Remote MR-Compatible Catheter Navigation System

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Introduction: MRI allows for high contrast visualization of soft tissue, including ischemic, infarcted and arrhythmogenic tissue in the heart [1]. These advantages are motivating factors for developing technology for guiding catheterization procedures using MRI [2, 3]. However, the practical implementation of MRI-guided catheterization procedures requires the addition of MR compatible viewing and control panels within the scanner room and certain procedures can be hindered by the limited access to the patient. Furthermore, the excessive noise levels within the room impede the communication between the interventionalist and staff. To address these limitations, we have developed an MRI compatible remote catheter navigation system (MR-RCNS) that allows the manipulation of a catheter from the scanner's control room.

Methods: The design of the MR-RCNS was based on a previously described RCNS [4] that enables the remote manipulation of percutaneous transluminal catheters from a location remote to the patient, while allowing the interventionalist to use his/her developed dexterous skills – applying push, pull and twist to a catheter's shaft. As the interventionalist manipulates an input catheter in the control room (Fig. 1) the catheter's rotation and translation are measured by a pair of sensors (master); the motion is transmitted to the MR compatible "slave" manipulator within the scanner room. The manipulator, which is fabricated of non-ferromagnetic materials, utilizes a pair of ultrasonic motors (Xi'an Ultrasonic Technology Co., LTD., China) to drive sets of rollers that grip the patient catheter, thereby replicating the rotation and translation of the input catheter. An embedded system was designed to calculate the appropriate signals to control the ultrasonic motors such that they manipulate the slave catheter with the same motion dynamics as the master with negligible time delay.

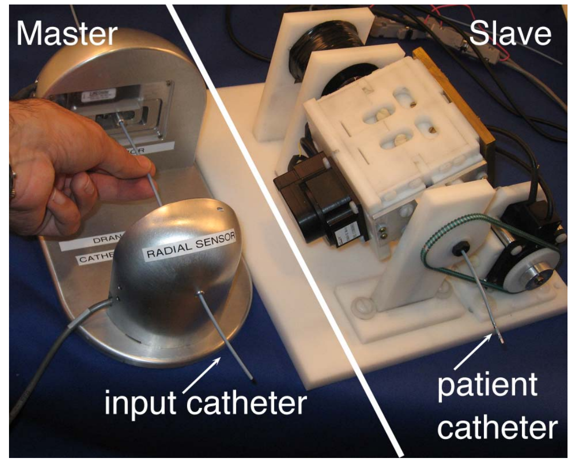

Fig. 1. Photograph of the MR-RCNS, showing both master and slave beside each other. In use, the manipulator is placed within the scanner bore while the sensor (master) remains in the console room.

The MR-RCNS was evaluated in terms of the accuracy of motion replication and effect on image quality during use. All experiments were performed using a 3T scanner (MR 750, GE). The master was placed in the console room and the slave on the patient bed within the scanner bore. For the accuracy experiments the input and patient catheters were confined to travel within 6-mm diameter Plexiglas tubes. To measure axial accuracy the input catheter was moved over a distance of 127 mm from a starting position; the experiment was repeated ten times in each direction. Each time, the position of the tip of the input and patient catheters was measured using vernier calipers. Radial accuracy was evaluated in a similar manner, using protractors mounted on each tube. The master was rotated 3600 degrees in the clockwise (and anticlockwise) direction ten times; the angle of the input and output catheters (as shown by a pair of pointers mounted on the catheters) was recorded at the end of each motion. The accuracy tests were performed during an imaging session using the FIESTA pulse sequence (TR /TE = 4.5/1.7 ms, slice thickness 6 mm, 256x256 matrix, 32 channel cardiac coil) to evaluate any effects the gradient switching may have on manipulator performance. In addition, the maximum system delay was measured by recording twenty motion profiles and calculating the cross-correlation between the master and slave motions. Lastly, the effect of the manipulator on image quality was evaluated. Following the NEMA guidelines [5], a 17 cm diameter Gd doped water phantom was imaged using the spin echo (SE) (TR/TE = 1300/20ms, slice thickness 6mm, 256x256 matrix, 32 channel cardiac coil) and FIESTA sequences at baseline, while the manipulator was powered up, and while motion was imparted on the patient catheter.

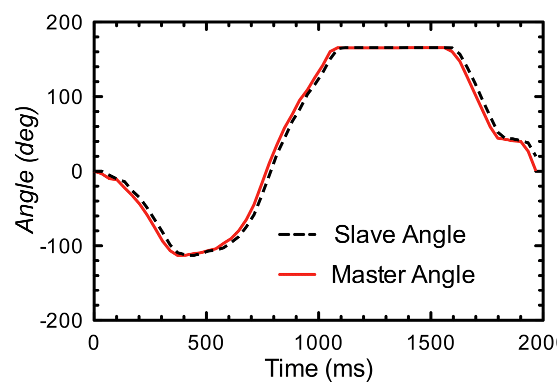

Fig. 2. Representative motion profiles from the master and slave, demonstrating minimal delay.

Results: The maximum system delay in replicating catheter motion, calculated from motion profiles similar to the one shown in Fig. 2., was measured to be 41±21 ms. An absolute value error of 2±2º was measured for radial motion over 360º. Similarly, an absolute error of 1.1 ± 0.8 mm was measured when replicating axial motion over 100 mm. The accuracy of replicating both axial and radial motions was not affected by the scanner or pulse sequences. For both SE and FIESTA pulse sequences, the SNR drop when the patient catheter was moving was less than 1% from the baseline values of 130 and 116 dB, respectively. Qualitatively, no artifacts were observed in the images during manipulator operation.

Discussion: We have developed and evaluated a master-slave catheter navigation system that measures the interventionalist's conventional motion on a catheter and replicates that motion through an MR compatible slave manipulator in real time. This MR-RCNS promises to facilitate MRI guided catheterization procedures by removing many requirements for MR suite modification and allowing the interventionalist to navigate the catheter from a convenient location away from the magnet bore, in the console room. Further evaluation is required under real-time MRI visualization of catheter motion, prior to *in vivo* verification.

References: [1] S. Pintillie et al., *ISMRM,* (2011). [2] K. Ratnayaka et al., *J Cardiovasc Magn Reson,*(2008). [3] R. Razavi et al., *The Lancet,* (2003). [4] Y. Thakur et al., *IEEE Transactions on Biomedical Engineering,* (2009). [5] NEMA Standard Publication MS 1-2008, (2008).