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Arduino Based Arm Rehabilitation Assistive Device

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Abstract: Arm rehabilitation process requires 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 rehabilitation process. This paper focuses on the design of arm rehabilitation monitoring device utilizing multi-sensors equipped with portable data logging capabilities. The sensors are connected to a patient portable main unit that acquires and elaborates signals and record it in SD card to store detail information regarding subject's various range of motions. The system enables clinician to do remote monitoring and provide organized sets of data on daily basis every time the user do rehabilitation workout at home.

Keywords: Arduino, arm rehabilitation multi-sensors, portable

1.0 INTRODUCTION

Stroke patient which mainly consists of elderly population may need to recover with the help of rehabilitation processes. Post-stroke rehabilitation is important for them 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 process. Such rehabilitation process which needed the patients to do repetitive physical exercises may result to a less attractive and may result to loss of interest of completing rehabilitation processes. Because of this, motivational support from caregivers, family and friends are essential to promote advancement in recovery process from stroke.

Researchers from various institutions and companies have been actively searching ways on how to design devices and training procedures which incorporate many high-tech systems that can help patients with disabilities and injuries. These systems maybe involve attaching devices to the affected human limbs in order to monitor patient's movement in any environment of rehabilitation. Nef et al. designed a novel arm rehabilitation robot which constructed with a semi-exoskeleton structure [1]. The robot is called ARMin which has six degree of freedom and equipped with position and force sensors. There are also other robot assisted devices [2,3,4,5] , which shows promising results. However, due to its heavy and complex structure, it is only suitable for daily living in clinics.

There are also researchers who designed devices based on motion sensors attached on human limb without bulky and complex design [6,7,8,9]. However, majority of the devices did not incorporate data logging capabilities that can store data for long period of time. Furthermore, motion sensor could only detect a mixture of motion and orientation, but could not detect activation of specific individual muscle. Strong muscle activity is important to provide information regarding fatigue towards certain physical workout.

Therefore, the work described in this paper involved the application of several sensors and the development of portable data logging method in the design and development of monitoring device for home-based arm rehabilitation. We aim 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 also motivate them to further use the device for rehabilitation. The portable data logging capabilities may enable clinician to do remote monitoring and provide organized sets of data on daily basis every time the user do rehabilitation workout at home.

2.0 MATERIALS AND METHODS

In this study, the development of the device consists of software and hardware development. The hardware which was developed consists of two parts: main unit and sensory unit.

2.1 Main unit design

The main unit consists of an Arduino Duemilanove microcontroller, a tactile push button and a 16x2 RT1602C Liquid Crystal Display (LCD). Arduino Duemilanove microcontroller has been used in this device to process and control signals generated from sensors. The Arduino microcontroller needs to be powered by constant 5V power supply through USB connection to a personal computer's COM port. LCD display and the pushbutton are connected to Arduino's input and output (I/O) ports. The LCD will provide the user with readings from sensor. The pushbutton enables the user to start or stop processing the data received from the sensors. The main functions of the main unit are to receive command signals from the computer and translate it into control signals, as well as to process the raw data collected from all sensors from the sensory unit and sending them back to computer.

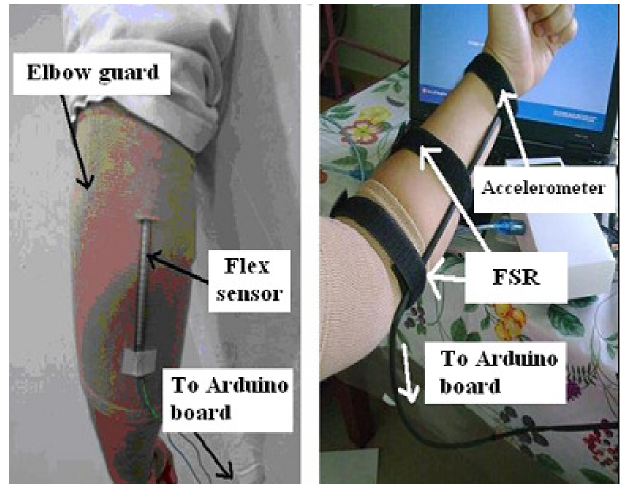
2.2 Sensory unit design

The main function of the sensory unit is to provide the main unit with information from all sensors. The main design of the sensory unit must be a users-friendly environment, which is to be easily worn and remove. The design of this device should be suitable for home-based unsupervised exercise activity or active range of motion (AROM) exercise.

