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„An fMRI-Compatible Manipulandum with Fluidic Actuation“

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An fMRI-Compatible Manipulandum with Fluidic Actuation

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I. INTRODUCTION

Robotic systems and devices compatible with Magnetic Resonance Imaging (MRI) technology find wide range of applications in academic and industrial fields. This results mainly from the fact that MRI is an established clinical diagnostic modality, and fMRI, its functional application, is an advanced research tool in neuroscience. An fMRI-compatible robot performs well controlled and reproducible sensorimotor tasks with the human subject, while the subject's corresponding brain activities are recorded by fMRI images. Therefore, an fMRI-compatible robot can be applied with fMRI to investigate sensorimotor functions of healthy subjects and neural recoveries of patients with neurological disorders like spinal cord injury (SCI) and stroke.

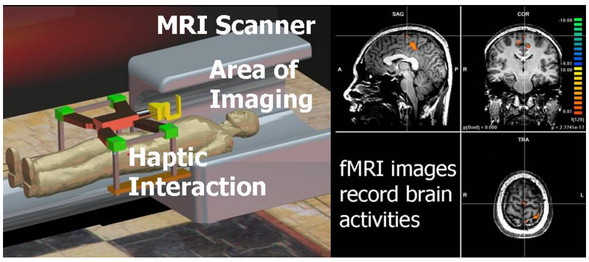


Fig. 1 fMRI compatible robot working with fMRI

II. TECHNICAL DESIGN

Construction and development of devices that are compatible with the MRI environment is rather challenging. It must be MRI safe, its use in the MRI environment must not affect the image quality, and it should be able to perform its intended functions in the MRI environment according to its specifications in a safe and effective manner. Besides, the device must be compact to fit into the small MRI scanner bore.

Traditional ferromagnetic materials and actuation techniques are not allowed to be placed into the MRI environment. Stiff polymer materials such as PET, PVC, are good alternatives. Some metals with low magnetic susceptibility and low electrical conductivity, such as bronze, brass, aluminum and copper, can be used for nonmoving parts. Electrical circuits introduce artifacts to fMRI images and should be avoided. Thus, optical measurement principle is preferred for sensors. Pneumatic and hydraulic actuations can be made fMRI compatible with long tube transmissions, as shown by the concept in Fig. 2.

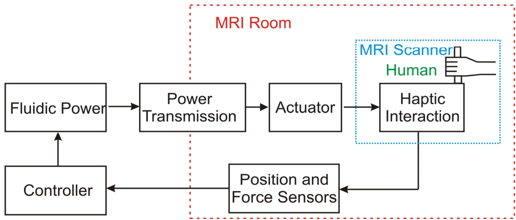


Fig. 2 Concept of the fMRI-compatible manipulandum

The desirable fMRI-compatible manipulandum has one translational degree of freedom, driven by a double acting cylinder. Force and position sensors are integrated for usage in different control schemes.

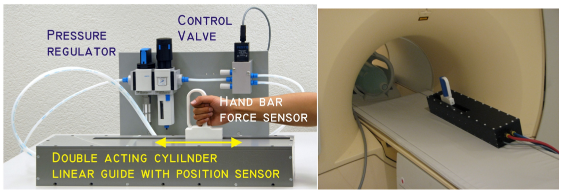


Fig. 3 fMRI-compatible manipulandum with pneumatic (left graph) and hydraulic (right graph) actuation

The realized manipulandum is shown in Fig. 3. In the left picture, compressed air after a pressure regulator is controlled by the directional valve to drive the handbar. The hydraulic system works in a similar manner with special oil for medical applications. While the pneumatic system is clean, light and fast, the hydraulic system has the advantages of no leakage, self-lubrication and smooth movement.

III: HAPTIC CONTROL

The movement range of the manipulandum is 20cm, which is sufficient to perform elbow/wrist extensions and flexions. The speed of motion is limited to 0.25m/s since fast arm movements induce image artifacts due to head movements. The device is planned to work in two modes: subject passive mode and subject active mode.

