Myoelectrically Controlled Robotic System That Provide Voluntary Mechanical Help for Persons after Stroke

R. Song, K. Y. Tong, X. L. Hu, X.J. Zheng

***Abstract* –This study described the operation of the myoelectrically controlled robotic system designed to assist wrist movement in a horizontal plane for patients after stroke. Electromyographic (EMG) signals from flexor carpi radialis (FCR), extensor carpi radialis (ECR) detecting subject's intention are used to control the mechanical assistance from the robotic system either to assist wrist flexion and wrist extension. This study had recruited five subjects after stroke. The results revealed that the range of motion (ROM) in the five subjects increased with the assistance of the myoelectrically controlled robotic system. The amplitude of agonist EMG signal decreased with the increase of assistance, which might reflect less effort was needed for the subject to perform the movement. This study demonstrates that it is feasible to apply myoelectrically controlled robotic system to provide substantial external torque to the affected wrist joint for subjects after stroke. Its therapeutic effect will be further investigated during stroke rehabilitation.**

I. Introduction

STROKE is a primary cause of serious disabilities in Hong Kong. Approximately 25,000 strokes occur each year, causing 3,000 deaths and significant disability for many survivors [1]. Patients after stroke have often been reported to have a lower quality of life (QOL) than normal subjects of similar age due to the disabilities. Conventionally, motor relearning training can be conducted in clinical setting in a one-to-one mode by therapists to help such patients with disabilities to regain physical functioning. Although conventional therapies have positive effect to restore the motion function, they are cost expensive, labour intensive for therapists and inconvenient for out-patients. Many new rehabilitation approaches and devices are developed as useful complementary units for stroke rehabilitation. In recent years, robotic systems have been developed to help subjects after stroke to restore the upper limb [2]-[4] and lower limb [5] [6] function for their well-controlled, repetitive, quantitative and adaptive characteristics. Myoelectrical control is a useful way to relate the subject's intention to the control variable since EMG signals could reflect the activities of the muscles. Many researchers have designed some exoskeleton systems, and used EMG signals as control source to assist the corresponding joint movements [7][8]. The use of myoelectrically-controlled robot-aided therapy for subjects after stroke has so far been reported in an EMG triggered 'on-off' control [9] and proportional EMG control [10]. A sensorimotor integration theory has been applied to explain that the voluntary efferent output as well as the afferent sensor input was helpful to promote the reorganization of the brain [15]. Subject can only control the initial-action time of external robotic system in the EMG triggered 'on-off' control, after this, the robotic system will run in a predefined mode, which has no direct relation with the EMG signal until next trigger. In proportional EMG control, not only the initial-action time, but also the intensity of the mechanical help from the robotic system can be controlled by the EMG signal after the system is triggered. It is hypothesized that the additional efferent output through the myoelectrical control might be beneficial in restoring motor function for patients after stroke.

Since neuromuscular dysfunctions had often been reported at the affected wrist of patients after stroke [11], this study investigated the feasibility of using EMG signals from selective partially paralyzed muscles of wrist joint to continuously and proportionally control the assistive torque during tracking movement. A myoelectrically controlled robotic system was developed for subjects after stroke and proportional myoelectrical control was applied to improve the ability of joint torque output during wrist movement in the horizontal plane. This study focused on the assistive function of the myoelectrically controlled robotic system for preparation of applying it as a therapeutically device in the stroke rehabilitation.