The proposed design of the arm rehabilitation device will be focused for the used on the right arm. This paper will measure three perimeters of arm movement: (a) arm bending angle, (b) muscle force generated from muscle activity and (c) force generated from arm movement. Based on these perimeters, three types of sensors were selected to be implemented in the device's sensory unit:

2.2.1 Flex sensor

One unit of 4.5 inch flex sensor (Spectra Symbol) is used to detect arm bending movement. Once the flex sensor is bent, the output will provide a change of decrease voltage value. This characteristic should be suitable to provide the device with the information regarding angle value between lower and upper arm. The flex sensor will be positioned on user's elbow (refer Fig. 1(a)). This can be done by fixing the flex sensor on the inner side of an elbow guard. Each of the two terminals on the flex sensor is soldered to a 0.5 meter long wire. The other end of the wire will be connected to the Arduino board. Output voltage value from flex sensor can be produced using voltage divider circuit as shown on Fig. 2.



(a) (b)

Fig. 1 (a) Elbow guard attached with flex sensor, (b) Location of the other sensors.

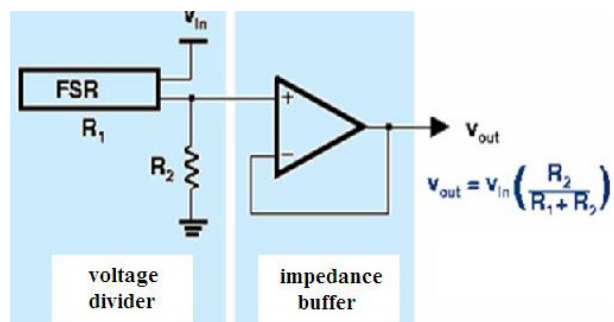


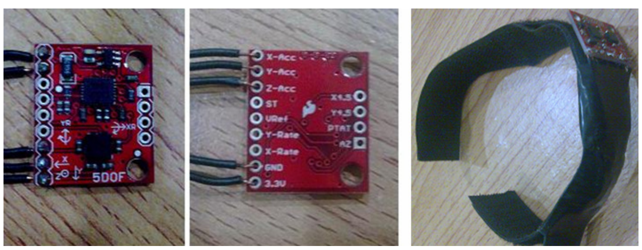
Fig. 2 Voltage divider circuitry for FSR or flex sensor.

2.2.2 Force sensitive resistor sensor (FSR)

Two units of FSR sensors (Interlink Electronics Inc.) have been used in this project. FSR are suitable to detect muscle force due to muscle flexion and extension activity. Both FSR are attached using Velcro straps on two specific muscle locations on the lower arm. Velcro straps are very useful in providing easy solution for wearable devices. Fig. 3(a) shows the FSR sensor. Both terminals on the FSR are soldered to wires which are connected to Arduino. Fig. 3(b) shows the actual condition of FSR sensors fixed on Velcro straps. The sensors can be firmly attached on the Velcro straps using black one-sided tape. FSR sensors are suitable to detect force generated from muscle on the lower arm [10,11,12] . FSR is a very sensitive sensor which changes its resistance value once its 12.5mm in diameter active surface is applied with force from 0 to 100 Newtons. Same as flex sensor, voltage output from FSR sensors can be produced using voltage divider circuit as shown on Fig.2.

(a) **(b)**

Fig. 3 (a) FSR sensor, (b) actual FSR sensors fixed on Velcro straps.



(a) (b)

Fig. 4 (a) Left picture shows front side of IMU, while right picture shows the back side, (b) IMU attached on the Velcro strap.

2.2.3 Accelerometer

This project utilized an Inertial Measurement Unit (IMU) analog combo board by InvenSens which consists of an IDG-500 dual axis gyroscope and ADXL 335 three-axis accelerometer. The dual axis gyroscope measures pitch and yaw which can be used for further upgrade project in the future. Fig. 4 (a) shows the front and back side of IMU. The back side of IMU shows only X-Acc, Y-Acc and Z-Acc are soldered with wire because the proposed device will only use three-axis accelerometer (ADXL 335). The IMU needed to be grounded and powered by 3.3V of power supply, which basically can be supplied by Arduino. The ADXL 335 consists of a low pass filter and capable to measure ±3g with sensitivity of 330mV/g. All the wires soldered on the IMU will be connected to Arduino's I/O terminal. Fig. 4(b) shows how the accelerometer was attached on the Velcro strap. It is firmly attached on the Velcro strap using black one-sided tape. The user can easily wear the device as easily as wearing a wrist watch. Three-axis accelerometer is suitable to detect inertial force that is directed in the opposite direction from the acceleration vector. So, it measures acceleration indirectly through an applied force. In short, the output voltage of accelerometer is directly proportional to the acceleration [13]. This is suitable to measure perimeter related to force generated from arm movement.

