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An EMG-driven Exoskeleton Hand Robotic Training Device on Chronic Stroke Subjects

Task Training System for Stroke Rehabilitation

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***Abstract*—An exoskeleton hand robotic training device is specially designed for persons after stroke to provide training on their impaired hand by using an exoskeleton robotic hand which is actively driven by their own muscle signals. It detects the stroke person's intention using his/her surface electromyography (EMG) signals from the hemiplegic side and assists in hand opening or hand closing functional tasks. The robotic system is made up of an embedded controller and a robotic hand module which can be adjusted to fit for different finger length. Eight chronic stroke subjects had been recruited to evaluate the effects of this device. The preliminary results showed significant improvement in hand functions (ARAT) and upper limb functions (FMA) after 20 sessions of robot-assisted hand functions task training. With the use of this light and portable robotic device, stroke patients can now practice more easily for the opening and closing of their hands at their own will, and handle functional daily living tasks at ease. A video is included together with this paper to give a demonstration of the hand robotic system on chronic stroke subjects and it will be presented in the conference.**

Keywords- exoskeleton; rehabilitation; robot; hand; stroke;

I. INTRODUCTION

Stroke is one of the diseases which leads to high disability and death according to the World Health Organization [1]. Often the stroke subjects' motor functions and mobility are greatly affected [2, 3]. Approximate 70 to 80 percent of the stroke survivors require long term medical care [4, 5] and live with a poor quality of life (QOL) [6, 7].

Some of the stroke survivors who completed a rehabilitation program for the upper extremities were able to recover some of the proximal motor functions at the shoulder and elbow joints but limited recovery for the hand and wrist joints [8, 9]. Hand functions such as hand opening and closing are useful for many daily tasks but it has been a challenge to develop an effective training device for the hand functions rehabilitation.

Robots have proved to be effective in assisting the therapist to provide safe and intensive rehabilitation training for the stroke subjects [10, 11]. Rehabilitation robot for elbow and wrist has already been proven effective in clinical trials [11-15]. Only few robotic devices for the hand rehabilitation are found in the market [16-20]. Therefore we have started this project to develop an interactive rehabilitation robot for hand functions task training to meet the needs of the stroke rehabilitation.

II. EXOSKELETON HAND ROBOTIC TRAINING DEVICE

We have specially designed an exoskeleton hand robotic training device for person after stroke to actively train their impaired hand functions. By measuring his/her surface electromyography (EMG) signals from the impaired hand muscles, this robotic device detects the stroke person's intention and assists in hand opening or hand closing.

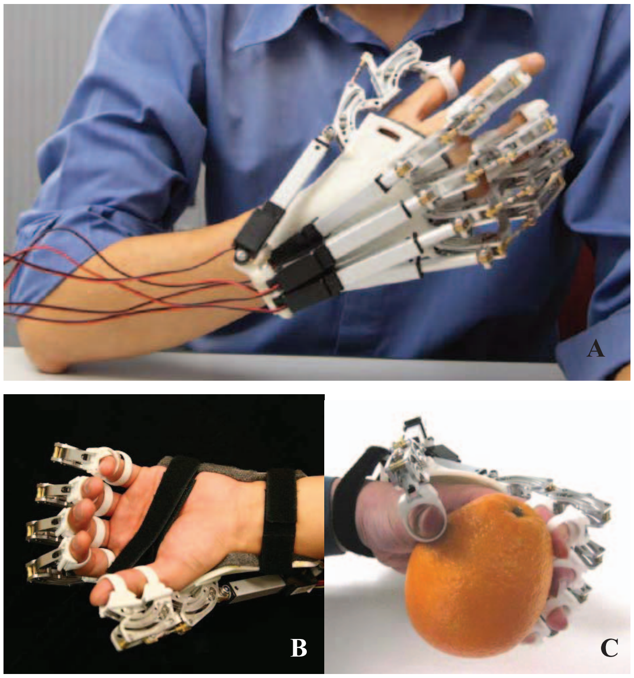

Figure 1. Exoskeleton hand robotic training device: A) robotic hand module with 5 linear actuators at the back, B) hand is secured with the robotic hand module using Velcro straps and C) holding an object with robotic hand

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The system consists of a robotic hand module (see figure 1) and an embedded controller. The fingers and the palm of the stroke subject hand are mounted comfortably on to the robotic hand module using finger rings and Velcro straps. The palm area of the hand and DIP joint on figure are left open to allow user to grip and feel the objects with their own fingers.

