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DESIGN THE UPPER LIMB EXOSKELETON ARM FOR REINFORCEMENT THE WEAKNESS IN THE HUMAN MUSCLES

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ABSTRACT

There is a group of patients especially stroke and spinal cord injury that suffering from loss of moving in a particular limb or have hemiplegia needs continuously physiotherapy exercises in order to restore the movement of the limb even a fraction. So, in this study, a device was designed to perform the physical therapy for this group of patients in order to rehabilitate the affected limb. This device called Exoskeleton. The basic principles of the exoskeleton are its dependence on electromyography signal; MyoWare sensor was used to measure surface electromyography signal, this signal goes to the microcontroller which in turn gives the order to the motor to move the actuator arm through a Bowden cable. The exoskeleton is one degree of freedom performs the flexion and extension of the elbow joint. After the design was completed, the exoskeleton was examined on 4 normal persons and then applied to 15 stroke patients and 4 spinal cord injury patients. After several sessions of physiotherapy exercises, the results showed that the benefit of the exoskeleton in strengthening the muscles as well as in increasing the elbow range of motion and in this way the exoskeleton has proven its possible to perform physiotherapy exercises, especially for stroke patients.

Keywords: exoskeleton, electromyography, stroke, elbow, myoware.

INTRODUCTION

Each person does not want to live dependent on other people to help him in any way and wants to spend his life as a healthy individual. Nevertheless, the physical problems suffered by human prevent him from achieving this. With the modernity of society, a large percentage of the population in the word are physically weak due to aging, congenital diseases, physical diseases, and occupational hazards. Also, in some cases, after a stroke, Traumatic Brain Injury (TBI), Spinal Cord Injury (SCI), and various neurological disorders are the main reason to make the sufferer will certainly have to submit physical rehabilitation in order to adjust him change the state of the body [1].

More than 600 muscles within the human body give the movement of the body and are linked to the effectiveness of his life. In general, these muscles are not only responsible for the vital functions within the human body, such as heartbeat and breathing, but are responsible for movement in all organs of the body as the movement is one of the most important needs of the human to carry out daily activities such as walking, eating, and communicating with the community, as well as movement, is necessary for human health to activate muscles and circulation system of the body [2].

In any way, any imbalance in the movement of the human body leads to a lack of quality of life, especially in the upper limbs, which restricts the person's freedom to deal with the requirements of life [3].

Many researchers are working on rehabilitation procedures for the therapy, to give the hope of independent life to these people. Alongside with different statistical reports on brain injuries, there is a considerable encouragement to look up rehabilitation of these patients (specifically stroke survivors). Although it has been found that therapy is effective in the treatment of movement disorders, due to economic burdens therapy hours per patient have decreased. Studies have shown that inclusive and optimal stroke care can decrease the associated costs significantly. This optimal care can be achieved through the application of new technologies [4].

The main goal of modern medicine is to rehabilitate people who are a loss of motoric functions and to make them able to restore functional deficiencies and depend on themselves instead of depending on the help of others [5].

Stroke is the main reason of disability and death in many countries. Because of the disabilities caused by the stroke, the surviving patients are often considered to be people with a minimize quality of life (QOL). This is due to the lack of movement of a part or often a paralysis of the half of the body, which impairs the daily functioning of them. It is important for them, their families and the community to improve their lives by helping them to regain their lost motor functions. Familiarly, these patients are subject to physiotherapy sessions to be treated in manual mode one by one by the therapists at the medical center. In last few years, the robotic system has become integrated with the medical therapist to rehabilitate the lost organs of the movement [6].

Clearly, the cost is the main factor in making advanced rehabilitation devices of limited use. Indirectly, As the science progresses, studies are being carried out to reduce the size of the medical rehabilitation equipment, thus reducing the cost and size, making it portable and easy to store, as well as being with the patient at home to perform physical therapy at home [7].

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There are some previous studies that offer topics that are concerned with the loss of the upper limb movement and the process of rehabilitation.

Roland W. [8] designed orthosis of fluidic actuators used for assisting the elbow function and the internal rotation of the shoulder. The result showed that elbow orthosis able to assist the shoulder and elbow task in healthy people with 100% of the demanded force, and the torque curves expressed that patients with limited motor functions can be assisted with up to 100%.

Marco C. *et al.* [9] developed a modified portable robotic elbow exoskeleton (NEUROExos), designed for handling of stroke survivors in acute/sub-acute cases. Series Elastic Actuation (SEA) system was used in designing. Spring deformation was measured by two absolute encoders and the spring stiffness was known for the torque applied to the joint.

