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# IoT-Based Rehabilitation Monitoring System for Carpal Tunnel Syndrome

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**Abstract**: Carpal Tunnel Syndrome is a typical disease that results in tingling and discomfort in the hand due to compression of the median nerve as it passes through the carpal tunnel, a tiny pathway on the palm side of the wrist. There are two ways to cure this syndrome which are surgery and rehabilitation. The current method used to cure this syndrome is the surgery method. This work is focusing on rehabilitation methods. IoT-Based Rehabilitation Monitoring System for Carpal Tunnel Syndrome is designed to monitor the measurement of bending angle during wrist flexion stretch exercise and measurement of grip force exaggerated on fingers. Patients can also check whether the exercises they have conducted are successful by referring to the measurement and alert shown. The main components used are the flexible bend sensor to measure the bending angle and force-sensitive-resistive (FSR) sensors to measure the grip force on fingers. ESP 32 is the microcontroller to controls the input and output of the system. The characteristics of the patient's bending angle and grip force were monitored using the Blynk application. The data is collected from 5 healthy subjects and one Carpal Tunnel patient. The collected data shows that there are improvements recorded from day 1 until day 4. 10.5% of improvement in the bending angle of the wrist is recorded. For the thumb finger, index finger, and middle finger, there are 6% improvements, 9% improvements, and 5.6% improvements respectively from the beginning of Day 1 until Day 4 in one week.

**Keywords**: Carpal Tunnel Syndrome, Internet of Things, Blynk, Flexible bend sensor, Force Sensitive Resistive sensor

## 1. Introduction

Carpal tunnel is the narrow rigid passageway of ligaments and bones which is shared by the median nerve. Carpal bones formed a semi-circle shape by eight small bones that are made up at the side and bottom of the ligament is a group of strong tissue located at the top of the tunnel and holds it. Carpal Tunnel Syndrome is a common condition that causes tingling and pain in the hand and is caused by a compression of the median nerve passing in the carpal tunnel, a narrow passageway on the palm side of the wrist [1]. It can be also caused acutely by fractures and other wrist injuries but mostly with

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long-term and a one-sided load of small muscles of the hand and forearm [2]. More than 80% of the patients are over 40 years old, the women being more affected than the men (5:1) [3]. Patients with this syndrome will find it hard to grip something for example dropping glass while holding it. Some of the early symptoms are tingling or pain in the fingers especially the thumb, index, and middle fingers.

Fractures and injuries can happen at any time during playing, driving and working, and other work. Many of them can have a fast recovery process that can last a few days but others may last longer or never fully recover [4]. Injuries can happen to body parts such as hands, legs, and head and also to internal parts such as injuries to muscles, limbs, and tendons. Carpal Tunnel Syndrome is one of the injuries that involve the wrist and the capability of fingers to hold something. In this situation, the patient might tend to have a lack of coordination and permanent nerve damage. Strengthening wrist exercises is an important element in the treatment of the syndrome. Exercises improve the patient's condition using control and coordination of movement [2].

This work is therefore to create a system that can monitor the rehabilitation progress due to the affected syndrome based on the selected parameters. The main focus is to design a system that is able to monitor the rehabilitation process efficiently to help patients with Carpal Tunnel Syndrome to recover from this syndrome. One of the parameters measured is the bending angle of the wrist during exercise. Once it reached the required angle, the patient is alerted by a buzzer. Another parameter is the grip force of the patient's fingers. There is also an application developed that monitor the rehabilitation process. This application can display the measurement of the bending angle of a patient's wrist and the grip force reading chart of the patient's finger including the thumb finger, index finger, and middle finger generated to analyze the patient's performance. Doctors also can monitor patient progress while doing exercise by logging in to the application at the same time.

## 2. Methodology

IoT-Based Rehabilitation Monitoring System for Carpal Tunnel Syndrome used ESP 32 as a microcontroller that controls the input and output of the sensor. ESP 32 also directed the values of measured parameters to the cloud and display the values at the application through a Wi-Fi connection. While the patient performing the exercise, the angle of the bending wrist in the wrist flexion stretch exercise is measured and alerted by a buzzer if it reaches the efficient angle at 90° [4]. The value of the angle measured from the wrist flexion stretch exercise and grip force generated by the patient's finger using the ball squeeze exercise is then displayed on the mobile application for monitoring and further analyzing the performance of the patient.

