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A Wearable Arm and Wrist Rehabilitation Exercise Device Equipped with Monitoring System for Post Stroke Rehabilitation

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Abstract

An analysis of rehabilitation activity for paralyzed patient. Monitoring rehabilitation activity for post-stroke patients is more common in hospitals and rehabilitation center worldwide. To develop user friendly and low price device for post-stroke patient's activity observance is difficult in rehabilitation engineering. Many technological devices have been developed like a Wearable Arm and Wrist Rehabilitation Exercise device equipped with monitoring system for post stroke rehabilitation were designed for and proposed. In this article, we identify several functional activities of arm and wrist motoring defect is achieved by the exoskeleton system. This system is controlled by the Arduino UNO Microcontroller and the LCD is acting as monitoring unit. This allows investigating patterns of patient's arm and wrist monitoring functional activity. These studies experimented the activation patterns in different experimental conditions such as water bottle take off, wrist stretching and grasp force. Furthermore, findings attained from this project may enable us to contribute towards the development of new arm rehabilitation monitoring device which can benefit human lives.

Keywords: *Stroke, Arduino, Rehabilitation, Wearable, Wrist*

INTRODUCTION

Stroke or Cerebral Vascular Accident (CVA) is the main cause of functional disabilities in adults worldwide. Stroke is the third leading cause of death, after coronary heart disease and cancer with one person dying every four minutes as a result. In general, it is common for stroke survivors to have upper limb dysfunction. According to the Centre for Disease Control, stroke is a leading cause of serious long-term disability in the world. As the survival rate from stroke has increased each year, more and more survivors are in need of rehabilitation. Movement therapy, as a typical form of rehabilitation, is generally recommended to begin as soon as critical conditions are under control and patients are able to resume self-care activities at some level [1, 2, 5]. Improving upper limb function is critical for stroke rehabilitation as arms and hands are involved in major aspects of activities of daily living.

Approximately two thirds of these patients suffer from motor difficulties, and almost half of them continue to remain deficient in the affected arms and severely limit to activities of daily living. It not only has a negative impact on the self-independent ability of stroke patients, but also increases the costs of medical care as well as labour consumption. Therefore, effective treatment interventions for upper limb rehabilitation after stroke are needed to improve the stroke survivors' motor control and functional abilities.

Rehabilitation activities need continuous observance method so as to supply info of rehabilitation results to be analyzed by healer. The reason of monitoring is to help them to improve rehabilitation process.

Moreover, a portable and simple user friendly rehabilitation device can help patients to improve daily rehabilitation activity [12]. Some previous studies regarding home-based rehabilitation process have shown improvement in promoting human movement recovery [9]. But existing rehabilitation devices are expensive and need to be supervised often by physical therapist, which are quite complex to be used at home. Some devices (such as exoskeleton-type devices) are not therefore economical to be used at home due to large size and complex system. In this current work combination of sensors were assessed in order to be implemented as a multi-sensor unit for a portable arm rehabilitation device.

It is important for post-stroke patients to regain back the mobility and fitness to do the things they did previously. Post-stroke rehabilitation process may include physical activity which requires extensive exercise plus patient's self-motivation to complete the work. Such rehabilitation process needs the patients to do repetitive physical exercises without knowing their improvement rate may result in loss of interest or de-motivated, thus the patients may struggle to complete the rehabilitation process [12]. Rehabilitation has been shown to improve motor function and is currently a basis of standard therapy for neurological disorders [1]. One of the most common neural disorders is hemi paresis: a condition in which one side of the body becomes impaired as a result of a contra lateral brain lesion. The standard causes of hemi paresis are stroke, cerebral palsy, multiple sclerosis, brain tumours and other neurodegenerative conditions. The leading cause of hemi paresis is stroke. Every year in the United States, over 750,000 people will suffer from stroke; of these, 80% will exhibit symptoms of hemi paresis. In 1965, exoskeleton research began in the United States and eventually crossed over into rehabilitation, leading to the emergence of robotic-assisted therapy [5]. Robotics for upper limb rehabilitation has improved substantially over the past decades. Initially, robotic assistance focused primarily on restoring arm function at the level of the shoulder and elbow. However, arm function is only part of the recovery process, and increasing focus has shifted toward robotics for hand [3, 10]. The rehabilitative systems involve, attaching devices to the affected human limbs in order to improve patient movement in any environment of rehabilitation. An unsupervised system which monitors the rehabilitation of patients can be considered as an important method to analyze the improvement of rehabilitation [11] and as a tool for displaying the results of certain tasks which may contribute in motivating patients to continue rehabilitation processes [2]. This automated monitoring system can be considered as a vital tool in the field of post-stroke. This device aims to produce a rehabilitation system which able to assist the rehabilitation of post-stroke patients or upper limb related patients in gaining quantified results or values which can influence them to further use the device for rehabilitation.

