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Robotic Exoskeleton for Elbow Rehabilitation

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Abstract:

The movement Impairments of motor function as a result of neurologic injuries causes in disabilities motions of subjects for performing the activities of daily living. The urgent need to regain the activities of daily living enabled the physiotherapists to perform considered exercises to recover the suffered patient's motions. This study aims to construct, and manufacture a robotic exoskeleton flexible, portable, comfortable and adjustable for a wide range of users to rehabilitate patients who suffer from spinal cord injury, stroke the rehabilitation concerned on elbow joints with comprehensively their one degree of freedom (1 DOF). The present exoskeleton offers a flexion/extension for the elbow. It is constructed using SoildWorks software program and manufactured with 3D printer technology using the polylactic acid thermoplastic material. The exoskeleton supports the home-based therapy. It is actuated using servomotors and controlled using the electromyography signal extracted from biceps muscles using myoware sensor for measuring muscle with angle data as an assistance of controlling using gyroscope sensor for measuring angle the controlling process using Arduino uno the exoskeleton was supported with visual by using Organic Light-Emitting Diode display(OLED). The exoskeleton supports active-assistive mode of operation

Keywords: *impairments, exoskeleton, organic*

Introduction

Stroke or Cerebrovascular Accident (CVA), Spinal Cord Injury (SCI), or different type of disorders of the motor neurons [1] causes hemiparesis resulting in impairment of the upper limb and disabilities in performing the activities of daily living, with consequent medical and social care consuming a huge amount of healthcare resources. When this type of accidents happens, the patient can recuperate from these disorders (at least partially) with the aid of rehabilitation treatments and therapy. The process of recuperation differs in function of the type of lesion and the period of time that has passed since the accident occurred. The rehabilitation therapy involves a series of repetitive movements executed by the patient with the aid of the therapist. This requires special attention and more therapists [2]. Robot-aided physical rehabilitation has been proposed to support physicians in providing high-intensity therapy, consisting of repetitive movements of the impaired limb. Robots can allow patients to receive more effective and stable rehabilitation process, and reduce the workload to the therapists. Robots can also offer reliable tools for functional assessment of patient progress and recovery by measuring physical parameters, such as speed, direction, and strength of patient residual voluntary activity [1]. Numerous rehabilitation-robotic devices have been developed since the late 90s, particularly for the neurorehabilitation of post-stroke patients. Most of these devices guide the movement of the hand in one plane. Some robots can passively mobilize the limb of patients with poor recovery or can provide precisely controlled active assistance as a function of patient's capacity. An advantage of robotic assistance is the possibility for patients to carry out a great number of movement repetitions, increasing the intensity of therapy [3]. In the last two decades, the upper-limb exoskeletons used for services and rehabilitation have attracted a lot of attention from the biomedical and engineering sectors. The technology is becoming important as a potential solution for physically weak or disabled people, so it help, they are assisting joint movements, rehabilitating and treating joint dysfunctions, muscle strength augmentation, and haptic interface [4]. In rehabilitation applications, the exoskeleton should be able to replicate with a patient the movements performed with a therapist during the treatment. Robotic rehabilitation devices come to aid the therapists, offering a more effective and stable rehabilitation process compared to the traditional rehabilitation sessions effectuated by therapists and reducing the cost of hospitalization [5]. In 2013, **Nicola et al.** [2] designed the NEUROExos where focused on three solutions that enable its use for post-stroke physical rehabilitation. First, double-shelled links allow an ergonomic physical human–robot interface and, consequently, a comfortable interaction. Second, a four-degree-of-freedom passive mechanism, embedded in the link, allows the user's elbow and robot axes to be constantly aligned during movement. The robot axis can passively rotate on the frontal and horizontal planes 30◦ and 40◦, respectively, and translate on the horizontal plane 30 mm. Finally, a variable impedance antagonistic actuation system allows NEUROExos to be controlled with two alternative strategies: independent control of the joint position and stiffness, for robot-in-charge rehabilitation mode, and near-zero impedance torque control, for patient in-charge rehabilitation mode. In robot-in-charge mode, the passive joint stiffness can be changed in the range of 24–56 N·m/rad. In patient-in-charge mode, NEUROExos output impedance ranges from 1 N·m/rad, for 0.3 Hz motion, to 10 N·m/rad, for 3.2 Hz motion. In 2019,**Soumya and Venketesh**[6] developed a portable elbow exoskeleton for delivering three stages of rehabilitation in a single structure without affecting the range of motion and safety features. Use of electric motor and springs have been arranged in the actuation mechanism to minimise the energy consumption. The developed exoskeleton enhances torque to weight ratio compared to existing models and all three modes of rehabilitation have been controlled using a single motor. In 2019, **Dorin et al.