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A Human Computer Interface Driven Rehabilitation System for Upper Limb Motion Recovery

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ABSTRACT

Rehabilitation for recovering the nerve motor system of patients with neuromuscular damage, such as those due to spinal cord injury and spasm, has been based on extremely labour intensive physiotherapy procedures. A potential solution for helping patients to expedite their recovery from neurological disorders and improve their ability in performing activities of daily living would be by using mechatronic-assistive devices that can be controlled by the patients themselves. The inclusion of modern input devices such as Head Mouse or brain-computer interface technology with neurological stimulation to help neural modulation has been advocated by others in the related research community. This paper introduces a power-assisted exoskeleton prototype system for producing elbow flexion-extension motion by using a Head Mouse as an input of control commands by the patient. Experiments were conducted to evaluate the effectiveness (Position, Velocity, Acceleration, and Torque) of the exoskeleton. Results demonstrate that the device would be a useful rehabilitation tool for patients with neuromuscular disorder.

KEY WORDS: Rehabilitation, Human Computer Interface, Exoskeleton, Neuromuscular Recovery.

1. Introduction

It was reported that about 650 million people worldwide are suffering from some forms of disability in 2008. In China alone, the number of patients with limb disability was 7.55 million. Many of them need to rely on caregivers to perform their daily activities. Research and development in the treatment methods for recovering the nerve motor system for patients with severe nerve damage, such as those due to spinal cord injuries, stroke, sports injuries and occupational injuries, is ongoing.

Some upper limb exoskeleton robots used for helping patients with motor disabilities have been developed. Some of them were used for amplifying limb strength [1], while some were designed for recovering full or partial loss of arm function [2]. Typical examples are the BONES[3], Assisted Rehabilitation and Measurement(ARM) Guide [4], REHAROB [5], Bi-Manu-Track[6], ARMin II [7], Neuro

rehabilitation Robot (NeReBot) [8], Mirror Image Motion Enabler (MIME) [9], and Arm Coordination Training 3-D (ACT3D) [10]. It was found that repetitive and long-term automated movements can improve muscular strength in patients with neuromuscular problems [11]. Hence, upper-limb rehabilitation devices with different degrees of freedom have been studied by many research teams. However, treatment for neuromuscular damage often relies on labor intensive physiotherapy procedures conducted by trained personnel. Moreover, contemporary rehabilitation devices are usually large in size. It is conceived that if patients with neuromuscular disorders can be enabled to control an exoskeleton for rehabilitation by using his/her physiological signals, the recovery process can be better monitored and expedited, thus making the rehabilitation process more efficient and effective. With the advancement of sensor technology, physiological signals can now be obtained from patients through a sensing system such as a Head Mouse or a Brain-Computer Interface (BCI) system. Motivated by this thinking, we designed and prototyped an elbow-joint rehabilitation device for studying the feasibility of using Head Mouse and BCI system for rehabilitation.

In this paper, the specification and construction of our developed exoskeleton system are introduced. The control structure of the elbow joint movement based on different therapy modes is described. Initial testing of the system for assessing its accuracy and response is reported.

2. Methods

A mechanical exoskeleton comprising an upper arm and a forearm support was designed based on several considerations, such as mechanical and electrical aspects, ergonomics, range of motion, and operation safety, etc.. In essence, the elbow joint is driven by a servo motor coupled with a gearbox through a servo control circuit board. A torque sensor is connected coaxially on the driving shaft for torque measurement.

2.1 Specification

The maximum human isometric strength for elbow flexion/extension was reported to be 72.5 Nm. As the exoskeleton system is for rehabilitation purpose, it is

considered that the design of its rotating torque capacity does not need to be set at the maximum human isometric strength. The designed torque level for the elbow flexion/extension motion in our developed rehabilitation system was set at 36.3Nm, which is 50% of the maximum human strength. By taking the weight of the exoskeleton as well as the weight of human forearm and hand into account, the total torque was set at 41 Nm.

The range of motion (ROM) of the exoskeleton needs to be in compliance with the human arm's average range of flexion and extension motion which lies between -5° and 152° (Fig.1a). However, for safety consideration, the ROM of the exoskeleton was set slightly smaller than the average human ROM so as to avoid over-exerting the elbow motion range of the patients, thus causing injury. The ROM of the exoskeleton was therefore designed to lie between 0° and 140° (Fig.1b).