### 2.1 Flowchart of hardware design

This system starts with the flexible bend sensor that measured the wrist bending angle during practicing the wrist flexion stretch exercise and then displayed the measurement in the Blynk mobile application. The declaration is set up in the coding when the angle measured is 90 degrees or greater, then the ESP 32 trigger the buzzer to alert the user as a sign that the effective angle bend had been reached [4]. If the measured angle does not exceed 90 degrees, the flexible bend sensor continues to measure and show the bending angle in the Blynk application.

In the second part of the hardware design, a patient needs to practice the ball squeeze exercise. This exercise is modified from the application in previous research papers to measure the force applied to the patient's fingertips [5]. In the exercise, the patient needs to squeeze a tennis ball and hold it for 15 seconds. During the patient the exercise, the FSR sensors measure the force exaggerated on each of the patient's fingers. The measurement is calculated to determine the force value and display it in the graph on the Blynk application. Figure 1 shows the workflow of the system.

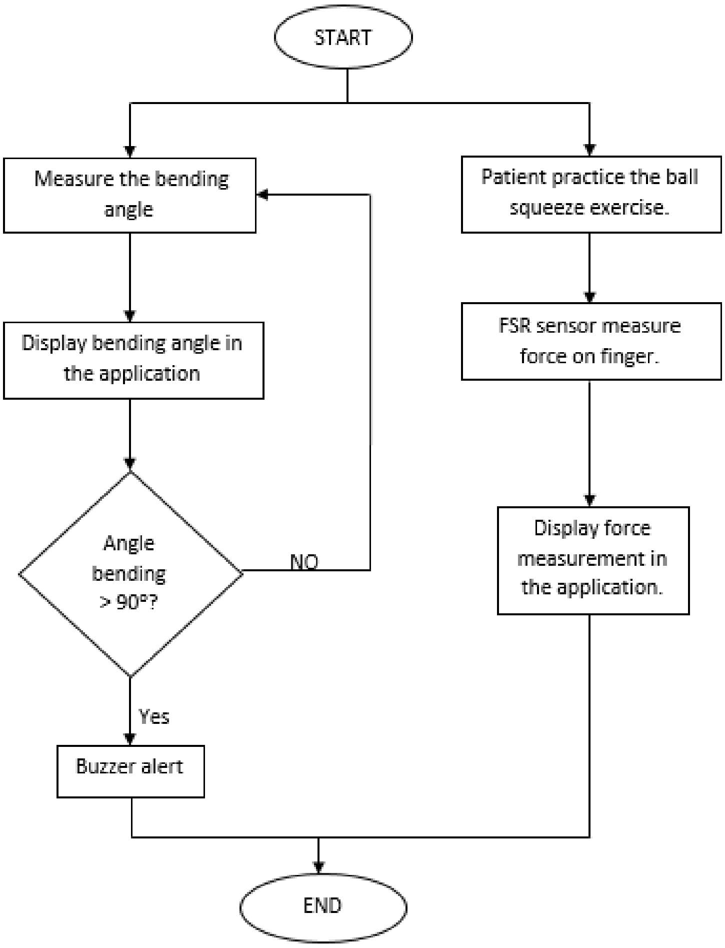



**Figure 1: Workflow of the system**

## 2.2 Circuit diagram

The connections must be in the correct order to prevent errors while measuring the parameters and producing the desired output. The flexible bend sensor is connected to analog pin 33 at the ESP 32. All three FSR sensors are connected to three analog pins of the ESP 32; pin 32, pin 34, and pin 35. All of these sensors are connected to the resistors to manipulate the analog value produced by the output of the sensors. There is only one digital pin used in the ESP 32 which is pin 25 connected to the output of the buzzer to alert when the output reaches the condition of the angle bending of wrist setup as coded. The ESP 32 is used to access the Wi-Fi connection and transmit it to the Blynk Cloud. Figure 2 shows the overall circuit diagram.

