CHAPTER 8

WRIST FLEXION REHABILITATION DEVICE USING ARM MBED MICROCONTROLLER FOR POST-STROKE PATIENT

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8.0 INTRODUCTION

Rehabilitation is a process of recovery of an individual from disabling or functionally limiting condition, whether temporary or irreversible, participates to regain maximal function, independence, and restoration [1]. The purpose of rehabilitation is to prevent and slow down the loss of function of the body, improve and restore the function, compensation for the lost function, and maintenance of the current function.

The wrist has four types of movement namely as flexion, extension, radial deviation and ulnar deviation as shown in Figure 8.1. Flexion is the movement of palm of hand towards anterior of forearm while extension is the movement of back of the hand towards posterior of forearm. Next, abduction or also called as radial deviation is the movement of the thumb side of the hand towards radial side of forearm whereas adduction or also known as ulnar deviation is the movement of the little finger side of the hand towards ulnar side of the forearm.

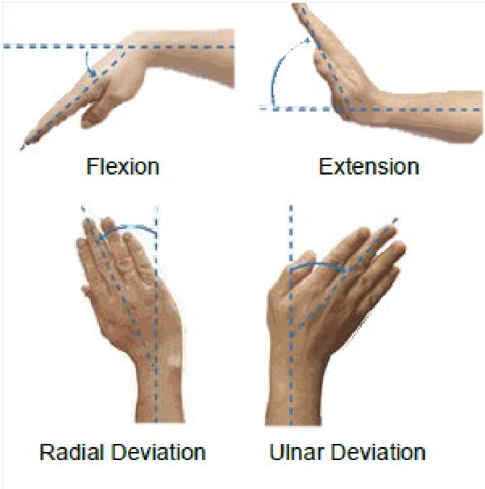


Figure 8.1: Wrist movement [2]

Stroke, which is also known as "brain attack", is a sudden interruption of blood supply to the brain [3]. Brain controls every movement of human body [4]. When insufficient of blood supply to the brain, the movement of the body will be affected. Patients who suffer from stroke will experience paralysation of the body [5]. They will have trouble to move the body consciously especially at limbs region. A proper rehabilitation process is needed for the patient to regain the movement of the body. This rehabilitation process can be started from the small movement such as flexion of the wrist.

Therefore, this research project focuses on the guided rehabilitation of the wrist flexion of post-stroke patient for recovery monitoring process. The proposed device is expected to collect the wrist rehabilitation data from daily exercise and can be viewed manually by the physiotherapist or doctor for further diagnosis. The objectives are to develop a guided instruction system by counting the wrist flexion, to measure the wrist bending as well as the wrist strength. Previous wrist rehabilitation device utilized Arduino Mega and strain gauge sensor to control input and output as well as to measure the wrist force, respectively whereas the flex sensor, which was used to measure the wrist flexion degree, was placed on the side of the developed device (tubular hand cover) [6].

As for this current project, several modifications have been successfully done. Firstly, the use of Arduino Mega and the bulky strain gauge sensor are replaced with the Arm Mbed microcontroller and force sensor, respectively and secondly, to measure the flexion degree, the flex sensor is attached on the glove. As compared to Arduino Mega, Arm Mbed microcontroller is much smaller and utilize simple coding. Besides that, the implementation of force sensor to replace the strain gauge sensor is due to its cheaper price and smaller size. Moreover, the force sensor is also replacing the limit switch (as utilized in previous study [6]) for counting the number of exercise sets. Meanwhile, accurate reading of wrist flexion can be obtained when placing the flex sensor directly on the glove and not at the side of the developed device as previously done.

This paper is organized as follows. Section 8.2 presents concise explanation on the design and implementation of the prototype. The experimental results are shown and discussed in section 8.3. Finally, the whole work of this research is summarized in the last section.

