Home-Based Online Multisensory Arm Rehabilitation Monitoring System

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Abstract. Arm rehabilitation activities need to be monitored continuously in terms of analysis by experts within sufficient information to discover arm dysfunction and disorders such as stroke early. Although there are numerous previous researches about the home-based rehabilitation procedures and arm performance, some drawbacks still exist. For example, current rehabilitation devices are too complicated and required supervision by qualified therapists rather than their high prices. Moreover, data from these devices take much time to be sent to doctors for monitoring purpose. Therefore, this paper proposes a home-based online multisensory arm rehabilitation monitoring system. This system is designed through three main stages which are data acquisition, data processing, and data logging respectively. Data acquisition is by three different types of sensors; flex sensor (for arm’s bending), force-sensitive resistors (for hand fingers’ forces) and accelerometer (for arm movement directions). In data processing, Arduino Mega Controller and ESP Wi-Fi shield are used to design Internet of Things (IoT) web-based system (ThingSpeak) for data logging that allows doctors to diagnose stroke recovery and give feedbacks for patients. Overall, this project showed a robust system for arm rehabilitation using portable, user-friendly, and low power consumption devices at a low cost.

Keywords: IoT; Arm rehabilitation, Healthcare.

1. Introduction

The internet of things (IoT) also called the industrial internet, is a modern technology where a network of machines and devices can interact with each other. IoT is realized in three paradigms which are internet-oriented (middleware), things-oriented (sensors), and semantic-oriented (knowledge). This technology is used widely in our daily life applications especially in the medical field for doctors to visualize and analyze patients’ health care at anytime from anywhere (Gubbi, 2013).

The rehabilitation process is the therapy of the patient’s performance of various physical activities and exercises to reach a physical level that drives him to retrieve his initial motor abilities after a stroke, an accident, or a surgery (Haydar, 2012). Intensive rehabilitation achieves optimal rehabilitation results in a short time. Furthermore, during rehabilitation exercises, therapists should monitor and rectify the patient continuously to avoid improper exercises. Supervision of patients continuously during long-term
rehabilitation therapy is a burden for medical staff and physical therapists, and cost patients much even. Therefore, these challenges are solved by developing practical, low-cost, and user-friendly IoT-based rehabilitation devices (Ambar, 2012). Table 1 illustrates the summary of the characteristics of the related works.

Ganeson et al. proposed a low-cost instrument glove utilizing flex sensors and force resistive sensors for post-stroke hand rehabilitation system (Ganeson, 2016). Rehabilitation robot was developed to assist post-stroke patients during rehabilitation therapy by Song et al. (Song, 2015). Ganesan et al. proposed upper limb exoskeleton using 3D modelling structure for the rehabilitation system (Ganesan, 2015). Flex sensor, force sensitive resistor (FSR) and accelerometer were assessed with Arduino to develop smart glove system for therapy treatment (Ali, 2015). GUI gaming devices were designed utilizing depth and camera sensors, and optical sensor respectively for rehabilitation exercise (Jonsdottir, 2019)(Contreras, 2020).

The main contribution of this paper is to implement and analyses a home-based online multisensory arm rehabilitation monitoring system.

Table 1. Summary of Related Studies

| Ref                  | Rehabilitation process | Prototyping                  | Sensors                       | Monitoring system |
|----------------------|------------------------|------------------------------|-------------------------------|-------------------|
| (Ganeson, 2016)      | Specific Exercising    | Self-Exercising              | Flex sensor and FSRs          | PC database       |
| (Song, 2015)         | Robotic assistance     | Control system               | 3D force sensor               | PC database       |
| (Ganesan, 2015)      | Specific Self-Exercising| Arduino                      | Flex sensor, accelerometer and FSRs | GUI               |
| (Ali, 2015)          | Specific Self-Exercising| Arduino UNO                  |                              | Online Data Logging|
| (Jonsdottir, 2019)   | Gaming-Exercising      | N/A                          | Depth and camera sensor       | GUI               |
| (Contreras, 2020)    | Specific Self-Exercising| Motor and microcontroller    | Optical sensor                | GUI               |
| Our work             | Specific Exercising    | Self-Exercising              | Flex sensor, accelerometer and FSRs | Online (ThingSpeak)|

2. Implementation And Evaluation

The concept of this project is to design and develop a device that can monitor the arm-hand rehabilitation process. This device aimed to be used for patients after stroke or related injuries to monitor their arms progress. A critical thing in this study, the device has many advantages such as low cost, home-based (portable), and low power consumption in software and hardware designing.

Figure 1 shows the overall concept of this project. The proposed system consists of three main units which is sensory unit, main unit and data monitoring unit. Arm-hand movement is detected by sensors that will send analog signal to Arduino. Digital outputs will be displayed on Arduino serial monitor. From Arduino also data will be logged into personal computer and shown in ThingSpeak website as a suitable IoT platform. The main components used in this project are:

- **The flex sensor** technology function is based on a resistive carbon element that can achieve great form-factor on a thin flexible substrate. The Sensor produces a resistance output correlated to the radius bending when the substrate is bent in inverse proportion (Appelboom, 2014). In this study, flex sensor is used to measure arm bending angles of patient.
• **Force-Sensitive Resistors (FSR)** detect physical parameters such as weight, squeezing, and pressure, the resistive value (Ω) of this sensor changes inversely based on applied pressure force as shown in Fig. 2 (Ambar, 2012). Five FSR are utilized in this study to measure the hand’s fingers forces of patients.

