Impaired Hand Training Device with Wireless Data Communication

Majd Gahreeb[1] Rabah Yehya[1] Ali Hage-Diab[2] Ali Bazzi[1] Hassan M. Khachfe[3]
[1] Department of Computer and Communication Engineering
[2]Department of Biomedical Engineering
[3]Center for Quality Assurance, Institutional Assessment, & Scientific Research
International University of Beirut, Beirut, Lebanon
Corresponding author's email: majd.ghareeb@b-iu.edu.lb

Abstract— **In this paper, we aim at combining assistive technology with the Internet of Things in order to create a system with an important health impact on the quality of life of people with disabilities. In this system, an impaired hand training device with real time data transactions has been designed and developed. This device allows patients to practice their hand rehabilitation routine daily at home avoiding the exhausting transportation to the clinic or the hospital. Then, it will wirelessly and automatically send the acquired data to a Web system accessed by the physician and the patient as well. Consequently, the physician will be able to view, monitor, and adjust the requested routines for each patient and communicate this information with him/her in order to achieve the best results in the shortest possible time.**

Keywords-assistive technology; stretching sensor; hand rehabilitation; Arduino Wireless communication; Web.

I. INTRODUCTION

"Based on the Hebbian theory, Siegrid Löwel claims that "Cells that fire together, wire together" [1]". The neuroscience Hebbian theory explains the ability of synapses to strengthen or weaken over time, in response to the increase or decrease in their "synaptic plasticity", which is the ability of synapses to strengthen or weaken over time, in response to increases or decreases in their activity. Hence, this insures that neurons are able to adapt with the correct learning process and clarifies how intensive training can help patients in many clinical cases to overcome their impairments [1]. Relying on this finding, a lot of research has been applied in the domain of assistive technology. Assistive technology includes any item, tool, device or study that is designed for assisting, adapting, and rehabilitating people with disabilities. Wheelchairs, hand helpers, reaching tools, prosthesis, etc., are all examples that could be included under this umbrella. Nevertheless, research goes far beyond these traditional pieces of equipment to follow the technology revolution with many assisting smart devices.

In the last decade, these devices have been seen on the market and continue to develop. However, each of them still raises concerns, such as, reliability, ease of use, weight, the relatively expensive cost of such technology, the lack of a database that stores the acquired information and the smooth interface between the patient and the physician.

Approximately 315,000 patients in Canada live with the after effects of strokes and it costs around 3.6 billion dollars per year in hospitals and rehabilitation centers, and more than 4.5 million days in a rehabilitation center and 639,000 days in the hospital [2].

A lot of research has already been done to develop a hand rehabilitation glove. One solution was proposed in [3], in which the angle achieved by the finger is observed. In this work, in case of a slow or lacking healing process, a physician can add a routine that may be considered as a missing part of the system. This draws the attention to the importance of having a flexible system that updates the patient with the daily exercise routine to promote the healing process.

Another solution is proposed by Panagiotis Polygerinos et al. [4] and it is an automated glove for people with practical handle pathologies to help improve the catch movement. The results obtained were very promising in this work and also in the work presented in [5] by Dominic E. Nathan et al. This latter examines the design, development and validation of a custom-made sensorized glove system and its custom grasp prediction model. The validation studies helped show the capability of this glove for real-time tracking. However, both presented gloves need the direct observation of the physician during the exercises and do not provide any means to communicate remotely with him or to save the obtained results into a database for future use and analysis. Many commercial hand rehabilitation gloves are available on the market. On the other hand, different other proposed gloves are inefficient or relatively expensive [6]. Additionally, the noticeable wiring on some glove models can be a problem [7].