Fig. 1 Diagram of the robotic system

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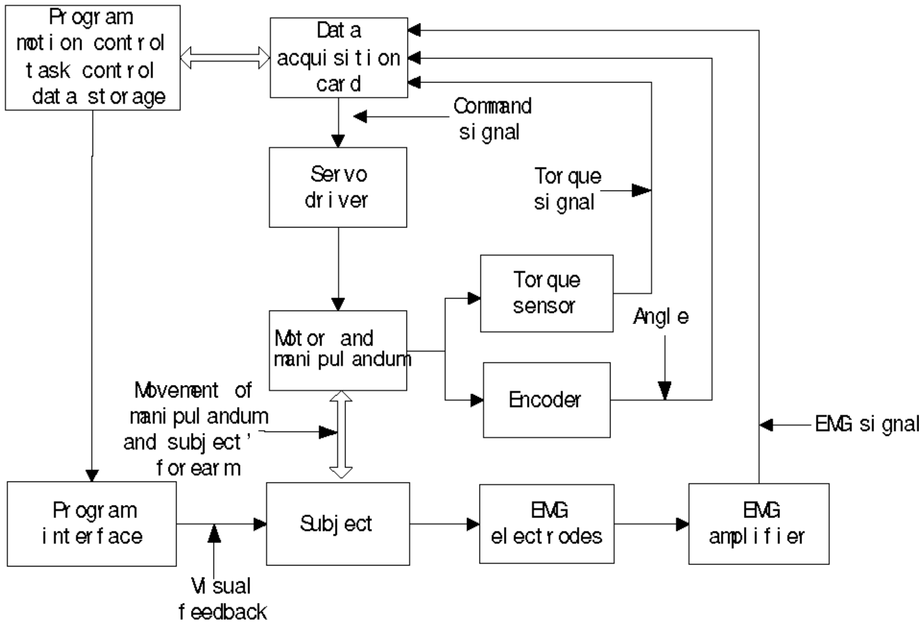

Fig. 2. Architecture of the myoelectrically controlled robotic system

II. Methodology

A. System

The mechanical part of a robotic manipulator with one-degree of freedom (DOF) was designed and fabricated for assisting the movement of wrist flexion and extension on a horizontal plane, which was shown in Fig. 1. The inputs to the system were the EMG signals, the torque signal and the angle signal, which were captured through the data acquisition (DAQ) card (PCI 6036E, National instrument, USA) These signals were inputted to the computer, and then the control signals would be generated and outputted to the servo driver to control the servo motor through the 16-bit analog output of the DAQ card based on the control strategy. The software also had an interface to provided task for subject to follow. Fig. 3 showed the software interface. The software programs were developed in Labview 6 and were run on a PC-based platform to control the robotic system with a CPU of Pentium IV. During real-time control of the system the data were stored into the hard disk for further analysis. The control flow of the system was shown in Fig. 2.

The servo motor could work in the following two different control modes:

1. In position control mode, motor positioning control was performed according to the command position sent from the higher-level motion controller. A proportional-integral-differential (PID) control algorithm was applied to make the output position equal to the target position based on the feedback of the digital encoder.
2. In torque control mode, the current which flowed through the motor was controlled by the input command analog voltage (-8.5 v to +8.5 v). There was no torque when the command voltage equaled zero and the maximum torque was produced when the command voltage equaled ± 8.5 v. The torque generated by the motor was almost linear with input analog voltage.

B. EMG Processing

Before sampling, the EMG signals were amplified with a gain of 1000 and were band-pass filtered in 10-400 Hz. The processed EMG signals were all sampled at 1000 Hz, and full-wave rectified and calculated with a moving window (100 ms).The processed EMG signals w_j were then normalized to the range 0-1 for $NEMG_j$ as follows[8][9]:

$$NEMG_j = \frac{w_j - w_r}{w_{mvc} - w_r} \qquad (1)$$

where w_r was the amplitude of processed EMG signal at rest, and w_{mvc} was the maximal amplitude of the processed EMG signal during maximum voluntary contraction (MVC). The assistive torque T_{assist} was estimated based on the normalized EMG signals:

$$T_{assist} = G * T_{mvc} * NEMG_j \qquad (2)$$

where G was the gain parameter between EMG and assistive torque, and T_{mvc} was the measured torque during the MVC.