**[1] introduced a prototype of exoskeleton for the evaluation and rehabilitation therapy of the elbow joint in flexion extension and pronation-supination. The main novelty is the use of bioinspired actuators based on shape memory alloys (for the first time) in an upper limb rehabilitation exoskeleton. Because of this, the device presents a light weight, less than 1 kg, and noiseless operation, both characteristics are very beneficial for rehabilitation therapies. In addition, the prototype has been designed with low-cost electronics and materials, and the result is a wearable, comfortable, and cheap rehabilitation exoskeleton for the elbow joint. The exoskeleton can generate the joint torque (active mode) or it can be used as a passive tool (The patient performs therapy by itself, carrying the device while it collects relevant movement data for evaluation.) The simulations and experimental tests validate the solution in the first phases of rehabilitation therapies when slow and repetitive movements are required. In 2016, **Bator and Svensson** [7] constructed full-size prototypes exoskeletons 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. It was physically tested with human movement. A servo motor was also used to simulate human arm movement and then the signals from the sensors and controller were monitored and compared to the signals used to control the servo. 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. In 2019, **Duha et al.** [8] proposed a smart arm exoskeleton robotic device 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 results indicated the feasibility of this exoskeleton to move according to muscle's signal and to tolerate the human arm's weight whatever the human weight. In 2022, **Maryam H. N.** . [9] designed a portable elbow exoskeleton to rehabilitate patients who suffering stroke, muscular or neuromuscular diseases. The goal of this study is to develop a device which will be able to unload the injured elbow, partial or fully compensate muscular effort required to bend the upper extremities also restoration of the joints moving functions during the rehabilitation period. The main advantages of the developed device are the improved functionality and low cost[10-14]. The exoskeleton was implemented and tested based on a 3D printed design, it worked on different cases, the mechanism can evaluate (flexion, extension) movements without any significant problems[15-19]. This study aims to Manufacturing, and constructing a 1 DOF, portable, low cost, upper limb–elbow robotic exoskeleton using Soildworks software program and 3D printed technique. controlled using surface electromyography signal assisted with angle sensor by providing the exercises for rehabilitation of patients who suffer from stroke and SCI. Provides Active-assistive exoskeleton robotic device to regain lost motor skills by helping the brain rebuild neural pathways lost as a result of disease or trauma. Manufacture the electronic circuit utilizing several electronic components. Evaluate the performance, and efficiency of the device.

Methodology

This section presents the electronic and mechanical construction using 3D printed technology and software programs used for processing and constructing an exoskeleton. It is based on the anatomy of the human's forearm and wrist taking into account the anatomical structure and rotational axis of the human in order to provide motions matching that of the human ones in terms of anthropometry, Range of Motion (ROM), axis of rotation, and velocity.

MECHANICAL DESIGN

The main role of the presented robotic exoskeleton is regaining the mobility for patients by rehabilitation therapy through motions in one anatomical plane, so the ROM must be of most importance. The human lower arm segments' anatomical lengths were used to guide the construction of the robotic exoskeleton to achieve the required rehabilitation. There are two main structure of the presented exoskeleton, the first one is the arm structure and the second one is the forearm structure, both of these structures are designed in such a way that matching the anatomical structure of the human. The design structure must be as easy as possible, its rotational axis matching that of the elbow joint, comfortable, low cost, and available for all patients. These components designed using SolidWorks, a computer-aided design (CAD) software program. There are many benefits associated with this software program include its simplicity, which enables the designer to make adjustments and change the design in a way that reduces errors and addresses design issues. Also, it has the ability to transform and store the design in a manner that is compatible with any type of 3D printer, enabling the production of each component. The exoskeleton was printed using 3D printer.