One of the disadvantages of Arduino microcontroller is the number of analog input pins are only six. So, there are not enough analog inputs to accommodate the number of sensors that this project needed. To solve this problem, we connected the output from FSR and flex sensor to a multiplexer HE4051BP. This is because we reserved Arduino's analog pin 4 and 5 for the use of Arduino data logger shield's I2C hardware pins. The HE4051BP multiplexer allows the user to choose between 8 analog inputs, reading them from one Arduino analog input pin. Fig. 5 shows the detail connections made to the multiplexer.

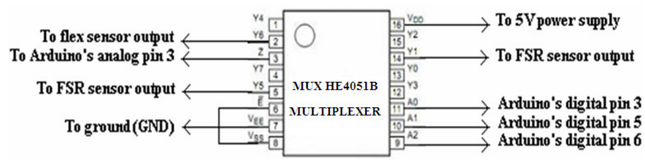


Fig. 5 HE4041BP multiplexer connection details.

2.3 Secure Digital (SD) memory card

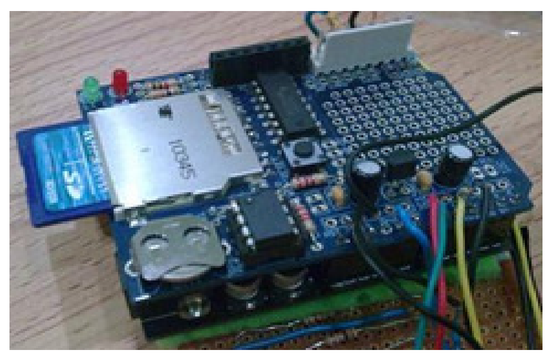


Fig. 6 Arduino data logger shields with 2 gigabytes SD card.

The Arduino microcontroller can be extended using shields. Shields are upgraded board which can be attached on top of the Arduino microcontroller. For this project, an Arduino data logging shield are used to enable portable data logging capabilities without using USB wire connection to personal computer. Fig. 6 shows the assembled Arduino data logging shield (Adafruit Industries) with a Kingston 2GB Secure Digital (SD) card. This project will also determine the possibility of portable data logging capabilities which is essential for home-based rehabilitation assistive device.

2.4 Software

Arduino is programmed in C/C++ language which uses Arduino IDE (Integrated Development Environment), which is a free software, that enables users to program the Arduino board. The IDE which is available for Windows OS and Linux systems enables the user to design a computer program, to be uploaded into Arduino. The Atmega 328 chips inside the Arduino board will process the programs and interact with sensors and other peripherals.

2.5 Experimental Method

2.5.1 Experimental setup

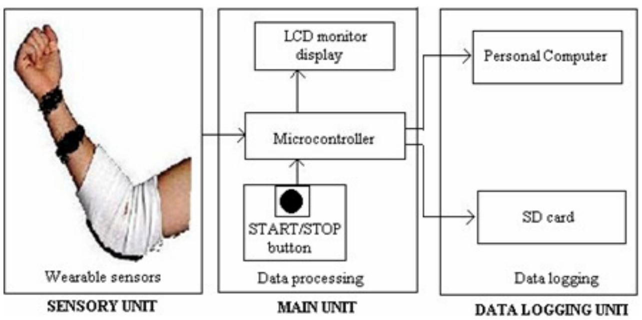


Fig. 7 Overall hardware setup diagram

Fig. 7 shows the overall hardware setup diagram. In this project, we proposed a wearable arm rehabilitation monitoring device based on flex sensor, FSRs and accelerometer. We proposed to use an elbow guard which can be bought in local pharmacy. A single flex sensor is attached on the below part of the elbow guard in order to detect easily the arm bending activities. Fig. 1(a) shows an initial setup of flex sensor on the elbow guard. Fig. 1(b) shows all sensors position. All sensors are connected to Arduino for analog voltage signal detection. Then, the analog signal is transmitted to the built-in 10 bit AD converter (analog to digital) for data processing.

In order for the device to start working, a sketch contains full instruction for the device to operate is downloaded into Arduino board. This arm rehabilitation monitoring device works when analog signal from sensory system is detected due to arm bending, sudden arm acceleration and muscle movement activity. The signals will be sent to the microcontroller and processed to be transmitted to PC via USB connection for data logging or directly into SD card for portable data logging.