• **An accelerometer** is an electromechanical device used to measure acceleration forces that may be gravity force (static), and movements or vibrations (dynamic) (Ambar, 2012). In this study the motion sensor is used in accelerometer to detect arm movements directions.

• **Arduino mega** microcontroller board, with 54 digital input/output pins, 16 analog input pins, 4 hardware serial ports, crystal oscillator (16 MHz), USB connection, a power jack, reset and switch buttons. It is a small and valuable microcontroller powered when connecting to a computer using the USB cable, AC-DC adaptor, or battery (Nayyar, 2016)(Pan, 2013). This board is the main unit in the device where data acquired by sensors are processed and interpreted.

• **ESP Wi-Fi** is an Arduino shield that provides low-cost Wi-Fi solution projects, and it is compatible with all types of Arduino microcontrollers. This shield equipped with AT firmware to allows using of provided library and implement Wi-Fi solution in any Arduino projects (Lim, 2010)(Pasha, 2016). The main function of this board is to transfer data to real time IoT monitoring system.

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**Figure 1. Overall project operational diagram**

Figure 2 shows the actual completed arm-hand rehabilitation device which consists of the main unit, sensory unit, Arduino shield, and ESP-Wi-Fi shield. The flex sensor is attached to the elbow-guard and five force resistors attached to a glove and accelerometer on the wrist. Pins connection of Arduino and ESP Wi-Fi shield is a critical matter which should be in concern. Therefore, a printed circuit board (PCB) is the most important part of this device which gives an accurate multi-connection to avoid short circuits due to many wires and gives project prototyping an amazing look. The circuit diagram in figure 3 demonstrates connections of sensors, Arduino and resistors.
Figure 2. The system hardware

Figure 3. Circuit diagram for sensor connections to Arduino mega
3. Results And Discussion
In this study, the results are organized in three experiments for flex sensor, FSR sensors, and accelerometer, respectively.

Experiment 1: this is the first experiment where a voltmeter was used for flex sensor value resistance verification. The digital reading values determined at certain angles of the flex sensor that was stuck into the anterior elbow-guard part (as in figure 4) to indicate arm bending movements. In this experiment, the patient involved in the specific exercise which was stretching and bending his arm four times. LCD is displaying TRY-HARD, GOOD, EXCELLENT based on arm bending angles (15º, 55º, and 97º respectively).

![Figure 4. Arm bending in different angles of flex sensor](image)

Figure 5 shows three graphs for three patients doing the same exercise within the same period of time. From these graphs, the results of the three subjects were almost the same due to high accuracy in the flex sensor.

![Figure 5. Angels’ measurement for arm bending in three different patients with same exercise](image)

Experiment 2: in this experiments, five FSR sensors were placed onto glove to measure forces of each finger. Therefore, patient in this experiment was asked to perform a specific task such a picking up an A4 paper from flat surface and crushing until it becomes round shape as shown in figure 6 below.
Figure 6. Crushing papers with the device

Table 2. Pressure forces measurement in Gram and Newton for fingers

| Finger | Force (N) | Force (g) |
|--------|-----------|-----------|
| Thumb  | 5.8       | 591.44    |
| Index  | 5.7       | 581.24    |
| Middle | 3.8       | 387.49    |
| Ring   | 2.9       | 295.72    |
| Small  | 2.6       | 265.13    |

Figure 7 illustrates graphs of all five fingers that displayed in MATLAB histogram automatically. For doing this step, Apps icon in channel platform was selected to choose MATLAB visualization. Also the more interesting thing is MATLAB code can be done and modified online at the same platform in ThingsSpeak. Normal-pressure forces of hand’s fingers are shown in Table 2 above which measured in Newton and Gram.

Figure 7. Forces of fingers in MATLAB
Experiment 3: this was the last experiment in the project, using an accelerometer sensor that was attached on the back wrist to measure arm movements by monitoring direction changing of the x, y, and z-axis. The subject (Patient) was stretching his arm on a flat table and started rising, holding and relaxing his arm in different directions as shown in figure 8. The acceleration range is from 0° degree to 360° degree as maximum. Figure 9 shows the graphs representing x, y, and z axis in MATLAB.

![Figure 8. Arm movements in three directions](image)

![Figure 9. Directions during arm's movements exercise by the patient in MATLAB](image)

4. Online IoT System
First of all, a channel named arm rehab was created in the ThingSpeak platform, by making an account. User may log in into the channel is by using email and password; channels are displayed as shown in figure 10 with widows where all data are represented during rehabilitation exercises of patient and stored for further analysis by doctors or physical experts.
Figure 10. Channel outlook and data representation in ThingsSpeak
5. Conclusion
This paper proposes a home-based online multisensory arm rehabilitation monitoring system. Construction of the device based on three main phases; data acquisition, data processing, and data logging. The data acquisition was by three types of sensors; flex sensor, FSR sensor, and accelerometer. After that data processing was applied using an Arduino Mega microcontroller and ESP Wi-Fi shield. Lastly, the data was logged into PC and being shown online in real-time and stored for further monitoring in an IoT web-based system (ThingSpeak) to allow therapists to diagnose patients any time anywhere. A liquid crystal display (LCD) was applied to give patient motivation during rehabilitation exercise. Overall, this project has many advantages which are portable, user-friendly, low power consumption and low cost. Furthermore, this is a robust system for arm rehabilitation that can store data of patients online for future analysis.

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