A Remotely Controlled Device for Real-time MR-Guided Interventions Inside Cylindrical MR Scanners

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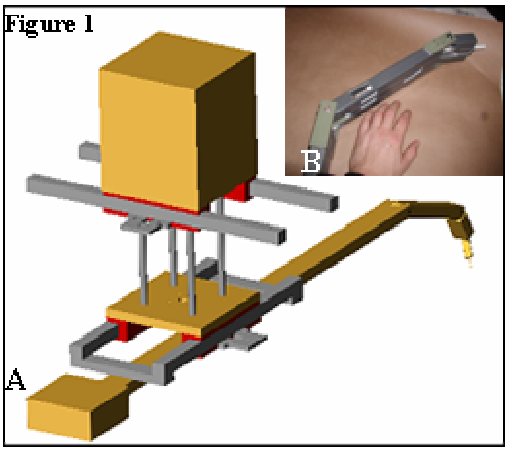
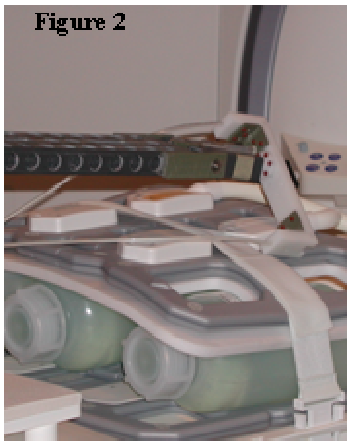
INTRODUCTION:

Performing interventions inside high magnetic field cylindrical MR scanners may offer additional benefits, such as higher sensitivity and more contrast options, when compared to the low field open systems. Reaching inside a cylindrical scanner to the patient is, however, almost impossible. A solution to this is the use of remotely controlled robotic manipulators. While robotic systems have been developed to operate inside double-donut or open scanners [1, 2], construction of devices for use inside cylindrical scanners is a major challenge because of the higher magnetic field and the workspace limitations. An MR-compatible, computer-controlled robotic manipulator with seven degrees-of-freedom (DOF) is presented.

METHODS

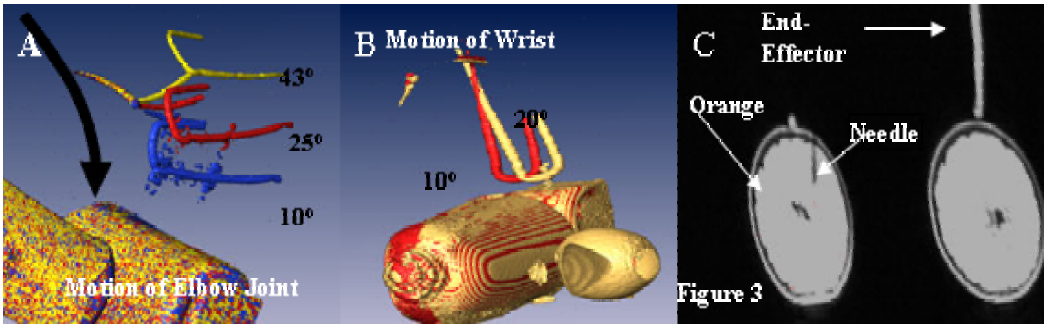
Description of the System: As shown with the solid model in fig. 1A, the device is an articulated arm mounted on a support structure which resides outside the scanner. The support structure also provides three Cartesian DOF for the macro-positioning of the arm. The arm extends inside the bore to reach the isocenter of the scanner, and has the remaining four DOF. These 7 DOF provide extended manipulability to the device and offer a wide envelop of operation to the user, who can select a trajectory suitable for the procedure. Figure 2 shows a photograph of the part of the arm that operates inside the scanner. The device is constructed of nonmagnetic and nonconductive materials for MR-compatibility and safety [3, 4] and it is actuated by ultrasonic motors. Gd-filled tubing was placed on the arm for MR visualization. The optical positioning sensors and actuators of the system are fully integrated to a control system, which utilizes embedded technology. A user interface fuses all sensor signals (MR and non-MR information) in a visualization, planning and control command environment.





MR Studies: All MR studies were performed on a 1.5Tesla scanner (Sonata, Siemens) with simple phantoms, composed of saline filled bottles and fruits (oranges) as targets. The phantoms were placed between the two pieces of a twelve-element arrayed coil and the operator was viewing the continuously collected MR images to control the device and insert a biopsy needle in the phantom through the openings of the coil. Real-time imaging was performed with two oblique to each other slices using an interleaved method developed previously for cardiac imaging [6]. Multislice sets were also collected when the device was stopped to evaluate volumetric imaging of the device within the area of interest and image processing, such as isosurfacing.

RESULTS: Figure 3 shows isosurface reconstructions of multislice sets depicting the end-effector in a series of movements while the robotic arm was en route to the target, and shows different rotations of the elbow (A) and the wrist (B) joints. The panel in 3C shows two slices, one depicting the inserted needle and the other the Gd-tubing of the end-effector. It is evident that the image quality is not compromised due to the presence of the robot. Such a robotic arm can be used to perform interventions, such as biopsies, ablations and localized delivery of therapeutic agents, in the abdomen, torso and head. Underway are in vivo studies to evaluate the capabilities of the system. The facilitation of real-time MR guided procedures, while the patient remains in the scanner, may provide new directions in interventional MRI. Moreover, the possibility of MR image guided interventions may address the limitation of current robotic surgical systems due to the restricted vision provided by endoscopes.



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