Implementation of Real-time Safety Control for Image-guided Procedures Inside Cylindrical Scanners with MR-Compatible Manipulators

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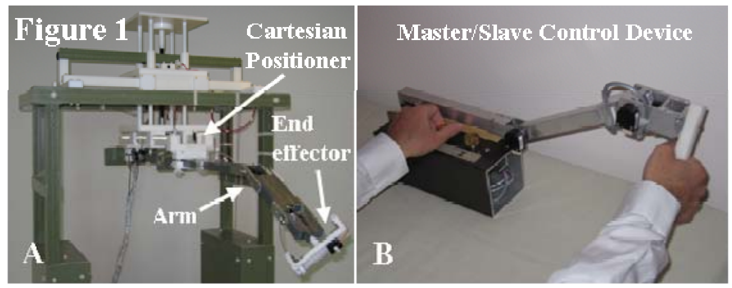
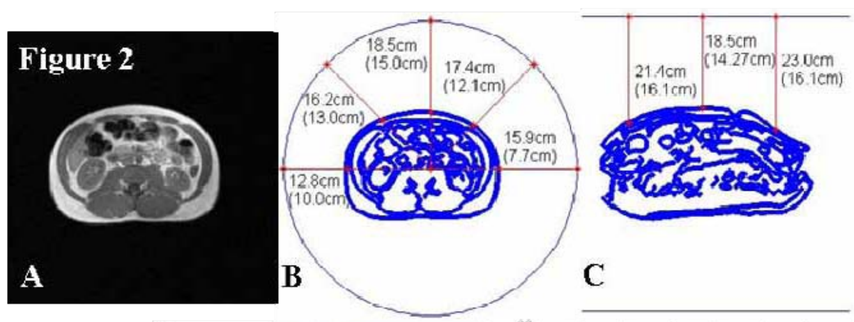
INTRODUCTION:

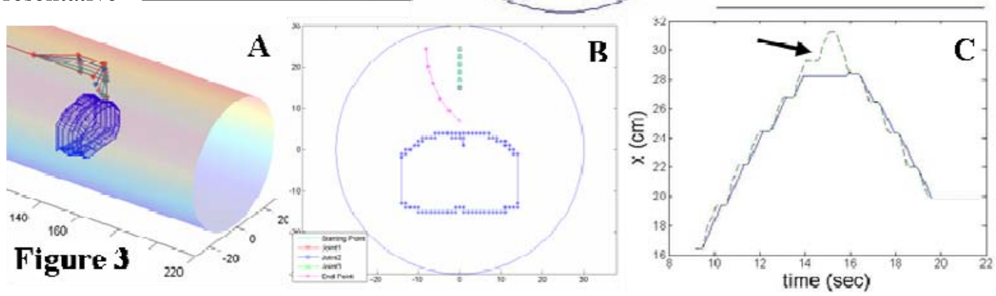
Recently several MR compatible remotely controlled manipulators have been introduced to facilitate the performance of interventions [1-4]. The primary reasons for their development are the need to reach the patient in the confined space of a cylindrical MR scanner for real-time guidance, and the improved accuracy and steadiness in positioning and holding diagnostic or therapeutic tools. Since such manipulators must operate inside the confined space between the patient and the bore of the scanner, collisions are likely to happen resulting to subject injuries and/or damage to equipment. This work presents an approach for automatic manipulator collision avoidance.

METHODS: An MR image-based Collision Safety Component (CSC) was implemented, which extracts the volume of the subject from a set of parallel transverse scout images at the area of interest. It also uses the known geometry and kinematics of the manipulator and its current spatial arrangement (from optical encoders) to locate it in space. When motion commands bring the manipulator outside the allowable volume, its operation is halted and resumes only when the command is again within this space. The CSC was tested with a robotic arm, Fig. (1A), designed to operate inside the confined space of high-field cylindrical scanners [4]. Control of the manipulator was performed either with a graphics user interface or a master/slave control handle for freehand control (Fig. 1B). All studies were performed on a 1.5 T Siemens (Sonata) MR scanner. Human studies were performed without the device in place.



RESULTS: Figure 2 shows single-slice example outputs of the boundary detection algorithm of the CSC depicting transverse (Fig. 2B) and sagittal (Fig. 2C) slices of two volunteers (subject #1: height = 1.65m, weight = 71kg and subject #2: height = 1.85m, weight = 99.8kg) inside a cylindrical MR scanner (bore diameter = 60cm). The calculated distances between the subject surface and the scanner gantry are reported at representative directions (Figs. 2B and 2C) and illustrate that motion inside such a highly confined space may easily result to collision with the subject and/or the gantry. In addition, preliminary work without the safety collision component demonstrated that the operator was highly preoccupied to avoid collisions and was often distracted from the main task of performing the procedure. Figure 3 illustrates the operation of the CSC component in three (Fig. 3A) and two dimensions (Fig. 3B) while the end-effector was maneuvered above the subject and within the permitted volume. Figure 3C shows an example of the performance of the CSC to prevent collision, during freehand control of the manipulator with the master/slave handle during motion along the X-axis of the scanner. When the commanded motion (dashed line) is within the allowable space, the manipulator tracks the controlled commands (continuous line). When the commands bring the manipulator outside the allowable space (black arrow) the manipulator is automatically stopped and its motion resumes when the control command reenters the allowed volume. Since the CSC extracts the motion of the manipulator's joints from the optical encoders, it does not require any additional hardware (e.g., fiducial RF coils) for tracking the manipulator while it eliminates misregistration due to gradient inhomogeneities. With the CSC component the operator could perform a procedure with highly reduced work load and effort while being focused on the actual interventional task.





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