Impedance Control and Remote Operation of Robotic Wrist Therapy Systems

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Abstract. In this paper, a concept for tele-rehabilitation between the patient and the physical therapist is presented and in order to provide haptic feedback between these two parties, an overview of an impedance controller for a two-part wrist rehabilitation is presented. For checking the output, the implemented control algorithm simulated an arbitrarily designed spring-damper system. in the practical part, the remote implementation of the impedance control algorithm to connect the two robots with a virtual spring and damper was also tested. To verify the haptic feedback, the position, velocity, and torque data from both robots were collected and analyzed and remote communication of the two-part robot is enabled by developing a control algorithm.

Keywords: Impedance control · Telemanipulation · Haptic Feedback

1 INTRODUCTION

Certain conditions such as hemiparesis and hemiplegia result in weakness or complete loss of strength in the upper extremities of the body. Physical therapy is required to treat these conditions to prevent muscle spasticity and joint stiffness [1]. However, this process is costly and repetitive, which has led to an increasing demand for remote physical therapy. A cost-effective alternative to physical therapy is the use of robotic systems that enable remote interaction between physical therapist and patient by providing haptic feedback. Telerehabilitation is defined as the delivery of rehabilitation services via information and communication technologies [2].

The iMEK Institute has proposed a wrist and forearm therapy system consisting of two identical robots. Each robot provides wrist abduction/adduction, flexion/extension, and pronation/suppination. In this paper, an impedance controller was designed and implemented to connect a virtual spring and damper between the two sides to create the sensation of haptic feedback.

2   Impedance Controller

The goal of impedance control is to control the system so that it behaves like a spring-damper system given the desired stiffness and damping constants [3],[4]. To create an impedance controller that connects the end effector to a reference via a spring and damper while reducing the effects of inertia and bearing friction, the control algorithm 1 described by [5] was used, where $\dot{\theta}_d$ and θ_d are the desired velocity and displacement profiles. B is the desired damping of the system and K is the desired stiffness of the system, K_f is a gain that the designer can set arbitrarily to reduce the influence of inertial and damping forces, T_a is the driving torque, T_e is the external torque, b is the rotational damping, and θ represents the angular displacement.

$$T_a = K(\theta_d - \theta) + B(\dot{\theta}_d - \dot{\theta}) + K_f[T_e + K(\theta_d - \theta) + B(\dot{\theta}_d - \dot{\theta})] \qquad (1)$$

3   Haptic Feedback

Once the system was modeled and the control algorithm for each side was determined, haptic feedback could be generated by setting the reference position and velocity of each side to its remote counterpart. In this way, both robots are connected with a virtual spring and damper, as shown in Fig. 1, where a linear model is shown for illustration. To communicate the position and velocity between the two sides, the Google Cloud Pub/Sub service was used.
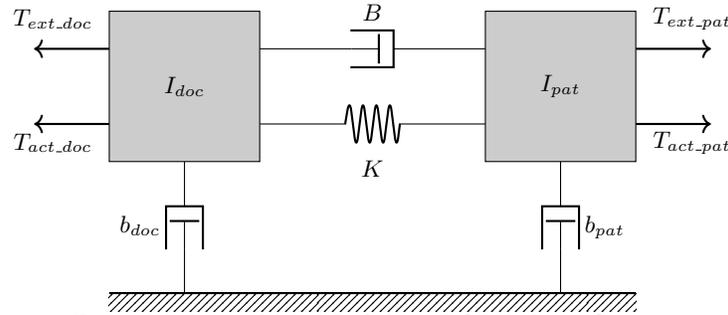

Fig. 1: Mechanical Model of the 2 DOF Robotic System

4   Experiments and conclusion

In order to verify whether the haptic feedback was achieved, some experiments were conducted. The first experiment consisted of moving the patient's end effector and observing whether the physician's end effector followed the movement. The experiments were performed with a stiffness of $0.5\mathrm{N\,m^{-1}}$ and a damping constant of $0.1\mathrm{N\,s\,m^{-1}}$. The right figure in Fig. 2 shows that the physician's end effector successfully tracked the patient's position. The average value of the

position error and delay were calculated to be 0.055 radians and 0.24 seconds which are small and hardly noticed.

The second experiment tested whether haptic feedback was achieved by analyzing the torque sent to the motors on each side based on the position difference between the two robots. The left figure in Fig. 2 shows the positions of the robots and their following situations. The right figure in Fig. 2 shows that when the two robots are in different positions, the torque commanded to the motors has similar magnitudes but different directions. This is explained by the effect of the virtual spring that was modeled, and it creates the haptic force and a sense of haptic feedback as both robots exert torques so that the positions are again aligned. Future work includes determining the optimal spring-damper parameters for better haptic feedback and increasing the stiffness of the system.
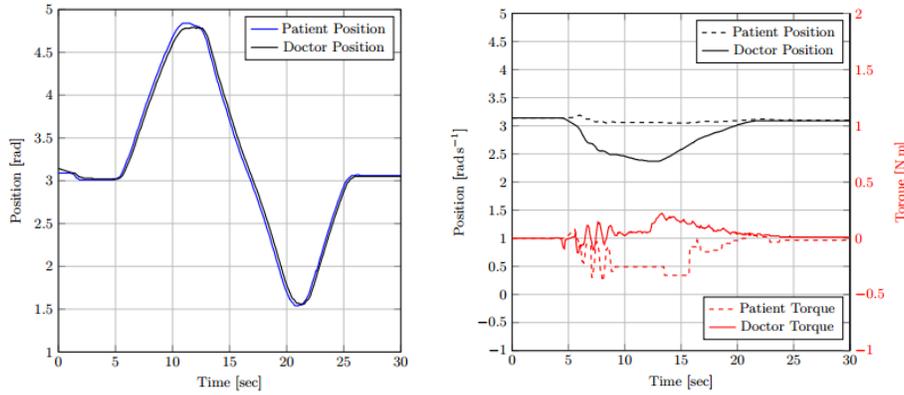

Fig. 2: Left: Position Plot of the Connected Robots (Patient Leading) Right: Motor Torque Versus Position

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