The experiment activity will be introduced in experimental scenario (next topic). The experiment environment was done in a room with a subject sitting on a chair, while right arm are placed on a meeting table.

2.5.2 Experimental scenario

The designed experiment was driven by information collected from local hospital rehabilitation centers. The activities contained a variety of basic gestures used on standard rehabilitation devices such as arm skateboard and arm pulley. The exercises were also designed based on active range of motion (AROM) exercises, where the patient performs the full range of motion of the exercise voluntarily without any assistance from the therapists and no resistance applied to the patientwhich may promote sensorimotor skills [14,15,16]. At the same time, we designed the experiments to further verify the characteristics of all sensors in order to develop a system which can produce quantified results.

Flex sensor characteristics can be determined by monitoring the value of the resistance when the flex sensor is bent by using a multimeter. It is expected that the more it is bent, the more resistive value will be shown [11]. Next, there is the need to determine the analog voltage value of the flex sensor at a certain angle. We proposed the use of these angles as indication for arm bending state to monitor arm bending movement progress.

FSRs characteristics were examined by attaching two units of FSRs to the lower arm onto two muscles which are known to be active during isometric activity (strain against resistance): M.brachioradialis and M. extensor carpi radialis[2]. The muscle activity of the lower right arm is recorded through 2 distinctive actions as below:

a) Grasping activity (opening and closing hand) – subject was sitting on the chair with right arm relaxing vertical to the subject's chest level. The arm is in flexion position 90° to the upper arm. It was known that at this position, the M.brachioradialis can produce maximum strength [10,11]. By imitating hand grasping activity, the hand was opened and closed for about 10 repetitions.
b) Lifting heavy object – Initial position is same as point a). Subject lifted an object located in front of him about for about 10 repetitions.

These actions should enable the FSRs sensors to read muscle activity. As a comparison, two EMG channels from a standard EMG device (KL-71001 Biomedical measurement system device) were attached on the lower arm as shown on Fig. 8.

Accelerometer characteristics were examined by mounting it on the back of the wrist to verify arm movement characteristics by monitoring lower arm inclination and force value of the x, y and z-axis analog value through 3 distinctive action as below :

a) Object reaching – subject was sitting on the chair with right arm relaxing on a table vertical to the subject's chest level. An object is located in front of subject within the right arm reach. Arm movement recording was done by reaching the object and move the arm back to initial condition. 10 repetitions were done.

b) Lifting object – subject was sitting on the chair with right arm pointed towards the floor. Subject lifted object about 90˚ from initial arm position, then return to initial position. For this experiment, approximately 10 repetitions were done.

c) Upward reach - Subject was sitting on a chair with right arm relaxing on a table vertical to the subject's chest level. Subject put up his hand upward, then, return to starting position. 10 repetitions were done.

These actions should enable the accelerometer to read arm movement and differentiate each axis according to its force vector.

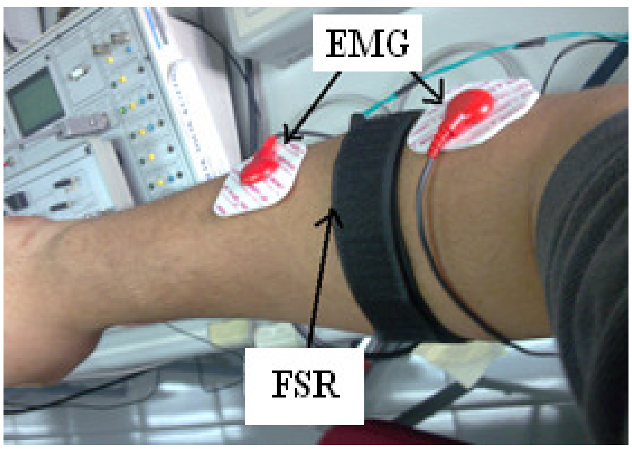


Fig. 8 Location of EMG and FSR targeted M.extensor carpi radialis on the lower arm.

3.0 RESULTS & DISCUSSION

3.1 Arm bending angle detection

As expected, the experiment on flex sensor shows that when it is bend inward, resistance value increased significantly as the angle of flex sensor is bend further. However, when it is bent outward, the resistance value decreased gradually. Fig. 9 shows the result of attaching flex sensor on the tip of subject's elbow. The result clearly shows 10 repetition of arm bending movement. Each repetition, the arm was bent to the maximum ability (about 245˚). These preliminary finding suggest that flex sensor is clearly suitable to detect bending angle by utilizing inward bend of the flex sensor.