Matteo M *et al.* [10] designed a prototype device for upper-limb rehabilitation featuring variable-stiffness assistance and force-feedback. The device designed for at home to be used as upper-limb neurorehabilitation. It was made with plastic material by a 3D printer.

Christoffer B. and Rickard S. [11] constructed full-size prototypes were in an iterative process to find the optimal structural solution. Low-cost materials were used to be able to easily change and enhance the design until a good solution was found. The result was a construction controlled by evaluating the torques from the user's movement with the use of force sensors placed at the wrist.

Victoria Wumi [12] evaluated the usability of a novel soft robotic module for providing elbow movement assistance. The soft robot consists of a wedged shaped silicone rubber actuator actuated by means of low air pressure pneumatics. To obtain visual information regarding the angle of motion, color tracking is done.

The Present Study Aims to the Following:

- Design and implement an exoskeleton arm based on electromyography (EMG) signal to rehabilitate of the disabled limb.
- Apply the system to the specific group of patients, it can speed up the muscle strength and the recuperation of stroke and spinal cord injured patients.
- Enable the patient to receive treatment exercises regularly without the need to help the therapist on a continuous basis. As well as reduce the time and cost as the therapist can supervise many of the patients at the same time.

Anatomy and biomechanic of elbow joint

The elbow is one of the complex joints connecting the upper arm with the forearm consisting of three bones (humerus, radius, and ulna) and articulated from two places (humeroradial and humeroulnar) as shown in (Figure 1). The humerus of the upper arm connects to the radius and ulna of the forearm [13].

Figure-1. Elbow complex [14].

Flexion-extension and pronation-supination are the human elbow joint movements, and that makes the joint considered as a 2 DOF joint [15]. The exoskeleton, in this study, is 1 DOF supported the flexion-extension movement of the elbow joint. The normal range of elbow movement in flexion and extension is approximately 0 to 150 degrees; with a range of 30 to 130 that human needs during most activities of daily living. These two movements have several muscles responsible for their movement and are divided into two groups:

a) The primary flexor muscles-the Brachialis, the Biceps Brachii, and the Brachioradialis.

b) The primary extensor muscle-Triceps Brachii [16].

In this study, the Biceps Brachii muscle was selected to capture the electrical signal produced by the group of flexion muscles Because of its proximity to the surface of the skin by noninvasive techniques.

Electromyography

High level of electrical activity in the muscle was resulted from tetanic frequencies that came from recruited of all motor units for produce maximum muscle contraction. This muscle electrical activity termed electromyography or EMG [17]. There are two methods for detecting EMG signal; invasively using intramuscular electrode or non-invasively using surface electrodes.

Surface EMG is a summation of single motor-unit action potential MUAP as shown in (Figure-2). The electrical activity of the muscle will generate the muscle force which in turn depends on the firing rate of stimulation and number of recruited motor unit [18].

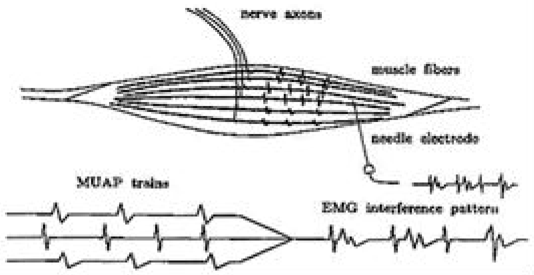

Figure-2. Schematic drawing, illustrating the summation of MUAP trains to form the EMG signal [19].

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The exoskeleton system

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 [16].With advances in modern technology the exoskeleton robot technology has acquired a quick expansion in the fields of electronic engineering, mechanical engineering, biomedical engineering, and artificial intelligence in recent years [14].

The most distinctive medical applications for an exoskeleton are as follows:

a) Stroke rehabilitation (ischemic and hemorrhagic ictus), thanks to brain plasticity to regenerate neurons in an anatomic and functional way. It is the most interesting application, and it is analyzed particularly in the following sections.

b) Muscular stimulation for aged people.

c) Spinal cord injury recovery.

d) Muscle injury recuperation [16].

The safety is the main request of each equipment that interacts with the human. So, safety is the highest preference for the upper-limb exoskeletons as it immediately interacts with the human user [20].

