an automated tracking system which both helps visualize the trajectory and automatically adjust the scan plane in real-time can be helpful. Here we describe initial feasibility tests in using a passive marker with a phase-only cross-correlation tracking technique for real-time adaptive needle trajectory tracking at 1.5T.

Materials

Procedures were performed in an outpatient interventional facility (with full anesthesia support) featuring a short bore (120 cm) 1.5T clinical MRI scanner (Magnetom Espree vB15, Siemens Medical Solutions) with a wide aperture (70 cm) for increased access to the patient during imaging. The system is equipped with an 18 channel receiver and high performance gradients (DZ-Engine, 33 mT/m amplitude; 170 T/m/s slew rate) for rapid, high resolution imaging. Signal reception was achieved using a receive only single loop surface coil or body matrix array atop the site of interest, with the Tim spine array providing signal from underneath. An in-room monitor (MRC) provided real-time visualization of procedure progress from either side or end of the bore. Communication between radiologist and staff was facilitated via an MR compatible communication system with digital noise reduction (IMROC, OptoAcoustics) (Fig 1).

A modified 3-plane acquisition (FLASH x2 followed by one orthogonal bSSFP) which used a phase-only cross-correlation (POCC) algorithm to track a contrast-containing needle sleeve (Invivo- Germany, Schwerin)[2] in real-time and adaptively update the MR-prescription to capture the needle trajectory[3-5]. To plan the location of the imaging slices, a single slice orthogonal to the sleeve is prescribed from a 5-plane bSSFP pre-planning sequence (TR/TE/FA=3.6ms/1.4ms/72º, 256x192, 5mm thick slices, 0.7s per acquired plane) (Fig 3a). From this two T1-W FLASH planes are prescribed (α=20°) with a distance of 2-6 cm of separation (Fig1). Real-time POCC was used to identify the location of the sleeve on these images and the trajectory was sent to update the 3rd plane prescription (bSSFP with α=70°) to maintain a view of the needle sleeve and needle. Real-time 3-plane sequence parameters were: TR/TE=4ms/1.9ms, matrix=256x192 (partial Fourier), slice thickness = 6mm, 1.5s-2s for 3 acquired planes based on asymmetric echo setting). A breast biopsy phantom (Invivo Corp.) (Fig 1) and tri-modality abdominal phantom (CIRS, Inc) were used for initial testing of the sequence prior to use in patients (Fig 2 & 3).

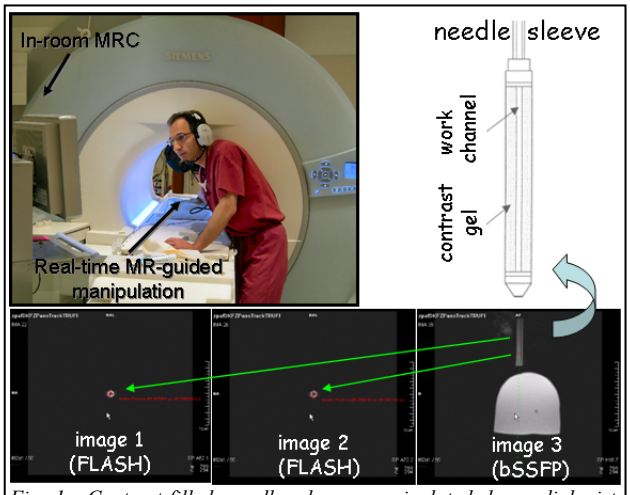

Fig 1: Contrast-filled needle sleeve manipulated by radiologist. Images 1-2 acquired using FLASH orthogonal to sleeve. POCC identification is performed in and scan prescription updated (bSSFP) in real-time (1.5-2.0 s). Only Image 3 is displayed on MRC.

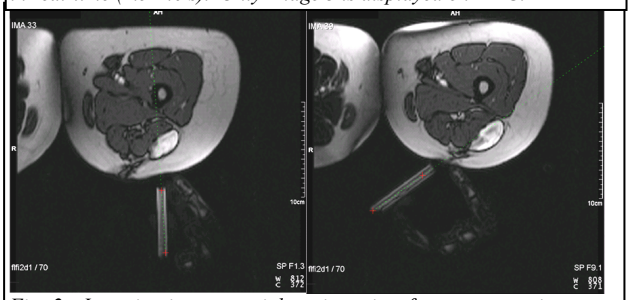

Fig 2: Investigating potential trajectories for an extremity mass. Crosses (red) show location of tracking planes and dotted line(green) shows POCC calculated trajectory.

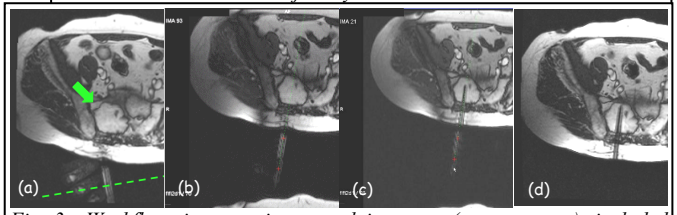

Fig 3: Workflow in targeting a pelvic mass (green arrow) included identifying a single initialization plane from which the 2 FLASH tracking planes are derived on the 5-plane bSSFP planning image (a), real-time adaptive trajectory display using single plane bSSFP (b) and (c) and verification using 5-plane bSSFP (d).

Results

The radiologist was able to reach into the scanner to manipulate the needle and needle sleeve in real-time while observing the projected needle trajectories on the in-room MRC (Fig. 2). The scan prescription followed the trajectory of the contrast-containing needle sleeve, which was consistently visible, on oblique axial and sagittal acquisitions. Periodically the tracking algorithm would fail to register on one of the FLASH planes. In many instances, the tracking algorithm could self correct after 1-2 acquisitions, other times, the sequence needed to be restarted. Retrospective analysis of the FLASH images revealed these failures were often the result of the algorithm locking onto structures in the hand/finger as opposed to the sleeve, or from placing the initialization slice too high/low. Mean deviation between the overlaid trajectory and the needle tip (n=10 time points) as a function of FLASH tracking slice separation demonstrated the mean deviation and uncertainty decreased with larger slice separation (Table 1).

Table 1: Needle-to-trajectory deviation (Δr)and tracking plane separation distance (Δx) in patient

Δx (cm)	Δr $\pm$ STD (Min-Max) (mm)
2	5.0$\pm$3.6 (0-10.5)
4	2.8$\pm$2.6 (0-5.9)
6	1.7+1.4 (0-4.5)

Discussion

We investigated the feasibility of using a passive tracking marker and POCC algorithm for real-time coordination between the scan prescription and needle trajectory for guidance of percutaneous interventions. The passive needle sleeve was easily integrated into the interventional MRI environment and can be manipulated by the radiologist in real-time for targeting lesions and predicted trajectories had good agreement with observed trajectories on images, but were a function of tracking plane separation. Passive marker tracking has some advantages over active tracking in that it doesn't rely on signal generation and so carries none of the same safety hazards, nor does it rely on special triggering, have problems with low gradient amplitudes near isocenter, or eddy current inducing objects such as surgical arms or robots. However, as the procedure is translated into patient use, work is needed to overcome issues related to periodic tracking loss as well as markers which are more easily removed from the guide needle facilitate access to deeper targets.

References

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