Exoskeleton Structure Parts

The exoskeleton structure was interred in the solidworks software and the parts were printed with 3D printer, this technique of printing offers high accuracy results when it comes to dimensions. The forearm structure is also constructed with a hole to position the display and the upper structure is constructed with a hole to position the servomotor.

Three arm and forearm holders were constructed to be applicable for all patients according to their restricted requirements. It is configured to hold the arm and forearm attaching with the strip to ensure the constancy of it. (see Fig 1)).

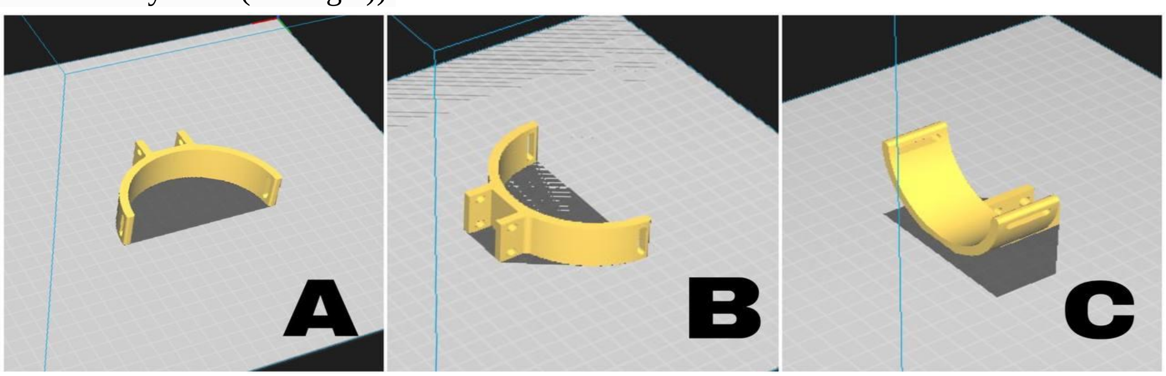

Figure 1 Arm and forearm holders, A and B: the arm holder, C-the forearm holder.

Forearm and arm levers were designed to give the device durability and flexibility to move in a smooth technique without harming the patient and to help provide plainness to the device (see Fig 2)).

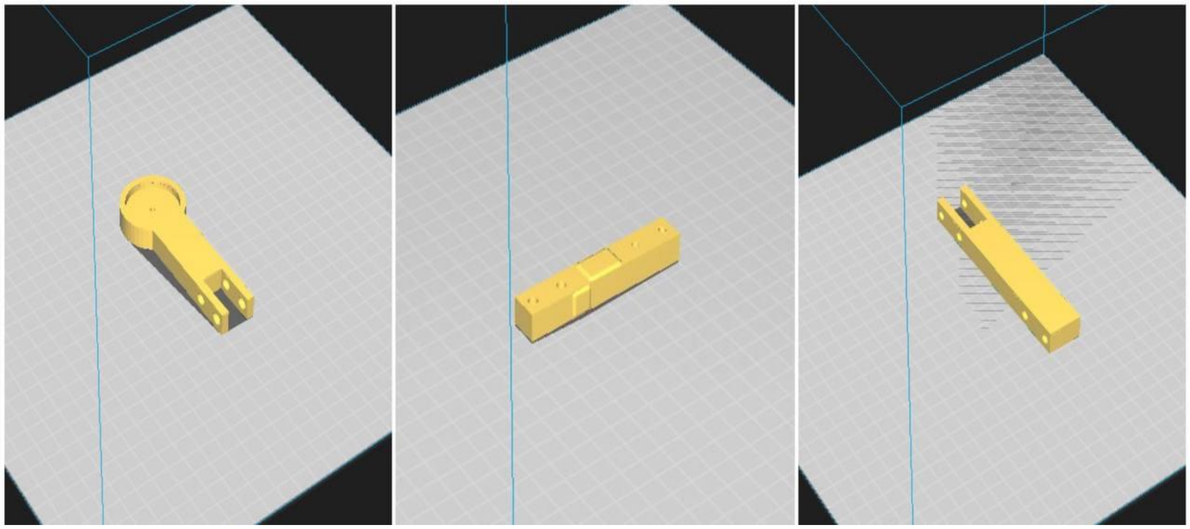

Figure 2 Forearm and arm levers

Servo motor holder was designed to provide holding and supporting to the servo motor, the servo motor is positioned in a way to provide center of rotation as that of the human (see Fig