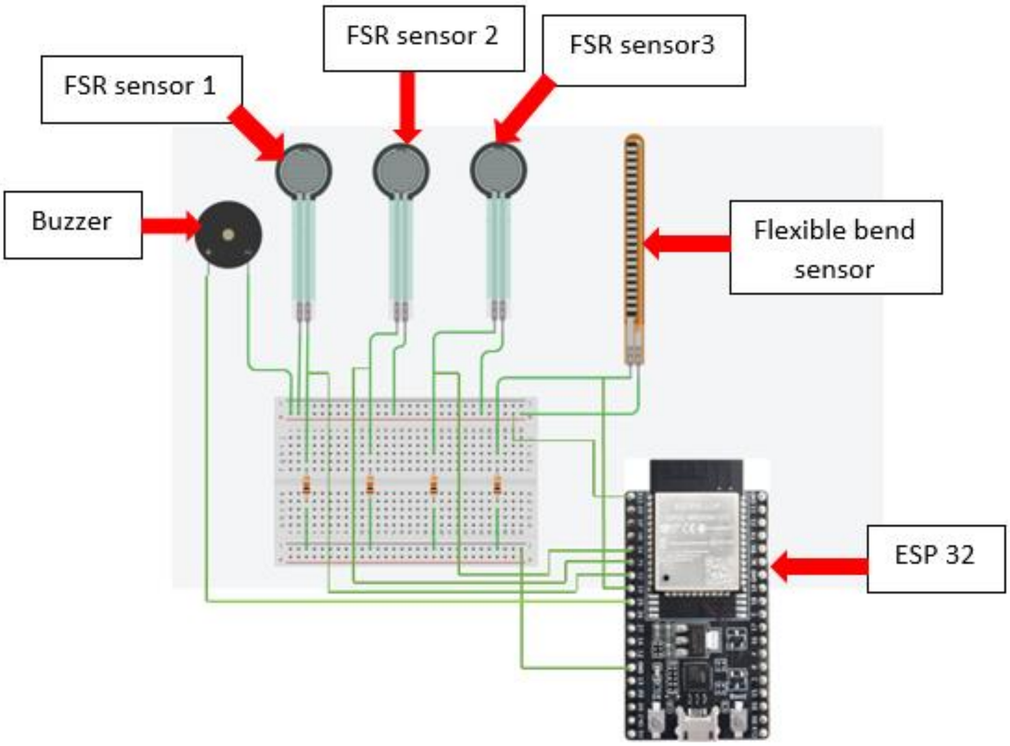



**Figure 2: Overall circuit diagram**

### 2.3 Software development

The block diagram in Figure 3 shows the flow of the sensor to be displayed in the Blynk application and web dashboard. When the circuit is connected to a power source, a flexible bend sensor and the force-sensitive resistive sensors begin to measure the bending angle and the force exaggerated on the patient's fingers. The output of both of the sensors then is transmitted to ESP 32. At the same time, ESP 32 is connected to a Wi-Fi connection set up in the range and stores the data in Blynk cloud storage. From the Blynk cloud storage, the data of sensor output can be accessed by the Blynk mobile application. Access to the mobile application and web dashboard is private which is only an authorized person can log in to the application. There is a token provided by Blynk that is declared in Arduino IDE to allow access. There are two parts to the Blynk application. The first part is displaying the bending angle of the wrist and the second part consists of 3 charts that represent all three fingers to monitor the force on each patient's finger. The angle bending is observed by patients themselves during practicing the exercise.