A. Robotic hand module

Each hand module consists of five finger assemblies and a palm support platform. Each finger assembly is actuated by a single linear actuator (Firgelli L12) and provides 2 degrees of freedom (DOFs) for each finger at the MCP and PIP together by the mechanical linkage system. The proximal section rotates around the virtual centre located at the proximal interphalangeal (PIP) joint whereas the distal section rotates around the virtual centre located at the metacarpophalangeal (MCP) joint (see figure 2). From fully extended position to fully flexed position, the finger assembly provides 55 degrees and 65 degrees range of motion (ROM) for the MCP and PIP joints respectively. When under no load, the maximum contraction speed of the robotic hand is approximately 2seconds to fully open or close the robotic hand.

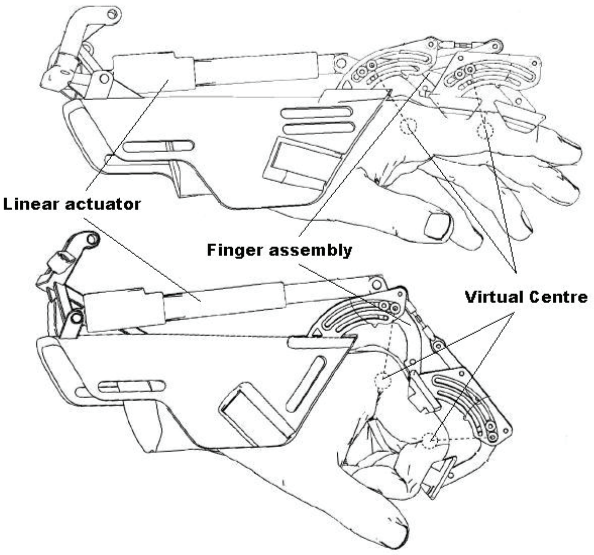

Figure 2. Movement of finger assembly around the virtual centres

All finger assemblies are identical and each can be adjusted to fit for different finger length and align the virtual centre of rotation to the MCP and PIP joints, thus provides a natural movement of finger flexion and extension. Including all 5 finger assemblies, 5 linear actuators and the palm support platform, the total weight of the robotic hand module is only 500 grams.

B. Embedded controller

An embedded controller is built to control the robotic hand module and monitor the surface EMG signals for hand opening and closing tasks. Microchip microcontroller is used to control all the linear actuators and measure the surface EMG signals from the two major muscle groups – abductor pollicis brevis (APB) and extensor digitorum (ED). EMG signal from the APB is used to control the hand closing task while the signal from the ED is used to control the hand opening task. Both channels of EMG signals (APB & ED) are sampled at 1 kHz.

The embedded controller contains a wireless module for wireless communication. Therefore, the therapist can configure the exoskeleton robotic hand and choose different training modes using the wireless remote control system (see figure 3).

