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Post-Stroke Range of Motion Measurement Tool with Black Box Boundary Value Analysis Testing

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Abstract— Stroke is the second cause of death and the third cause of disability in the world. One of the treatments for post-stroke patients is physiotherapy. This treatment is expensive and requires mobility. Additionally, the level of adherence of post-stroke patients in carrying out physiotherapy also influences the effectiveness of healing. Therefore, this research proposes a new tool - named "the Post-Stroke Range of Motion (ROM) Measurement Tool with Black Box Boundary Value Analysis Testing – for physiotherapy telemonitoring of post stroke patients. This tool is designed on the left hand for measuring the ROM with the integration of MPU6050, MAX30102, and Flex sensors connected to ESP WROOM 32. This study uses a quantitative research type with a laboratory and field experimental method approach. The flex sensor was tested by measuring the minimum and maximum resistance values, which are converted into straight (0<11), bending (11<46), and fully bending (46<90), and the software was tested using the Black Box Boundary Value Analysis method. The outcomes unveil that the proposed system - with its various features - has the potential to be widely applied, and readily utilized by patients in physiotherapy rehabilitation exercise at home.

Keywords— Internet of Things; Physiotherapy; Post Stroke; Range of Motion; Measurement tool; Telemonitoring.

1. INTRODUCTION

Stroke is a disease that affects the arteries leading to and within the brain. This occurs when the blood vessels that carry oxygen and nutrients to the brain are blocked by a clot or burst, causing parts of the brain to not get the blood and oxygen they need, which will lead to brain cell death [1]. The main causes of stroke are hypertension, physical inactivity and obesity [2].

Based on data for 2020 [3] of patients diagnosed with stroke at the National Brain Center (NBC) Hospital, Jakarta, Indonesia, it was found that higher occupations and educational levels have a lower stroke risk of developing more severe strokes. Stroke can cause disability and even death; stroke is the second cause of death and the third cause of disability in the world[3, 4]. If a stroke patient escapes death, it does not mean that the problem is over. This is the beginning of the struggle to recover as before. Therefore, repeated exercises are needed to train limbs that cannot function normally after a stroke. The exercise aims to encourage neuroplastic changes in the brain. Exercise to restore the function of body movement is referred to as physiotherapy [4, 5]. However, unstable economic conditions are one obstacle to physiotherapy for post-stroke patients.

Physiotherapy programs in mild-to-moderate stroke patients require a relatively long time, so patient compliance is required [4]. In addition, physiotherapy is also relatively

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expensive and requires mobility. Research shows that Age, gender, marital status, occupation, education level and monthly income have a relationship with health related to quality of life; the higher the level of education, the higher the health score related to quality of life [5-17]. This shows the need for education on the importance of understanding physiotherapy exercises to help the post-stroke recovery process, as well as increasing adherence to physical activity and exercise will improve the functional recovery of mild-to-moderate stroke patients [4]. Range of Motion (ROM) exercises are part of the physiotherapy rehabilitation process. ROM is an exercise that can maintain or increase the level of perfection of muscle tone, muscle strength, and ability to move joints. In increasing muscle strength, ROM exercises can be done early. The more motor units that are produced, the more muscle strength will increase [6, 18, 19]. ROM exercises can increase the patient's muscle strength as long as they are done with the right technique and are done regularly. The results showed that there was an effect of Range of Motion (ROM) on muscle strength in post-stroke patients who experienced an increase in muscle strength scale after ROM rehabilitation [4, 6]. Increasing muscle strength can optimize impaired body functions and prevent disability in post-stroke patients.

