Freehand Performance of Interventions with Manipulator-driven Real-time Update of the Imaging Plane

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INTRODUCTION:

Recently several MR compatible remotely controlled manipulators are evaluated for performing interventions inside cylindrical MR scanners with real-time imaging [1-3]. In most cases the procedures are performed in a stereotactic manner, i.e. a trajectory is planed by reviewing scout MR images and the manipulator automatically aligns the interventional tool to match it. An alternative to stereotactic planning, is the manual remote control of the manipulator in a manner resembling the freehand performance of a procedure with ultrasound guidance. This can be combined with the recently introduced on-the-fly dynamic update of the imaging parameters [4]. In this work, a freehand master/slave remote control of a robotic manipulator was combined with manipulator-driven update of the position and orientation of the imaging plane to scout the subject, identify a target and guide a procedure.

METHODS:

MR-Compatible Manipulator: Studies were performed with an MR-compatible manipulator, designed to operate inside high-field cylindrical scanners, described in [3]. The device has seven degrees-of-freedom (DOF), three orthogonal X,Y and Z, three rotational θ1, θ2 and θ3 and a linear for setting the depth of insertion (Δ). Manual remote control of the manipulator was performed by means of a master/slave control handle which resembles the geometry of the actual arm. With this implement, the manipulator replicates the motion of the handle (as shown in Fig. 1A).

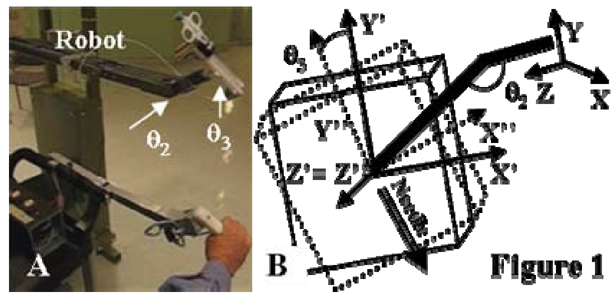

Figure 1

Manipulator-Driven MR Imaging: We implemented control software and combined it with a TrueFISP sequence which allows updating of the position and orientation of the imaging plane. Initially, the manipulator was registered relative to the MR scanner, from the position of a cross-like fiducial marker attached to a known position on the end-effector. During maneuvering, the control software continuously calculated the transient position of the end-effector solving its forward kinematics and using the optical encoder readings (which provided the changes of the DOF). In parallel, from these data and the initial registration of the manipulator, the position and orientation of a plane centered on the end-effector was calculated and this information was send via a TCP/IP connection to the scanner for on-the-fly update of the sequence (Fig. 1B).

RESULTS: Figure 2 shows results from using the manipulator-driven dynamic update of the imaging plane to acquire a target on a phantom with an MR-compatible needle (white arrows). The phantom consists of a piece of beef with embedded Gd-filled tubes and a saline bag rested on its side. To visualize the manipulator, two Gd-filled tubes (Gd-markers) were attached on each side of its end-effector. The operator maneuvered the manipulator above the area of interest, scouting the phantom with the updated plane and identified the targeted structure (cross). The upper panel shows frames while the manipulator moves along the X-axis and, the middle panel, frames while the wrist DOF of the manipulator is actuated. In both cases the position and orientation of the FOV changes dynamically as it follows the motion of the end-effector providing the operator with a "forward looking" view which always includes the tool at the center of the FOV. After the tool was aligned with the trajectory of insertion, the needle was inserted hitting the sought target. Overall, an accuracy of 3.2 mm was achieved in all studies (n=6). Freehand remote control of the manipulator combined with on-the-fly adjustment of the imaging plane proved straightforward and intuitive, in a similar way with ultrasound-guided procedures.

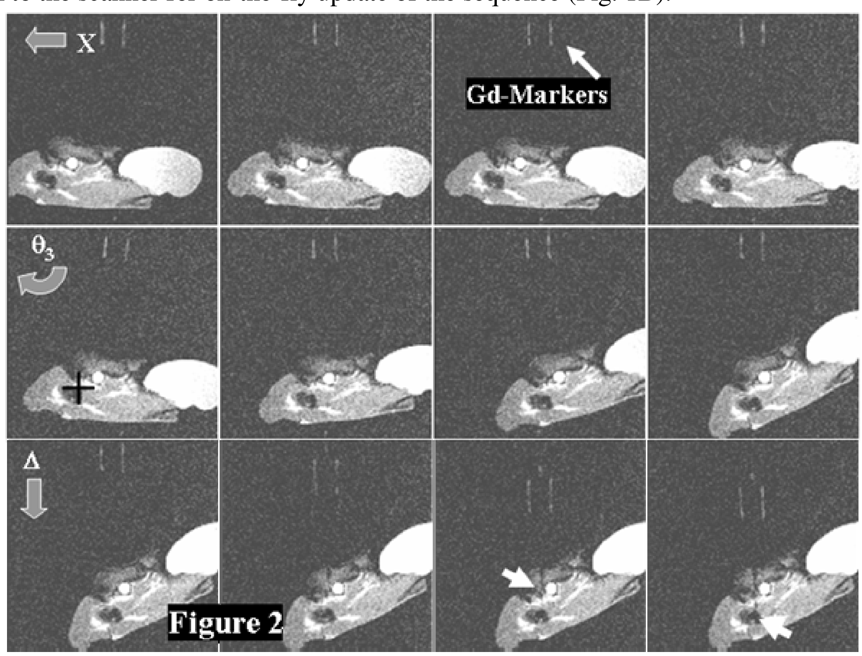

Figure 2

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