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Preliminary Design of a Robotic Exoskeleton for Arm Rehabilitation

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Abstract. This research paper presents the design of a low-cost and easy-to-use 2 degree of freedom (DOF) robotic exoskeleton for arm rehabilitation. The developed exoskeleton consists of a 2 DOF robotic arm attached on a chair. Force sensitive resistors are also utilized in the design of the device to measure muscles activities during rehabilitation process. Kinovea software is used to analyse the performance of the patient during exercise via video capture. The measured data hopefully can assist physicians and caregivers in designing suitable rehabilitation process for stroke patient. The proposed design provides a novel tool towards upper limb stroke rehabilitation process. Although there are many exoskeleton robotics arms which are commercially available, however, due to the disadvantages such as weight, high-cost and complex mechanisms, this paper proposed new ideas on solving these problems by designing an exoskeleton which is functional, low-cost and users friendly

1. Introduction

The objective of developing a robotic exoskeleton or robotic arm is to replicate or imitate sensory-motor capabilities of the human hand [1]. Development of new methods and sensors for various application contributes in the development of novel techniques for biomechanical applications that promote studies on human motion analysis and rehabilitation processes [1, 2]. Furthermore, due to the advancement of robotic technologies, it has changed the method of utilizing grippers with only two rigid fingers, and no phalanges, to the development of human-like hands with at least three to five functional fingers, each with two to three phalanges [3].

A master-slave robotic system is a popular tool in application related to rehabilitation and remote handling operation [4, 5]. This system enables the personnel to maintain safe working distance from hazardous work environments. Moreover, in the field of healthcare such as tele-surgery and rehabilitation, remote handling tools involving the usage of robotic hands are also employed to improve human limb function. There are many types of five fingers robotic hand that has been developed. The robotic hand, involving innovative mechanisms or myoelectric control systems are an example of the advanced types. Vinet et al. develop a five finger adult sized anthropomorphic hand called the Montreal hand with passive adaptive capabilities by means of a clutch, a cable system, and a spring-loaded pulley mechanism [6]. Rajiv et al. developed a multiple motor and sensory feedback robotic hand which can grasp objects [7]. From both cases, the robotic hand gave a more human-like finger function. But there are many setbacks mainly due to oversize, overweight and costly. It is proven that imitation is an element which is important in proper improvement of social and communicative skills [8]. Mirror Visual Feedback (MVF) therapy or mirror therapy is an imitation method introduced back in early 1990s, which is based on mirror illusion to help patient's limb practice due to cerebral vascular accident (CVA) injuries, post-stroke or amputated [9]. Motivated by this study, the authors have developed a master-slave robotic hand that substitute the paralyzed hand in MVF therapy to aid in recovery process of patient's upper limb function [10].

The objective of this study is to develop a low-cost, modular and easy-to-use robotic exoskeleton that can be utilized as a tool for arm rehabilitation. This paper describes the preliminary design of the robotic exoskeleton that consists of a robotic arm attached on a chair and flex sensors to record muscle activities during movement. Preliminary experimental result to show the usefulness of the device are demonstrated at the end of the paper.

2. Design Description

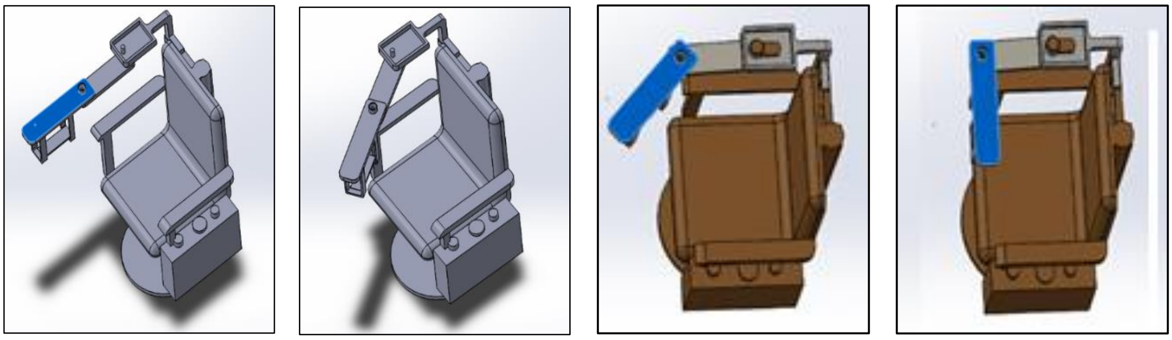
Figure 1(a) shows the 3D design and schematic of the developed planar two (2) degree of freedom (DOF) exoskeleton with coordinate frames of the base and each joint that allows movement at the shoulder and elbow. The planar exoskeleton that is fixed on a portable adjustable seat chair. As seen in the figure, the mechanism of the exoskeleton is positioned above the user's arm, where all actuators are located on top of the user's arm and aligned with the user's elbow and shoulder joints positions. In the current design, the joints movements are directly actuated by DC motors which are fixed on two (2) links (Link 1 and Link 2) made using polymer material which is not only solid but also lightweight. Furthermore, as shown in Figure 1(a), Link 2 is fixed with an arm carriage that supports user's arm. Figure 1(b) shows the image of the actual exoskeleton.