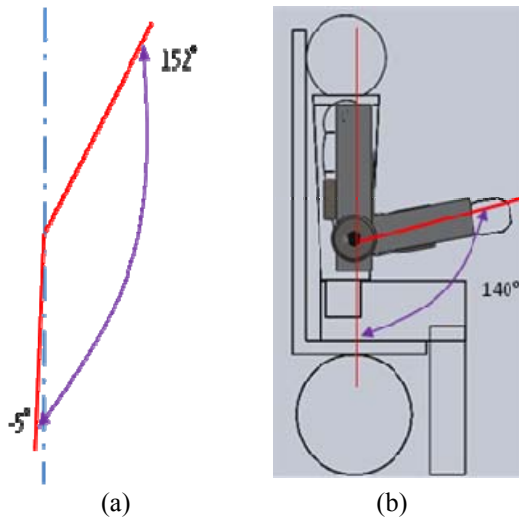


Fig.1. Average ROM of human arm (left) and ROM of the developed exoskeleton (right)

The angular velocity of the elbow motion can be specified by the user patient through the use of a Head Mouse (in the future by using a BCI sensing system).

2.2 System Design

Based on various design considerations, such as operation safety and comfort of wearing, the exoskeleton system was designed to consist of a mechanical upper-limb structure and a servo motor control system (Fig.2). The mechanical structure is for supporting the upper arm and forearm while the motor control system comprises a servo motor for actuating the elbow joint motion, a motor control circuit and a power supply unit. The servo motor and gearbox assembly is attached to a mounting flange of the exoskeleton. A torque sensor is connected between the gearbox output shaft and the forearm support of exoskeleton for detecting the torque applied on the exoskeleton. The centre of rotation of the elbow joint is coaxial with that of the motor and gearbox driving shaft.

With the current implementation, a Head Mouse is used to detect the user patient's head motion. The head motion signal is then transmitted to the servo motor control circuit. The rotating angle, velocity, acceleration, and torque signal detected by the torque sensor are fed back to the servo control circuit to form a closed-loop control. In a later study, it is planned to replace the Head Mouse with a BCI system for obtaining EEG signal from the user patient's brain as input signal to control the exoskeleton.

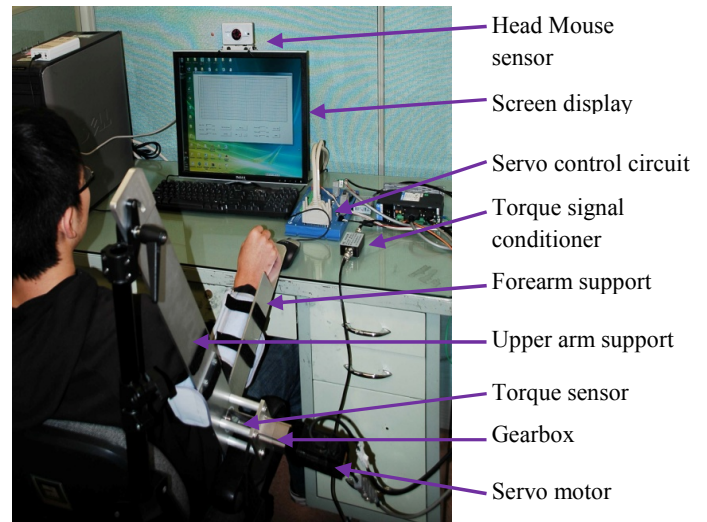


Fig.2. Exoskeleton controlled by a Head Mouse

In order to achieve the appropriate torque and velocity ranges, an AC servo motor combined with a gearbox with a transmission ratio of 60:1 is employed. The servo motor has a built-in incremental encoder with a resolution of 0.045 degrees/pulse for positional and velocity measurements. The elbow joint torque is measured by a torque sensor HX-900T with a measurement precision of 0.005Nm. Signals from the torque sensor and the encoder are fed back to the control circuit board. The patient's head motion is detected by the Head Mouse and transmitted as optical signal to the controller circuit board. In turn, the input signal is converted into the respective control command by the control program and is then sent from the control circuit board to the servo motor for actuating the exoskeleton to produce the corresponding motion. The design of the control program can allow the use of three different therapy modes, (i) passive repetitive mode, (ii) resistive mode, and (iii) assistive mode. The Head Mouse control and system response are displayed graphically on the computer screen.