The Exoskeleton for Arm and Wrist Rehabilitation which is to provide intensive rehabilitative training, monitoring and assist of the patient who suffer from arm motor functions such as stroke and cerebral palsy. The Arduino UNO microcontroller is integrated with Exoskeleton to control the operation of the device [5]. The Accelerometer sensor is used to sense the upper, lower extremities of the arm and have been used to track motion of human arm [2]. The Fingertip heart beat sensor is used to measure the heart beat rate of the person during rehabilitative training. The pressure sensor which will be placed on the patient palm is used to sense the pressure the person can exert during the recovery stage [2, 3]. The motoring action is done by DC geared motor. The resulting signals are communicated to the Arduino UNO microcontroller. The LCD displays the extremities and the heart beat rate. The advantage of the exoskeleton device is its light weight, active-assistive motion, user friendly, easy to wear, portability, patient safety, minimal recovery time, cost effective, longer power backup.

SYSTEM DESIGN

Upper Limb Caliper (Aluminium Exoskeleton Arm)

The material used for the upper limb exoskeleton is Aluminium. Aluminium is a flare metal with a specific weight of 2.7 g/cm3, about a third that of steel. It naturally produces a protective oxide coating and is highly corrosion resistant. Due to ductile property, it has a low melting point and density. In a molten condition it can be handled in many ways. It is 100 percent recyclable with no downgrading of its qualities. The re-melting of aluminium requires small amount of energy: only about 5 percent of the energy required to produce the primary metal initially is needed in the recycling process.

Accelerometer Sensor

An accelerometer sensor is an electromechanical device used to measure acceleration forces. Accelerometer measures acceleration indirectly through an applied force. Thus, the output voltage of accelerometer is directly proportional to the acceleration. It also can monitor the vertical leaning of body parts relative to ground in ambulatory studies. Two accelerometers are used in this device. One accelerometer sensor was fixed on the lower arm using Velcro strap and the other is fixed on the wrist to sense the position, orientation and to measure the orthogonal axes. The accelerometer (Analog device, GY61 ± 3 g) is a thin, low power (5V) and small 3-axis accelerometer which can give analog voltage output.

Four Module SPDT Relay

Relay is an electrical device, typically integrating an electromagnet, which is triggered by a current or signal in one circuit to open or close another circuit. It uses an electromagnet to mechanically activate a switch. Single Pole Double Throw (SPDT) relay is used in this device. It has one common terminal and 2 contacts in 2 dissimilar configurations: one can be closed and the other one is opened or it can be Normally Open and the other one closed. The SPDT relay as a way of transferring between 2 circuits: when there is no voltage applied to the coil one circuit “receives” current, the other one doesn’t and when the coil gets wound up the opposite is happening. The input power supply for a relay is 12V. Four relays are used in this device and they are used to control the forward and reverse directions of the DC geared motors used in exoskeleton of arm and wrist for rehabilitative training. Two relays are used for the arm motor and other two relays are used for wrist motor.

DC Geared Motor

A geared DC Motor has a gear assembly fond of to the motor. The gear assembly supports in increasing the torque and reducing the speed. To perform task oriented training, the exoskeleton must move the elbow as well as some distal joints. The motoring action for the exoskeleton of arm and wrist is done by DC gear motor. The gear motor combination is back drivable. The DC Geared motor will be fitted on the exoskeleton of arm and wrist for the angular movements required for rehabilitative training. The input voltage for the gear motor is 12V. The Rotations per minute (RPM) is in the range of 30-100. It gives a massive torque of 30 kgcm. The advantage of this motor is its low rpm which is very useful for the device in rehabilitative training.

