Localization and tracking with RF coils that are optically detuned by the control of an MR compatible manipulator

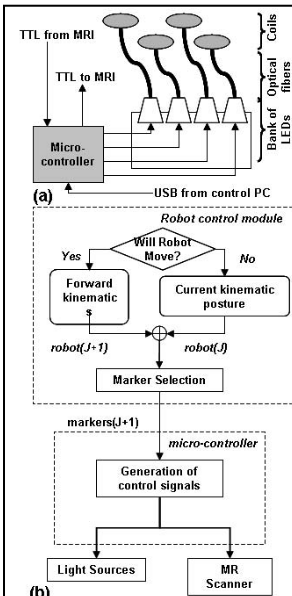
Junmo An[1], Nicholas von Sternberg[1], Karen Chin[2], Dipan J. Shah[2], Andrew G. Webb[3], and Nikolaos V. Tsekos[1]

[1]*University of Houston, Houston, Texas, United States,* [2]*Houston Methodist, Texas, United States,* [3]*Leiden University, Leiden, Netherlands*

TARGET AUDIENCE: Researchers and clinicians in interventional MRI

PURPOSE: Localization and tracking of interventional devices with MR-visible markers is an active area of research for real-time MR guidance.[1] Among the different passive MR-visible markers are inductively coupled RF coils that are optically detuned for the identification of individual markers for MR-compatible manipulators.[2, 3] The purpose of this work is to implement a technique to use robotic control to select which markers need to be visible in order to monitor with MRI the motion of the device. With a lower number of markers active, fewer acquisitions are needed. Here we investigate an approach for robust localization and accurate tracking of our 7-degree-of-freedom (DoF) MR-compatible robotic system[4] using multiple markers that are selectively tuned and detuned so that only one or a combination of them is visible each time on the MR image.

METHODS: Figure 1(a) shows the control circuit, and Figure 1(b) the process, that links the robot fiducial MR marker control. Based on the ordered motion, i.e. which degrees-of-freedom (DoF) will be actuated, the robot control code selects which markers [marker(J+1)] need to be visible to track this motion. This set is sent to the marker microcontroller that in turn loops through the list marker(J) turning ON only one of the selected markers, triggering the MR scanner to collect an image or a projection. When data collection finishes, a TTL pulse from the MR scanner triggers the microcontroller to turn ON the next marker in the marker(J+1) list. The markers were 3-mm OD inductively coupled solenoid coils wound around a 1H source with a photoresistor in their tuning circuit. The micro-controller selectively activates an LED and detunes the coil OFF via the photoresistor. Figure 2(a) shows the positioning of four such markers on the MR-compatible robotic arm.[4] Figures 2(b) to 2(e) illustrate how the control code selects which markers are actuated and how the DoF can be measured: for DoF-1, markers #1 and #2 are selected; for DoF-2 (that is orthogonal to DoF-1) markers #3 and #4 are used, and for the insertion of the tool markers #3 and #4 (marker #3 is anchored onto the tool carriage).



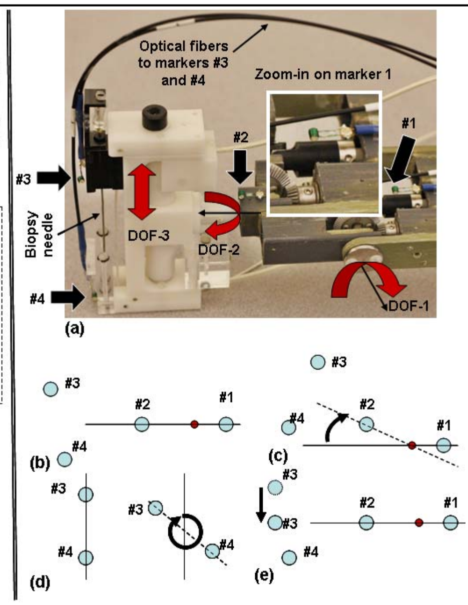


Fig 1 (left panel): (a) The marker control circuit, (b) flowchart of the process that links the robot and marker control (dashed boxes show the parts of the code that run on the robot control PC and the marker microcontroller). **Fig 2 (right panel):** (a) the robotic arm with the four markers (b-e) principle of measuring the DoF (b-c) DoF-1 rotation; (d) DoF 2 rotation and (e) insertion.

RESULTS: Figure 2 shows representative results of controlling the visibility of the MR-markers from the robot control at 1.5T. A gradient echo sequence was run (TE/TR/angle = 1.75/227.72ms/1°, matrix size = 192 X 140, field of view = 192 X 140mm, slice thickness = 8mm, bandwidth/pixel = 723Hz) with the markers placed on a cylindrical phantom. Figures 2(a) and (b) were collected when all markers were detuned or tuned, respectively. Figures 2(c) to 2(f) were collected when the operator requested a motion of all DoF. The robot control module sent to the micro-controller the coils(J=1) = {1111} (i.e. all coils). This resulted in the sequential collection of images each of which has only one of the four coils ON.

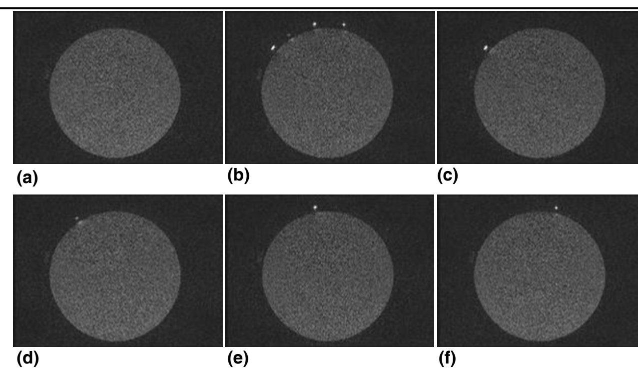


Fig 3: (a-b) MR image acquired with all coils detuned (a) and all coils tuned (b). (c-f) Four consecutive frames from continuous real-time MRI, during which the robot control module sequentially detuned the coils so only one marker is visible per frame: markers 1 to 4 in (c-f).

DISCUSSION: In MRI-guided and robot assisted interventions, linking robot control with the MR modality offers opportunities to optimize guidance. This concept has been demonstrated previously with the robot control adjusting on-the-fly the orientation of the imaging plane to always image the end-effector as it maneuvers for real-time guidance.[5] In this work, selecting which markers are visible based on the motion of the robot allows speeding up of MR tracking (since only certain markers needs to be visible). Also, by tuning only one marker per acquisition repetition, the location of this particular point of the instrument is unambiguously identified simplifying data acquisition and processing. This approach can be used to track via full two-dimensional imaging or one-dimensional projections in articulated robots or steerable catheters.

CONCLUSION: This work describes a technique for linking robot control and MR marker visibility for localization and tracking.

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