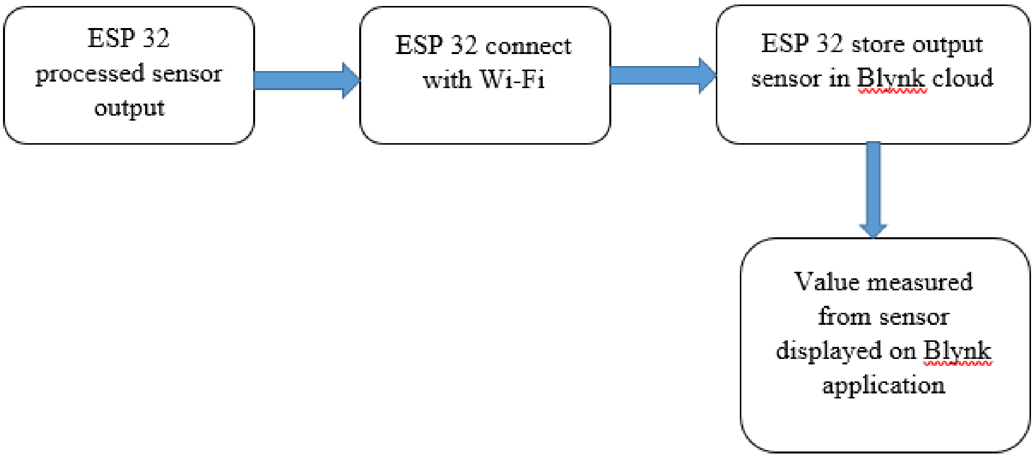



**Figure 3: Block diagram for Blynk application**

The new Blynk as shown in Figure 4 provides a Blynk cloud, Blynk library, Blynk app, and web dashboard which is upgraded from the previous version. The user has to set the data stream as in Figure 4 to generate the output in the Blynk application. In this application, the user can design the web dashboard and the application. The web dashboard can be set up on the website. The measurement of the parameters will be displayed at the display gauge on the mobile application.

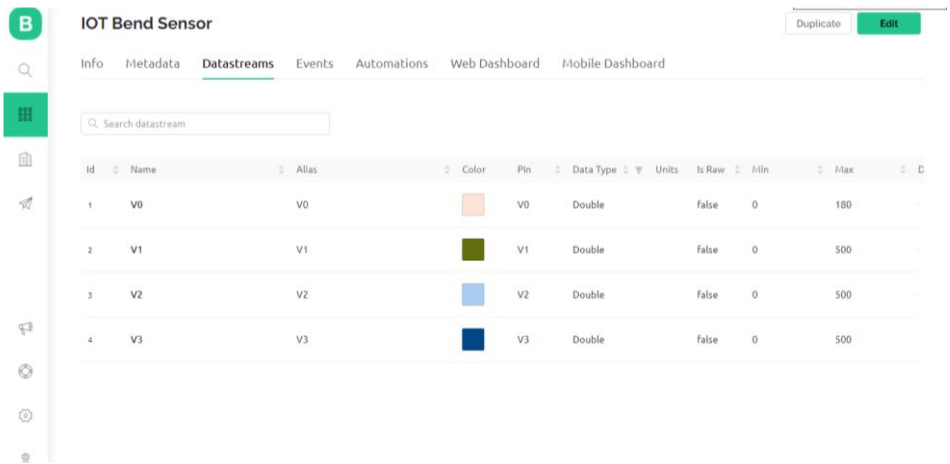



**Figure 4: The user interface of the Blynk dashboard**

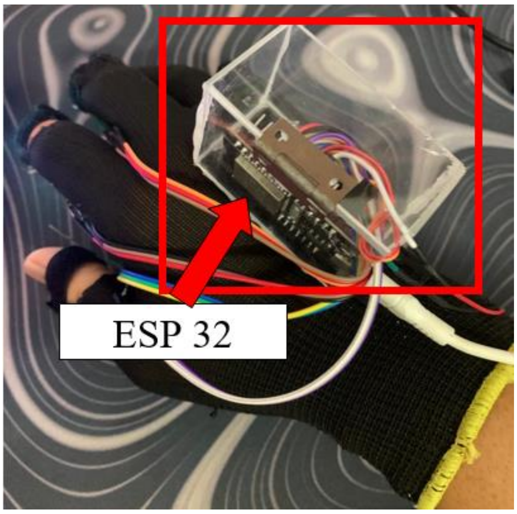
## 2.4 Type of exercises

There is a total of 5 healthy subjects and 1 subject with Carpal Tunnel Syndrome has been selected to test this prototype. The healthy subjects are not taking any supplements such as mass protein. All the participants need to do two types of exercise which are wrist flexion stretch and ball squeeze exercise. From this exercise, the bending angle of the wrist is recorded to monitor the progress of the patient from day to day. Another exercise is the ball squeeze exercise. The tennis ball had been chosen because the size of the ball is moderate, so the patient and subjects can grab and squeeze the ball. In this exercise, the grip force is measured by the FSR sensors on each the thumb finger, index finger, and middle finger.