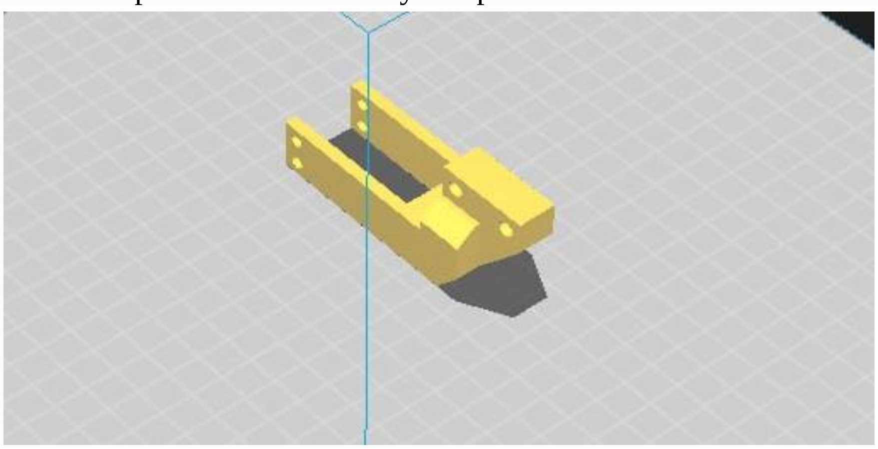

Figure 3 Servo motor holder

An additional supporter base was constructed and printed to place the overall electronic circuit inside the exoskeleton. The box components consist of two parts, the first part is placed on the arm and it contains the Arduino and the electronic components, the second part is placed on the forearm and it contains the batteries, in addition, the box components give support and rigidity to the device. (See Fig (4)).