8.1 DESIGN AND IMPLEMENTATION OF WRIST FLEXION PROTOTYPE DEVICE

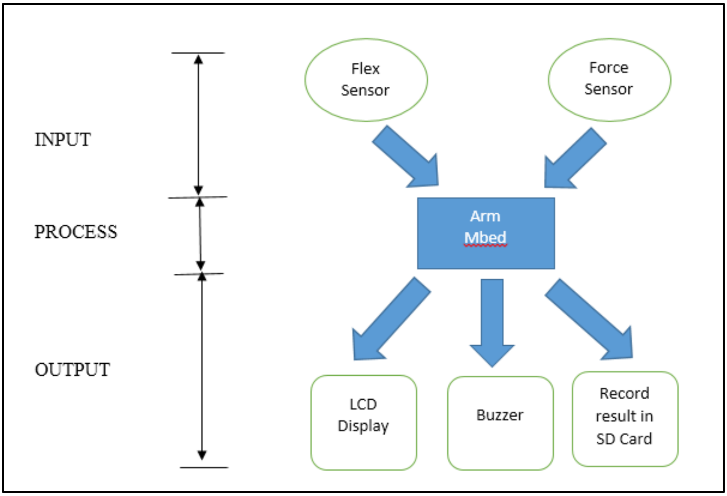


Figure 8.2: Overall block diagram of the wrist rehabilitation device

The overall block diagram of the proposed system is shown in Figure 8.2. There are three main stages in the system namely as input, process and output. The input stage involves collecting analogue signal from flex sensor and force sensor. Then, the input signal is sent to Arm Mbed microcontroller. Finally, the LCD display and buzzer are used to output the resulted signal whereas the Secure Digital (SD) card is used to store the obtained result.

Briefly, there are three main (3) phases to develop the project. Phase 1 includes the sensors selection and connection, data acquisition as well as data logging. Phase 2 involves software development, and Phase 3 is the rapid prototyping of the wrist flexion device using 3D printing technology.

A. Phase 1: Sensors Selection, Circuit Connection, Data Acquisition and Data Logging

As mentioned previously, there are two main sensors that have been chosen namely as flex sensor and force sensor. The details function of each sensor is described in the following section.

i. *Flex sensor*

The flex sensor was used to measure the bending degree of the wrist. Therefore, it was attached on the wrist glove. Whenever the sensor is bent, the resistance will also increase. The corresponding resistance increment will be processed by the Arm Mbed to produce the output voltage based on the voltage divider principle. The voltage output, V_{out} can be calculated using the following Equation (1):

$$V_{out} = V_{in}\ \left(\frac{R_1}{R_1+R_2}\right) \tag{1}$$

where V_{in} is the input voltage, R_1 is the input resistance from the flex sensor and R_2 is the series resistor (47 k Ω) connected to the flex sensor.

ii. Force sensor

The second sensor is the force sensor, which was attached at the joint between tubular hand cover and the handgrip holder. As the patient flexes the wrist, the grip holder will also move down accordingly and will touch the active layer of the force sensor. The hypothesis is the stronger the patient flexes the wrist, higher wrist strength will be obtained. To calculate the output voltage, V_o, Equation (2) is used:

$$V_o = V_{in} \left(\frac{R\_FSR}{R+R\_FSR}\right) \tag{2}$$

where V_{in} is the input voltage, R_FSR is the input resistance from the force sensor and R is the series resistor (10 kΩ) connected to the flex sensor.

iii. Circuit connection, data acquisition and data logging

This circuit requires 5V DC power supply to function. Figure 8.3 below illustrates the circuit connections between Arm Mbed microcontroller and the sensors (flex sensor and force sensor), buzzer, LCD, LED as well as the SD card reader. There are total of fourty pins on the Arm Mbed but the complete circuit only requires seventeen pins. The flex sensor is connected to Pin 20 while force sensor is connected to Pin 19. As can be noticed in the figure, both sensors require a series resistor to create a voltage divider circuit (refer previous explanation on sensors). The LCD is connected to Arm Mbed from Pin 12 to Pin 17. It requires a potentiometer for contrast adjustment; therefore, Pin 2 of potentiometer is connected to Arm Mbed Pin 3. As for the data logging, the SD cardholder has six pins, which is connected to Arm Mbed pins from Pin 5 to Pin 8. The whole circuit is drawn using Proteus software.

