IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684,p-ISSN: 2320-334X, Volume 16, Issue 2 Ser. II (Mar. - Apr. 2019), PP 43-47
www.iosrjournals.org

Design a Smart Exoskeleton Robotic Arm for Elbow Rehabilitation

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Abstract: *This study presents a smart arm exoskeleton roboticdevice that designed to perform the physical therapy for disabled patients in order to rehabilitate the affected limb. The basic principle of this exoskeleton is its dependence on electromyography signal; MyoWare sensor was used to measure surface electromyography signal. Surface electrodes were used between skin and MyoWare to pick up the signal from biceps brachii muscle.*

The microcontroller processes the signal of muscle activity and outputs a voltage to control the direction of a motor. The motor moves the actuator arm through Bowden cable.

The exoskeleton robot is one degree of freedom performs the flexion and extension of the elbow joint. After the design was completed, it was tested according to some parameters to check its efficiency.

The resultsindicated the feasibility of this exoskeleton to move according to muscle's signal and to tolerate the human arm's weight whatever the human weight.

Date of Submission: 04-03-2019 Date of acceptance: 20-03-2019

I. Introduction

Studies and research are concentrates on building a modern system that merge human and robot into single system that works to help healthy and disabled people. Where human possesses mechanisms and systems that enable him to move in a flexible, developed and natural movement, but this movement is limited by the strength of muscles[1]. Most people who mean loss of movement are due to muscle weakness coming from neurological and muscular diseases and central nervous system injuries[2].

On the other hand, the robotic system can move with great force but it lacks to the pliability and good performance that can be achieved in natural by a human. So studies have worked on merging these two systems (human and robot) in single system that is man-centered in an integrated manner In order to take advantages of the properties of both systems[3].

An exoskeleton is an external structural mechanism whose joints correspond to those of the human body. The name stems from the words exterior and skeleton[4].Accordingly, the name upper limb exoskeleton denotes that it can be worn on the arm externally, ensuring free movement of the arm with increased strength and performance[5].

The same device may be used with different control algorithms in four basic operating modes: - 1) Assistive device, 2) Physiotherapy, 3) Master device, 4) Haptic device[6]. The interest in developing new robotic devices for medical rehabilitation is due to their capacity to perform repetitive tasks and also because they allow to analysis the patient evolution objectively[7].

II. Materials And Methods

This study aims to design the appropriate exoskeleton robotic arm with different materials and test it on healthy subject to determine whether it can apply to disabled patients as physiotherapy device.

The materials used in this study are:-

1) EMG Sensor, 2) Electrodes, 4) Microcontroller, 5) Actuators, 6) Motor, 7) Driver, 8) Pulley, 9) Bowden cable, 10) Battery, 11) Charger, and 12) Switches.

Steps of designing the exoskeleton robot is as follow:-

- MyoWaremuscle sensor was connected to the microcontroller by wires as in figure 1.

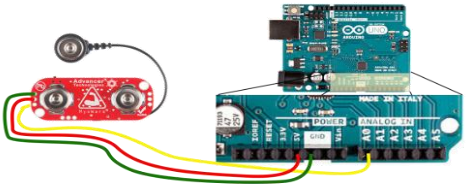

Figure 1: Connecting the Myoware with the microcontroller**.**

- Ag/Ag-Cl electrodes were connected to the Myoware then placed it in a bipolar arrangement on the middle of the muscles in direction of the biceps brachii muscle fibers as in figure 2.

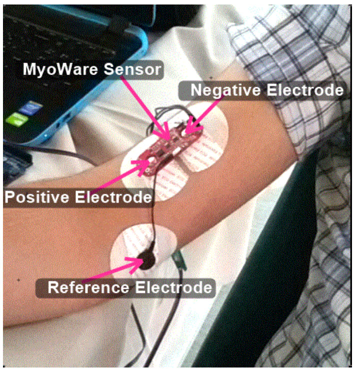

Figure 2: The electrodes fitted on biceps brachii muscle.

- Before putting the electrodes on the skin, the skin was cleaned with a piece of cloth and alcohol to remove dirt and oil.
- The first design of exo-arm is a Polytetrafluoroethylene (PTFE) or Teflon exo-arm shown in figure 3, this material has properties of hard, can bear high load, low mass and easy to fabricate.

Figure 3: Teflon exo-arm.

- The second design of exo-arm is a metal-arm brace as shown in figure 4. It consists from aluminum shafts, stainless steel joint, two bandages, and four straps.

Figure 4: Metal-arm brace.

- This metal arm brace was converted to active orthosis that gives flexion and extension of elbow joint by putting Bowden cable in forearm actuator that works to flex the exo-forearm toward the exo-upper arm like the human flexion muscle of elbow joint, and by putting a resistive spring that works as exo-extension and works as resistant forgive strong to muscle when holding forearm.
- Flexion and extension angle of the metal-arm brace was limited between (0° and 130°) measured it by goniometer as illustrated in figure 5.

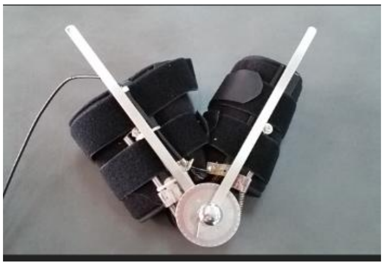

Figure 5: Using goniometer to limit the angle of the metal-arm brace.

- Switch was connected to the DC motor to run it directly for moving exoskeleton-arm passively and also for testing the device.
- Precautions have been implemented on three levels, built into the mechanical, electrical, and software designs
- Lithium polymer (LiPo) battery, three cells, 11.1V, and 2200 mA was used as a power supply to the motor of the exoskeleton robot. The battery was charged by three cells charger.
- The motor takes its power either from LiPo battery or from 20v DC converter.
- For software; programming MATLAB and Arduino were used to analyze the EMG signal, control movement of motor and draw curves of elbow angle.