Furthermore, patients, such as children and elderly, might not be able to attend physical therapy due to the exhausting road trips to and from the medical facilities and that might hinder their healing process. We believe the "specificity of learning" principle should be ensured [8], which predicts that the learning of a new skill is improved when conditions of practice match those of the task in real life [9]. Hence, home-based rehabilitation could prove to be more advantageous than hospital based or outpatient treatment based since it permits a repeated practice of occupationally embedded tasks in the individual's own environment [10]. Many works have been done with the objective of moving the clinic to the home whenever possible. CNNTECH [11] is a biomedical oriented company that developed a smart glove that helps

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stroke patients rehabilitate. However, the clinical studies are still at an early stage. Another training device called "RAPAEL Smart Glove for Hand Rehab [6]" was released by NEOFECT and it is a sensory technology that captures the patient's hand movement data and transfers it via WiFi. However, the cost is too expensive for many hand impaired individuals since it costs $15,000 according to the digital trend [6]. A recent low cost and light weight device [12] like ours was developed by our colleagues in the Lebanese International University in 2016. However, it lacked wireless interface and real time data transmission.

From all the above mentioned needs and issues in the existing work, we could observe the vital need for a reliable, affordable, light-weighted, and portable hand assistive device that can help patients to perform their hand repetitive therapeutic routines at home and that can also provide an interface between patients and their physicians.

In this paper, we present a prototype of an assistive glove that can help patients in practicing their hand rehabilitation routine daily at home. Via a Web based application and a wireless communication, the system will automatically transfer and save the achieved results of each exercise. Hence, physicians can from their part approve or ask to improve the followed routine by the patient to guarantee faster recovery.

The rest of the paper is structured as follows. Section II presents the general overview of our idea. Then, Section III contains the user requirements and specifications of the system. Section IV presents the tools used to implement the system with a few important details about the implementation steps. Finally, we conclude the article in Section V.

Figure 1. System architecture design

II. SMART GLOVE SYSTEM ARCHITECTURE

In addition to a previous work done by our colleagues at the Lebanese International University last year [12], different approaches have also explored the use of assessment devices to monitor the impaired hand function during daily life activities. However, even in the work presented in [12], monitoring and data saving is basically done over an SD card, an ultra-small flash memory card designed to provide high-capacity memory in a small size, which makes data reading, searching and retrieval a complicated mission, especially for patients and physicians who are not familiar with recent technology advances. Most of the already existing solutions are to be used in clinics under physician supervision. Nevertheless, we benefited from them to create a standalone system that could be used by the patient, with no need to go to the clinic or to be under the direct supervision of an expert since all the needed utilities could be managed by the patient at home.

The objective of the project presented in this paper is to develop a smart assistive glove that will monitor the improvement of the impaired hand, and save this information directly into a permanent storage that could be accessed remotely by the physician and the patient for review and edit.

As shown in Figure 1, our system is composed of the assistive glove that is mounted by the same stretching sensors used in [7][13]. These sensors are basically made from elastic rubber and graphite, which have lower cost and lighter weight compared to other existing sensors with the high accuracy required to monitor the movement of the hand. Moreover, these stretch sensors have a role in converting the physical parameters into an electric signal, allowing them to reflect the finger's motion and angles as the individual moves his/her digits.

The glove will be connected wirelessly to the Internet via a node MCU (ESP8266) WiFi wireless module which is an open source IoT platform. This node includes a firmware which runs on the ESP8266 Wi-Fi SoC from Espressif Systems and hardware which is based on the ESP-12 module. In addition, the sensor readings will be shown on an LCD (Liquid Crystal Display) screen in order to help the patient directly see his achieved results. Accordingly, the results will be transmitted wirelessly to a website that will be connected to a database which organizes all the requested information by the physician and performed by the patient for future monitoring and reviewing.

This real-time reading will allow the physicians to make better treatment plans and optimize the given routines in order to increase the number of patients who improve their condition in a short period of time. Moreover, it will allow easy access for both physicians and patients to check the progress of the daily routines requested for rehabilitation and to facilitate and declare the aforementioned missions by each one of them according to their roles.