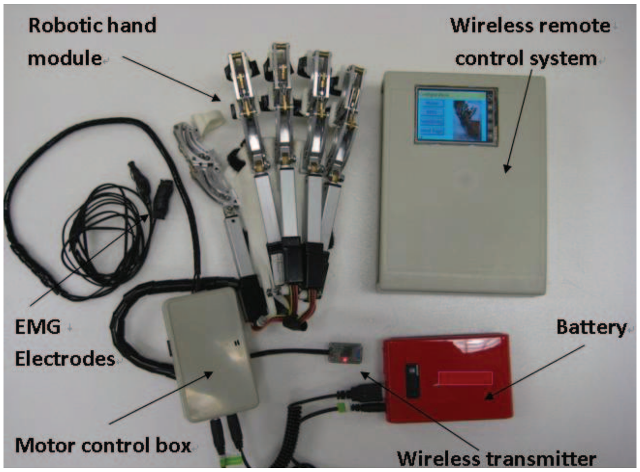

Figure 3. Full set of exoskeleton hand robotic training device

The whole system is designed to be portable and self contained allowing the stroke patient to carry it around to practice daily activities.

III. METHODOLOGY

Eight chronic stroke subjects were recruited to evaluate the exoskeleton hand robotic training device with hand function task training. The evaluation was conducted at the department of Health Technology and Informatics, the Hong Kong Polytechnic University.

A. Training set up

Stroke subjects would sit comfortably in front of a table to do the task training. When fitting the robotic hand module with the impaired hand of the stroke subjects, Velcro straps were used to securely hold the hand in place and mount individual fingers on the finger assemblies. On average, it took 30 seconds to don the exoskeleton. Surface EMG electrodes (Ambu Blue Sensor SE-00-S/50) were used to collect the surface EMG signals from the extensor digitorum (ED) and abductor pollicis brevis (APB) (see figure 4).

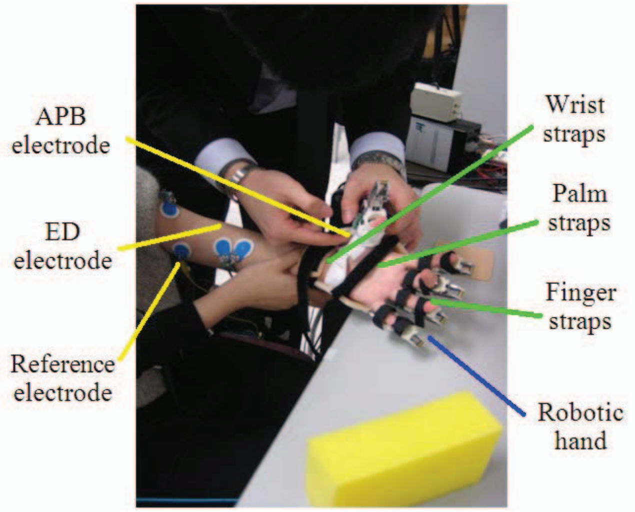

Figure 4. Donning process for the wearing the robotic hand

B. *EMG Control strategy*

The control strategy used in the training was the EMG-triggered training mode. A threshold of 20% of the maximum voluntary contraction (MVC) EMG signals was used to trigger the hand opening and hand closing motions. Therefore, baseline and maximum voluntary contraction (MVC) of the EMG signals were measured at the beginning of each training session. When the robotic system was running in a hand closing triggering mode, it would wait until the EMG signals from the APB muscle exceeded the 20% of its MVC value before starting the hand closing action. And when it was running in a hand opening triggering mode, it would wait until the EMG signals from the ED muscle exceeded the 20% of its MVC value before starting the hand opening action. See figure 5.

