Muscle coordination in stroke patients' upper limbs

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INTRODUCTION

Robot-aided rehabilitation is getting popular in the rehabilitation of the strokes. Compared with conventional therapies, a major benefit of rehabilitation robot is that it is able to offer stroke patients repetitive rehabilitation exercise with high intensity and steady quality. Furthermore, sensors deployed on the robot provide abundant information on patient's motor functions. Physiological data such as EMG and biomechanical signals such as joint torque and ROM can be utilized for motor function assessments on stroke patients.

With a laboratory-made rehabilitation robot [1], motion data of patient's upper limb was recorded throughout the treatment [2]. In this work, analyses of load sharing by model simulation were utilized to characterize variation in muscle coordination and improvement of patient's motor function. Model validation was prerequisite for further studies and was the primary topic in this abstract to ensure that the model does reflect faithfully the interaction between patients and the robot to an extent.

METHODS

All the recruited patients were asked to perform horizontal circular tracking motion at shoulder level with visual cues and under resistance applied by the rehabilitation robot. The patients were requested to perform the tracking motion as accurate as possible. A 6-axis load cell and electro-goniometer were fixed to the end-effector of the robot and the patient respectively to measure the force and motion data.

To estimate the muscle force/neural excitation in patient's upper limb during treatment, a neuromuscular model of human upper limb [3] were modified by adding five muscles [4,5]. The kinematic structure of the shoulder was also modified to fit the treatment movement. An optimization was employed to solve the force distribution problem and the neural excitation distribution which could be utilized to characterize the coordination in affected muscles. In the present study, a widely accepted objective function as following [6] was employed for solving the load sharing problem:

$$J = \sum_{j=1}^{9} \left(\frac{F_j}{PCSA_j} \right)^2$$

where F_j is muscle force of the j^{th} muscle. When solve the inverse dynamics problem, only the steady state muscle forces were considered to generate the required muscle activations. When the muscle activations were known, neural excitations could be obtained from the following equation:

$$\dot{A}_j = C_j \left(u_j - A_j \right)$$

where u_j was neural excitation, A_j was muscle activation and C_j was a time constant of the j^{th} muscle.

RESULTS AND DISCUSSION

A simplified human upper limb (Figure 1) was utilized to validate correctness of the optimization procedure. It was assumed that the limb was performing horizontal circular motion with a constant angular velocity ($\omega = 2\pi/5$ (rad/sec)) at shoulder level. For simplicity, only parts of deltoid and pectoralis major muscles were used to generate the required torque at shoulder joint to validate the optimization procedure. In the first 2.3 sec, muscle DS was activated to horizontally extend the shoulder joint and DC and PM were silent. Conversely, during 2.3~4.3 sec, DC and PM were co-activated to horizontally flex the shoulder joint and DS was silent. The resultant torque of these three muscles was equal to the estimated torque. Due to physiological differences, the torque contribution between DC and PM were different. Results of validation showed that the optimization procedure could determine the load sharing condition under the given objective function, the antagonist remained silent while the agonists were both activated.

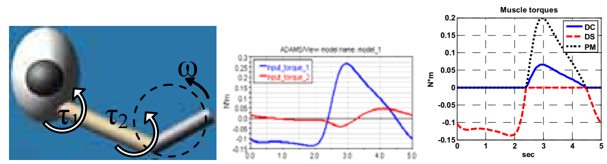

Figure 1: A simplified human upper limb for validation of optimization procedure for the load sharing problem. On the middle, estimated joint torques are depicted. On the right, the torques applied at shoulder joint by DC, DS and PM are depicted.

CONCLUSIONS

The biomechanical model of human upper limb coupled with the optimization procedure was suitable for analyzing load sharing of stroke patient's upper limb. By modeling interaction among muscles, it provided a feasible way for further investigation on various possibilities of a patient's muscle coordination before and after the robot-aided treatment.

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