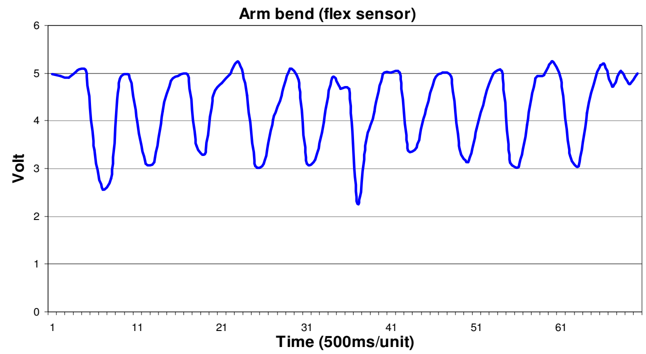


Fig. 9 Flex sensor voltage value due to arm bending movement.

3.2 Muscle flexion and extension activity

The characteristic of FSRs sensor towards the detection of muscle flexion and extension activities have been recorded. Two types of distinctive movement have been done to verify the characteristics. The sensors were attached on two specifically selected muscle based on previous studies, M. extensor carpi radialis (Force sensor 1) and M.brachioradialis (Force sensor 2) [10]. Fig. 8 shows the location of EMG electrodes and FSRs targeted M.extensor carpi radialis. Fig. 10 shows the result of EMG measurement using standard EMG device

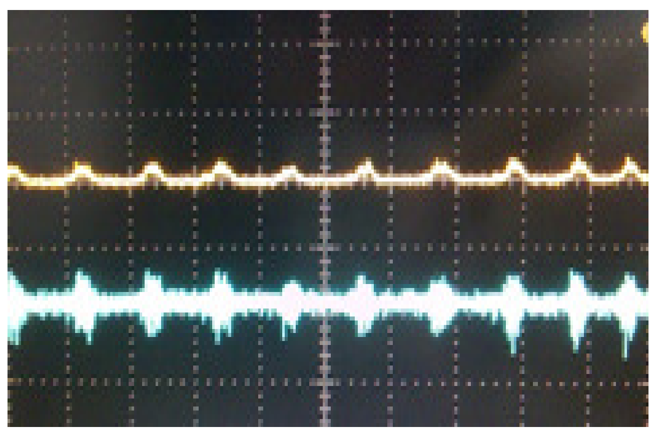


Fig. 10 EMG test result on M. extensor carpi radialis muscles based on hand grasping activity (10 repetitions).

. Fig. 11 shows the result of voltage values for both FSR based on 10 repetitions of hand grasping activity. The result shows both sensors were able to detect muscle movements with force sensor 1 gave larger muscle activity.

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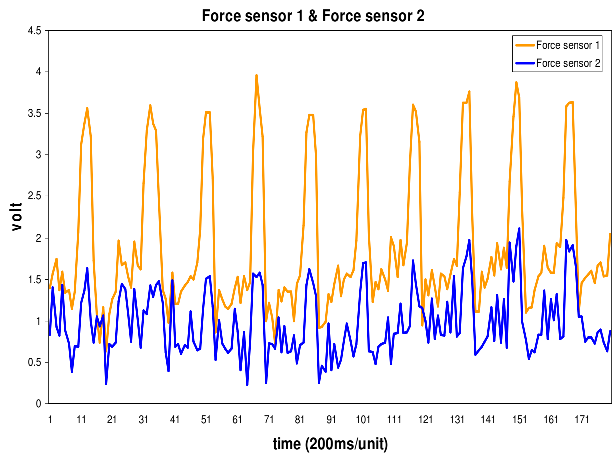


Fig. 11 Force sensitive resistor's voltage results based on hand grasping activity.

Fig. 12 shows the result of voltage values for both FSRs based on object lifting activity. This activity also gave a clear result of the subject completed 10 repetition workout. Again, FSR attached on M. extensor carpi radialis gave a significant larger value than the location at M.brachiaradialis. These data supports the previous studies finding that M.extensor carpi radialis muscle provide the most muscle activity [10]. By comparing both of these results with the standard EMG amplitude results, we confirmed that the FSR can properly detect muscle activations. So, we can conclude that FSR can be used to monitor individual muscles which also confirmed the findings on previous study[10,11].

