A NEW METHOD FOR MR COMPATIBLE ACTUATION: SOLID MEDIA FLEXIBLE TRANSMISSION

Nicholas C von Sternberg[1], Junmo An[1], Karen Chin[2], Dipan J Shah[2], and Nikolaos V Tsekos[1]
[1]University of Houston, Houston, Texas, United States, [2]Houston Methodist, Houston, Texas, United States

Target Audience: Researchers and clinicians in interventional MRI

Purpose: The future of MRI guided interventions relies on the research, development, and exploration of compatible actuation technologies which must provide safe and precise actuation within the confined space and high magnetic field of the MRI environment. Non-magnetic piezoelectric motors have been used by many groups, but these motors still require electrically conductive materials and wiring which may cause heating, or inteference.[1-3] In response, many groups have opted for pneumatic or hydraulic approaches, but kinematic performance of such systems is limited compared to the use of motors due to a lack of stiffness and non-linear dynamics[4,5] Recently, a novel method of linear force transmission has been developed specifically to meet the needs of MRI compatible actuation. The method presented within, referred to as Solid Media Flexible Transmission (SMFT), is used to transfer force through flexible hoses similar to pneumatic or hydraulic hoses, but without the use of fluids. The desired outcome of this transmission method is to enable the use of commercially available and standardized electromagnetic motors for MRI compatible actuation through a kinematically stiff, but flexibly routed MR safe transmission.

Methods: Removal of fluid dynamics provides greater kinematic performance and stiffness providing for a transmission which is more suitable for image-guided interventions, especially percutaneous interventions which require stiffness during needle insertion. Since the transfer tubes and end effectors are created without the use of conductive or magnetically susceptible materials this force transmission method can be used to transfer force into the MR environment without propagating electromagnetic waves that could reduce SNR. SMFT tubes, and the discrete motion elements used within the tubes to transfer force, were constructed of nylon, PTFE, and Delrin plastic materials. The entire force transmission system was constructed using only off the shelf hardware. A four degree of freedom positioning robot, also constructed of Delrin (polyoxymethylene) plastic, was designed for positioning a needle or surgical tool within the MRI scanner. Standard NEMA 23 stepper motors were used as the remote actuator and kinematic performance and MRI compatibility were tested in a 1.5 T scanner because they offer precise motion and automatic braking.

Fig 1. SMFT actuates the compatible robot inside the scanner.

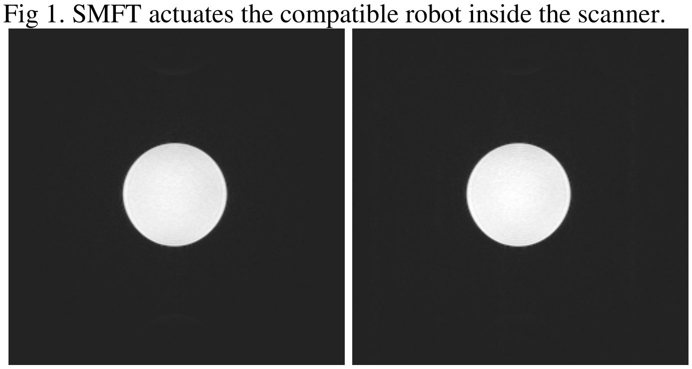

Fig 2. Bottle Phantom a) baseline b) robot operation.

Results: Preliminary experiments were performed using the proposed method of actuation and a four degree of freedom positioning robot. Force was effectively transmitted over 4 meters from the electromagnetic stepper motor to the MRI compatible end effector using SMFT. A bottle phantom was used as a signal source during the scans and average SNR reduction was calculated to approximately 5%. Selected images from the baseline and operation are shown in Fig. 2a and Fig. 2b respectively. The images were acquired using a True FISP pulse sequence (TR=41.86 TE=1.41 Flip Angle=79 Bandwidth/pixel=930). The average step response of the system was tested for a step size of 5 cm over six trials. Average rise time during these trials was measured to be 187 ms. Backlash of the SMFT tubes was measured to be approximately 7 mm, but it is automatically corrected during actuation by closed-loop position control of the end effector.

Discussion: The SNR results achieved by this method of actuation are equivalent to those published using pneumatic approaches and piezoelectric approaches[5] with filtered drive signals[3]. Comparison between step response of this system with published results for similar pneumatic and hydraulic approaches[4] shows a significant benefit in kinematic performance. Benefits of this system over piezoelectric approaches include the removal of conductive materials from the imaging environment. Although piezoelectric motors can provide nanometer precision, it is not a requirement of most robotic applications. SMFT can provide millimeter precision with the additional benefit of providing significantly more force output than piezoelectric motors. Additionally, this system can be implemented without the need for specialized hardware or control algorithms. Standard robotic actuators and control techniques can now be used in an MR compatible application greatly simplifying the development of MR compatible robotic systems.

Conclusion: A novel method of MR compatible actuation and force transmission has been presented. Results demonstrate sufficient kinematic performance and compatibility to provide MR safe and compatible actuation to enable MR guided interventions.

References: 1. Gassert R, et al. Actuation Methods for Applications in MR Environments. Concepts Magn. Reson. 2006;29B: 191–209.
2. Tsekos N. V., et al. MR–Compatible Robotic and Mechatronics Systems for Image-Guided Interventions: A Review Study. Ann. Rev. of Bio. Engr. 2007;9: 351-387.
3. Fischer G.S., et al. Approaches to creating and controlling motion in MRI. EMBC 2011 Ann. Conf. 2011; 6687-6690.
4. Yu N, et. al. Comparison of MRI-Compatible Mechatronic Systems With Hydrodynamic and Pneumatic Actuation. IEEE Trans. Mechatronics. 2008;13(3):268-277.
5. Fischer, G.S., et al. MRI-Compatible Pneumatic Robot for Transperineal Prostate Needle Placement. IEEE Trans. Mechatronics. 2008;13(3):295-305.