C. Experimental protocol

During the experiment, the subjects were asked to sit beside the system. A strap was used to hold the affected forearm to a supporter in the horizontal plane and the shoulder was in 90 deg abduction. The affected hand was fixed by a customized aluminum orthosis (shown in Fig. 1). A screen was placed in front of the subject to provide guidance, and all the subjects were instructed to complete the following tasks:

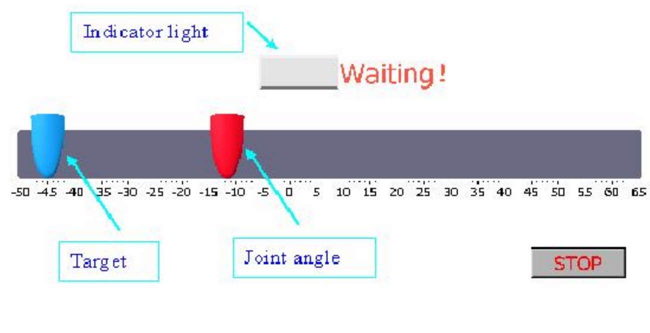

Fig. 3 The software interface for the robotic system

The maximum isometric voluntary extension (MIVE) and flexion (MIVF) torques were measured for the affected wrist flexor and extensor when the wrist was positioned at neutral position in the horizontal plane. The EMG signals during MIVE and MIVF were captured to normalize the EMG signals of the FCR and ECR. The system was in the position control mode as a dynamometer.

After the torque measurements, the system was changed to torque control mode. The subjects were asked to perform a repetitive arm tracking test which began with the wrist at 45 deg extension. In each trial, after a 3-sec delay from the beginning of the program for the subject to be ready, the indicator light in the middle of the screen turned green to instruct the subject to start following the target. First, the target would move from 45 deg extension to 60 deg flexion at a constant speed of 10 deg/s, and the 0 deg was defined as the neutral position in this study. Since most of affected wrist could be passively moved to 45 deg extension and 60 deg flexion [11] and 10 deg/s was a reasonable speed for most of the subjects after stroke to follow. The subject then controlled its affected together wrist with the myoelectrically controlled system to follow the target; then the target pointer would pause at 60 deg flexion for 3 seconds; then the target pointer would come back from 60 deg flexion to 45 deg extension at a constant speed of 10 deg/s to complete one cycle, and the subject extended his/her affected wrist with the myoelectrically controlled system to follow it again. In each trial, the subject was asked to finish five cycles' movement. The LCD monitor in front of the subjects displayed both the target angle and the actual joint angle with the two pointers shown in Fig 3. The subjects could correct the joint angle to match the target pointer with this real-time visual feedback. If the subject could not flex or extend his wrist joint to follow the target pointer, he would be suggested to stop at the largest position and wait for the target pointer to come back so that he could follow it again. During the wrist extension and flexion, the robotic system would generate assistive torques to assist the movement, which were proportional to the amplitude of the processed EMG signals of ECR and FCR, respectively. Subject was tested with each of the EMG-torque gain (0, 50% and 100%) twice. There was no assistive torque from the robotic system when the gain equaled to 0.

III. Results

This study was reviewed and approved by the Human Subjects Ethics Subcommittee of the Hong Kong Polytechnic University. Five subjects after chronic stroke were recruited for this test. Before the experiment, all the subjects were made to understand the experimental procedures and duration, and they signed the consent forms. Fig. 4 shows typical trajectories of a subject together with processed EMG signals of FCR and ECR at different EMG-torque gains during wrist tracking experiment. The comparison of trajectories revealed that the subject could extend his/her affected wrist joint to a larger ROM with the assistance of the robotic system. Table 1 showed the comparison of the ROM at different EMG-torque gain, which reflected the consistent trend. Fig. 4 also represented that agonist EMG signal is decreased with the increased of EMG-torque gain during wrist flexion and extension, which was more obvious in the FCR signal during wrist flexion. The amplitude of agonist EMG signal when without assistance (Gain=0) seemed also larger than those with assistance (Gain=50% and 100%), while there is no obvious difference between 50% and 100% of the EMG-torque gain in the antagonist EMG signal.