Using robotics technology in the modern world is currently being applied in the medical field for physiotherapy, namely as patient hand training equipment that is monitored in real-time via a mobile application; this tool uses a flex sensor and ESP 32 to determine the angle of hand movement while controlling it through a mobile application [7]. Smart gloves equipped with flex sensors on each finger can measure the patient's finger dexterity present data in a systematic and easy-to-understand structure, and allow real-time remote data flow monitoring via the internet and data recording for further analysis. This glove consists of a flex sensor, Arduino Mega 25060, Raspberry Pi, and an Android device [8, 20]. An IoT-based remote stroke monitoring system that measures patient movement uses the MPU 6050 sensor, which will measure rotational speed and detect tilt angles [9]. Data is then sent to a cloud server, where relevant medical professionals can remotely access it to analyze and monitor the patient's progress [10, 16]. However, various breakthroughs were also made, such as using Fuzzy in physiotherapy activities which were developed to build inverse dynamics from the controller for the online parameter learning phase [11]. In addition, technological adaptations to walking aids are carried out by integrating them into the robot. The aim is to assist in orientation and movement during physiotherapy sessions. [8, 9, 12].

Therefore, it is necessary to have an innovative, efficient, and ergonomic physiotherapy telemonitoring tool for post-stroke patients based on the Internet of Things that can be accessed without meeting a therapist in person. The innovation from this research is expected to make it easier for post-stroke patients to do physiotherapy and for doctors and therapists to monitor patients. This innovation is designed on the forearm and spokes and works by integrating the MPU6050, MAX30102, and Flex sensors connected to the ESP32. Data from sensors can be sent via the cloud to be accessed by related medical personnel using the method. The update from this research is the integration of various sensors with Android, the addition of various features to make it easier for patients to perform physiotherapy using the analysis method, black box limit value analysis and range of Motion (ROM) measurement tool.

2. RESEARCH METHOD

This research is of a quantitative nature with an experimental method approach. This quantitative study involved respondents from several clinics in the city of Malang based on the type of patient service, namely the Dempo Physiotherapy Clinic, Physioset, Tidar Medika, and Kedota Physiotherapy to find knowledge using data in the form of numbers as a tool to analyze information about what you want to know, for example, medical rehabilitation activities for post-stroke patients and component datasheet literature. Then the researchers used an approach to the experimental method in which a study attempted to find the effect of certain variables on other variables under tightly controlled conditions. In this study, a laboratory experimental and field experimental method approach was used, which carried out direct testing of post-stroke patients using the black block analysis method.

2.1. System Block Diagram

The block diagram of the system is illustrated in Fig. 1. The value of the movement angle will be read by the MPU 6050 sensor, as well as heart rate and oxygen saturation will be read by the Max 30102 sensor; then, the curvature data of each finger will be read by the Flex sensor. All of this data will be sent to ESP WROOM 32 to be displayed on the OLED Display and to the cloud server to be accessed via the Android application.

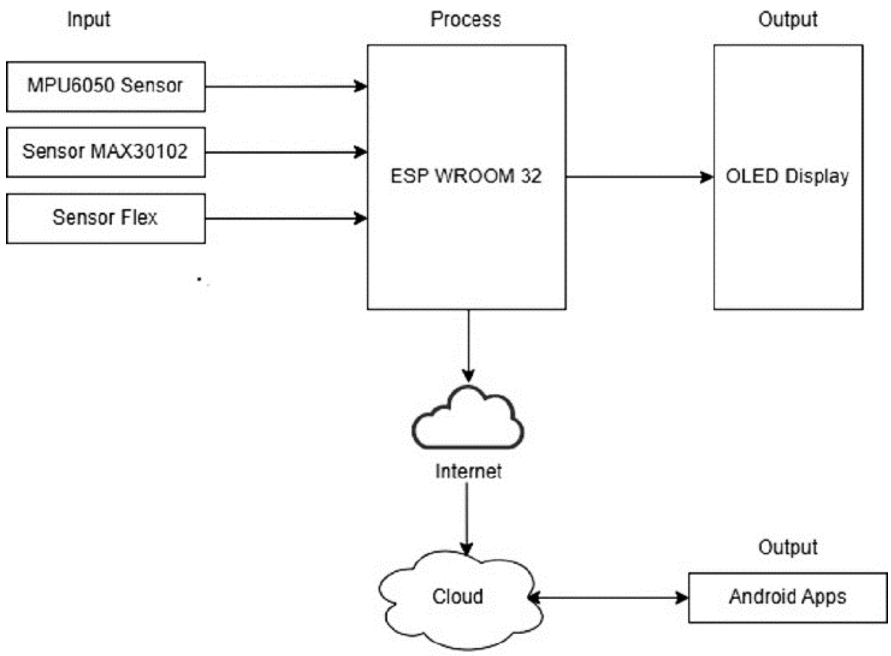


Fig. 1. System block diagram.