Finger Tip Heart Beat Sensor

Heart rate is referred as the number of heartbeats per minute. Generally heart rate is expressed as beats per minute (BPM). A normal heart rate for adults ranges from 60 to 100 beats per minute (BPM). Heart Beat can be measured based on optical power variation as light is scattered or absorbed during its path through the blood as the heart beat changes. It consists of an infrared led and a light dependent resistor embedded onto a clip like structure. The clip is attached to the finger with the detector part on the flesh. The heart beat sensor has 4 pins. Pin1: To give supply voltage to the LED Pin2 and 3 are grounded. Pin 4 is the output. Pin 1 is also the enable pin and pushing it high turns the LED on and the sensor starts working. It is embedded on a wearable device which can be worn on the wrist and the heart beat rate of the person during rehabilitative training is displayed on the Microcontroller. The finger tip heart beat sensor uses Infra red, LED and gets 5V DC as input supply.

Pressure Sensor

The pressure sensor is fitted on the palm of the wrist of the patient to sense the pressure the person can exert during the recovery stage of the rehabilitative training. The type of pressure sensor used is capacitive. The capacitive Pressure sensor uses a diaphragm and pressure cavity to create a variable capacitor to detect strain due to applied pressure, capacitance decreasing as pressure deforms the diaphragm. Common technologies use metal, ceramic, and silicon diaphragms. Pressure is expressed as force per unit area. Uses I2C 7-bit address 0x77. The pressure sensing range is 300-1100 hPa.

SIMULATION CIRCUITS AND RESULTS

Simulation Circuits

The Figure 2 shows the simulation circuit of exoskeleton of arm and wrist rehabilitation. The circuit has Arduino UNO (ATmega328P) 28 pins. It has 6 analog input pins, 14 digital I/O pins (of which 6 pins gives PWM output).

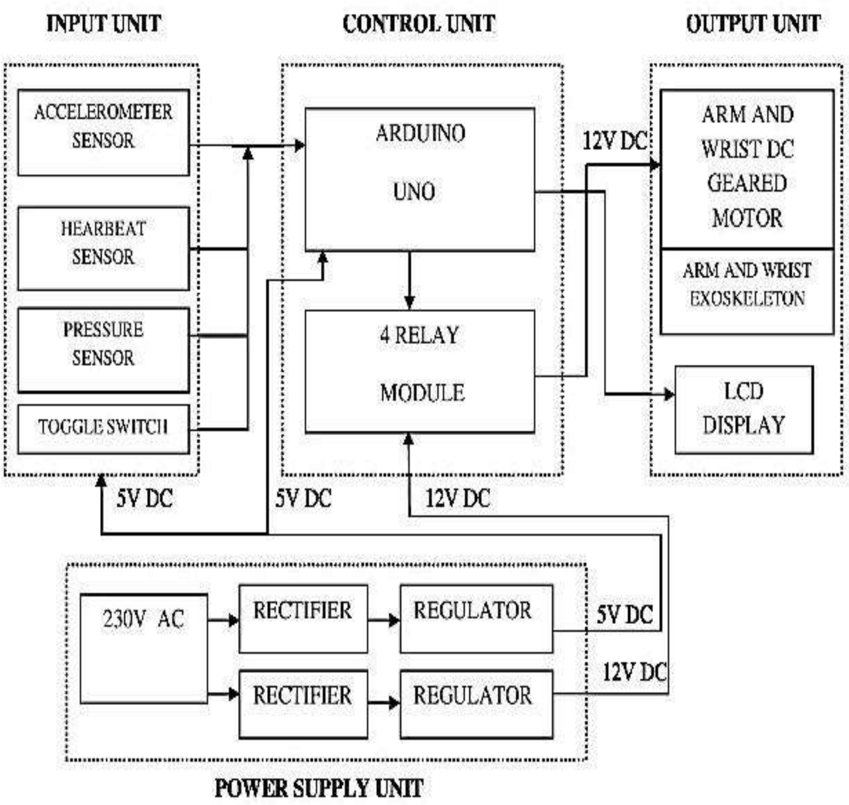

Figure 1: *Block Diagram of Arm and Wrist Exoskeleton for Rehabilitation Exercise.*