Patients can access the website by logging in their specific page where they are able to check what they have to do and their progress. This process will help in improving patient health, since it is proved that integration of augmented feedback and exercises can stimulate the learning process in rehabilitation therapy by making patients more

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conscious of their performance [14]. An additional feature of the smart glove system is to communicate with the patient via SMS (Short Message Service) messages from the website to inform him about his progress or about any urgent issues.

Finally, the cost of our system is very low taking into account the parts used to build it, the expected delivered service, and the flexibility of use in different aspects.

III. User Requirements and Specifications

Our proposed system consists of two main components that are the assistive glove used by the patient at home to rehabilitate his routines, and the website that could be used by the physicians and the patients as well, each according to his/her role. Below, we list the requirements of each component of the system. This is also shown in the use case diagram presented in Figure 2.

A. Glove (Patient side):
- Easily wearable with hidden wires and flexible stretch sensors.
- Easy to change the battery by simply plugging the corresponding cable into the box.
- Enable monitoring the angle value using an LCD.
- Wirelessly connected to the WiFi router at home in order to send the corresponding information to the server.

B. Website (Physician side):
- Ability to login/out, change/reset the password.
- Ability to add to the patient's list their patients and their general information that will be directly saved in the database.
- Ability to submit a mission or, in other words, the tasks the patients should try to do in the routine process by adding a specific routine to each patient.
- Ability to check all their patients' routines that they have submitted.
- Ability to check the routine progress analysis of their patients (advancement) in a table and in a graphical form.
- Ability to send an SMS text directly from the website to their patients' mobile phone according to the phone number that has been registered in the patient page.

C. Website (Patient side):
- Ability to login/out, change/reset their password.
- Ability to check his routine only and the remarks added by the physician.
- Ability to check his routine progress analysis (advancement) in a table and graphical form.

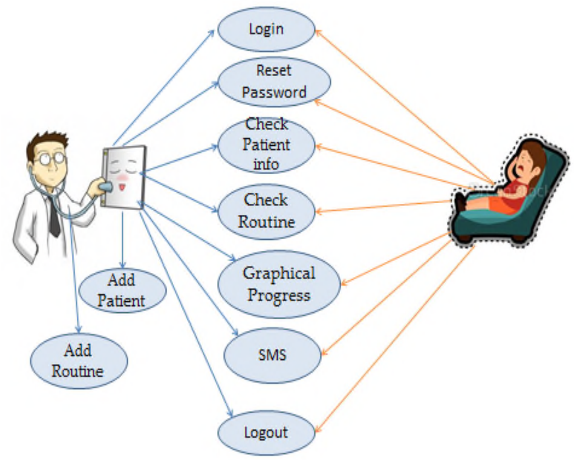

Figure 2. Use case diagram of the system

IV. Implementation Tools and Summary

As indicated in Section III, the smart assistive glove system consists of two major components that are the glove and the website. We will start this section by listing the technical tools that we used for creating these components. Then, we present the details followed to implement the glove. A summary of the main pages of our website are then listed and explained.

A. Implementation tools:

➢ Glove:
- Arduino -Node mcu 0.9 (ESP8266 – 12 Module)
- Accelerometer ADXL 345.
- Stretch sensor.
- LCD monitor 16 x 2.
- A light-weighted medium thickness glove
- Connecting wires, resistors, a 10K potentiometer, regulators, and a 9V battery.

➢ Web application:
- Use XAMP to run the servers APACHE [15] and MYSQL [16].
- Use PHP for server side programming [17]
- Use PHP MyAdmin and MYSQL to create database [18]
- Use Arduino Software [19].
- API for SMS.

After listing the technical tools used in the development, we briefly explain below the steps followed to implement the system.