2.2. System Design

System design parameters in this study include mechanical planning, electrical planning, and software planning.

2.2.1. Mechanical Design

This mechanical planning is the first discussion in device planning to facilitate manufacture at a later stage; this mechanical planning is presented as a three-dimensional design as shown in Fig. 2. 3D Design Prototype tool consisting of one arm support device made of plastic material measuring 28 cm then covered with a cloth for comfort and adhesive provided on the front so that it can be adjusted to the size of the user's arm, then equipped with gloves that are equipped with a sensor holder on each finger and don't forget to be equipped with an OLED holder and an electric module.

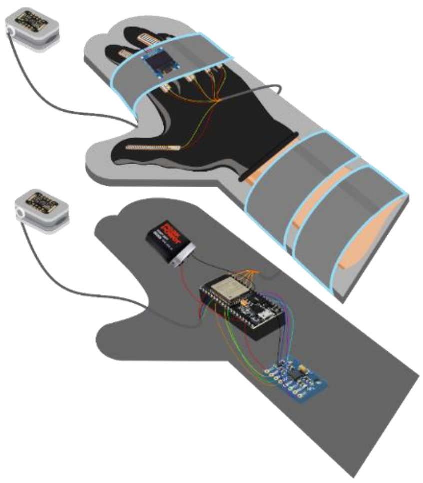


Fig. 2. Design of the 3D prototype tool.

2.2.2. Electrical Planning

The system schematic circuit consists of 5 flex sensors, a multiplexer, an MPU 5060 sensor, a Max 30102 sensor, WROOM32 ESP Node and a 9V battery. The inputs as five flex sensors are connected to the multiplexer input while the multiplexer output is connected to the ESP WROOM32 input, the MPU 6050 sensor output and the MAX 30102 output are connected to the ESP WROOM32 input, while the ESP WROOM 32 output is connected to the OLED Display Input as shown in Fig. 3 below.