The subject passive mode can be realized by a standard position controller, which moves the hand of the human subject to track a desired trajectory. In the subject active mode, the manipulandum simulates a virtual spring so that the subject can push/pull against the device. This is achieved by an admittance controller with an underlying position controller (Fig. 4). The desired position is determined by the reference position xref, the measured human force Fact, and the virtual admittance Z:

xdes= xref+Fact/Z.

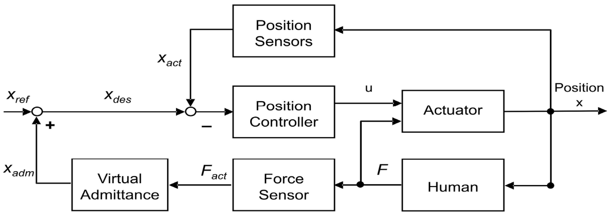


Fig. 4 Admittance control scheme

Two position control results are shown in Fig 5, with the continuous line being the desired position and the dashed line being the actual position of the handbar. The upper graph shows the step responses of the system with accuracy of better than 0.5cm and and delay of 0.8s. In the lower graph the manipulandum tracks a sinusoidal curve with frequency of about 1Hz and peak to peak amplitude of 12cm. The position error goes up to 1.5cm and time delay is 0.3s.

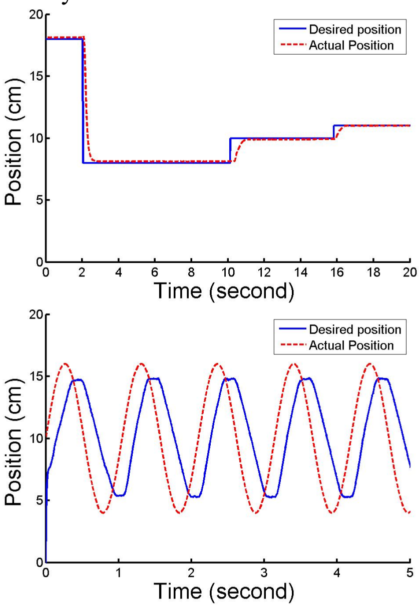


Fig. 5 Position control results for step responses (upper graph) and sinusoid curve tracking (lower graph)

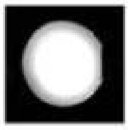
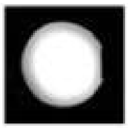
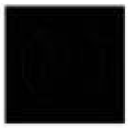
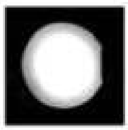
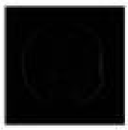
IV: MR-COMPATIBILITY TEST

We studied whether the quality of fMRI images was deteriorated when the device is set up and operated within the MRI environment. The imaging object is a mineral oil phantom placed in the isocenter of the scanner. An fMRI sequence, echo-planar-imaging (EPI) was used, and fMRI images of the phantom were taken for each of the following conditions:

a) No device
b) Silent device: the manipulandum was in the scanner bore, switched off and not moving
c) Moving device: the manipulandum was in the scanner bore, switched on and moving.

The results were evaluated by image subtraction and Signal-to-Noise Ratio (SNR), as in Tab.1. Image of step a) was subtracted from those of step b) and c), and the resulted images show no significant difference after the manipulandum was introduced into the MRI scanner and moved. High SNR values were obtained in all fMRI experiments and the differences were very small.

Tab. 1: fMRI test results of image subtraction and SNR comparison

Condition	Example Image	Example Subtraction	SNR (dB)
No Device		Referen ce .	54.6975 ±0.6359
Silent Device			54.6985 ±0.6503
Moving Device			54.4557 ±0.8735

V: CONCLUSION

A manipulandum with fluidic actuation has been built up to work inside the MRI scanner with fMRI procedures. Position control and admittance control have been realized to achieve active and passive subject movements. It was shown by fMRI experiments that the device is fMRI-compatible and yields no image artifact.

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