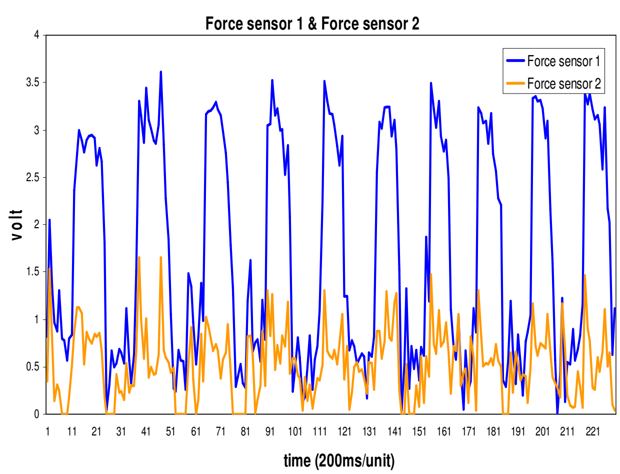
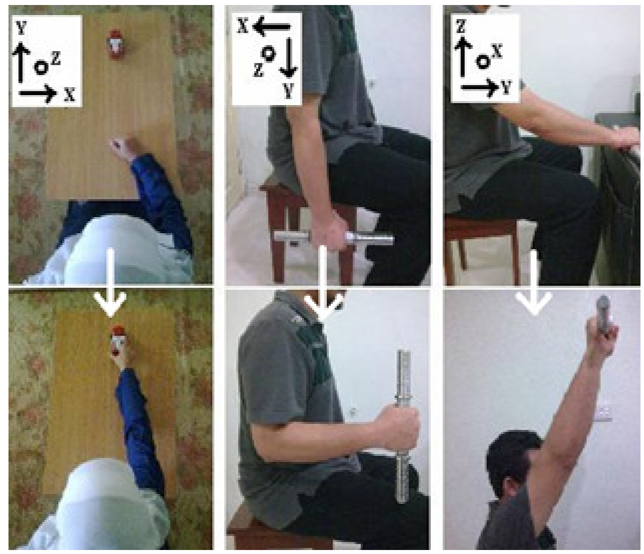


Fig. 12 Force sensitive resistor's voltage results based on object lifting activity.

3.3 Force generated from movement

In this experiment, through 3 different arm movements shown on Fig. 13, the force distribution among X,Y,Z of the accelerometer have been recorded.



(a) (b) (c)

Fig. 13 Three arm movement for accelerometer measurement activity. Top-left are the axes positions of accelerometer during each activity.

For the first activity which was to reach an object (Fig. 13(a)), the movement of the arm was on the positive y direction from initial position. This can be seen on Fig. 14, where about 0.4g force towards positive Y direction was recorded at the 1st repetition. Then, as the arm returned back to initial position, 0.5g force towards negative Y direction was recorded. This pattern was continually recorded for approximately 10 times. Although the movement was directed towards Y axis, small amount of force excited towards X axis maybe due to untrained subjects and also the tendency of the right hand to react naturally to the right side. Much smaller readings found on Z axis. This was predicted due to the subject's arm movements did not supported by any mechanism from beneath the arm.

For the second action which is to lifting an object (Fig. 13(b)), the movement of the arm was on the positive Y direction and negative direction from initial position. The accelerometer measurements can be seen on Fig. 15, where about 0.6g force towards positive Y direction, at the same time about 0.6 negative X direction was recorded at the first repetition. This pattern was continually recorded 10 times. Again, much smaller readings were found on Z axis.

Finally, the last action was upward reach (Fig. 13(c)). The accelerometer position was the same as the second action. Due to this, similar results can be seen on Fig. 16, where about 0.6g force towards positive Y direction and at the same time 0.2g force towards negative X direction was recorded at the 1st repetition. From these 3 experiment results, we can conclude that by using accelerometer, we can monitor the number of force generated towards a certain X, Y or Z direction. The quantified results such as forces generated during certain workout could be useful in estimating fatigue condition of subject due to certain repetitive workout.