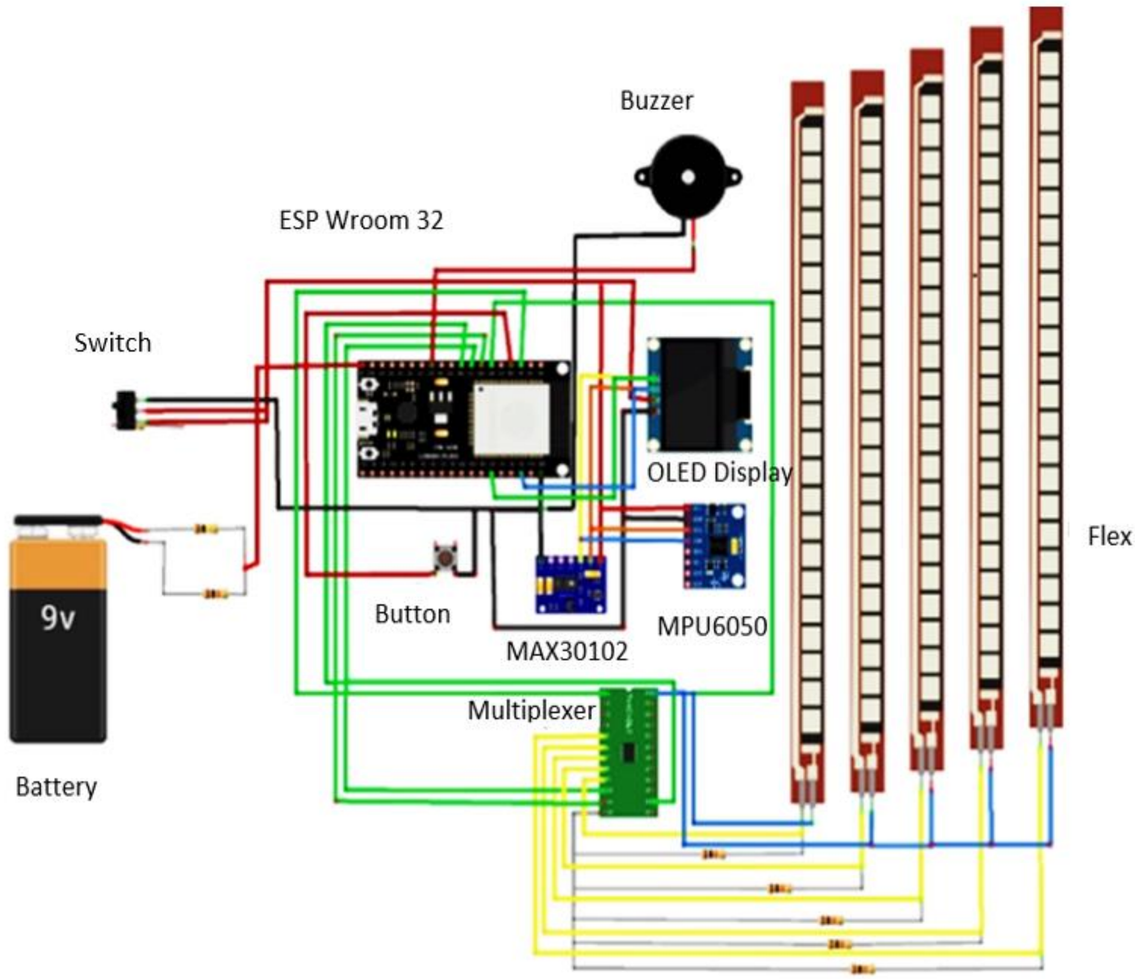


Fig. 3. System schematic circuit.

2.2.3. Software Planning

Software planning is illustrated through DFD level 0 in Fig. 4 below, where users are divided into 3, namely therapists/doctors, admins and patients. The patient menu consists of patient logins, patient data, therapist names, action history, and results of consultations and physiotherapy exercises. The Admin menu consists of admin login, observations, patient biodata, physiotherapy results from patients, checking conditions at the location, and validating patient registration, while the doctor/therapist menu consists of the therapist login menu, patient consultations, and physiotherapy results.