3. Results

As shown in Fig.3, a time delay between the theoretical computed values and the measured values was observed in each test. However, the delay was quite steady and was less than 0.5 second. It can be hardly sensed by the subject or the therapist, and hence it is considered that it will not introduce any appreciable effect to the system performance.

It can be seen that the theoretical computed values correlate very well with the measured values. It is considered that the system can be used for carrying out clinical study.

In the torque test, the sampling points were taken at intervals from -15 to 15 Nm. It was found that the largest difference between the reference torque given by the precision torque wrench and the measured torque given by the torque sensor was 0.88 Nm. This difference only accounted for 5.86% of the reference torque value. The coefficient of determination was 0.99, which means the measured data and reference data are in close correlation, so it is considered that the system can be used for carrying out clinical study at a later stage. The tests also show that the position, velocity, acceleration and torque curves can be recorded easily for further analysis.

A fitting curve was shown in Fig.4 with the coefficient of determination of 0.91. In general, the sine curve equation has four parameters which can be determined for each

subject in each of the three therapy modes.

4. Discussion

The ROM of the developed elbow joint exoskeleton is designed to operate within the safe ROM of a human elbow joint. The maximum torque of the exoskeleton is designed at 50 Nm which can satisfy most of the daily activities of living of a healthy subject. Velocity and acceleration of motion can be controlled to within safe operation range required in performing daily activities. The exoskeleton is easy to be worn and its dimensions can be easily adjusted for fitting different subject body sizes.

In the system response test, a small time delay is experienced. Some small residual torque is observed to exist, possibly due to the inevitable presence of joint friction.

