Comparison of Two Real Time Tracking Methods for a Robotic Assistance System

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Introduction

Percutaneous interventions are difficult to perform in closed-bore MRI systems, because access to the target organ is restricted due to the limited space in the magnet. This limitation was overcome with a commercial robotic assistance system (RAS), which can precisely position and orient a medical instrument (e.g., a needle) with a robotic arm. To co-register the robot position in the magnet with the MR coordinate system, passive markers filled with contrast agent are attached to distal end of the arm.

Compared to localization techniques with active MR marker coils [1], passive markers do not require any additional rf hardware and, thus, do not lead to potentially dangerous device heating at conducting structures [2]. To localize passive markers with sub-pixel precision, recently a fully automatic cross-correlation algorithm has been developed [3, 4]. In this work a real-time pulse sequence with integrated cross-correlation algorithm is developed to track the medical instrument during the intervention. The precision of this marker localization sequence is compared to a tracking method that uses marker coordinates measured by the RAS.

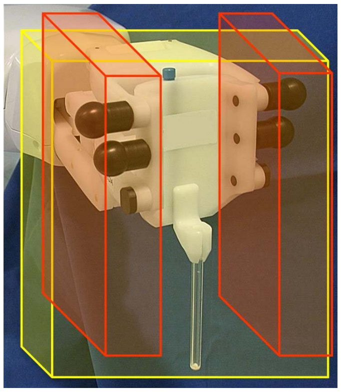

Fig.1: Robotic assistance system with 4 passive markers (block spheres) Two sagittal (red) and one transverse (yellow) slices were used for marker localization.

Materials and Methods

Real time needle tracking was performed using a clinical 1.5T whole body MR system (Siemens Symphony, Erlangen, Germany) and the MR-compatible RAS Innomotion (Innomedic, Herxheim, Germany). The RAS consists of a pneumatically driven robotic arm, which is mounted on an arc to fit into the 60-cm bore of a solenoid MR system. Position and orientation of the arm, which has an instrument holder at its end (Fig. 1), are continuously measured by the RAS using optical sensors for five of the six degrees of freedom. Initially, coordinate systems of robot and MR were co-registered using the laser positioning system of the MR, and final co-registration was done by the RAS using high-resolution MR images of the markers.

Passive marker localization algorithm (PMLA): To localize the four 10 and 15 mm-diameter markers (filled with Gd-DTPA:H_2O 1:200) three 50 mm-thick slices (one transverse, two sagittal) were acquired to encompass the whole markers and to avoid marker losing while robot movement. A FLASH pulse sequence with following parameters was used for image acquisition: TR = 5.8 ms, TE = 2.9 ms, $\alpha = 20°$, voxel size: $1 \times 1 \times 5$ mm^3, TA = 1.7 s/slice. The position of the four markers was quantified in these images using (1) the phase only cross correlation for automatic detection [4] and (2) a center-of-mass calculation with sub-pixel precision [3]. Fig. 2a-c shows white crosses at the detected positions (note: crosses are shown with pixel precision). Once the marker positions were found in the three images, the needle axis and the rotation matrix for slice positioning were calculated to automatically position a trueFISP imaging slice (TR = 5.8 ms, TE = 2.9 ms, $\alpha = 70°$, voxel size: $1 \times 1 \times 5$ mm^3) with the needle plane.

Needle tracking using robot coordinates: For comparison, a TCP/IP network interface was developed to transfer the current marker coordinates from the RAS to the MRI host computer. On the MRI console, robot coordinates were converted into MR coordinates to allow automatic parallel or orthogonal alignment of the imaging slice with the needle axis. To compare the two real time methods a contrast-agent-filled glass tube was inserted into the needle holder (Fig. 1). The robot arm moved to 8 positions and both methods were used to align an imaging slice with the needle plane. Additionally a high-resolution 3D FLASH data set (TR = 10.2 ms, TE = 4.3 ms, $\alpha = 15°$, voxel size: $0.7 \times 0.7 \times 0.4$ mm^3) was acquired to determine the angular misalignment between needle axis and image plane.

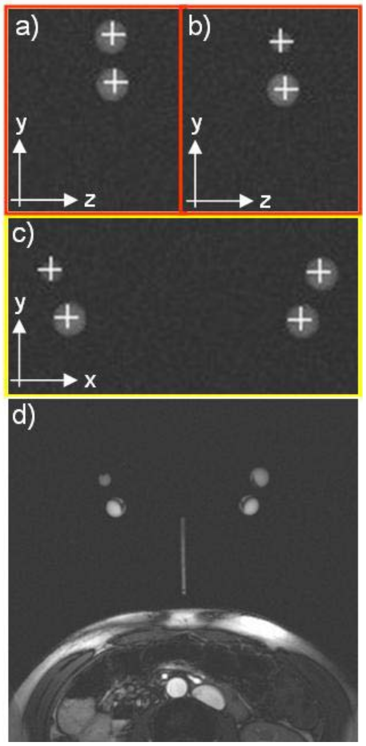

Fig. 2: a) and b) show the two sagittal images to determine y and z position and c) the transverse image for x coordinate calculation. The white crosses assign the marker positions. d) trueFISP image acquired at the position of the needle plane.

Results and Discussion

As an example a needle plane image acquired by PMLA is shown in Fig. 2d where the RAS was positioned above a volunteer. All four markers and the glass tube representing the needle are clearly visible in the image. Table 1 presents the angular misalignment result determined from the 3D FLASH data. Within their statistical uncertainties, both methods provide a comparable precision. While the method using robot coordinates is faster because no additional images need to be acquired during real-time imaging, the PMLA method is completely independent of the robot hardware used, and can be easily translated to other marker systems. The current acquisition time of 7 s of the positioning and imaging slices will be significantly reduced in future implementations using partial Fourier and parallel imaging techniques.

	PMLA algorithm	**robot coordinates**
Mean	1.38°	1.19°
StdDev	0.72°	0.83°

Tab. 1: Needle plane angular misalignment.

References

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