Tracking of a Robotic Device by Controlling the Visibility of Markers from the Robot Control

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Synopsis

Integrated control system of the manipulator and marker control is important for localization and tracking of multiple optically detunable MR markers on MR-compatible manipulators. Selecting which markers are visible on MR images by the motion of the maneuvering portion of the MR-compatible manipulators allows unambiguous identification of a combination of markers and simplifies both the data acquisition and the post processing. This proposed technique can be employed to track multiple marker positions on interventional devices such as the steerable catheters and the end-effectors of the MR-compatible manipulator.

Introduction

Localization and tracking of interventional tools with MR markers is among the most important factors in real-time MRI guided procedures.[1] In order to distinguish the markers on the MR images, optically detunable markers have been proposed to make one or all markers together MR visible per MR data collection cycle.[2,3] In this study, the integrated control system of the manipulator and marker control synchronizes the ON/OFF state of the LED source, controls the manipulator, and triggers the MR scanner; therefore, it also allows for tracking a combination of markers that correspond to the specific maneuvering part of the manipulator. Furthermore, we describe a technique for accurate localization and fast tracking with multiple optically detunable MR markers that are selectively tuned and detuned by the actuated portion of the MR-compatible manipulator. This technique allows unambiguous identification of the particular marker points of the maneuvering manipulator on MR images, and simplifies both the MR data acquisition and the post processing methods.

Methods

Each MR marker consists of a 3.0 mm outer diameter inductively coupled solenoid coil, a variable non-magnetic capacitor and a photoresistor which is optically tuned and detuned; moreover, it is connected to the marker control module via a 15.0 meter long optical fiber cable. Figure 1 shows our MR-compatible manipulator arm [4] attached to four optically detunable MR markers. This robotic arm consists of two rotational degree of freedoms (DoFs) (i.e., DoF-1: rotating by an angle ϕ around the X axis, DoF-2: rotating by an angle ψ around the oblique axis that is orthogonal to X) and one prismatic DoF-3 (i.e., inserting the end-effector). Marker #1 and #2 are adequate to calculate its link length and the rotation angle (ϕ) of DoF-1. In addition, marker #3 and #4 are needed to measure the insertion length (Δ) and the rotation angle (ψ) of the end-effector. Figure 2 displays the flow diagram of integrated control system of the manipulator control and marker control. The manipulator control module maneuvers the robotic arm and determines from manipulator maneuvering (robotStates) conditions which markers are needed to be switched ON/OFF, markerStates. The module then sends markerStates to the marker control module. The marker control module controls the marker visibility, sends TTL pulses to the MR scanner to trigger data acquisitions, and receives a return TTL pulse after completing data acquisitions.

Results

A manipulator operation and MR imaging at 1.5T with the manipulator-driven tracking were performed in various different manipulator maneuvering (robotStates) states. Figure 3 shows transverse MR images collected with (a) all markers OFF, (b) all markers ON, (c-f) the result by sequentially turning ON marker #1, #2, #3 and #4 (TR/TE = 384.4/1.46 ms, flip angle = 1°, bandwidth/pixel = 723 Hz, matrix size = 192 X 134, FOV = 350 X 244 mm^2, slice thickness = 10 mm). Figure 4 shows sagittal MR images collected with (a) all markers OFF, (b-e) and collection of four sequential images of markers #1, #2, #3 and #4 turned ON in turn, which was the result of control state (markerStates) 1111 being sent by the manipulator control module to the marker control module (TR/TE = 403.37/1.41 ms, flip angle = 3°, bandwidth/pixel = 723 Hz, matrix size = 152 X 192, FOV = 336 X 425 mm^2, slice thickness = 10 mm). Figure 5 shows transverse MR images acquired with marker #3 and #4 with a TurboFLASH sequence (TR/TE = 403.37/1.41 ms, flip angle = 3°, bandwidth/pixel = 723 Hz, matrix size = 192 X 152, FOV = 192 X 152 mm^2, slice thickness = 10 mm) as $\phi = 0$ and the rotational DoF-2 rotates the end-effector randomly.

Discussion

The described technique was designed to study accurate localization and fast tracking methods of the MR-compatible robots using computer-controlled MR markers for MRI-guided and manipulator-assisted interventions. This technique can be used to track the motion of multiple marker points on articulated surgical instruments such as steerable catheters, bendable tools, and the end-effector of the manipulator.

Conclusion

This study demonstrates the manipulation-driven tracking technique that employs the integrated control system of the manipulator and marker control to select on-the-fly which MR markers need to be visible on the MR images to track the maneuvering part of the MR-compatible manipulator.

Acknowledgements

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References

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Figures

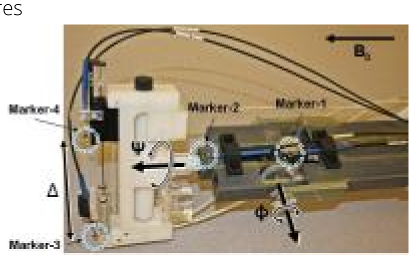

Figure 1. Photograph of the manipulator arm attached to four MR markers.

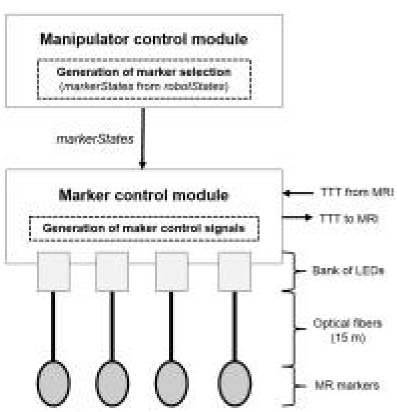

Figure 2. Flow diagram of integrated control system of the manipulator control and marker control.

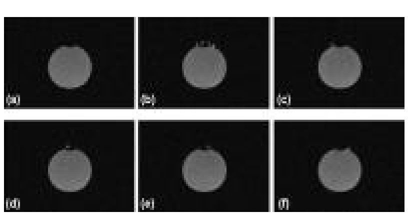

Figure 3. Transverse MR images collected all markers detuned (a) and all tuned (b). (c-f) Only one marker is MR visible per frame.

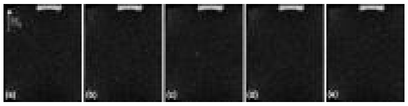

Figure 4. Sagittal MR images collected with the manipulator under different markerStates conditions.

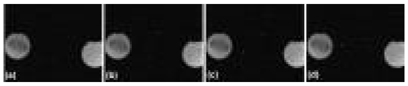

Figure 5. Manipulator-driven tracking represented by transverse MR images acquired as DoF-2 rotates.