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Adaptive Force-field Control of a 2-DOF Upper-extremity Rehabilitation Robot

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Introduction

For the last twenty years, rehabilitation robots have been in development to augment conventional therapy methods. Robot-assisted therapy can provide stroke survivors with repetitive tasks while delivering measured therapy that is able to objectively evaluate patients' progress [1]. An important control design criterion for rehabilitation robots is finding the best motion to maximize the effectiveness of rehabilitation [2].

Objective

In the current study, an adaptive force-field control algorithm has been proposed for a 2-DOF manipulandum upper-extremity rehabilitation robot. The objective of the control algorithm is to find the best adaptive force field for a given patient, considering their performance over time. This research uses simulation studies to test the proposed algorithm for two different modes of rehabilitation: resistive and assistive.

Methodology

Stroke patients can be described in terms of two categories of kinematic behavior during a reaching task [3]:

(1) Category 1: Patients who have the power to move their hands, but the coordination of the muscles is weak, which represents itself in high lateral error in point to point reaching tasks.
(2) Category 2: Patients who have good muscle coordination, but the muscle force is not enough to perform the task in a given time.

Two force fields are explored to provide complementary rehabilitation for these behaviors:

(a) **Lateral force field** will add an attractive or repulsive force perpendicular to the desired trajectory. In the case of assistive or resistive mode, respectively, a lateral force will actively guide or challenge the patient along the desired movement trajectory. The patients in Category 1 will likely benefit most from a lateral force field.
(b) **Radial force field** will add an attractive or repulsive force directed toward the goal point. In the assistive mode, a force will guide the patient towards the goal. In resistive mode, this field will make the reaching task more challenging. A radial field will likely help the patients categorized in Category 2 more.

As the first step in validation, to test the proposed method, a stroke rehabilitation patient was modeled using the human motor adaptation scheme proposed in [4]. The model was tailored by adding a biased step disturbance signal to the original motor command model and modifying the maximum value of the hand force to replicate the motor control impairment in post-stock patients. The dynamic model of the robot was derived via the Virtual Work principle since this was considered to be more efficient compared to conventional methods, such as Newton-Euler, as the internal forces can be eliminated at the outset, which avoids the use of explicit constraint equations [5].

Results

It was observed that, for both lateral and radial fields, the simulated subject had the best performance when using assistive force-fields, but after removing the force fields, the same subject had worse performance compared to resistive mode. On the other hand, the simulated patient has the worst performance when using resistive force-fields while having good improvement after removal of force-fields. This phenomenon has been reported in the literature, which indicates that the resistive mode of training is more likely to be effective for motor function recovery of stroke patients than assistive or passive ones [6].

Conclusion and Future Work

In this research, a force-field algorithm was developed to address different types of stroke patients' kinematic behavior during a reaching task. The simulation results indicated that the resistive mode of therapy results in the best rehabilitation outcomes. Based on patients' performance, the intensity of two force-fields can be adjusted concurrently and independently in the proposed algorithm which, to the best knowledge of the authors, is a novel contribution. As future work, we will investigate the effectiveness of the proposed algorithm in both resistive and assistive modes by implementing it on the robot and testing it on real post-stroke subjects.

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