Procedure methodology

It is important to take care of the design by selecting a material with appropriate characteristics and designing it professionally to suit the intrinsic interaction between human and the exoskeleton arm. Teflon exo-arm was designed, and then it was replaced by a metal-arm brace for many reasonsinclude low friction in its joint, low cost and less time.

In this study, rectified signal was used for reading muscle activity and as input signal to the microcontroller. Since, the EMG signal act as calibration for each patient according to patients muscle strength.

The microcontroller converts the analog signal that come from muscle to digital signal that act as input to motor driver. Servo motor was converted to DCmotor to avoid the limited in its rotation or ROM that found in servo. Pulley was connected to the motor shaft supported with a Bowden cable that matches the motor with the actuator.

For safety factor:

1. Two limit switches were put to limit the continuous movement of DC motor, in which to prevent segments from excessive excursions that could hyperextend or hyper flexion individual joints.
2. Switch was connected to power supply.
3. Switch for run the motor in two directions.

After the exoskeleton device was designed, it was tested according to motor velocity, motor torque, ROM, lifetime of the battery, time for charge the battery, use the best type of electrodes, velocity of microcontroller process and the efficiency of EMG sensor.

III. Result

To determine the device's ability to carry the weight of the lower arm whatever the weight of the person, the device was tested on a donor of known weight and length. The weight needs to find lower arm's weight and the length to find the location of lower arm's center of mass (COM). Instead of checking the device on number of people with different weight and length, the same donor was used with the addition of weights in his hand to achieve a weight equal or greater than the weight of the lower arm of fat human.

The torque is the product of force and the perpendicular distance from the force's line of action to the axis of rotation. So the weights that put in the hand have a high moment arm. In this way, the torque will be greater than if the weights were in the COM of the lower arm.

The device is turned on by passive exercises "by turn motor directly without receiving a signal from muscle" with the guidance of the donor not to flex his lower arm and stay without movement to let the lower arm to flex only by effect of motor torque to rise exoskeleton arm alone, figure 6.

Figure 6: The device can hold the arm with different kilograms of weights.

Figure 7, presents torque calculations, where:
L = 3 kg and 2 kg, presents the weights hold in the hand when the motor moves with power 20v and 11.1v respectively.
W = 1.89 kg, presents the mass of donor's lower arm which came from donor's total body mass (75 kg) multiplied by anthropometric segment mass of lower arm.
A = 37 cm, presents the distance between elbow joint and weights in the hand.
B = 17.18 cm, presents the distance between elbow joint and the COM of lower arm that came from donor's total body height (178 cm) multiplied by anthropometric segment length and by segment COM of lower arm.

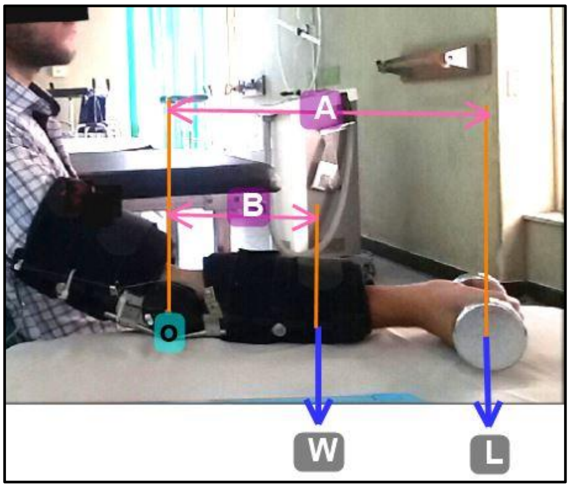

Figure 7: Torque calculation.

The torque about exoskeleton arm joint can be calculated as:
$T_{\circ} = (L*A) + (W*B)$ ……. (eq. 1)
For power 20v the torque is:
$T_{\circ} = (3*37) + (1.89*17.18)$

$\boxed{T_{\circ} = 143.47 \text{ kg.cm}}$

For power 11.1v the torque is:
$T_{\circ} = (2*37) + (1.89*17.18)$

$\boxed{T_{\circ} = 106.47 \text{ kg.cm}}$

The speed of exoskeleton arm movement was calculated according to the time of moving the exoskeleton arm to reach the maximum flexion angle where:

Time = 8 s and speed = 16.25 °/s when power is 20v, and
Time = 14 s and speed = 9.286 °/s when power is 11.1v.
The battery consists of 3 cells, and through the test of the device, it has shown that the life time of one cell is half hour. So, the total battery lifetime is 1 hour and half.

IV. Discussion

The present study aimed to design the appropriate exoskeleton robotic arm with different materials and test it on healthy subject to prepare it to apply to disabled patients as physiotherapy device
The choice to have the motor on the arm instead of on the package put a higher demand on the motor as it needs to be light and at the same time strong. If it would have been mounted on the back a heavier motor could have been used as it is easier to have a "package" with motor and pulley.

Although studies have shown that the use of EMG as a control system has positive influences in patient recovery, a myoelectrically controlled exoskeleton system has frequently been implemented as an assistive device or human power augmentation device instead of therapeutic device.

Many articles studied just the design of exoskeleton system with electronic results, while the present study investigated the therapeutic effect of exoskeleton arm device physiotherapy using continuous myoelectric control in terms of robot-measured parameters.

V. Conclusion

The result shows that this exoskeleton robot has a mechanical engineering specification that enables it to perform physiotherapy exercises for patients with arm disorders.

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Duha Qais Abdul-Amir. "Design a Smart Exoskeleton Robotic Arm for Elbow Rehabilitation." IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) , vol. 16, no. 2, 2019, pp. 43-47.