B. Glove Implementation

As presented in the previous work in [12] and [13], the stretch sensors are made from elastic rubber dipped in finely

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grated graphite-alcohol mixture, then dried out and fixed with a thin layer of white glue to keep the graphite from falling off the rubber. Since graphite is a good electrical conductor, the nonconductive rubber will turn into a stretch sensor that converts the physical parameter into an electrical signal to be acquired by the board for monitoring and control.

A voltage divider is used to convert the change of the resistance into an electric analog voltage readable by the Node MCU module. This voltage will be mapped into angles indicating the flexion or extension of the digits. The patient should reach the desired angles set by the physician during each routine and repetition, so in order to do that, an LCD monitor will display the values of the angles and the position of the patient's hand indicated by the attached accelerometer on the wrist.

In order to map the stretch sensor, one must wear the glove, extend his/her fingers and note the measured value as zero, then flex the fingers to the maximum point and note the obtained value as 90. Mapping these two values will serve as a range for the voltages with their corresponding angles.

The stretch sensor is connected to another resistor of similar resistance to create a voltage divider, thus converting the changes in resistance into changes in voltages. Then, the voltage divider's output is connected to the only analog pin A0 of the Node MCU to acquire the data.

An accelerometer is also connected to the Node MCU input digital pins to measure the wrist's acceleration and map it into an angle. The LCD is connected to the Node MCU in order to display the values of the stretch sensor and accelerometer clearly visible to the patient.

C. Website Implementation

The implemented website consists of two main users that are the physician and the patient. Each can access the system using his own credentials. Below, we list for each of the two roles the main activities and actions that could be implemented.

- **Physician's Side**

When the physician logs into his page, a list of his patients appears with their information (name, phone number, gloveID and email address). Moreover, a button for each patient will take him to this latter corresponding page to display every patient's routine separately, add routine to every patient, check his routine progress analysis (advancements) in a table and in a graphical form and send him/her an SMS to the number saved in the database for that patient.

Figure 3 shows the "Add routine" page where the physician is supposed to submit the routine (the required angle that the patient is supposed to practice with, the number of times he is supposed to repeat the exercise, etc.). On the other hand, the patient will be able to see this information directly and hence could start his routine on the given date.

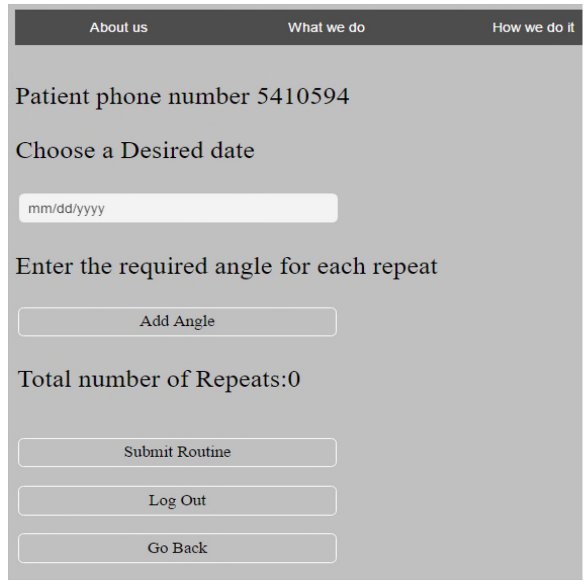
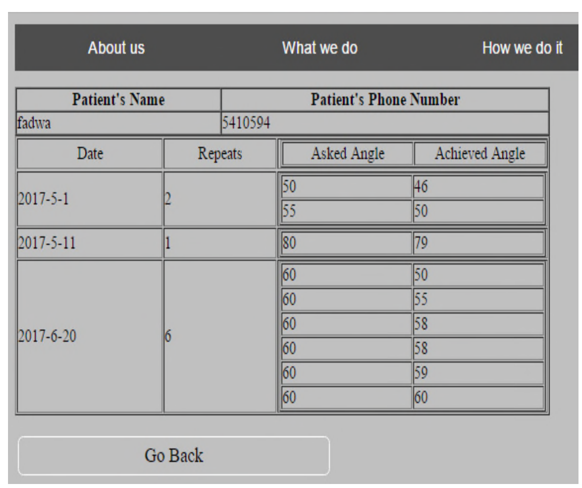


Figure 3. Add Routine

- **Patient Side**

When the patient logs into his page, his achievements records appear with a well specified number of repeats and desired angle for every repeat that he is supposed to do during a certain period of time, as shown in Figure 4.

