An Evaluation of Hemiplegic Upper Extremity Coordination by A Robotic Support System to Reconstruct The Reaching Movement Using Functional Electrical Stimulation

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Abstract

We evaluated hemiplegic upper extremity coordination by using robotic support system for reconstruction of the reaching movements using Functional Electrical Stimulation (FES). Six normal subjects and 3 cases of hemiplegic patients from cerebral stroke participated in this study. We measured reaching movement of the two groups by using the robot system and we compared the difference of the specified travel time and the actual travel time of the normal subject group with the hemiplegic group, and secondly we compared the value of six-axis Force/Torque sensor of one group with the other group to evaluate how much they applied force following the orbit of robot. The results indicated that the difference between both groups is shown in the allocation method of force to inside and outside. It was observed that the normal group exerted much more force outward against the body when pushing, and much more force inward against the body when pulling, on the other hand, the hemiplegic group exerted much more force inward against the body when pushing and pulling. The evaluation of the robotic support system for the upper limb coordination pointed out that it is necessary to consider the stability in horizontal direction for reconstruction of reaching movement using FES.

1 Introduction

We have been developing a robotic support system for upper limb exercises that automates a part of medical therapy and training. This system consists of a robot, a display, a magnetic position sensor, and helps repetitive exercises focusing on the upper limb as well as enables to analyze its 3 dimensional movements. Meanwhile, there are few reports on analysis of reaching movement with the data from force sensor attached to robotic systems. In this paper, we would like to report an evaluation of coordination for hemiplegic upper extremity by using the data from force sensor of our robotic system to reconstruct the reaching movements using Functional Electrical Stimulation (FES).

2 Methods

2.1 Structure and Control of the Robot

The robot body consists of PA-10, a 7-Axis Robot Arm made by Mitsubishi Heavy Industries Ltd. (Figure 1). It is an all-purpose arm with 7 joints and a weight of 35 kg. Each joint has AC servomotors, electromagnetic brakes and angle detectors. The terminal device can be moved to arbitrary positions with high precision. We have installed an NITTA-made, 6-axis force/torque sensor at the terminal device of the robot. It controls mechanical resistances such as inertia, rigidity, and viscosity according to the force to the sensor applied by patients; thereby the robot can assist the patient’s movement and conversely add resistance to the movement. We mounted a handle to evaluate coordination of upper extremity movement.

2.2 Subjects

The study included 6 normal subjects and 3 cases of hemiplegic patients from cerebral stroke. The group of normal subjects included 4 women and 2 men having no problem related to motor function, and their average age was 32 years old. The hemiplegic group included 1 woman and 2 men whose ages ranged from 63 to 75 years old. Among them, 2 cases had a mild right hemiple-
gia with Brunntstrom stage 5 and the other 1 case had a moderate left hemiplegia with stage 4.

2.3 Measurement

Each participant was asked to perform the reaching movement with dominant arm in the normal subject group and paralyzed upper extremity in the hemiplegic group for examination by using the robot. In such movement, each person sat in a chair with his/her trunk upright, with the elbow joint at 90 degree and forearm in a pronated position, then pushed the handle of the robot 60cm parallel to the floor and returned it (Figure 2). Normally the robot moves passively, but in this case, we set its handle to move only on a line where the robot goes precisely 60cm forward from the starting position and returns to the initial position. If the subject applies force following the pre-set track, the robot moves without resistance, but as more force is applied off the set track, the stronger the resistance becomes. It facilitated the subject to understand the direction of force to move the robot more smoothly. We specified the duration of one shuttle for this reaching movement at 4 seconds and recorded data of 5 shuttles. The sampling frequency of the measurement was 50Hz. In the 4th movement of all of the reaching movements, firstly we compared the difference of the specified travel time and the actual travel time of the normal subject group with the hemiplegic group, and secondly we compared the value of six-axis Force/Torque sensor of one group with the other group to evaluate how much they applied force following the orbit of robot.

3 Results

The average absolute value of the difference between the specified travel time and the actual travel time was 0.07 seconds in the normal group and 0.1 second in the hemiplegic group. Figure 3 and 4 shows the change of the movement distance and the value of six-axis Force/Torque sensor. Figure 3 shows a typical example of the normal group and Figure 4 shows a typical example of the hemiplegic group. In the initial stage of pushing movement in both groups, a pushing force forward and downward is strongly applied to operate the robot. As the handle of robot approaches the farthest point, such force becomes weaker. In the return movement, contrary to the pushing movement, a pulling and upward force is strongly applied to operate the robot. The difference between both groups is shown in the allocation method of force to inside and outside. It was observed that the normal group exerted much more force outward against the body when pushing, and much more...
force inward against the body when pulling, on the other hand, the hemiplegic group exerted much more force inward against the body when pushing and pulling.

4 Discussion

Characteristics of robotic support for exercises include availability of accurate control and quantification of the exercise strength and availability of an objective evaluation of changes in muscle strength and kinematics. In this experiment, the difference was observed in a simple reaching movement between the mild hemiplegic group and the normal group.

Eder et al. developed a device to examine cooperativeness based on errors to sample by having subjects trace the straight line on tablet with a mouse, and showed the correlativity of the average deviation of vertical error and horizontal deflection to the target with Ashworth Scale [1]. Since we limited the orbit in the experiment to 60cm, no errors to the target occurred, but the difference was shown in the result of horizontal direction between the normal group and the hemiplegic group, and disturbance of cooperativeness in hemiplegic upper limb was observed in the level surface the same as Eder et al. Therefore, we need to examine a method focusing on horizontal stability to rebuild the reaching movement of hemiplegic upper limb using FES.

The main limitation of this study is that no unrestricted reaching movements have been analyzed in the patients. There is no direct evidence that the results of the study can be used on severely affected patients (Brunnstrom stage 3 or lower).

5 Conclusion

The evaluation of the robotic support system for the upper limb coordination pointed out that the reaching movement of the hemiplegic group had a problem in cooperativeness of horizontal direction. It is necessary to consider the stability in horizontal direction for reconstruction of reaching movement using FES.

6 Literature