A new method for MR compatible actuation: Solid Media Flexible Transmission

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PURPOSE

The emergence of intervention with *real-time* MRI guidance have motivated the pursue of remotely actuated manipulators to achieve physical access to the patient while she/he resides inside the gantry of the MR scanner. One of the many engineering challenges, and an area of active research and development, in manipulator-assisted MR-guided interventions is MR-compatible actuation. This must provide safe and precise actuation within the MR environment stemmed by the confined space, a high main magnetic field, rapidly switching magnetic field gradients, RF pulses and of the sensitivity of the modality to electromagnetic interference. Many groups worldwide have pioneered MR-actuation methods, including:

• The commonly used piezoelectric motors require electrically conductive materials and wiring which may cause heating, or interference (1-3)

• Fluidic actuators (pneumatic or hydraulic) require special control to deal with their non-linear dynamics and are of high cost and complexity (4,5)

Toward a quest for simple, scalable and low cost actuation, we developed a novel method of linear force transmission 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.

OVERVIEW

This novel method of force transmission makes use of many discrete solid elements to provide a flexible but non-compressible connection between the actuator and the end effector providing remote force transmission without fluid dynamics. This transmission method is referred to as Solid Media Flexible Transmission (SMFT).

METHODS

Solid Media Flexible Transmission (SMFT):

Leak-free operation:

- versatility in designing the manipulator
- force transmission at any site via slots on the hoses
- no need for pistons or brakes

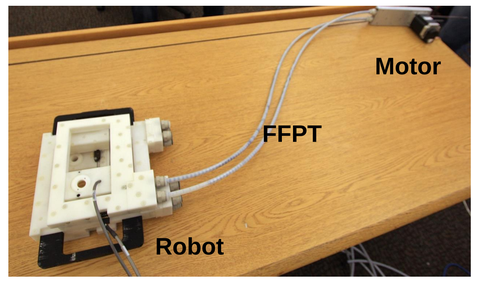
• Semi-flexible routing

• Non-magnetic and non-conductive materials

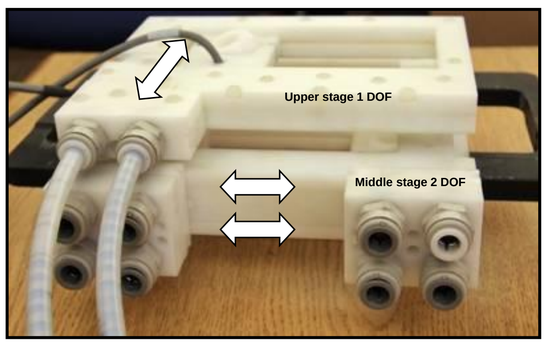
• Simple control and electronics

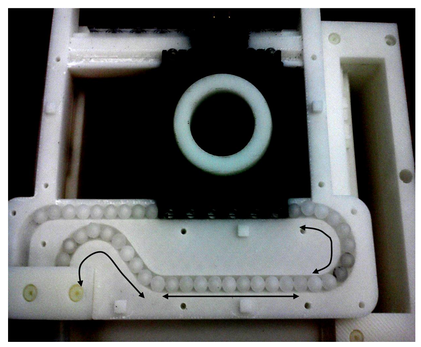
• Low cost

Photograph of the SMFT like showing the spheres interleaved with bushings. The diameter of the spheres is 6.35 mm

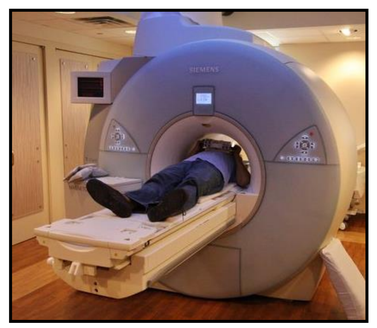


A bidirectional SMFT line linking the manipulator to a NEMA 23 motor with a filtered drive signal



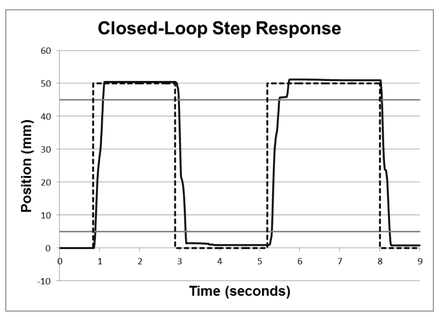


SMFT-actuated Manipulator composed of two 2D Cartesian stages providing a Mechanically simple and Scalable device. The leak-less transmission allows cutting channels inside the frame of the manipulator to deliver transmission.



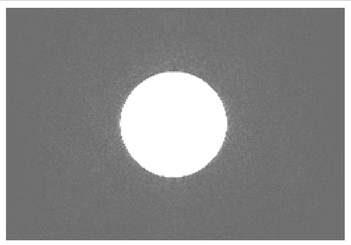
The system in place (left) showing it deployed with the SMFT line extended to keep the motors outside the 5 Gauss line and (left) held onto the abdomen of one of the co-authors.

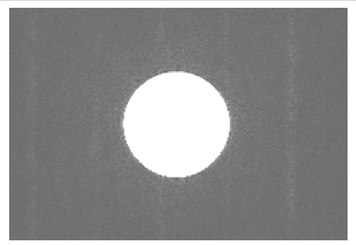
RESULTS



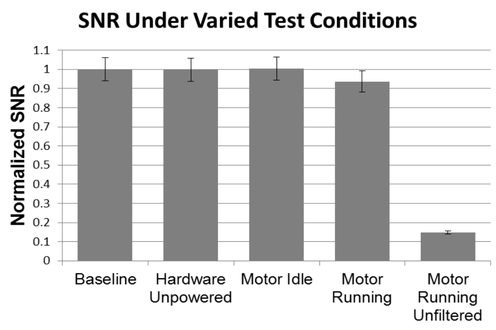
Closed-loop step response for 50 mm step. Dotted line is the commanded and solid line is the actual position. Horizontal lines indicate 10% and 90% of the commanded position. Four steps shown with alternating direction to include any effects of backlash.

With 7-mm nylon tubing, 6.35-mm HDPE spheres interleaved with 20-mm long bushings (6 mm OD), NEMA 23 motors and 4-m long SFT (straight or spooled with bend diameter ~33 cm), the accuracy was 1.9 ± 0.5 mm and bandwidth of 14 Hz. Closed loop PID position control tested using a 24 point dataset demonstrated an error of ± 2.0 and ± 1.9 mm for SMFT length of 1 and 3 meters, respectively. In another test, we measured the settling time for the PI controller to rest within ± 0.5 mm of the target position, that measured at 0.4 and 0.5 sec for 1 and 3 meter long SMFT lines.





Representative images when the manipulator is (left) idle and (right) actuated by an electromagnetic motor



SNR (average over 20 repetitions) at: baseline (system not in place), system in place but not powered, powered and motor idle, motor running filtered driver signal and unfiltered

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SMFT is a novel method for MR compatible actuation that uses hoses filled with discrete solid elements (spheres and bushings). Results demonstrate sufficient kinematic performance and MR compatibility. The leak- and piston-free SMFT offers high flexibility in developing scalable and compact manipulators.

ACKNOWLEDGMENTS

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