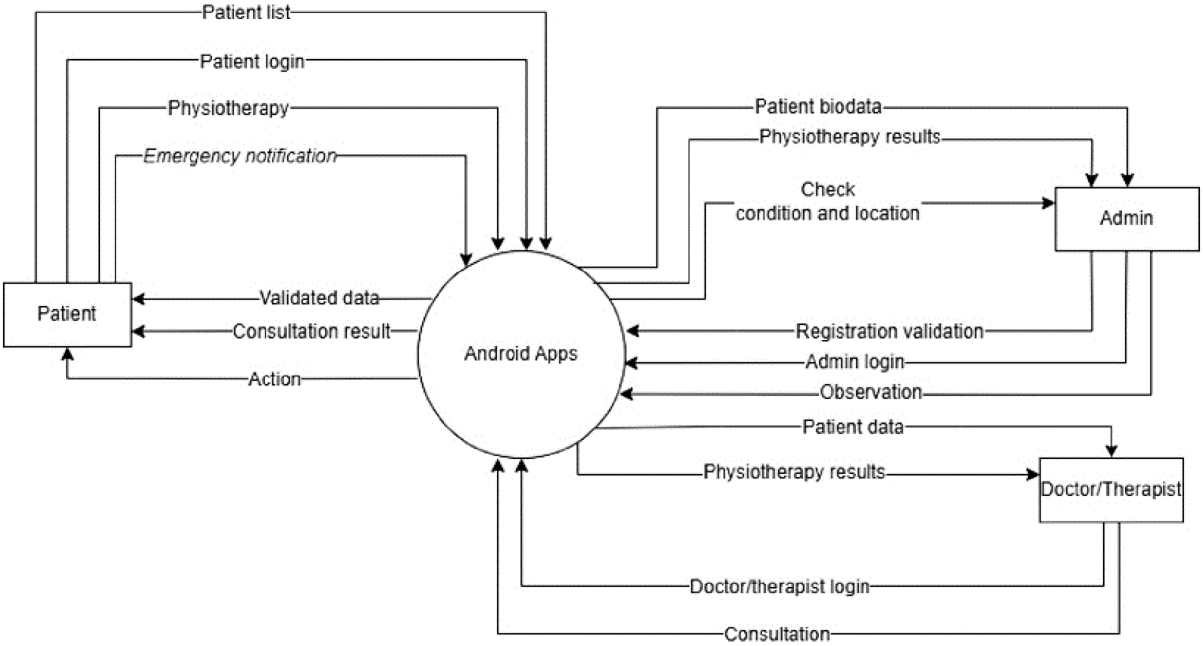


Fig. 4. DFD Level 0 software planning.

3. RESEARCH METHOD

3.1. Hardware Implementation

The results of the hardware implementation describe the entire system of this physiotherapy tool. This system consists of components such as a battery, WROOM32 ESP, MPU6050 sensor, MAX30102 sensor, Flex sensor, Buzzer, and OLED Display. Fig. 5 shows an overview of this telemonitoring physiotherapy device.

Fig. 5. Hardware implementation of arm and finger movement physiotherapy tools.

The results of testing the movement of the arms and fingers are represented through a display on the OLED Display attached to the device, as shown in Fig. 5. Hardware Implementation of Arm and Finger Movement Physiotherapy Devices. This tool has technical specifications in Table 1. The following are the Technical Specifications of the Arm and Finger Movement Physiotherapy Equipment.

Table 1. Technical Specifications for arm and finger movement physiotherapy equipment.

Parameters	Value
Power supply	9V battery
Flex sensors	5 pcs
Dimensions	7cm x 31 cm
Heavy	±300 gr
Software telecontrol application	Android Studio

This section describes the sections that explain the features and benefits of an application built using the Android Studio software. In addition, visualization results and test results from the stroke patient monitoring application are also presented using the Black Box Boundary Value Analysis test method. This software development uses Android Studio with the Java programming language, see Fig. 6. The database uses Firebase which is a real-time database service provider, and backend as an application service that allows developers to create API to be synchronized for different clients and stored on the Firebase cloud. Because this design is still in the early stages there are still limits in storage and related to the security of patient data, it will be submitted directly to the hospital for data processing so that data backup or data reports can still be seen by patients.