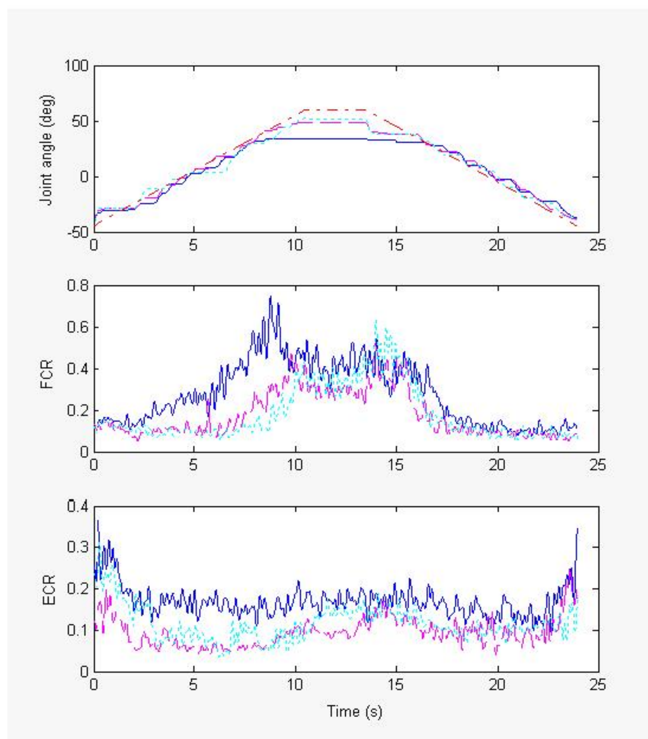

Fig. 4 The wrist trajectory and the NEMG signals of FCR and ECR of a representative subject during the voluntary tracking at a velocity of 10 deg/s (dash-dot line: target trajectory; solid lines: gain=0; dashed line: gain=50%; dotted line: gain=100%)

Table 1 Comparison of the ROM at different EMG-torque gain

	ROM (deg)		
	0	50%	100%
Subject A	41.29	70.91	75.97
Subject B	77.85	92.21	96.68
Subject C	56.99	61.22	80.95
Subject D	27.49	73.19	97.17
Subject E	85.39	97.40	96.52
mean	57.80	78.99	89.46
s.d.	24.26	15.23	10.20

IV. DISSCUSSION & CONCLUSION

Some studies had suggested that the training at shortened muscle length was more effective in developing muscle strength at such muscle length [12] [13]. However, subjects after stroke often had difficulties in arriving at such position with their own efforts due to contracture, muscle cocontraction or muscle weakness. This study demonstrated that it is feasible to apply a myoelectrically controlled robotic system providing external torque to the affected wrist joint for subject after stroke. The primary feature of this system was that the subject's effort could be detected from his/her EMG signal and was directly linked to the assistance from the robotic system. Subject could voluntarily control both their own affected wrist joint and the robotic system. The assistive function of the myoelectrically controlled robotic system could enable subjects after stroke to perform movement within a larger ROM (shown in Fig.4 and Table 1). The results implied that subject after stroke could also take use of the advantage and perform voluntary wrist rehabilitation training within this larger ROM with the assistance of the myoelectrically controlled robotic system, which might be beneficial to restore the motor function especially at shortened muscle length mentioned in Ada et al's studies [12] [13]. On the other aspect, only the EMG signal from the agonist was considered in this movement, since excessive antagonist muscle activation was found in subject after stroke during movement [14], and our system did not want to amplify the involuntary effect of antagonist. The innovative assistive function of the system might enable the robotic system to be applied as a rehabilitation robot for subject after stroke. Its therapeutic effect will be further confirmed in the following robot-assisted stroke rehabilitation using myoelectrical control.