Exoskeletons and rehabilitation

For both stroke and SCI, current rehabilitation protocols include multiple sessions with repetitive movements of the affected limb distributed over multiple weeks. The goals of these treatments are to enhance neuroplasticity and restore of motor function [21]. Originally, exoskeletons have the capability to give precise and topical by nature magnitude assistance for each the dynamics and the kinematics of motion. This can be applied to measure efficiency and observe the recovery step with much more sensibility and accuracy than conventional functional outcome [22]. Furthermore, exoskeletons can produce controlled movements with facility and sensitivity. The automatic work of the exoskeleton system made it possible to monitor many patients by one physiotherapy with each other which reduces the burden on the health care system [13].

MATERIALS AND METHODS

Using the muscle activity (Electromyogram signals) is one of the substantial processes which are used to control exoskeleton arm. The benefits of using the surface EMG signal are that it does not need surgery, and surface electrodes are very easy to put it on the skin [4].

To collect the surface EMG signal, MyoWare sensor was used to measure a muscle's activity as shown in (Figure-3), which was intended to be wearable and to have adaptable obtain, the voltage supply is +5 Volts, current supply 9mA with protect polar reflection. The MyoWare sensor measures and amplifies the muscle's electrical activity as an analog signal that can be read by the controller with an analog to digital converter. When the amplitude of the EMG signal is promptly concerning to the exerted force by the muscle, it is used to determine the force signal sent to the exoskeleton.

Figure-3. MyoWare sensor.

The Myoware gives two types of signals, raw and rectified signal as shown in (Figure-4) (Figure-5) respectively. In this study rectified signal was used for reading muscle activity and as an input signal to the microcontroller. EMG signal act as calibration for each patient according to patients muscle strength. The microcontroller converts the analog signal that comes from muscle to digital signal that acts as input to the motor driver. Pulley was connected to the motor shaft with a Bowden cable that matches the motor with the actuator.

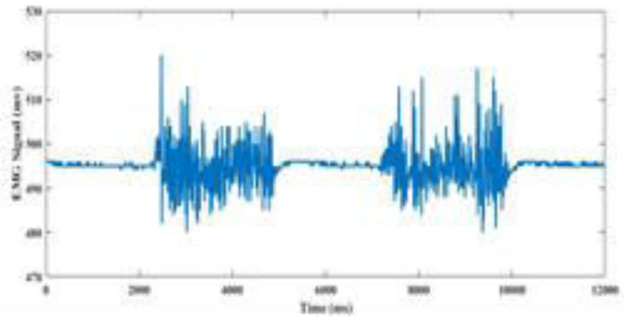

Figure-4. RAW Signal.

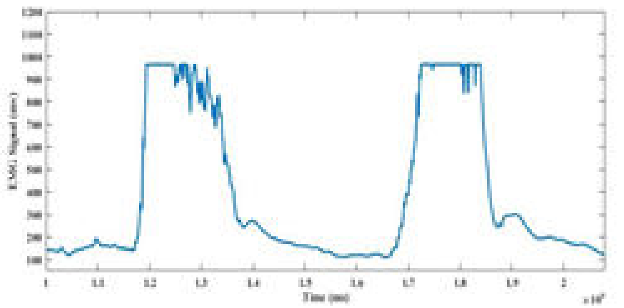

Figure-5. Rectified signal.

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Teflon exo-arm was designed; this material has properties of hard, bear the high load, low mass and easy to fabricate (Figure-6). This Teflon exo-arm was replaced by an exo-arm brace for many reasons include low friction in its joint, low cost and less time in fabrication (Figure-7). This 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 for giving strong to muscle when holding forearm.

Figure-6. Teflon exo-arm.

Figure-7. Exo-arm brace.

Gyroscope sensor was connected to the microcontroller and put it in the forearm for measuring the elbow angle.

The motor takes its power either from lithium polymer (LiPo) battery or from 20v DC converter. The switch was connected to the DC motor to run it directly for moving exo-arm passively and also for testing the device. For safety:

a) Two limit switches were put to limit the continuous movement of DC motor.
b) The switch was connected to power supply.
c) Switch for running the motor in two directions.

For software; programming MATLAB and Arduino were used to analyze the EMG signal, control movement of the motor and draw curves of elbow angle.

Testing the device

After the exoskeleton device was completely designed, it was tested according to motor velocity, motor torque, range of motion (ROM), a lifetime of the battery, time for charging the battery, using the best type of electrodes, the velocity of microcontroller process and the efficiency of EMG sensor.

Apply the device to the patients

In this study, the exo-arm was applied to stroke and SCI patients for rehabilitation the arm through flexion and extension of the elbow joint (Figure-8). Elbow angle was measured for the healthy arm of the same patient as a reference.

Figure-8. Apply the device to the patient.