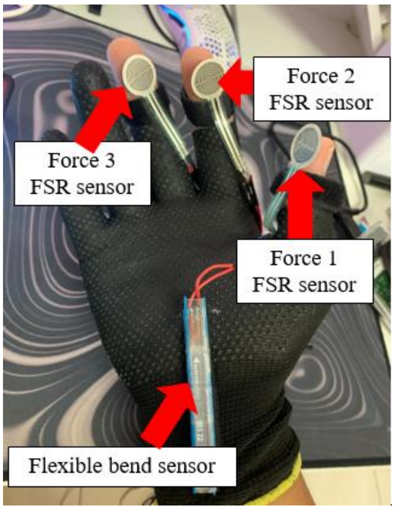
## 3. Results and Discussion

The final prototype is shown in Figure 5. Figure 5 (a) shows the location of the ESP 32 on the glove. The ESP 32 is placed in a casing to protect it exposed to other substances that can harm the microcontroller while performing the exercises. Figure 5 (b) shows the location of the FSR sensors and the flexible bend sensors.

Figure 6 shows the user interface of the Blynk application on the user's smartphone. For the user interface, there is a meter gauge that is used to monitor the bending angle of the wrist during the wrist flexion stretch exercise. The meter gauge is limited to 180°. Below the meter gauge is the 3 charts that are used to monitor the force exaggerated to the fingertips. Force 1 is the chart that shows the force reading of the thumb finger. Force 2 shows the force reading on the index finger and force 3 displays the measurement of force on the middle finger.




(a)




(b)

**Figure 5: (a) Location of ESP 32, and (b) location of sensors on each finger**

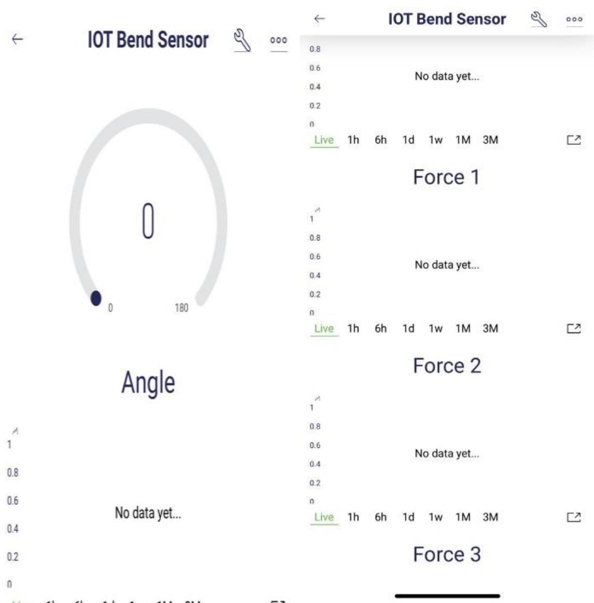
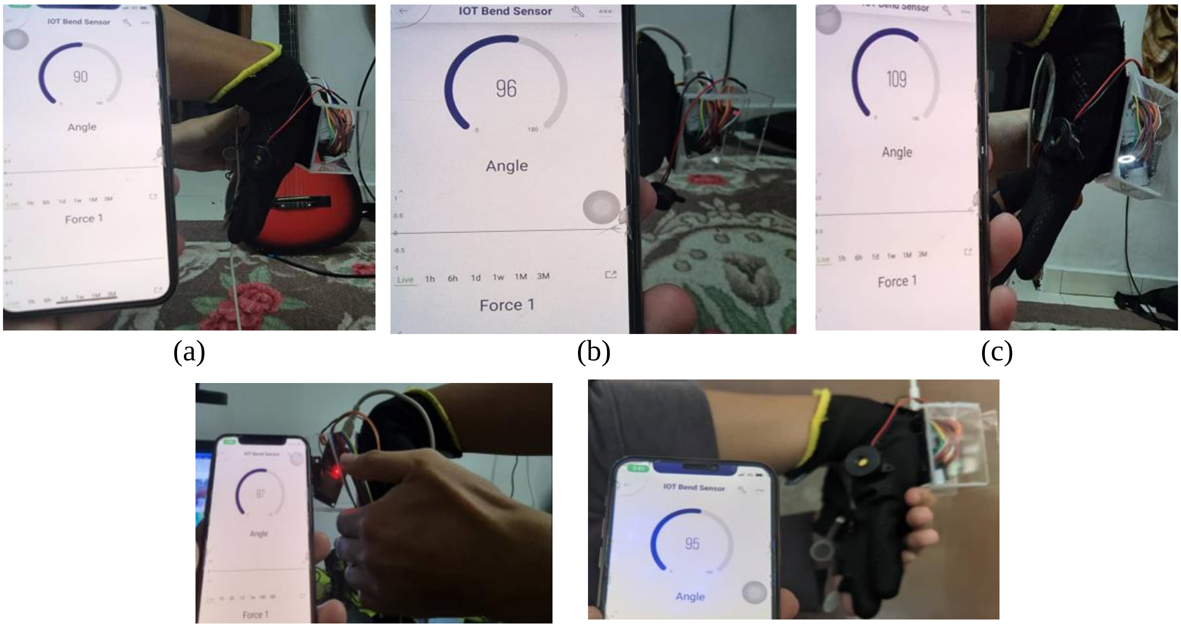