REFERENCES

[1] Hong Kong Hospital Authority Statistical Report 1994-2002. (2004). Available: http://www.ha.org.hk

[2] R. Colombo, F. Pisano, S. Micera, A. Mazzone, C. Delconte, M. C. Carrozza, P. Dario, and G. Minuco, "Robotic Techniques for Upper Limb Evaluation and Rehabilitation of Stroke Patients," IEEE Trans. Neural Sys. Rehab. Eng., vol. 13, no. 3, pp. 311- 324, 2005.

[3] H. I. Krebs, N. Hogan, M. L. Aisen, and B. T. Volpe, "Robot-aided neurorehabilitation," IEEE Trans. Rehabil. Eng., vol. 6, no. 1, pp. 75-87, 1998.

[4] D. J. Reinkensmeyer, L. E. Kahn, M. Averbuch, A. N. McKenna-Cole, B. D. Schmit, and W. Z. Rymer, "Understanding and treating arm movement impairment after chronic brain injury: Progress with the ARM Guide," J. Rehabil. Res. Dev., vol. 37, no. 6, pp. 653-662, 2000.

[5] K. Y. Tong, M. F. W. Ng, and L. S. W. Li, "The Effectiveness of Gait Training of Body Weight-supported Cyclic Walking Exercise and Functional Electrical Stimulation in Patients with Subacute Stroke," *Archives of Physical Medicine and Rehabilitation.*, vol. 87, pp. 1298-1304, 2006.

[6] K. Y. Tong, M. F. W. Ng, L. S. W. Li, and E. F. M. So, "Gait Training of Patients After Stroke Using an Electromechanical Gait Trainer Combined With Simultaneous Functional Electrical Stimulation," *Physical Therapy,* vol. 86, pp. 1282-1294, 2006.

[7] J. Rosen, M. Brand, M. B. Fuchs, and M. Arcan, "A myosignal-based powered exoskeleton system," IEEE Tran. Sys. Man. Cy. B, vol. 31, no. 3, pp. 210-222, 2001.

[8] H. S. Cheng, M. S. Ju, C. C. K. Lin. Improving elbow torque output of Stroke patients with assistive torque controlled by EMG signals. J Biomech Eng; 125: 881-886, 2003.

[9] L. Dipietro, M. Ferraro, J. J. Palazzolo, H. I. Krebs, B. T. Volpe, and N. Hogan, "Customized interactive robotic treatment for stroke: EMG-triggered therapy," IEEE Trans. Neural. Syst. Rehabil. Eng., vol. 13, no. 3, pp. 325-34, 2005.

[10] R. Song, K. Y. Tong, X. L. Hu, S. F. Tsang, and L. Li, "The Therapeutic Effects of Myoelectrically Controlled Robotic System for Persons after Stroke-A Pilot Study," presented at The 28th IEEE EMBS Annual International Conference, New York, U.S.A., 2006.

[11] X. L. Hu, K. Y. Tong, S. F. Tsang, R. Song," Joint-Angle-Dependent Neuromuscular Dysfunctions at the Wrist in Persons after Stroke," *Archives of Physical Medicine and Rehabilitation.,* vol. 87, pp. 671-679, 2006

[12] L. Ada, C. G. Canning, and T. Dwyer, "Effect of muscle length on strength and dexterity after stroke," Clin. Rehabil., vol. 14, no. 1, pp. 55-61, 2000.

[13] L. Ada, C. G. Canning, and S. L. Low, "Stroke patients have selective muscle weakness in shortened range," Brain, vol. 126 no. 3, pp. 724-31, 2003.

[14] C. G. Canning, L. Ada, N. J. O'Dwyer, "Abnormal muscle activation characteristics associated with loss of dexterity after stroke," J. Neurol. Sci., vol. 176, no. 1, pp. 45-56, 2000.

[15] J. Cauraugh, K. Light, S. Kim, M. Thigpen, and A. Behrman, "Chronic motor dysfunction after stroke: recovering wrist and finger extension by electromyography-triggered neuromuscular stimulation," Stroke, vol. 31, no.6, pp.1360-1364, 2000.