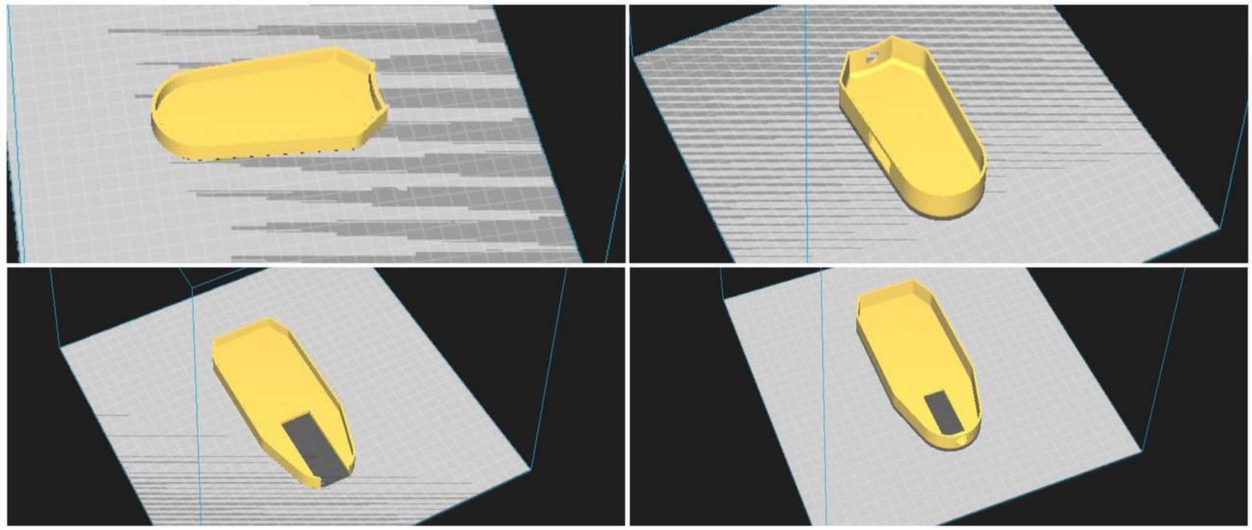
Figure 4 Box Components.
After designing each part of the elbow exoskeleton, all parts are assembled together to show the final design of the exoskeleton before printing, the overall mechanical design of the exoskeleton is shown in Fig. (5).
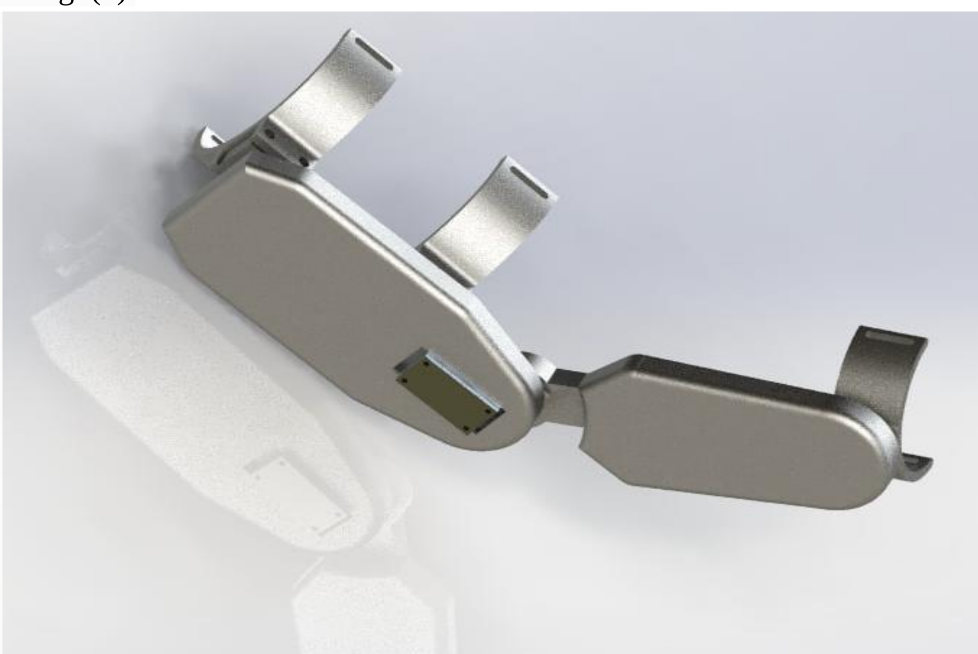
Figure 5 The overall exoskeleton mechanical design.
Manufacturing the Exoskeleton
The construction of the exoskeleton began with the selection of an appropriate material PLA (Poly lactic Acid) material constructed and assembled using a 3D printing additive manufacturing technology. It is distinguished by its innocence, customization, and affordable production.The printer used in this project is the anycubic mega S and is shown in Fig (6).[20-24]