**Figure 6: The user interface of the Blynk application**

### 3.1 Results of measurement on wrist bending angle

All of the participants are healthy subjects that did not have any health problems related to hands or fingers. Figure 7 shows the results of the angle bending of the wrist that had been measured on Subject 1 until Subject 5. The average age of participants is between 23 to 30 years old.

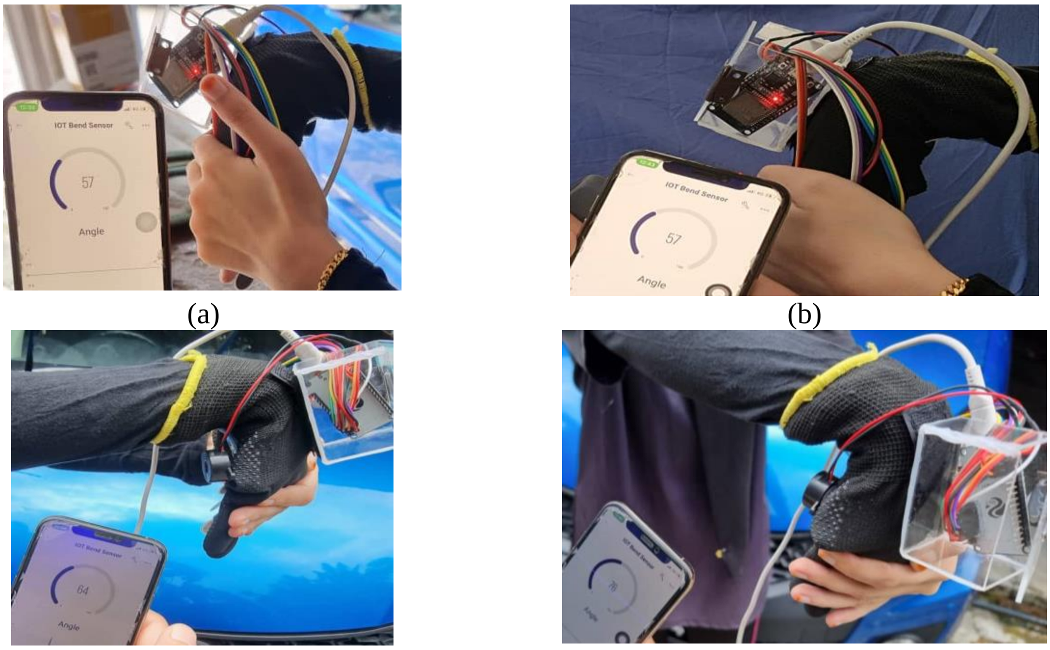



(a) (b) (c)