Fitting the recorded torque values for each subject in each

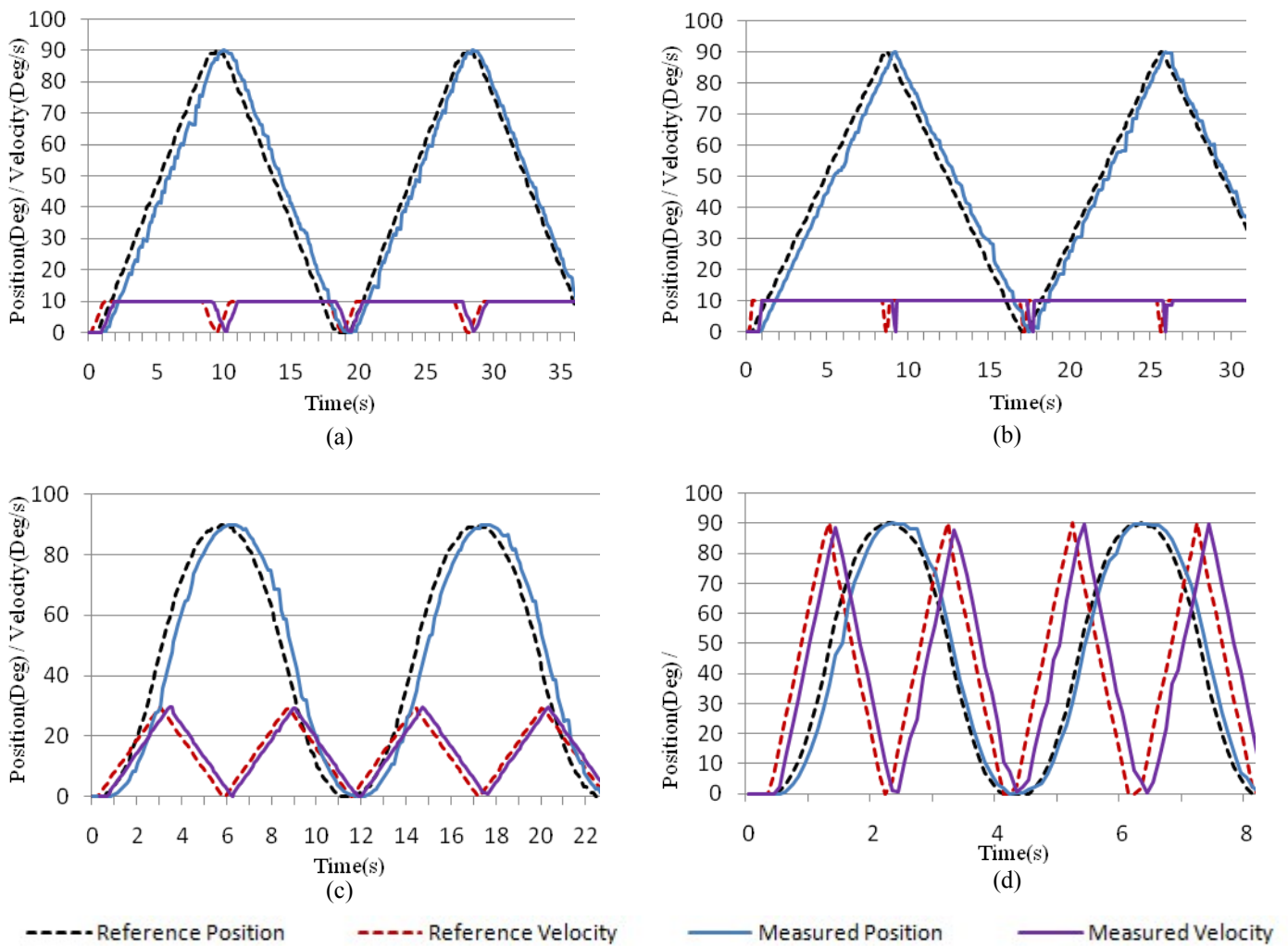


Fig.3. System behaviors

therapy mode with a sine curve can produce four equation parameters. The roughly equal values of w in the three modes for each subject mean that the periods for torque variation are quite similar. This is reasonable as the same speed was used in the three modes. The values of $(C/w)^* \pi$ in the resistive mode and passive mode are quite similar, and they are representing the same shift angle for the sine curve in both modes for each healthy subject. The y_0 is between 0~2.7Nm in both resistive mode and assistive mode, which shows that the torque difference between moving upwards and downwards is very small, and further indicates that the torque is controlled well by healthy subjects. The y_0 value in the passive mode was around 2~3 Nm, which represents the torque caused by the resistance of the forearm structure and the weight of the subject's arm. These parameters would be useful for describing and monitoring the recovery progress.

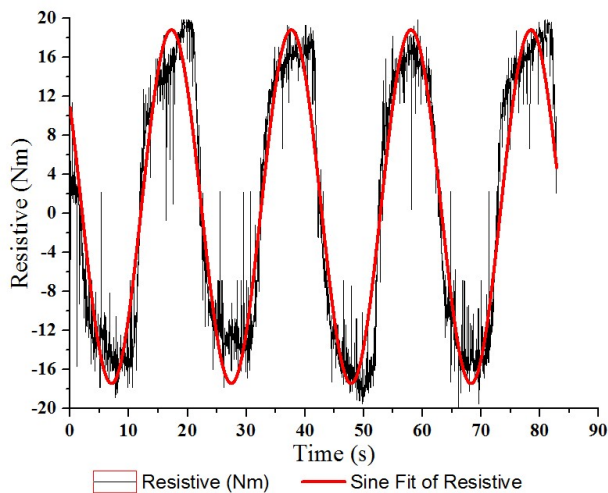


Fig.4. Fitting curve for resistive therapy

5. Conclusion

A portable exoskeleton controlled by a Head Mouse input device for elbow joint rehabilitation has been developed and evaluated by four healthy subjects under three different therapy modes. The measured torque values were fitted with sine curve for further analysis. Preliminary tests demonstrated that the device would be a useful rehabilitation tool for patients with neuromuscular diseases such as those due to spinal cord injury and spasm. In the subsequent work, the control methods will be refined, and the use of BCI input method will be introduced. Clinical test will then be carried out on patients to study the use of the developed exoskeleton system for elbow joint neuromuscular recovery.

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