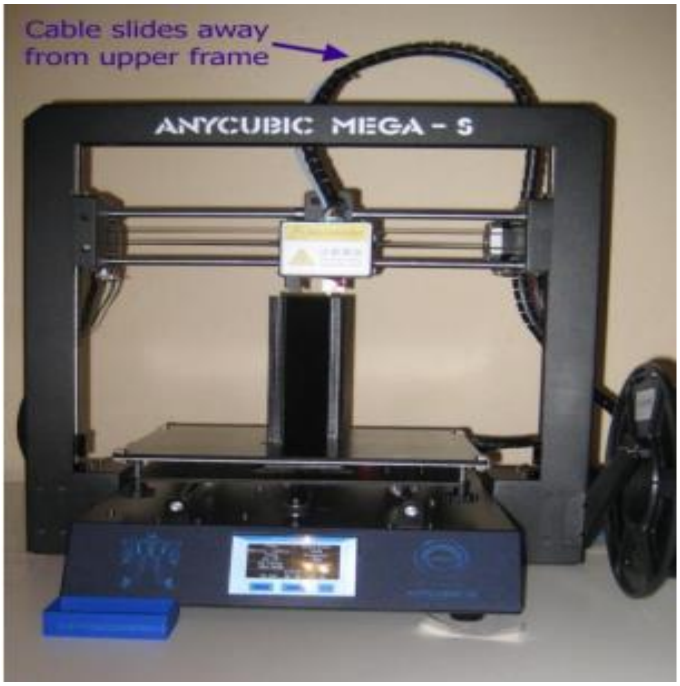

Figure 6 Anycubic mega S 3D Printer Machine.

GONIOMETER

is a device used to measure joint angles or range-of-motion (see Fig. (7)) [25-29]. In this project, the goniometer used in measuring the angles of the elbow joint which is the flexion and extension angles for both of male and female,

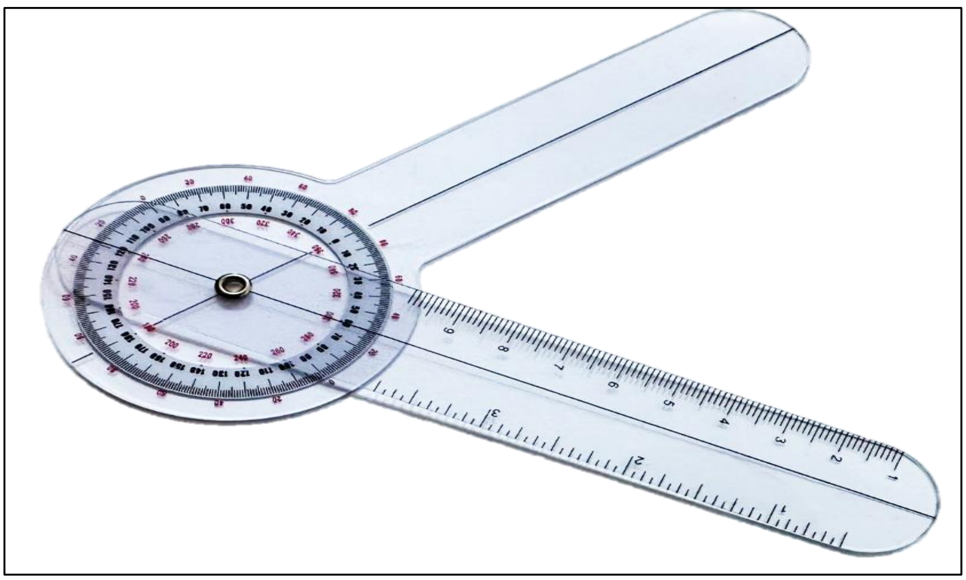

Figure 7 Goniometer **ELECTRICAL PARTS**

Arduino

is an open-source programmable circuit board that can be integrated into a wide variety of makerspace projects both simple and complex. It is flexible and easy to use. An ardunino uno has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz ceramic resonator, a USB connection, a power jack, an ICSP header and a reset button. This board contains a microcontroller which is able to be programmed to sense and control objects in the physical world. By responding to sensors and inputs, the Arduino is able to interact with a large array of outputs such as LEDs, motors and displays [30] (see **Fig (8)**).

