Interaction Control of a Linear MR-Compatible Series Elastic Actuator

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ROBOT-AIDED rehabilitation offers the ability to provide repeatable and effective therapy to patients with neurological impairments, such as a stroke or spinal cord injury. However, the details of the process by which movement training promotes brain plasticity and therefore functional improvements are not yet fully understood [1]. Through the advent of functional magnetic resonant imaging (fMRI), it is now possible to monitor brain activity before and after therapy. Assessing brain plasticity through fMRI before and after robotic therapy could potentially allow researchers to determine improved strategies for these therapies. A study using fMRI with passive robots has shown the potential to predict functional outcomes from imaging before training [2]. However, the use of a passive motion tracking system does not allow the required degree of repeatability of a movement protocol during fMRI, which is needed for a large scale study, nor does such a system allow for extension of movement protocols to more severely impaired subjects.

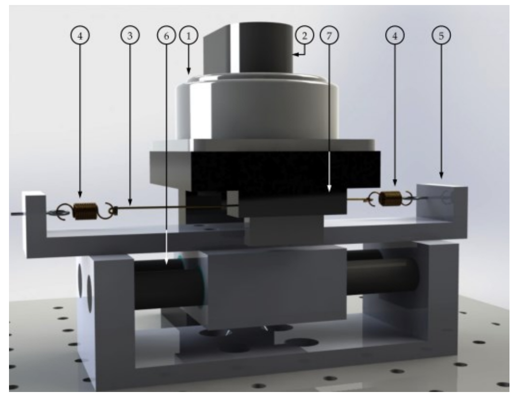

Fig. 1. CAD rendering of the 1DOF prototype. Motor (1) rotation is measured by a rotary encoder (2) and converted into linear motion through a cable transmission (3). The cable is spooled around the motor and attached at both ends to extension springs (4). Both spring ends are connected to a slider (5), supported by two custom linear bearings (6). Slider displacement is measured through an optical encoder (7) and allows estimation of interaction forces.

We are currently developing an MR-compatible equivalent of the RiceWrist, a rehabilitation exoskeleton for wrist and forearm robot-aided therapy [3]. The feasibility of a novel actuation architecture capable of implementing interaction control during continuous fMRI, a crucial capability for our system, is being investigated. The ultimate goal of this project is to be able to measure brain activity before and after therapy while using the MR-compatible version of the RiceWrist during imaging and the RiceWrist for therapy outside of imaging, allowing for a neurologically grounded, accurate and repeatable analysis of the dose-response relationship of robot-aided therapy.

To guarantee MR-compatibility, ultrasonic motors are employed. The inclusion of custom-designed compliant force sensing elements in series between the actuator and the load provides possibility of force-feedback control, thus allowing rendering of different desired haptic environments in the MR scanner. In a previous study, we examined in simulations the possibility of interaction control of a non-backdriveable ultrasonic motor in series with a compliant force sensing element [4]. In this paper, we present the design of a linear prototype that includes a piezoelectric ultrasonic MR-compatible actuator, and custom low friction linear bearings made from a Pyrex sleeve and graphite rods. Pre-loaded phosphor bronze extension springs, in conjunction with an optical encoder, provide the series elastic element capable of measuring interaction forces (Fig. 1). With this platform, the novel application of series elastic elements for interaction control of MR-compatible actuators can be experimentally explored. This is accomplished using a switching force-feedback control law to implement stiffness and zero-force interaction modalities. Exploring control modes on the 1DOF prototype allows determination of the experimental modes that can be used for motor protocols during continuous fMRI with the 3 DOFs robot.

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