We notice from this figure how routines are organized according to the date of their occurrence, with the required angle to be done by each requested repeat and the achieved angle that could be reached by the patient during practice time. Moreover, the system automatically generates these records in graphical form to make result observation easier for the patient and the physicians as well, since both are able to show the results as presented in Figure 5.



Patient's Name	Patient's Phone Number
fadwa	5410594

Date	Repeats	Asked Angle	Achieved Angle
2017-5-1	2	50	46
		55	50
2017-5-11	1	80	79
2017-6-20	6	60	50
		60	55
		60	58
		60	58
		60	59
		60	60

Figure 4. Data transferred saved in a table form

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Figure 5 shows graphically the comparison between the asked and the achieved angles.

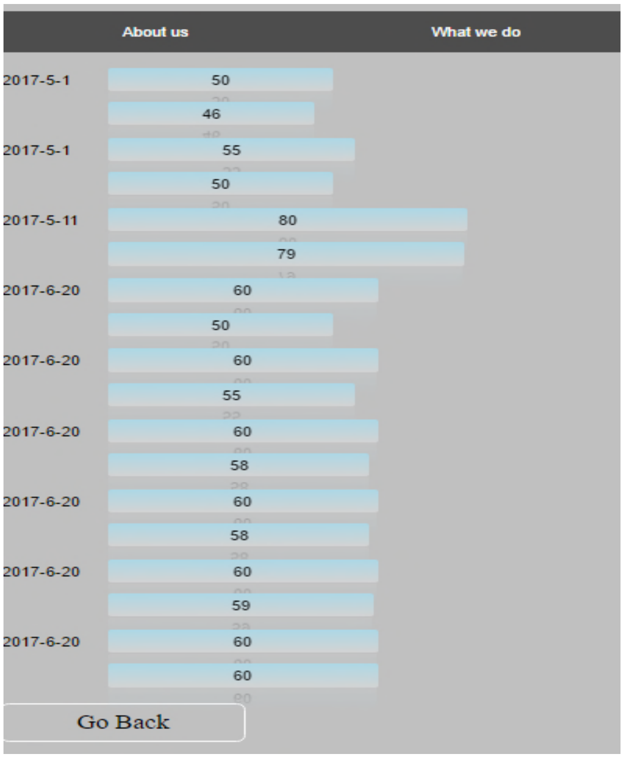

Figure 5. Data transferred shown in a graphical format.

V. CONCLUSION AND FUTURE WORK

The proposed system could save a lot of time and effort for all involved users. This can be achieved by spending less time at the clinics, analyzing patient's activities and planning. These activities could be done at home where patients are more comfortable, thus increasing the benefits of the session.

Physicians can take their time interpreting the results and conducting a detailed analysis of the data obtained and taking the appropriate next steps. In addition, the system is based on a database that will always be reachable and secured. Physicians and patients can easily access this website that is clear enough and simple to use.

The contribution proposed in this paper is the preliminary step towards a more developed and stable system that would surely take its place among other existing conventional devices in terms of accuracy, speed, etc.

Smart assistive glove is a very helpful device for people with impaired hands and there will always be room for improving system functionality. The accuracy of the stretch sensor can be improved by using more stretch sensors. The standard deviation can be computed after conducting many experiments and improving the calibration of the sensors.

Moreover, the website could be improved and augmented in different pages. Besides, all the trails on the website were done locally and it should be tried on a real domain to make sure everything is working perfectly to be prepared for using the smart glove on the market.

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