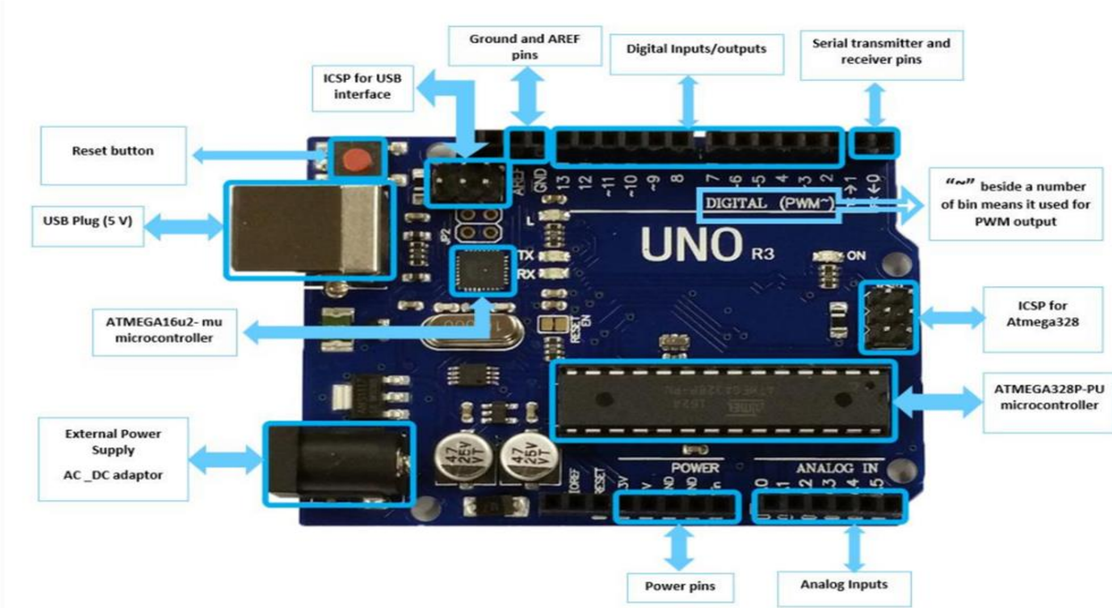

Figure 8 Arduino uno

EMG Sensor

The EMG sensor measures the muscle response or electrical activity in response to a nerve's stimulation of the muscle. The EMG is used to help detect neuromuscular abnormalities. 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 [6, 30-32].

In this project, one EMG myoware sensor is used in which one electrode is placed over the middle of the muscle and the other electrode is placed at the end of the muscle in the direction of its length , while the reference electrode is placed over the bony structure, the function of the reference electrode is to obtain an accurate signal as possible

Results and Discussion

This section details the conclusions achieved with this device as it tested alone, and with normal subjects. In addition, It also deals with suggestions that can be added which in turn aim to possible improving the performance of the device,

Pre-Testing The Exoskeleton

After manufacturing the device and making sure it works, different tests were carried alone for flexion/extension for different positions were carried out to examine the functionality of the exoskeleton.

Then the same procedure was carried out with the ROM of the exoskeleton were calculated with gyroscope sensor. **Fig (1)** shows the pre-testing result.

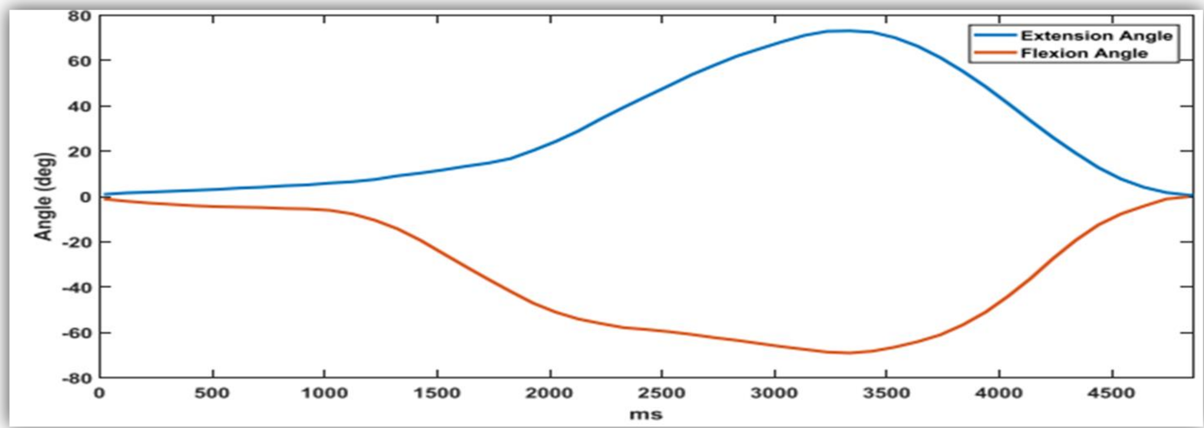

Figure 1 ROM of the Flexion and Extension motion of the exoskeleton..