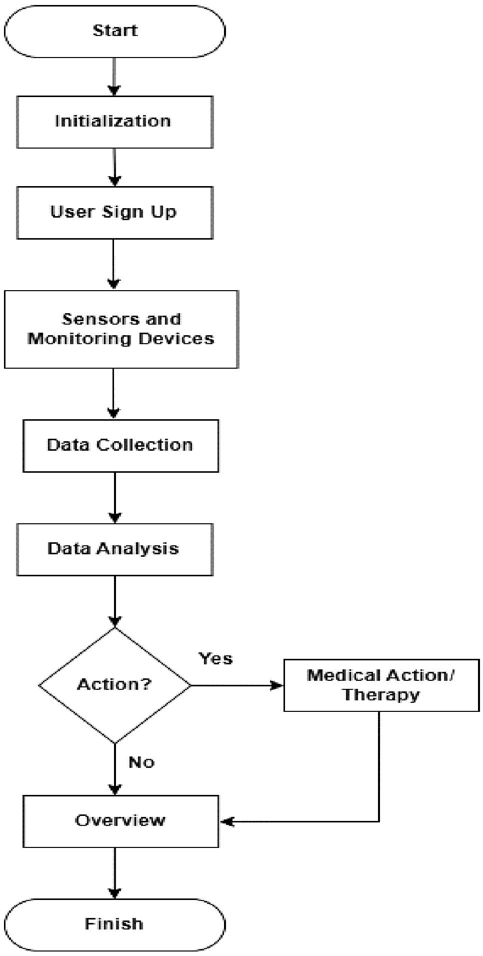


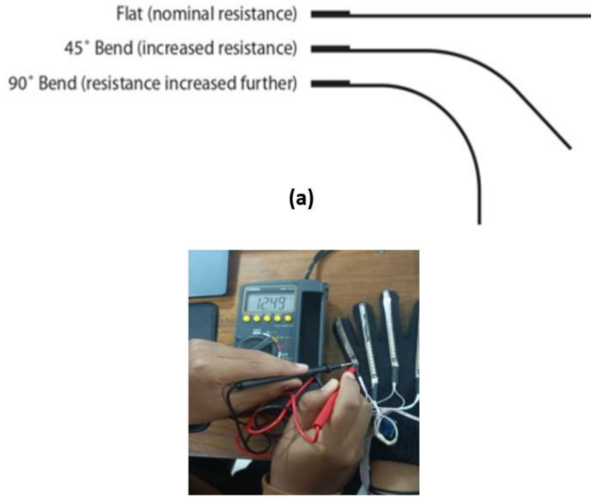
Fig. 6. Software algorithm.

3.2. FLEX SENSOR TESTING

A flex sensor is basically a variable resistor, whose resistance varies when bent. Because the resistance is directly proportional to the amount of bending, it is often referred to as a Flexible Potentiometer, so that the value will change according to the change in the value of the potentiometer. The conductive ink on the sensor serves as a resistor. When the sensor is straight, this resistance is minimal. Flex sensor working when the sensor is bent, the conductive layer is stretched, resulting in a reduced cross-section (imagine stretching a rubber band) and increased resistance. At a 90° angle, this resistance is maximum.

When the sensor is straightened out again, the resistance returns to its original value. By measuring the resistance, we can determine how much the sensor is bent. This method or way of working is used as a basis for sensor calibration. In this section, testing the accuracy of the flex sensor is carried out by measuring the maximum and minimum resistance values in three flex sensor conditions, as shown in Fig 7. The measurement process is carried out using a digital multimeter-type SANWA CD800a.

From Fig. 7, the resistance value measured from the flex sensor describes 3 different positions or conditions of the fingers. This will be the basis for converting the resistance value into a value range of 0 to 90. Below are the results of testing the resistance value on the flex sensor.



(b)

Fig. 7. a) Range flex sensor resistance measurement; b) testing the resistance value of the flex sensor.

The Flex sensor is tested in a flat position by testing on one variable and in a range of 10 different times. The results of the resistance test using a multimeter are shown in the graph of Fig. 8. The data shows the resistance value of the flex sensor 2.2" in the range 13 kΩ - 14 kΩ, while for 4.5" in the range 10 kΩ - 12 kΩ.

The flex sensor is tested in a flat position by testing on one variable and in a range of 10 different times. The results of the resistance test using a multimeter are shown in the graph of Fig. 9. The result of the flex sensor resistance value is 2.2" in the range 12 kΩ - 13 kΩ, while 4.5" is in the range 8 kΩ - 9 kΩ.

The flex sensor is tested in a flat position by testing on one variable and in a range of 10 different times (Test-to). The resistance test results using a multimeter are then depicted in a graph, as shown in Fig. 10. The data shows the resistance value of the flex sensor 2.2" in the range 15 kΩ - 17 kΩ, while for 4.5" in the range 13 kΩ - 15 kΩ.