The operating output voltage of ATmega328P is 5V. The input voltage to the microcontroller is given to the pin 7 (Vcc). The input voltage recommended for the microcontroller is 7V-12V and the input voltage limits are 6V-20V. The DC per I/O pin is 40mA and DC for 3.3V pin is 50mA.

The device uses 16*2 LCD display gets the input onto the pins 2, 3, 4, 5, 11 and 12. The reset (RS) input from the Arduino is given to pin 12 of the LCD, enable (EN) to the pin 11, Digital input D3 to the pin 5, D5 to the pin 4, D6 to the pin3 and D7 to the pin 2. The pins for the DC geared motors are Pin 7, 8, 9 and 10 respectively. The accelerometer input is given to the pin A0 of Arduino, the pressure sensor to pin A1 and heart beat sensor to A2. The pin 11 and 12 of the microcontroller is connected to the relays of DC geared motor (arm). The pins 21 and 22 are connected to the relays are DC geared motor (wrist) and the pole of the relays are connected to the motor terminals respectively. The switch is connected to the digital input pin 7 (also a controllable input supply pin).

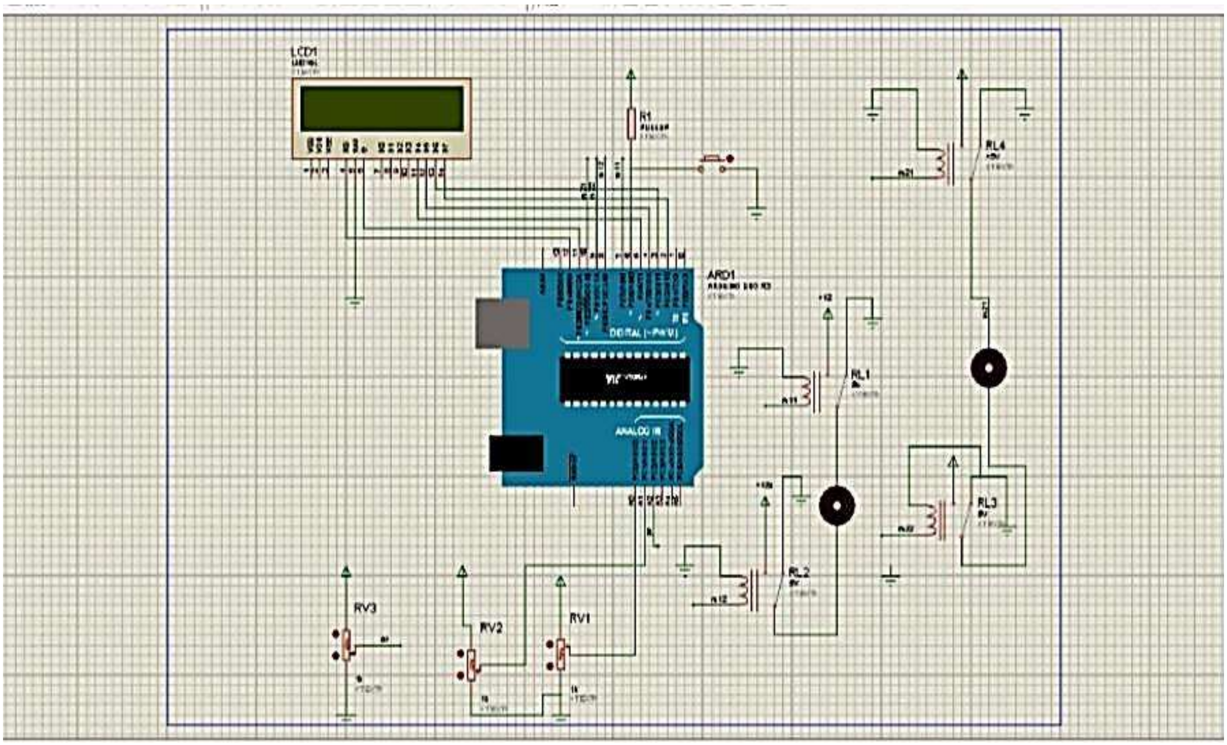

Figure 2: *Simulation Circuit.*

Simulation Results

The simulation results for the forward and reverse motions of arm and wrist exoskeleton for rehabilitation exercise are shown below.