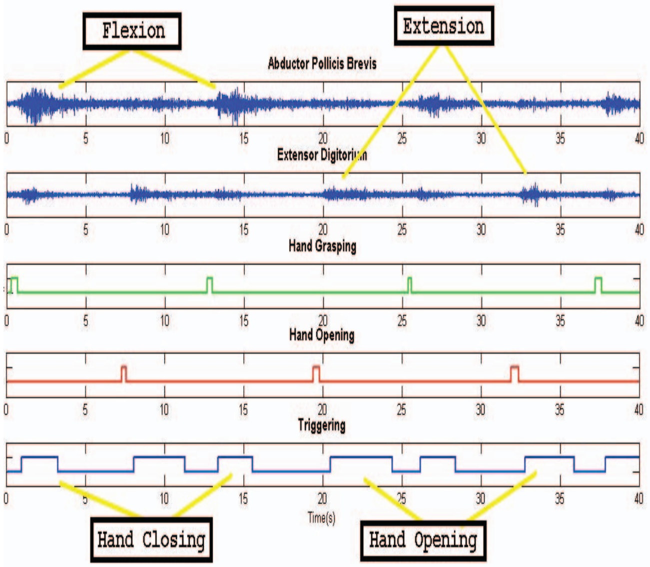

Figure 5. EMG signals with EMG-triggered status

C. *Hand function task training*

In this evaluation each subject was required to attend 20 training sessions with training intensity about 3-5 sessions per week. Clinical outcome measures were assessed before and after the 20 sessions.

During the training session, the stroke subjects were required to complete 2 sets of upper limb training tasks assisted by the exoskeleton hand robotic training device, each with 10 minutes training period. First task required stroke subject to move an object, which is a foam, across a table horizontally for a 50cm distance. And the second task required stroke subject to move an the foam vertically above the table for 20cm. In each 10 minutes, the stroke subjects repeated the same task with hand opening, grasp the foam, move to the target position and then release the foam at their comfortable speed (see figure 6). And there was a 5 minutes rest between these two tasks.


[redacted]
[redacted]

Figure 6. Vertical upper limb training task

D. *Stroke subjects*

Eight chronic stroke subjects were recruited to evaluate the effectiveness of the hand functions task training using the exoskeleton hand robotic training device. All attended 20 hand functions task training sessions. The demographic data of the recruited subjects is shown in Table 1.

TABLE I. DEMOGRAPHIC INFORMATION

Subject	Gender	Age	Stroke Type	Affected Limb Side	Time after Stroke
Chronic					
1	F	28	Hemo.	Left	4 years
2	M	42	Hemo.	Right	14 years
3	F	63	Isch.	Left	4 years
4	M	67	Hemo.	Right	14 years
5	M	49	Isch.	Left	8 years
6	M	58	Isch.	Left	3 years
7	M	64	Isch.	Right	4 years
8	M	51	Isch.	Left	10 years

Female (F); Male (M); Hemorrhage (Hemo); and Ischemia (Isch).

E. Outcome measurements

Clinical assessments such as Fugl-Meyer Assessment (FMA) and Action Research Arm Test (ARAT) were used to evaluate the motor improvement after the robot-assisted hand functions task training. FMA which evaluates the voluntary motor functions of the upper limb contains two separate measurements of the shoulder and elbow section (S&E) and the wrist and hand section (W&H). ARAT focuses on the measurement of the hand functions based on common daily activity tasks such as picking small objects like marble for pinching or holding a tennis ball for grasping.

IV. RESULTS

Table 2 provides a statistical summary of the training effects on the subjects before and after the 20-session hand robot training. It was found that there are significant motor improvements in the FMA-S&E, and FMA-W&H, and ARAT clinical assessments. The improvement in ARAT score reflects the motor recovery in hand and finger functions. The increased FMA scores suggest there is motor improvement in the whole upper limb after the training.

TABLE II. STATISTICAL SUMMARY

Assessments	Mean ± SD		Paired t-test
(max. score)	Pre	Post	
FMA-S&E (42)	21.50±2.59	28.00±7.40	**0.0426***
FMA-W&H (24)	7.83±5.11	11.83±5.85	**0.0035***
ARAT (57)	21.833±8.66	29.67±9.14	**0.0121***

* Mean value changes with statistical significance (P<0.05, paired t-test).

V. CONCLUSION

This study showed a newly design EMG-driven exoskeleton hand robotic training device for stroke rehabilitation and reported the clinical results after 20 session of training on 8 chronic stroke subjects. The robotic device encourages the stroke subjects to use their impaired hand muscles to control the robotic hand module. With the repeatedly open and close functional task training, the preliminary data showed the motor functions on the hand and upper limb had been improved after 20-session training. A larger clinical was needed in future clinical studies.

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