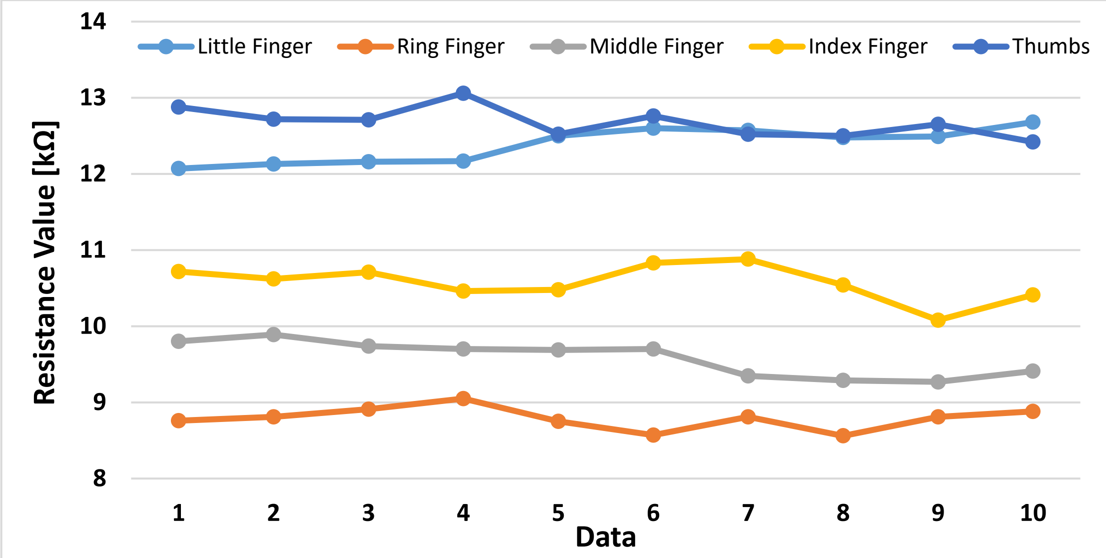


Fig. 8. Flex sensor resistance values in flat position.

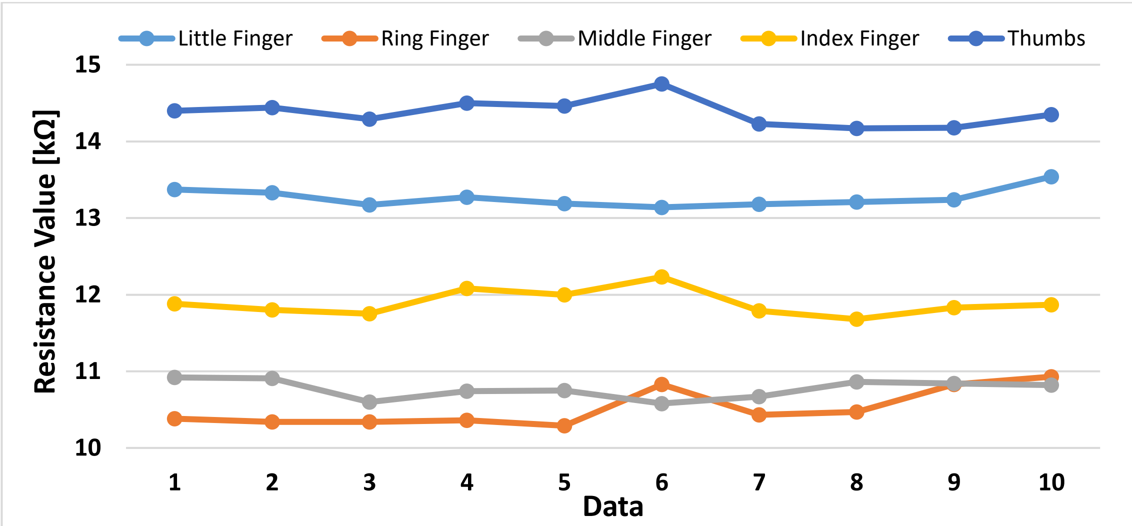


Fig. 9. Flex sensor resistance value at position 45.