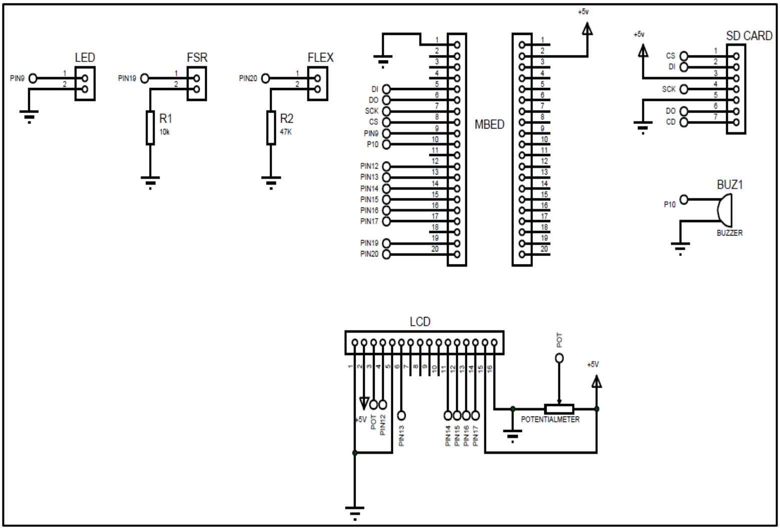


Figure 8.3: Schematic circuit diagram of the device

B. *Phase 2: Programming C++ in Arm Mbed platform*

The second phase involved the programming of the Arm Mbed to process all the input data from the sensors. Following the previous study in [6], the routine for wrist flexion rehabilitation is to complete the twelve sets of exercise where each set of the exercise requires the user to perform three times of wrist flexion movement and follows by the five second rest. Therefore, the Arm Mbed needs to collect the wrist flexion count data triggers by the input from the force sensor as well as how much the force applied and the degree of the bending wrist.

The flow chart in Figure 8.4 shows how the training counting system works. First, the LCD will display “Start Exercise” (after switching the On button) indicating that the patient can start the exercise. The patient can then wear the glove and hold the grip holder. When the patient starts to flex the wrist, the flex sensor will measure the degree of wrist flexion whereas the force sensor will measure the force applied from the wrist. The Arm Mbed will process the data from the sensors and the corresponding output will then be saved into the SD card. The buzzer will produce "beep" sound and the LCD will display "Rest 5 second" after completing one set of exercise. This exercise will end when all twelve sets of exercise are completely done and the LCD will display "Training success".