Steps of rehabilitation therapy

The first and most important step is that each patient must know the objective and importance of the exoskeleton device. Steps of physiotherapy start with a passive exercise where the patient can't move his arm in the first sessions. Then, passive exercise turns to active exercise when the patient begins to flex his arm weakly. EMG signal from biceps brachii muscle was measured with the beginning of each session and according to this signal, the microcontroller was programmed to give the order to the motor driver to start moving. With each session elbow ROM and EMG signal were measured as a biofeedback, that's mean that EMG signal was measured as aninput to the microcontroller and as biofeedback. Elbow ROM was measured with and without exoskeleton for the affected arm to see how the ROM develops from first to the last session. This exoskeleton robot was applied to 4 normal volunteers, 15 stroke patients, and 4 SCI patients. Each patient submits to many sessions with an average of two sessions per week. A number of total sessions depend on the severity of the injury or stroke for each patient.

Patient's information has been taken which includes: (name, gender, age, length, weight, type of disease and other diseases).

Elbow angle was measured for the normal arm and the affected arm by using goniometer (Figure-9).

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Figure-9. Measuring elbow angle by goniometer.

RESULTS

Results are for the patient who submits to fifteenth sessions of physiotherapy by exoskeleton. Patient's information present in (Table-1). Results include the curves of elbow ROM and the curves of EMG signal:

The first session shown in (Figure-10) indicates to passive exercise, the fifth session shown in (Figure-11) indicates to the first active exercise and the fifteenth session shown in (Figure-12) indicates to the last active exercise.

Table-1. Patient's information.

Name	**A.H.**
Gender	Male
Age (year)	67
Length (cm)	160
Mass (kg)	70
Type of disease	Stroke
Affected arm	Right
Time between passing the disease and starting therapeutic exercises (week)	4

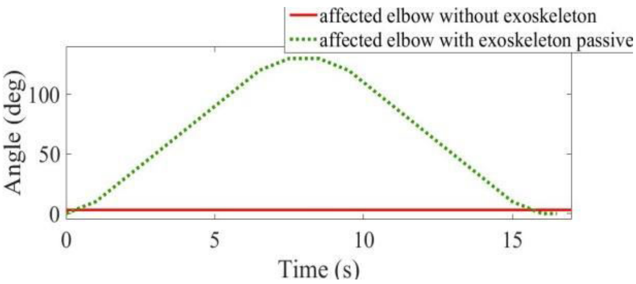

Figure-10. A: Elbow ROM through passive exercise.

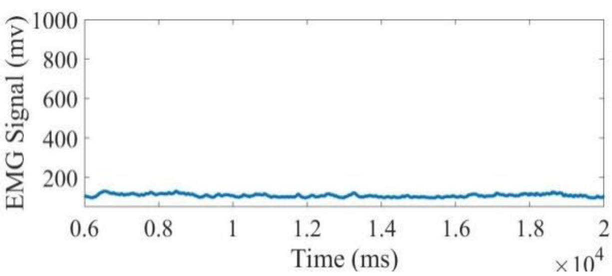

Figure-10. B: EMG signal of biceps brachii muscle without exoskeleton.

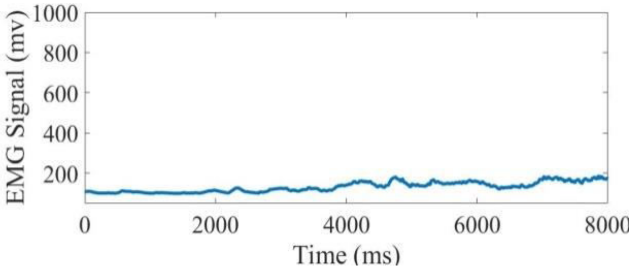

Figure-10. C: EMG signal of biceps brachii muscle with exoskeleton through passive exercise.

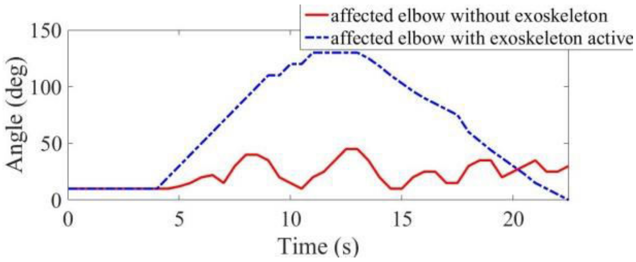

Figure-11. A: Elbow ROM through first active exercise.

