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A Robotic Rehabilitation Arm Driven by Somatosensory Brain-Computer Interface

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***Abstract*—**It was expected to benefit patient with hemiparesis after stroke by extensive arm rehabilitation, to partially regain forearm and hand function. This paper propose a robotic rehabilitation arm in assisting the hemiparetic patient to learn new ways of using and moving their weak arms. In this study, the robotic arm was driven by a somatosensory stimulated brain computer interface (BCI), which is a new modality BCI. The use of somatosensory stimulation is not only an input for BCI, but also a electrical stimulation for treatment of hemiparesis to strengthen the arm and improve its range of motion. A trial of this robotic rehabilitation arm was performed in a stroke patient with pure motor hemiparesis. The initial trial showed a promising result from the patient with great motivation and function improvement. It suggests that robotic rehabilitation arm driven by somatosensory BCI can enhance the rehabilitation performance and progress for hemiparetic patients after stroke.

***Keywords*—**Robotic rehabilitation arm, brain computer interface (BCI), hemiparesis, stroke, somatosensory stimulation.

I. Introduction

THERE are over 25,000 new stroke diagnoses in Hong Kong every year [1]-[3]. At present, it is the fourth fatal disease in Hong Kong. Hemiparesis is a common symptom after stroke [4], [5]. Post-stroke hemiparesis may have trouble moving their arms. Thereafter, the hemiparetic patients are difficult in their everyday activities, such as grabbing objects, dressing, eating etc [4], [5]. Physical therapy can help stroke survivors get back the use of weak arms [5]-[8]. In addition, electrical stimulation has been used in the treatment of hemiparesis to strengthen the arm and improve its range of motion.

Clinical research found that repetitive and function based neurological rehabilitation can benefit patients suffered from hemiparesis [6]-[8]. However, some studies showed that the motivation of patients with stroke plays a major role to gain recovery from physiotherapy [9]. Therefore, the aim of this research is to study the feasibility of using a Brain Computer Interface (BCI) [10] based mind-driving robotic rehabilitation arm with real-time bio-feedback and progress assessment for facilitating neuromuscular recovery.

In this study, a power-assisted exoskeleton robotic arm was developed for elbow joint motion rehabilitation. It can be worn by a patient to control his/her elbow flexion and extension movement directly by inputting control commands from BCI. An electrical stimulation applied on finger at left hand to produce somatosensory inputs for BCI. This electrical stimulation, on the same time, is also a rehabilitation tool for hemiparesis. An initial clinical trial was performed in a post-stroke hemiparetic patient with one-week rehabilitation by the developed robotic rehabilitation arm.

II. BCI Based Robotic Rehabilitation System

A. Robotic Rehabilitation Arm

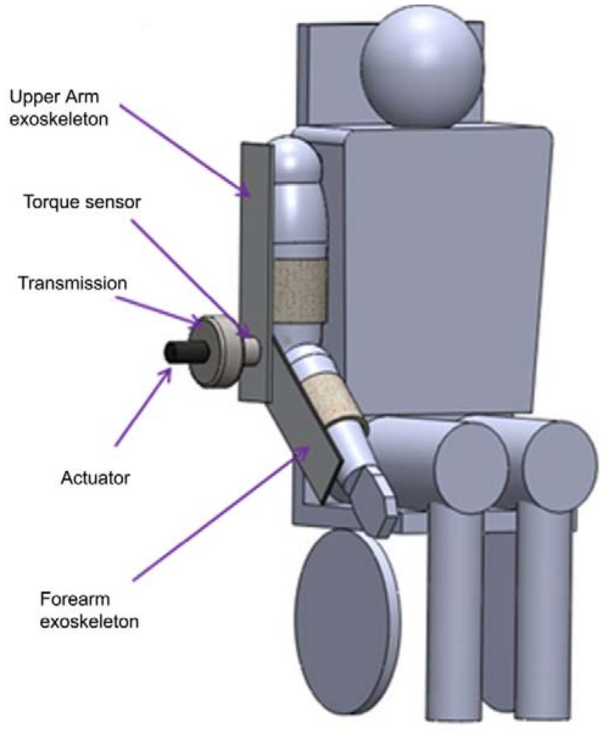

Fig. 1 Basic structure

A design of robotic rehabilitation arm is shown in Fig. 1. It consists of an upper arm exoskeleton, a forearm exoskeleton, an actuator, a transmission and a torque sensor. The upper arm and forearm exoskeletons are secured to the upper arm and forearm of the patient respectively. A servo motor is employed to rotate the forearm exoskeleton through a transmission gearbox and torque sensor. During operation, feedback information will be

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collected simultaneously for system control. For safety and ergonomic design reasons, the elbow joint rotational axis is aligned with the transmission shaft axis.