As shown in Figure 1(a), Joint 1 represents the shoulder joint and its axis of motion is along z_0 axis. This joint provides a rotational angular motion around z_0 axis in x_0-y_0 plane. On the other hand, Joint 2 represents the elbow joint and its axis of motion is along z_1 axis. This joint provides a rotational angular motion around z_1 axis in x_1-y_1 plane.

(a) (b)

Figure 1. (a) Schematic of the proposed exoskeleton, (b) 3D design of the proposed exoskeleton

Figure 2(a) to (d) show CAD drawings of the proposed device demonstrating the range of motions for shoulder and elbow joints. Figure 2(a) and (b) show the initial position and 45deg inward movement of the shoulder joint, respectively. Figure 2(c) and (d) show the elbow joint inward motions from 45deg and 90deg, respectively. The range of motions for both shoulder and elbow joint are similar, which is [-90deg, 90deg].



(a) (b) (c) (d)

Figure 2. Movement of robotic arm: (a) Shoulder and elbow joints initial angles; (b) Shoulder inward 45deg; (c) Elbow joint 45deg inward movement at shoulder joint initial angle; (d) Elbow joint 90deg inward movement at shoulder joint initial angle.

2.1. Hardware Design

Figure 3 shows images of the developed two DOF exoskeleton for assisting patient in arm rehabilitation process. Modular design of the exoskeleton that can be reconfigurable to be suited for the use of either left or right arm will be developed in the future. However, in the current preliminary design, the exoskeleton is developed for upper right hand only.

As shown in the figure, the exoskeleton is fixed on an office chair via a 20cm x 10cm x 5cm base made from metal sheet. This base is attached with a DC power window motor with 1:10 gear ratio. This DC power window motor drives the shoulder joint which is connected to Link 1 and the lower arms that consists of the elbow joint and Link 2. The DC power window motor is covered by a semi-transparent box as a cover. Furthermore, the links (Link1 and Link 2) of the robotic arm are made of polymer material which is strong and lightweight. Technically, the structure of the shoulder is designed so that it is directly attached to the elbow joint's actuator.

Figure 3. Exoskeleton for arm rehabilitation

On the other hand, the rotational joint of the elbow uses a low-cost and compact-sized 20W SPG20 DC brushed motor with 50:1 gear ratio as shown in Figure 3. This DC brushed motor consists of a 4mm diameter D-shaft. One of the most critical components of this devices is the motor shaft. Each actuator's shaft on the shoulder and elbow joint is positioned with a twelve teeth motor shaft. In this work, the design of the gear system mechanism is crucial to control the exoskeleton to mimic the movement of human arm. Both actuators are powered by 12V power supply. Each actuator is a self-contained drive unit with a built-in motor, controller, amplifier, and communication interface. Table 1 shows the specification of the torque produced by each actuator and its angle range of motion. The rotational movement of the elbow and shoulder joints are limited from 0deg to 90deg only. A stopper spring mechanism is designed on each joint to limit the movement for only up to 90deg.

An Arduino microcontroller controls the overall system of the device, which communicates with motor driver and interfacing between hardware via serial communication for data processing. Each joint of the exoskeleton is controlled by a motor driver. The shoulder joint is also passive, manually positioned units that use friction or a lock to hold their position.

Table 1. Joint range of motion (ROM) and torque value

No	Joint	Angle (deg)	Torque (NM)
1	Shoulder	0 to 90	20
2	Elbow	0 to 90	20

2.2. Force Sensitive Resistor

A force sensitive resistor (FSR) is a type of resistor that composed of thick polymer film. The FSR works by changing its resistance when physical pressure applied to the active surface. Figure 4 shows the relation between the sensor's resistivity against physical force on its active surface. When there is no pressure, the sensor looks like an infinite resistor (larger than 1MΩ), while the resistance may reduce to several kΩ when the pressure on the active surface increases. FSR as shown in Figure 4 is very ideal for body-worn sensors and robotic applications since it require less power and easy interface, very lightweight and relatively sensitive to small physical force. In this work, the bicep and forearms of the user are attached with FSRs to record muscles excitation during rehabilitation.

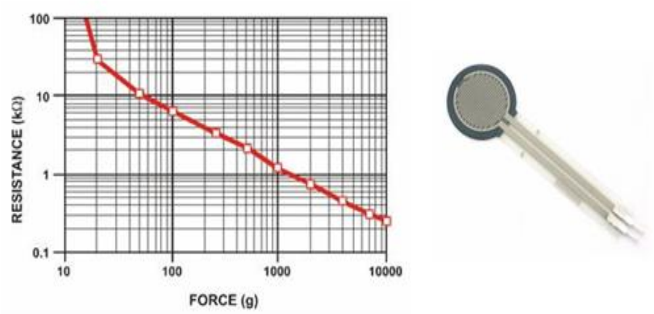


Figure 4. Force sensitive resistor

(a) (b)

Figure 5. FSR attached on user's (a) bicep and, (b) forearm.