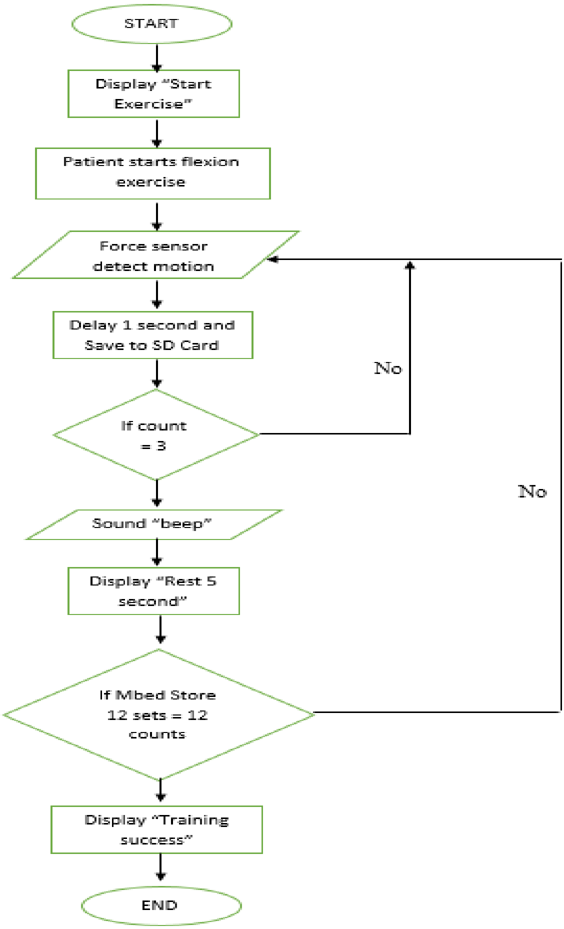
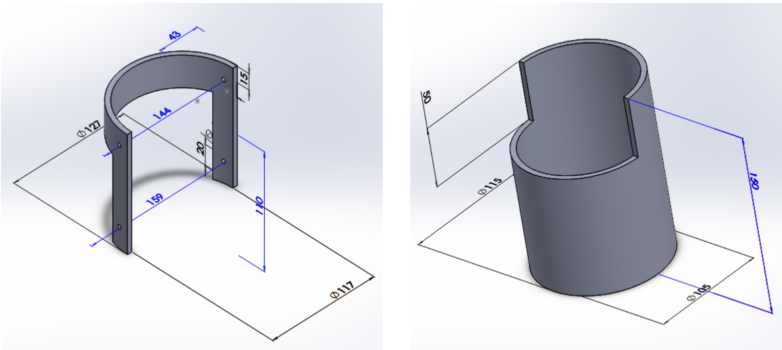


Figure 8.4: Flow chart of how training counting system works

C. Phase 3: Mechanical Design of Prototype Pieces

The SolidWorks software was used to design the 3D model of the prototype. SolidWorks is a useful 3D modelling program to design

3D object. During designing phase, the size and length of the prototype were taken into account. As shown in Figure 8.5, there were two major components to be designed namely as (a) handgrip holder and (b) tubular hand cover drawn using SolidWorks software. Details of these components measurement can be referred to [6].



(a) (b)

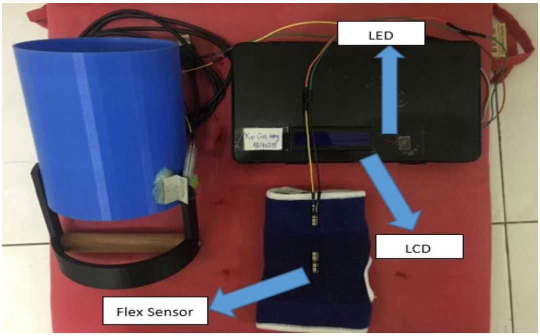
Figure 8.5: a. Hand grip model design and b. Tubular hand cover model design

8.2 EXPERIMENTAL RESULTS AND DISCUSSION

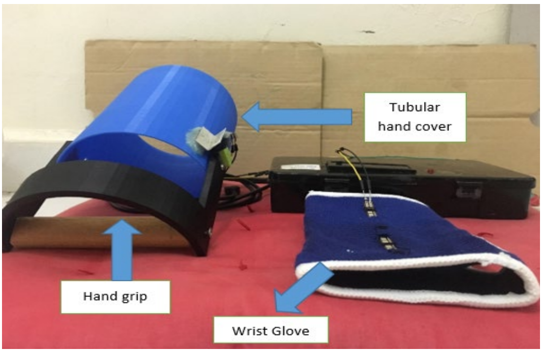
There are four main results to be discussed in this section. The first one to be discussed is the completed assembly of the wrist exerciser, which had been rapid prototyping using 3D printing technology and SolidWorks software. Second, the selected sensors underwent function ability experiments in order to ensure that the sensors were able to produce desirable outcome. Then, an evaluation study was conducted based on the mock training session to assess the programming outcome and finally, how the training data was saved by SD card to be used for further analysis was presented here.