B. Somatosensory Brain Computer Interface

BCI is a communication system designed to enable users to communicate with external environment by translating human intentions into control signals. Due to the noninvasiveness and high communication speed, electroencephalogram (EEG)-based BCIs attracts much attention in recent years.

The P300 evoked potential is a positive EEG potential that occurs around 300ms after specific task-related stimuli presented. Inputs for EEG BCI are usually from visual and auditory modalities. Somatosensory stimuli can be an alternative for BCI purpose. in this study, a particular advantage of using somatosensory stimuli is that it can stimulate the weak neuromuscular function in forearm of the hemiparetic patient.

Fig. 2 A healthy subject to control the robotic arm by somatosensory stimulated BCI

As Fig. 2 shown, somatosensory stimuli, including lower intensity (s) (non-target event, stimuli intensity = 1.5±0.1 mA [three times the sensory threshold]; duration = 1ms) and higher intensity (S) (target event, stimuli intensity = 1.0±1 mA [three times the sensory threshold], duration = 1 ms), administered to the left index finger via metallic rings.

EEG was recorded by a 16 channel amplifier (pass band: 0.05 -100 Hz, sampling rate: 1000 Hz) using a standard EEG cap based on the extended 10-20 system. Four electrodes were chose to record EEG activities: Fz, Cz, Pz and Oz. The EEG electrodes were referenced to linked mastoid electrodes, and the impedances of all electrodes were below 5 kΩ. Continuous EEG data were sampled with a frequency of 1000 Hz and band-pass filtered between 0.1-30 Hz. EEG data were online analyzed from 200 ms before stimulus onset until 800 ms after stimulus onset. In order to remove electro-oculographic (EOG) and other noises that could distort P300, trials with signals exceeding 100 μV were discarded. P300 amplitude was measured in every trial (Fig. 3). The linear discriminate analysis method (LDA) was selected to perform classification analysis.

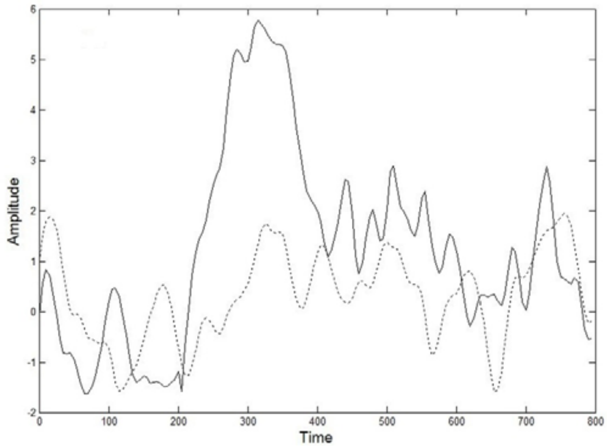

Fig. 3 P300 for BCI inputs (real line: Up, dot line: down)

C. Rehabilitation System

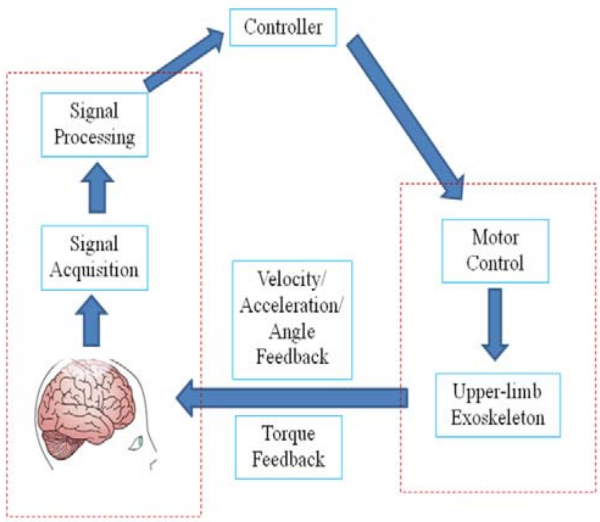

Fig. 4 Flow of system control

The flow of control in the control program is illustrated in Fig. 4. Four parameters, including position, velocity, acceleration and torque, were determined by the physiotherapist. The position, velocity and acceleration control signals are for controlling and monitoring the rotational position and velocity of the elbow joint. The torque sensor signal is for controlling the rotational torque of the system in response to the torque exerted by the patient. The detected input commands from BCI are transmitted to the control computer. After processing by the control program, the corresponding control command is transmitted to the control circuit board for actuating the servo motor.