Table 1: *Simulation Result.*

S.No	Accelerometer Values		Heart Rate (BPM)	Pressure Value (hPa)	Count of The Exoskeleton Movement
	Lower Extremity (g)	Upper Extremity (g)			
1	271	310	79	420	2
2	277	297	74	478	4
3	273	285	67	340	5
4	280	310	78	590	3
5	273	303	80	557	6

Arm Exoskeleton in Forward Motion

The arm motor runs in clockwise direction which makes the arm exoskeleton to make a forward move in Figure 3 During the clockwise direction, the terminals of the arm motor are connected so as the forward current flows through it. Thus making forward movement.

Arm Exoskeleton Reverse Motion

The arm reverse movement is achieved when the arm motor runs in an anti-clockwise direction. In Figure 4 the anti-clockwise motor rotation, the reverse current flows through the motor.

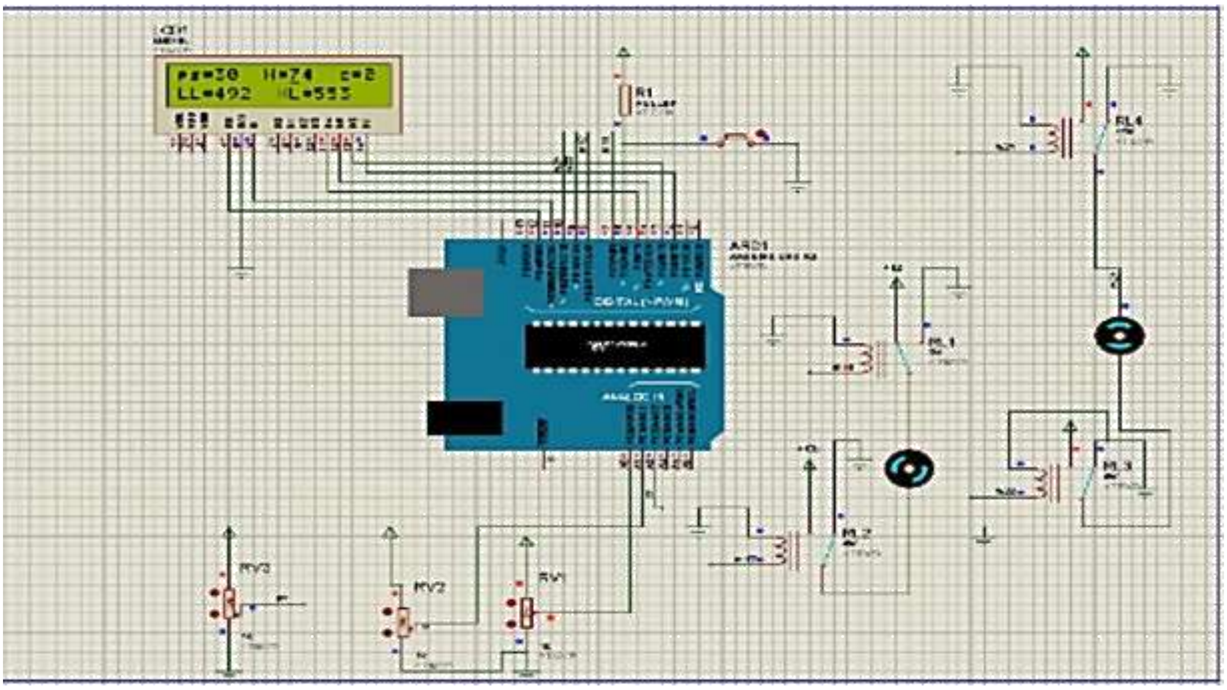

Figure 3: *Simulation Circuit of Arm Exoskeleton in Forward Motion.*

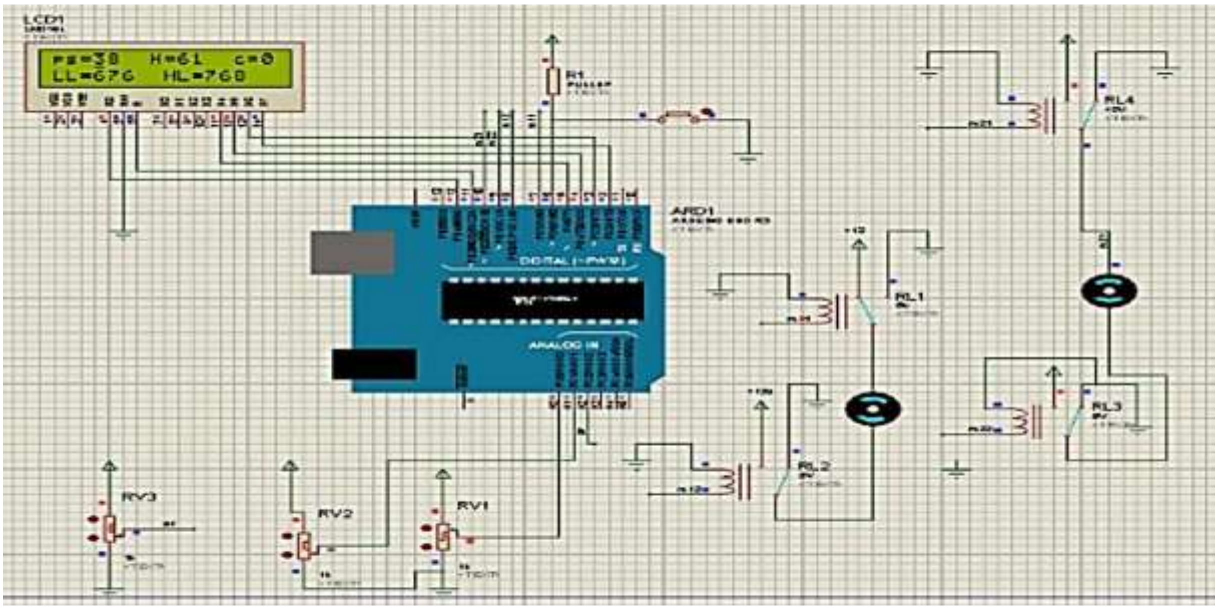

Figure 4: *Simulation Circuit of Arm Exoskeleton in Reverse Motion.*

Wrist Exoskeleton Forward Motion

The wrist exoskeleton makes a forward move when the wrist motor runs in a clockwise direction. There is a forward current flowing through, that makes the motor to run in clockwise direction in Figure 5.