A. Wrist exerciser prototype device

Figure 8.6 shows several views of the completed assembly of the prototype; top view (a), front view (b), right view (c), left view (d) and rear view (e). Notice the placement of the flex sensor that was attached on the glove and the position of the force sensor at the joint between tubular hand cover and the handgrip holder.



(a)



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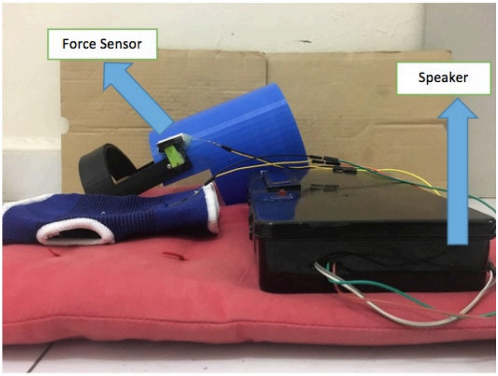

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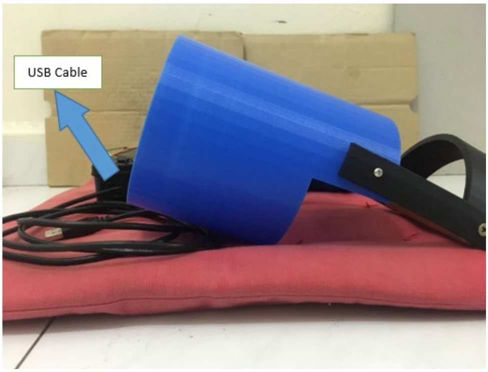
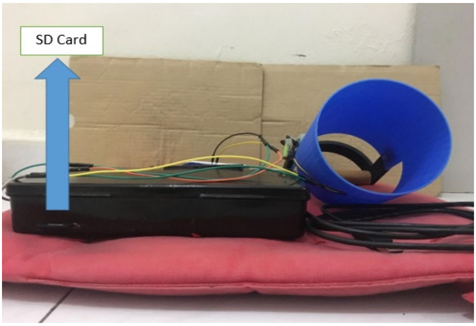


(d)



(e)

Figure 8.6: (a) Top view, (b) Front view, (c) Right view, (d) Left view and (e) and Rear view of wrist flexion prototype with corresponding labelled of the main components

B. Individual Sensor-Testing Experiments

Before the system can be implemented in real application, several sensor-testing experiments were conducted. This was to ensure that the sensors were not only able to function as expected but can also produce desire outcomes.

i. Flexible sensor test result

Table 8.1 Flexible sensor reading

Testing Bending Degree, °	**Testing 1 (°)**	**Testing 2 (°)**	**Testing 3 (°)**	**Average (°)**	**Error (%)**
30	29	29	30	29	3.33
45	47	47	44	46	2.22
75	76	77	77	76	1.33
90	90	89	88	89	1.11

Table 8.1 listed the flexible sensor reading during 30º, 45º, 75º and 90º bending that was successfully measured by the flex sensor. The principle of flex sensor measurement is based on the resistance changes within the flex sensor. The changes in the resistance was recorded and calculated by microcontroller Arm Mbed. For each sensor position, three repeatable tests had been conducted and the error percentage for each position was calculated. From the table, it is found that the largest and the smallest average error is 3.33 % and 1.11 % at 30º and 90º bending, respectively.

ii. Force Sensor Test Result

Table 8.2 Corresponding applied resistance of force sensor

Applied Force	**Resistance, R (Ω)**
Light Object	11.7
Heavy Object	32.9
Flat Object	Not Available

This simple experiment tested the functioning of the force sensor active layer by pressing the active layer using different objects. The results were tabulated in Table 8.2. Worth to note that if the object is flat surface, no resistance can be detected, as the force was not centered on the active layer as shown in the last row in Table 8.2.

iii. Overall Prototype Testing Result

The maximum of handgrip bending device is around 60° as shown in Figure 8.7. This is sufficient to observe the bending of the wrist of the post-stroke degree patient. If the patient can flex more than 60° this means that the patient is recovering up to 80% of the wrist flexion movement [8].