(d) (e)

**Figure 7: Wrist bending angle for healthy subjects; (a) Subject 1, (b) Subject 2, (c) Subject 3, (d) Subject 4, and (e) Subject 5**

The reading measurement on the wrist angle bending of the Carpal Tunnel Syndrome patient is taken once every two days in a week. The readings are taken to monitor the progress of the patient's flexibility during the wrist flexion stretch exercise. Figure 8 shows the reading of angle bending taken during the patient undergoing wrist flexion stretch exercise.



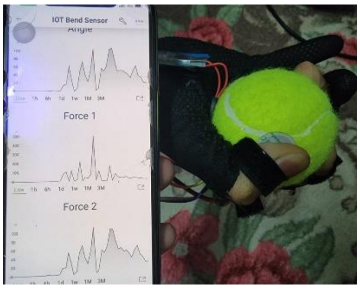

(a) (b)

(c) (d)

**Figure 8: Wrist bending angle for patient; (a) Day 1, (b) Day 2, (c) Day 3, and (d) Day 4**

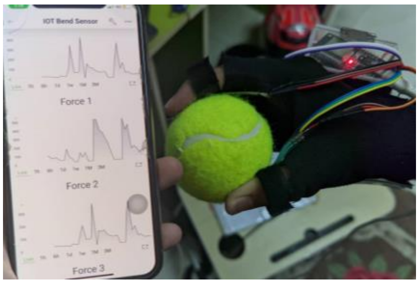
### 3.2 Results of measurement on the force applied to fingertips

The second exercise is the ball squeeze exercise. When the subject squeezes the ball, the graph obtained in the Blynk application is monitored and recorded to determine the force applied to the subject's fingertips. Figure 9 shows the 5 healthy subjects practicing the ball squeeze exercise and the forces exaggerated are being recorded.

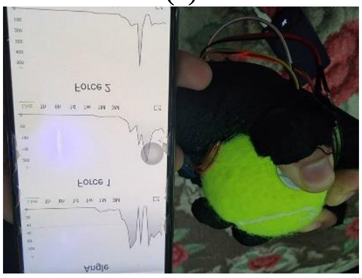



(a)


(b)




(c)



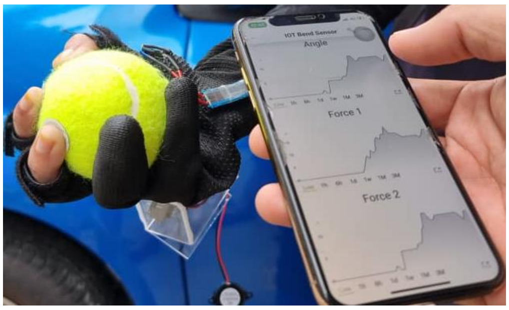
(d)


(e)

**Figure 9: Force generated by healthy subjects; (a) Subject 1, (b) Subject 2, (c) Subject 3, (d) Subject 4, and (e) Subject 5**

After the wrist flexion stretch exercise, the patient practices the ball squeeze exercise. Figure 10 shows the result of the force applied to the patient's fingertips. During the exercise, the patient was advised to apply the maximum force to the tennis ball but if there is pain patient needs to stop to avoid any injuries. As the result for the first day, the reading of force applied recorded the lowest value. But after the second day, the reading of force slightly increases from the previous days.

(a)




(b)

(c)

(d)

**Figure 10: Force generated by patient; (a) Day 1 (a), Day 2 (b), Day 3 (c), and Day 4 (d)**

### 3.3 Discussions

After all the data were collected, there is a need to make a comparison between the healthy subjects and the Carpal Tunnel Syndrome patient. Table 1 shows the data collected for the 5 healthy subjects while Table 2 shows the data collected for the Carpal Tunnel Syndrome patient.