POST-TESTING THE EXOSKELETON

The exoskeleton was tested with normal subjects, the ROMs and activity of the muscles were recorded with normal human (see **Figure 2)**). The ROM is calculated with gyroscope sensor, the post-testing result of the exoskeleton motion with and without subject is shown in **Table (1)** and **Fig (3)** respectively. The subject has 23yrs old and weighted 80kgs and has 91 cm arm length with no medical condition.[33-35]

Figure 2 The exoskeleton test with normal subject.

Table 1 Normal human average data

Exoskeleton Motion	**Angle**
Elbow Extension	76 º
Elbow Flexion	74 º

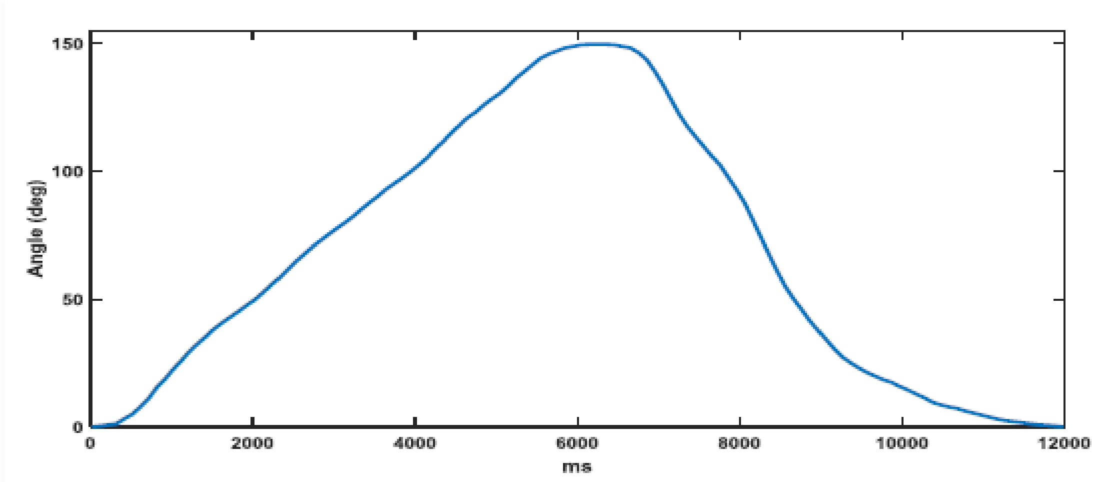

Figure 3 The post-testing result of the Flexion /Extension motion.

Conclusion

In the last decade, the increase of the number of persons with physical disorders, either from strokes , SCI, or different types of motor neurons disorders, has become a matter of concern. A significant portion of these disorders can be recuperated with the aid of rehabilitation therapies. These therapies can be more beneficial for the patient if they are made with the aid of rehabilitation devices.

The results demonstrated the ability of the exoskeleton device to perform physical therapy especially for stroke patients through its performance of the kinematic exercises similar to the exercises performed by the physiotherapist, the device is flexible, portable, comfortable and adjustable for wide range of patients, actuated mechanism included was compatible with little noise during the operation of the exoskeleton and compatible for the overall structure thus increases the comfort ability of it during the rehabilitation process. Furthermore, it was shown that the exoskeleton reflects range of motions approximately the same as the normal human ones, an emg sensor and an angle sensor was used to facilitate a more acurate control system.

The myoelectric controlling with angle information shows precise control of the exoskeleton as performing its one DOF in addition to utilizing an EMG and gyroscope sensor sensors to controlled the process, the EMG sensor that already used is easy to apply with their electrode placement being compact with it so it facilities the user to apply it over the specific muscle with more accuracy in addition to its small size. The use of myoelectric signal as a control to the exoskeleton promises optimum strategy that increases to provide accurate control of the exoskeleton. most components were constructed by 3D printing technology using the polylactic acid material this material is light weight and has a low cost, The exoskeleton exhibits a simple structure, adaptable in function of the patient, which permits an easy installation, and it can be purchased by patients to be used at home

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