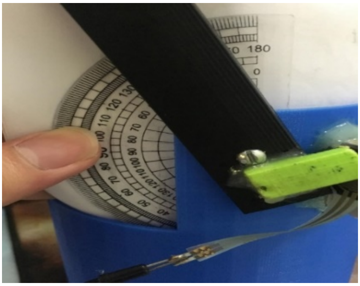


Figure 8.7: The maximum bending of the device

C. Data collection protocol and prototype evaluation

To assess the programming training outcome, one mock training session was carried out. Figure 8.8 shows how the wrist exerciser prototype was used during evaluation process. This device was powered up by connecting the USB cable to power bank.

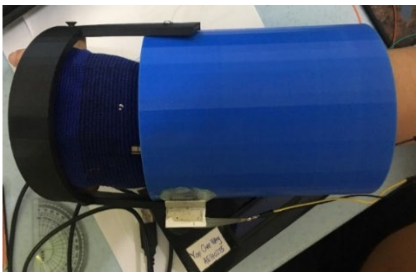


Figure 8.8: Example on the use of wrist flexion prototype during mock

training process

i. Data Collection Protocol

Following are the data collection protocol one should fulfill during data collection procedures. Firstly, the patient needs to sit in a comfortable state. The user is then required to wear the hand glove as the flex sensor is attached on the glove. Then, the user can start to bend their wrist. The user can start the training by following the instructions as displayed on the LCD (See Prototype Evaluation). Finally, the physiotherapist is able to view the recorded exercises (saved in the SD card) for further diagnosis and evaluation.

ii. Prototype Evaluation

For a better understanding, Figure 8.9 explained the sequence instructions in the form of pictures flow during mock training session. When the device is powered up, the LCD display will show “Start Exercise” caption (Figure 8.9(a)) signifies that the user or patient can start the training by pulling up the handgrip holder downward. After three motion of the handgrip flex, the LCD will display “Rest 5 Second” via the LCD display as shown in Figure 8.9(b). At the same time, the buzzer and LED will alert the user to rest for every five seconds. When the LCD displays “Continue…” as shown in Figure 8.9(c), the user can continue the exercise. For each successfully flexion, the LCD will display two important information as in Figure 8.9(d) namely as the force and bending degree. The exercise will continue until reaching 12 sets and the LCD will display “Training Success” (Figure 8.9(e)) indicating that all twelve sets are completed. This shows that the training exercise session is completed. The information data is saved into the SD card for every flexion of the wrist.

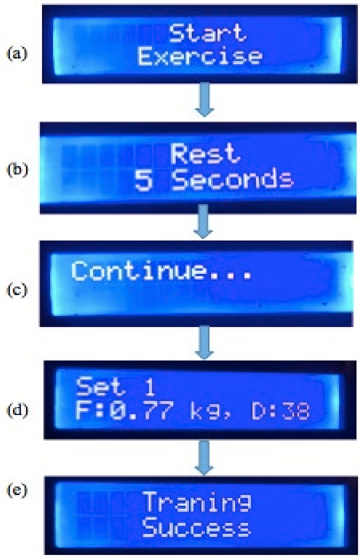


Figure 8.9: LCD displaying the sequence of training instructions during mock session

D. SD Card Output

Figure 8.10 shows the example of how the data during training session is recorded in the SD card. This recorded information will be useful for the user or physiotherapist to evaluate the recovery performance.