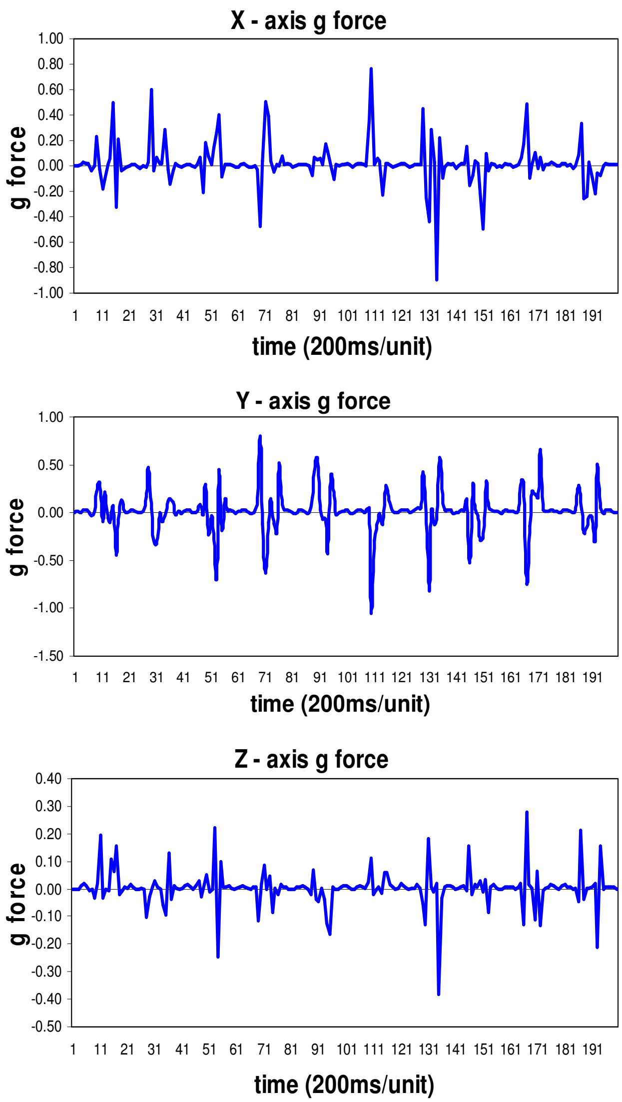


Fig. 14 Signals from accelerometer for object reaching activity.

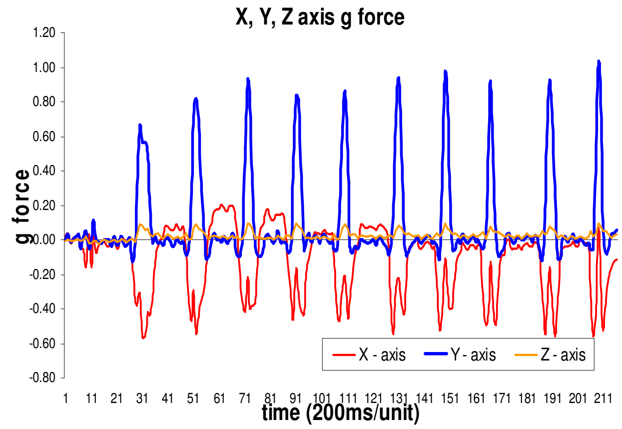


Fig. 15 Signals from accelerometer for lifting object activity

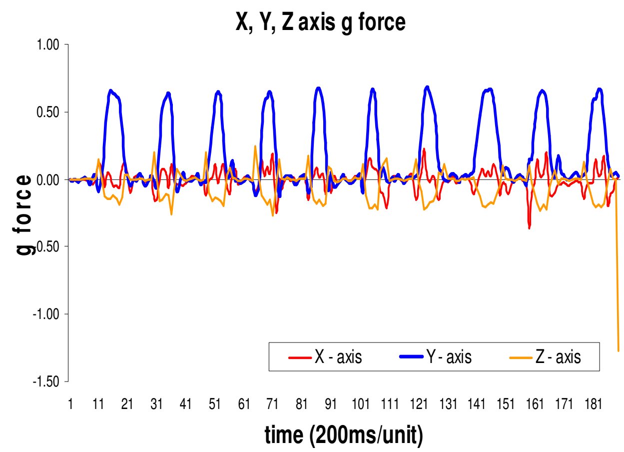


Fig. 16 Signals from accelerometer for upward reach.

3.4 Monitoring System

We designed two types of data logging capabilities for the purpose of monitoring system. For online real-time PC monitoring, data from sensors are logged into PC as a .txt format through Microsoft Windows HyperTerminal tool. The .txt files can be further processed by a macro conFig.d Microsoft Excel file to create graphs which can clearly show the characteristics of lower arm movement by all sensors.

The second type of data logging is by using SD card which is portable and do not need USB connection to PC for data logging. We attached an Arduino data logging shield for portable data logging. Once the user finished any rehabilitation workout, the SD card needed to be taken out from the shield and transferred to PC via a SD card reader. From here, data processing can be done similar as real-time PC monitoring. Dual data logging capabilities are the advantages of this project.