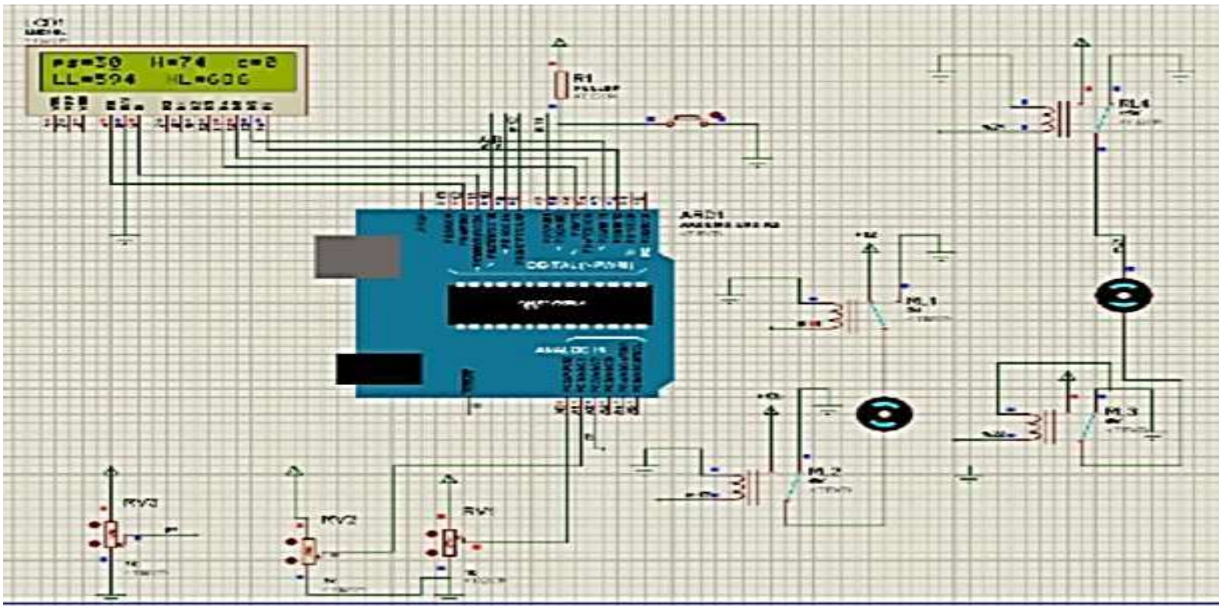

Figure 5: *Simulation Circuit of Wrist Exoskeleton in Forward Motion.*

Wrist Exoskeleton Reverse Motion

Wrist exoskeleton reverse is achieved when the wrist motor runs in an anti-clockwise direction. In this reverse movement, the reverse current flows through the wrist motor in Figure 6.