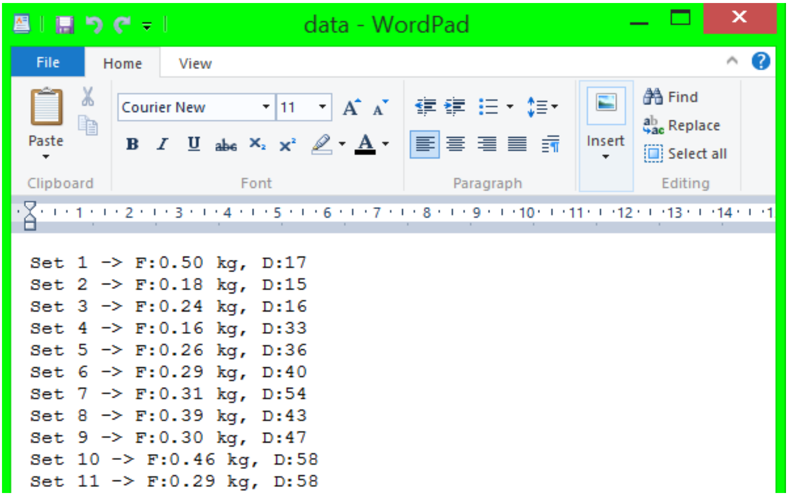


Figure 8.10: Data recorded in the SD card

8.3 CONCLUSION

In conclusion, the objectives of the project have been successfully achieved. The guided wrist rehabilitation device had been successfully developed with intention to help and assist the recovery of the wrist of the stroke patient. This device can record the patient exercise data namely as wrist bending degree and wrist strength by suing flex sensor and force sensor, respectively. This project used Arm Mbed microcontroller to control and process the input sensors. The user has to follow the instructions appeared on the LCD screen. The user is required to complete twelve sets of exercises. During the flexion exercise, for every three flexion movement, the buzzer and LED will ON to indicate that the user needs to take 5 seconds rest.

In the future, this device can be improved by integrating the prototype with the Internet of Thing (IoT) so that the exercise data can be directly uploaded to the Internet cloud-based for remotely data monitor and retrieval by using IoT platforms or apps such as FavorIOT, ThingSpeak or Blynk. This can reduce the usage of the SD card, as the storage of the SD card is limited as compared to the Internet cloud-based storage. Furthermore, this project can be further improved by adding the user personal health details and date to the system. This can help the physiologist or doctor to track the user recovery process more accurately.

8.4 ACKNOWLEDGEMENT

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REFERENCES

[1] K. L. Mauk, "PART I General Concepts and Principles of Rehabilitation Nursing Chapter 1 Overview of Rehabilitation," *Rehabil. Nurs. A Contemp. Approach to Pract.*, pp. 1–13, 2012.
[2] B. R. Wang, J. Reed, and J. Leone, "A Systematic Approach To A Painful Wrist," *Can. J. Diagnosis*, vol. 1, no. August, pp. 86–97, 2001.
[3] S. Belagaje and B. Kissela, "Epidemiology of stroke recovery," *Brain Repair After Stroke*, vol. 114, no. 3, pp. 163–172, 2010.
[4] G.-M. B. M.Gund, M. P. N.Jagtap, V. B.Ingale, andR. Y.Patil, "Stroke: A Brain Attack," *IOSR J. Pharm. Www.Iosrphr.Org*, vol. 3, no. 8, pp. 2250–3013, 2013.
[5] D. Dauria, F. Persia, and B. Siciliano, "Human-Computer Interaction in Healthcare: How to Support Patients during Their Wrist Rehabilitation," in Proceedings - 2016 IEEE 10th International Conference on Semantic Computing, ICSC 2016,

2016, pp. 325–328.
[6] N.A. Jumadi, M.S.Kinatu and M. Fairuz M.Nasir, "Portable Therapeutic Guided Wrist Flexion Exerciser Device for Recovery Monitoring," *JTEC*, vol. 6, no. 85, pp. 1–6, 2017