There is one setback when using Arduino SD card data logger shield. The data logger shield uses 6 analog pins. There are I2C hardware pins which use analog 4 and 5 pins. I2C is a two wire serial computer bus that is used to attach low-speed peripherals to an embedded system such as microcontroller. For SD card, it uses digital pins 13, 12, 11 and 10. The problem is, LCD display also uses the same pins. Through this project, we found both LCD display and data logger can not be used at the same time. This is one of the problem existed when using this data logger shield. However, this project provides the opportunity to show that portable data logging is possible. For future upgrading, by using other type of Arduino microcontroller which consists of more digital and analog pins, such as Arduino Mega 2560, a customized data logger which supports LCD display module can be built.

3.5 Device development

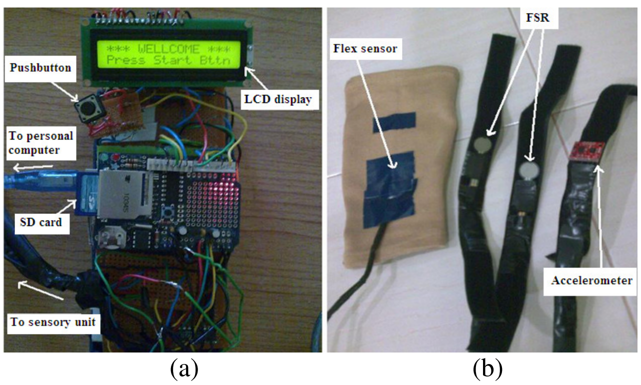


Fig. 17 Complete arm rehabilitation device consists of (a) main unit (b) sensory unit.

Fig. 17(a) shows the actual circuitry of the main unit. Fig. 17(b) shows the main unit with its custom built box. Basically, this device can be powered by 12v adaptor power supply and 9v battery, but due to online data logging purpose, USB connection to PC is needed. Thus, it is powered by 5v power supply from USB connection to PC. When power is ON, the device will display initializing process information on LCD monitor. Sensory unit will start to work by pressing Start/Stop button. At this state, sensory systems will start to send data. Any movements due to arm bending, sudden arm acceleration and muscle movement activity will be detected and sent to Arduino microcontroller and processed to be transmitted to PC via USB connection for online real-time data logging or SD card data logging (non-USB connection). The device will stop working when the button is pressed once again. Fig. 18 shows a flow chart on how to simply operate the main unit of this arm rehabilitation monitoring device.

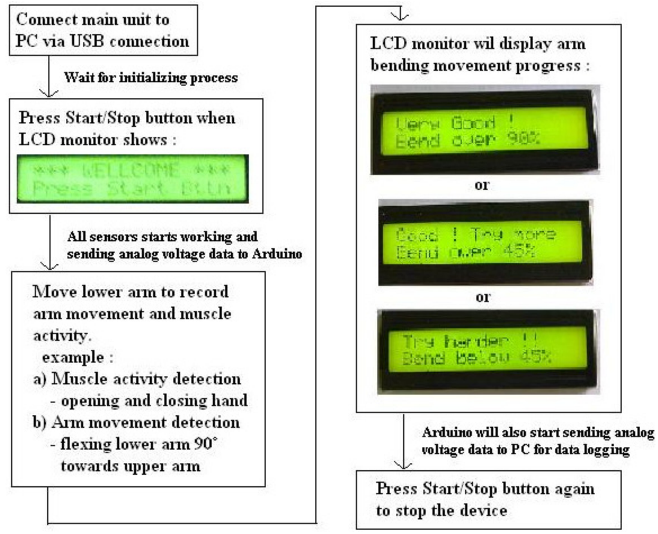


Fig. 18 Flow chart for the operation of portable arm rehabilitation device.

4.0 CONCLUSION

A wearable arm rehabilitation device equipped with monitoring system for post-stroke rehabilitation were designed and proposed. The described Arduino-based microcontroller system includes a flex sensor, 2 force sensitive resistors and an accelerometer is equipped with real-time monitoring (LCD monitor) and data logging functions (online real-time data logging using HyperTerminal or SD card data logging using Arduino data logger shield) translating to the following advantages:

- The system is compact, lightweight and does not restrict movement during usage.
- The proposed system is easy to be attached onto arm with minimal external assistance.
- It has data logging systems which can store data into personal computer or SD memory card for certain period of time that can be used by physical therapist for further analysis.
- With this low cost device, stroke patients can utilize this system at their home with minimal assistance from doctors and clinicians.

Our future work will focus on further enhancing the capability of sensory unit by adding 2-axis gyro sensor and an Ethernet shields. By using 2-axis gyro sensor, we predict to be able to improve the rehabilitation process which can be determined by measuring arm joints rotational motion which can give more accurate analysis such as subject’s performance and limitation towards any specific rehabilitation workout. In conclusion, the findings 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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