The robotic arm can provide an assistive therapy mode. The subject would extend or flex the elbow repeatedly at a selected velocity and acceleration while the exoskeleton system provided a torque to assist the patient's motion. All the movement information for each subject was recorded for performance evaluation.

III. Clinical Trial

A young male patient (36 years old) has pure motor hemiparesis on his right arm for about eight months (Fig. 5). After an eight-month recovery process, he still has right arm weakness. He was invited to join this study, to join a week extensive rehabilitation with one hour every day. The objective of the clinical test was introduced to him clearly, and he was pleased to attend this trial. The exercises procedures and the usage of the system were understood and accepted by him. A verbal consent was collected with approved by institute ethic committee.

Fig. 5 Clinical tests in a post-stoke patient

The clinical test results for this patient before and after rehabilitation were shown in Figs. 6 (a), (b) respectively. It can be seen that the position and velocity curves were relatively smooth, indicating that the patient could collaborate well with the exoskeleton system. Cyclic torque patters was readily observed with an increase in comparison between post-rehabilitation to pre-rehabilitation. Moreover, the torque curve before rehabilitation exhibited an erratic and momentarily higher spike level during the flexion motion as highlighted in Fig. 6 (a). This phenomenon indicated that the patient may have spasm in the flexion movement. It is also observed that the torque level in the resistive mode is lower than that of healthy subjects, meaning that the patient may have some degree of arm muscle weakness.

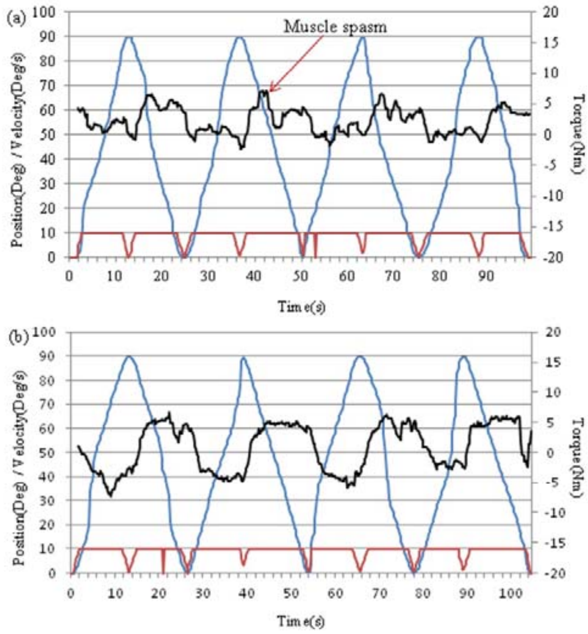

Fig. 6 Clinical test results for a stroke patient: (a) before rehabilitation; (b) one week after rehabilitation (red line: position; blue line: velocity, black line: torque)

In observation of this patient's performance, he was able to achieve flexion-extension motion in the range of 50 to 65 degree before rehabilitation. After one week rehabilitation, he can achieve the target at 90o, which is the maximum angle in the robotic arm.

In robotic assistive therapy, the subject would be exerting a torque to assist the elbow joint motion of the exoskeleton. The benefits of using the exoskeleton system for neuromuscular rehabilitation with the use of somatosensory BCI-driving device have been verified in this initial clinical trial. More relevant exercises should be carried out by patients themselves to improve their recovery indications.

IV. Conclusion

Clinical tests were conducted on 14 healthy subjects and 6 patients with 4 therapy modes. The measured torque data were fitted by curves and equations for analysis. The different results between healthy subjects and patients were discussed and the dissimilarities among patients themselves were also addressed by using different indications. The feasibility and the function of using the elbow joint exoskeleton system based on mind-driving control for patients with NMDs have been verified. Results show that the developed mind-driving elbow joint exoskeleton system can be used to monitor the progressive neuromuscular recovery under different therapy modes. The feedback information from the healthy subjects and patients is useful for improving the exoskeleton system in the future.

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