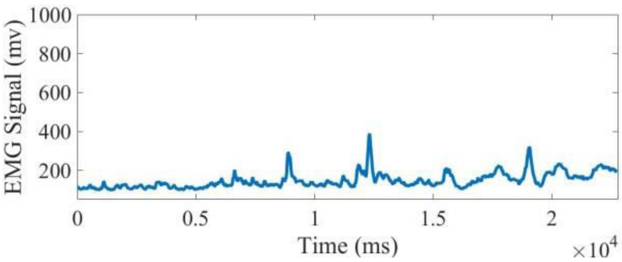

Figure-11. B: EMG signal of biceps brachii muscle without exoskeleton.

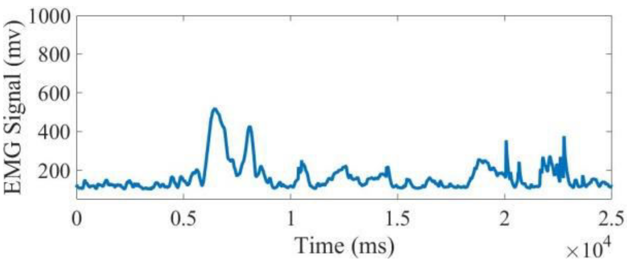

Figure-11. C: EMG signal of biceps brachii muscle with exoskeleton through active exercise.

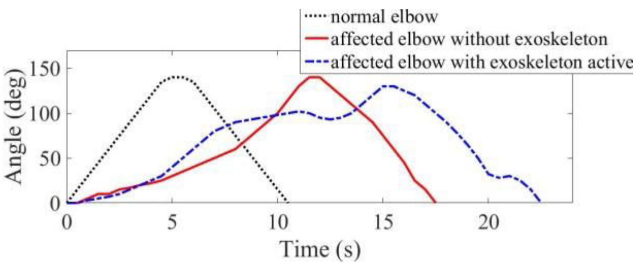

Figure-12. A: Elbow ROM through last active exercise.

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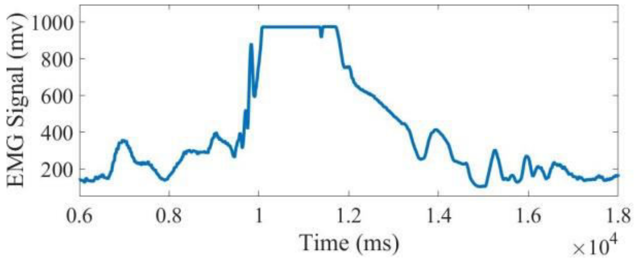

Figure-12. B: EMG signal of biceps brachii muscle without exoskeleton.

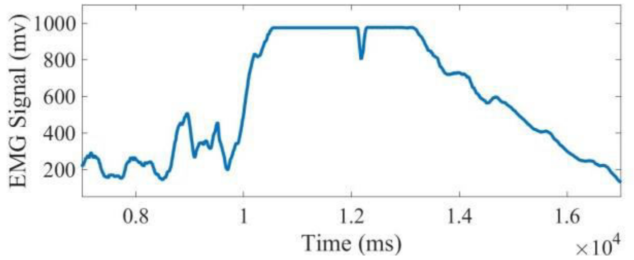

Figure-12. C: EMG signal of biceps brachii muscle with exoskeleton through active exercise.

DISCUSSIONS

The present study aimed to evaluate the effect of a training program using exoskeleton for physical rehabilitation, with an emphasis on improving the performance of activity daily living in participants with upper limb motor squeals as a result of stroke and SCI. The results of this study indicated that the tested exoskeleton can benefit the functional capacity of the upper extremity in patients with hemiplegia. This exoskeleton device works to perform two kinds of therapeutic exercises: passive exercise and active exercise. It starts with the patient from the first session of physiotherapy, but if the de-vice gives only active exercise, in this case, the therapy will begin from advanced sessions when there is enough muscle force to move weakly. Passive exercise acts as an external force that move the limb, and this movement don't related with muscle force, therefore there is no effect to muscle signal EMG through passive exercise because it is not voluntary movement.

CONCLUSIONS

For this study, the following conclusions can be reached:

a) The results illustrate the importance of using EMG signal as an input control for exoskeleton arm and this occurs in EMG biofeedback as follow:

- The muscle signal is silent through passive exercise.
- There is very strong muscle signal through active exercise, this occurs from moving the muscle from its own force and the presence of spring in exo-arm as a resistant that give to muscle more strong.
- There is a high change of EMG signal from first to the last session.

b) The result shows a high change in ROM from first to the last session.

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