**Table 1: Data collected for healthy subjects**

| Subject | Angle bending of the wrist (degree) | Force (N) | | |
|---|---|---|---|---|
| | | Thumb finger | Index finger | Middle finger |
| 1 | 90º | 100 N | 500 N | 100 N |
| 2 | 96º | 120 N | 500N | 150 N |
| 3 | 95º | 400 N | 500N | 300N |
| 4 | 106º | 100 N | 200 N | 500 N |
| 5 | 96º | 80 N | 150 N | 80 N |

**Table 2: Data collected for Carpal Tunnel Syndrome patient**

| Subject | Angle bending of the wrist (degree) | Force (N) | | |
|---|---|---|---|---|
| | | Thumb finger | Index finger | Middle finger |
| 1 | 57º | 10 N | 15 N | 11 N |
| 2 | 57º | 12 N | 16 N | 11 N |
| 3 | 64º | 16 N | 25 N | 15 N |
| 4 | 76º | 40 N | 60 N | 39 N |

From the data collected, all 5 healthy subjects were able to do the wrist flexion stretch exercise without any problem. All of the subjects can bend their wrist until reaching 90° which is efficient to do the exercise. As for the ball squeeze exercise, only Subject 5 recorded the reading of force applied below 100 N for the thumb finger and 80 N for the middle finger because the subject practice the exercise right after playing bowling.

Table 2 shows the data collected for the Carpal Tunnel Syndrome patient which is taken once every two days a week. As for the Carpal Tunnel Syndrome patient, the ability of wrist bending and force applied to fingertips are lesser than the healthy subjects. With this system, the patient can monitor the progress day by day. Referring to Table 2, on the first day the bending angle in wrist flexion exercise only reach 57° while in ball squeeze exercise, the force applied to fingertips is below 20 N. On the second day, the wrist flexion stretch exercise has the same output but there is a slight improvement in the ball squeeze exercise. The force applied on the thumb finger increased from 10 N to 12 N and the index finger from 15 N to 16 N. On the third day, the patient has positive progress on both of the exercises. The reading of the bending angle of the wrist has increased to 64° and for the ball squeeze exercise, the thumb finger can apply 16 N of force to the fingertips. The index finger can reach 25 N and the middle finger reach 15 N. On the last day, the patient was able to reach 76° on the bending angle of the wrist increase of 6.7% from the previous day while the force applied to the fingertips also increased for the thumb finger from 16 N to 40 N. The index finger also increases from 25 N to 60 N while the middle finger from 15 N to 39 N.

In one week, the patient improved on the bending angle of the wrist and the pressure applied to the fingertips with this IoT-based rehabilitation monitoring system for Carpal Tunnel Syndrome. Although the patient cannot bend the wrist angle to the efficient angle for the wrist flexion stretch exercise, there are improvements from the first day until day 4. On the first day, the patient only can bend at 57° but on the fourth day, the patient can bend to 76° which there is a 10.5% of improvement in one week. For the thumb finger, there are 6% improvements, the index finger 9% improvements, and the middle finger has 5.6% improvements from the beginning day 1 until day 4 in one week.

However, there are much more rehabilitation exercises that could be useful to cure Carpal Tunnel Syndrome patients. This work only can measure the parameter for the two exercises. The limitation occurs because of the user interface used, Blynk application is a free access application which is if there are plenty more of the other features that can be accessed by subscribing to the given option in the Blynk application.

## 4. Conclusion

In conclusion, this IoT-Based Rehabilitation Monitoring System for Carpal Tunnel Syndrome can help patients suffering from Carpal Tunnel Syndrome to perform the rehabilitation process. The monitoring system measured the wrist angle bending in the wrist flexion exercise and measures the force exaggerated on the patient's finger in the ball squeeze exercise to increase the efficiency and let the patient recover from Carpal Tunnel Syndrome. With the implementation of the Internet of Things (IoT), the system also provides easy access between the doctor and the patient during the rehabilitation process. Patients can use the mobile application to monitor the measured parameters while doctors can do the same using the Blynk application. As the measurement result is obtained, the data can be further analyzed by the doctor. For further work, the limitation of the parameter measured from exercises could be improvised to maximize the functionality of this system that can help patients suffering from Carpal Tunnel Syndrome.

## Acknowledgement

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