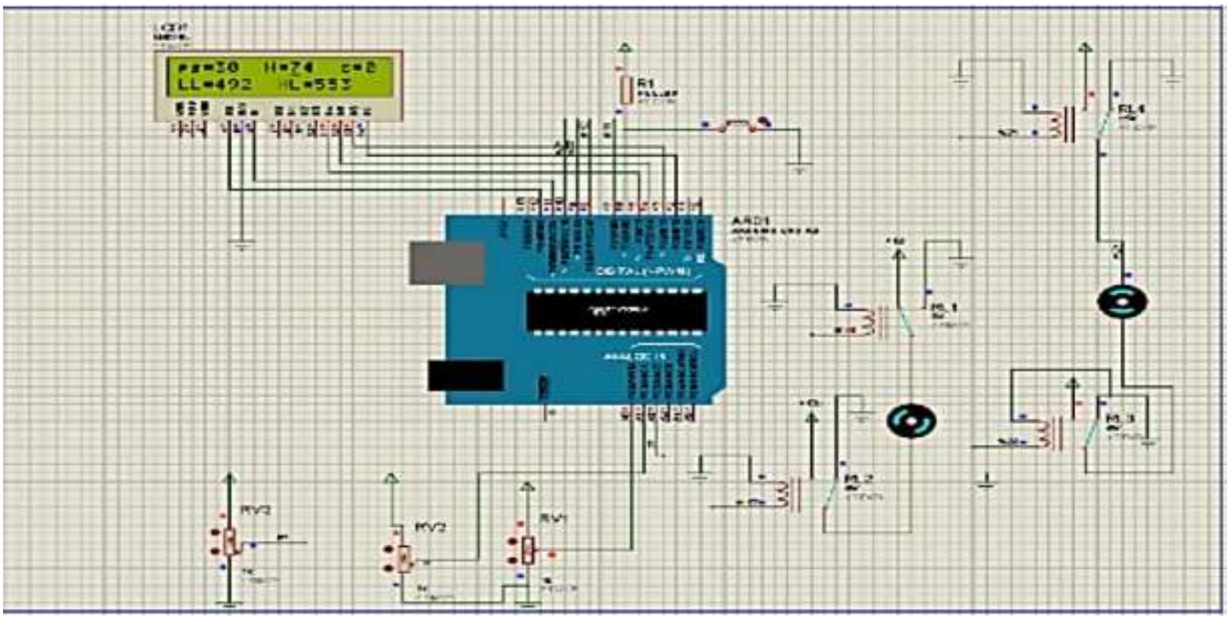

Figure 6: *Simulation Circuit of Wrist Exoskeleton in Reverse Motion.*

RESULTS AND DISCUSSION

The system is successfully designed and implemented for the Arm and Wrist rehabilitative training of the patient with Arm and Wrist motoring defect as shown in Figure 7 and Figure 8. The Arduino UNO microcontroller controls the motoring action of the exoskeleton. The LCD display of the system shows the heartbeat rate, pressure value exerted by the patient and count of exoskeleton movement. Thus the results of the system is monitored and achieved. For control purposes, the hand and the arm are considered as two separates subsystems that represented by the rehabilitation sensor and microcontroller.

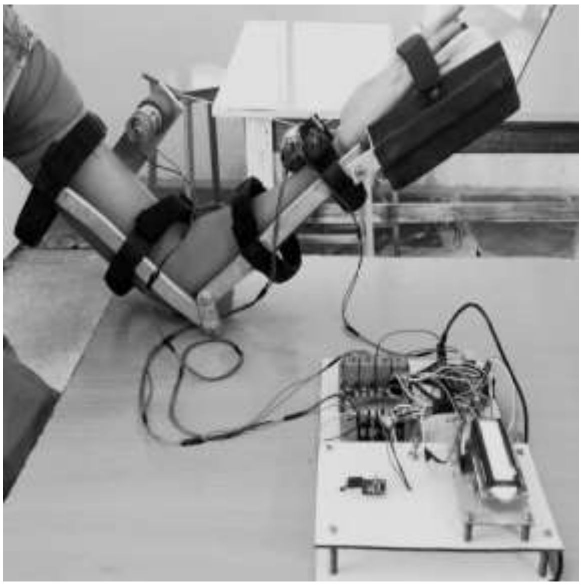

Figure 7: *Results of the Exoskeleton for Arm Rehabilitation Exercise.*

The subjects were comfortable with the weight of the device even without rubber bands attached. There were no reports of muscle/joint soreness, skin irritation, and other safety concerns. Thus the rehabilitative training was achieved using exoskeleton device.

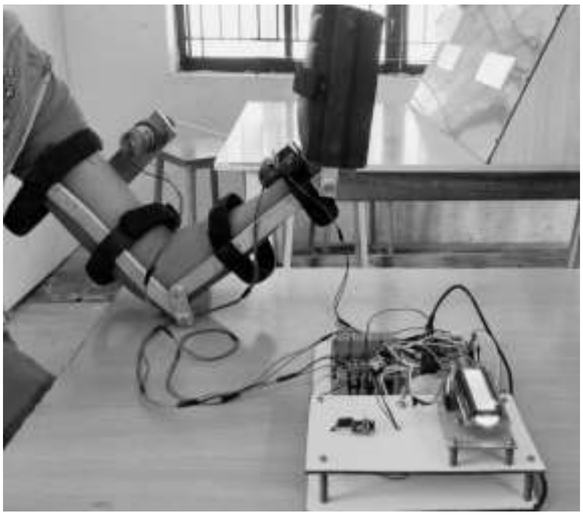

Figure 8: *Results of the Exoskeleton for Wrist Rehabilitation Exercise.*

CONCLUSION

A Wearable Arm and Wrist Rehabilitation Exercise device equipped with monitoring system for post stroke rehabilitation were designed for and proposed. The system assists controls and monitors the patient's rehabilitation on arm motoring defects. The physical training and assist the patient's arm and wrist motoring defect is achieved by the exoskeleton of the system. The forward and reverse action of the exoskeleton is controlled by the Arduino UNO Microcontroller which in turn communicates the signals to the DC Geared motors respectively. The LCD of the system is the monitoring unit that displays the value of heart rate; pressure exerted by the patient during the recovery stage and the count of the exoskeleton movements. The physical training and assist for the patient's arm and wrist motoring defect is achieved by the exoskeleton of the system. In conclusion, this preliminary finding attained from this project may enable us to contribute towards the development of new arm rehabilitation monitoring device which can benefit human lives.

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