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3. Preliminary Experiments and Results

This section describes the preliminary experiment to verify the usefulness and usability of the developed device.

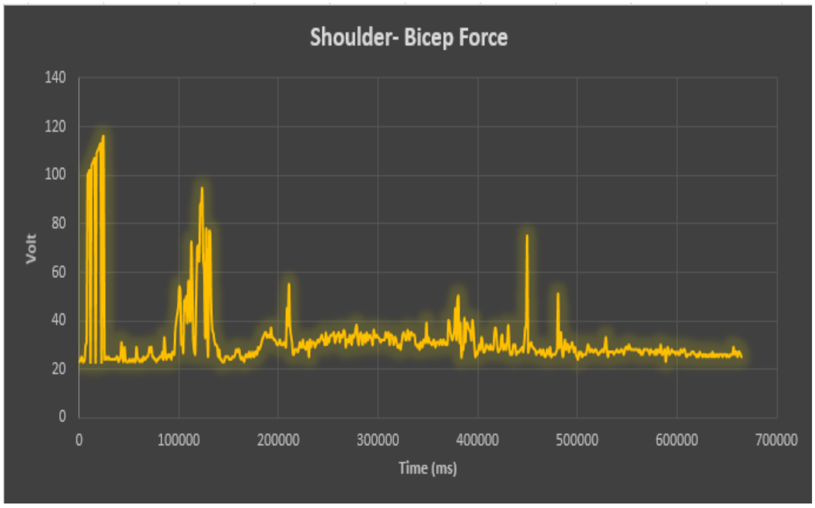
In this preliminary experiment, a patient with arm disability (level 3) was asked to do a simple elbow inward bending movement with the support of the exoskeleton robotic arm as shown in Figure 6. During the movement the arm, the muscle activities on bicep and forearm were recorded using the FSR explained in previous chapter. Then, the raw data from FSR were processed by Kinovea software. Kinovea is a free and open source video analysis software for viewing and analysing techniques of human motions [12].

For the purpose of analysis, the recorded data are divided into three (3) analysis criteria, where each of the criteria follows Modified Ashworth Scale (MAS) rehabilitation grading system for clinical applications. MAS measures resistance during passive soft-tissue stretching. FSR sensor was determined by measuring the latency of bicep and forearms extensor reflex force relative to the onset of muscle reflex myoactivity.

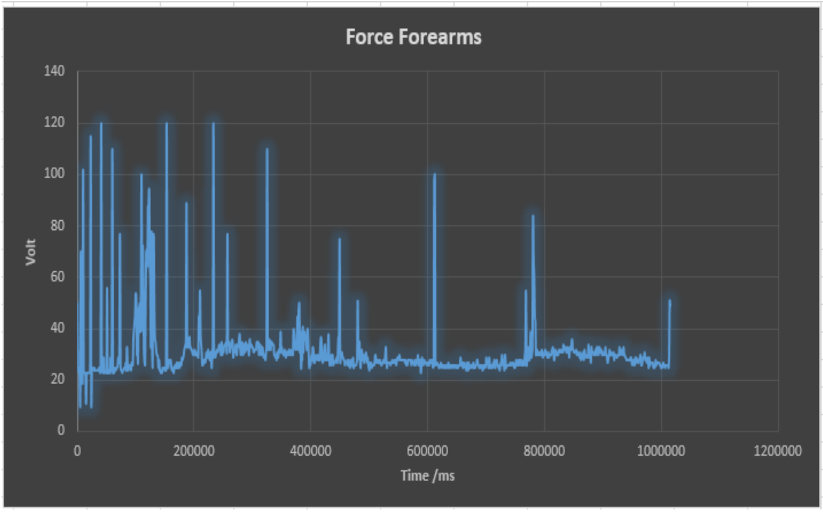
Figure 7(a) to (b) show the result of the preliminary experiment based on Kinovea software. Figure 7(a) shows the result of force exerted on the FSR attached on the shoulder. Figure 7(b) shows the result of force exerted on the FSR attached on the bicep. Both results show different peaks which is the position where the strength of the robotic arms is at the maximum use. From this signal, it shows that the Kinovea recorded the robotics arms and human arms kinematics in different angle. With respect to the way the bend sensors are utilized, it makes sense to take advantages from a step wise linear behaviour.

(a) Initial condition (b) 30deg arm bend (c) 90deg arm bend

Figure 6. Preliminary experiment involves simple arm bending movement to record muscle activity



(a) Force exerted on shoulder



(b) Force exerted on bicep

Figure 7. Results show muscle activities during experiment while using the developed device.

4. Conclusion

This paper presents preliminary design and development of a robotic exoskeleton for arm rehabilitation. The design of this device is for right hand use only. However, taking into account modular design, the device will be able to be used for either hand in the future. As this device is still in developing stages, continuous efforts are being done to make the device useful in real application. Preliminary experimental result shows the device equipped with force sensitive resistor can provide information on how the muscle respond during robot assisted rehabilitation. Acknowledgement

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