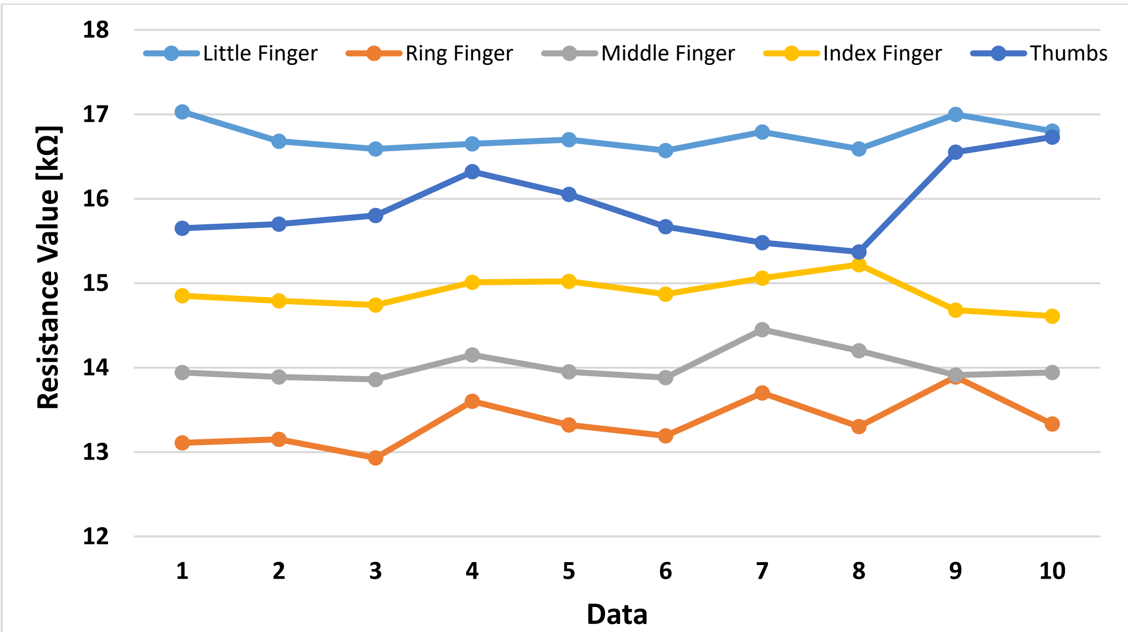


Fig. 10. Flex sensor resistance value at position 90.

Furthermore, from the three previous results, an average value can be taken, which will later be used to determine the measurement tolerance value. Measurement tolerance with multimeter type SANWA CD800a is ± (1.5%+5) as shown in Table 2.

Table 2. Flex sensor tolerance limit values

Condition	Installment-installation [kΩ]	Upper limit tolerance [kΩ]	Lower limit tolerance [kΩ]
Straight/flat	10,8014	15,96	5,63
45	12,1642	17,32	7,00
90	14,9852	20,14	9,82

The tolerance value shown in Table 2 is the tolerance value for post-stroke patients who experience certain conditions such as over flexion, which is the condition of the fingers when normal is not straight. The next step is to change the output of the flax sensor using the encoding method and expert assistance to match the ROM (Range of Motion), so that the results are obtained as shown in Table 3:

Table 3. Conversion of resistance values to ROM with ADC.

Finger section	Condition		
	Straight	Bend	Full bend
Pinkie	0 - 11	11 - 46	46 - 90
Sweet	0 - 11	11 - 46	46 - 90
Middle	0 - 11	11 - 46	46 - 90
Pointer	0 - 11	11 - 46	46 - 90
Thumb	0 - 11	11 - 46	46 - 90

The results of the resistance test for the five fingers in Table 3 show that the greater the curvature of the finger, the greater the output value of the flex sensor, and this value is converted into three forms, namely flat, bent, and full bent.

3.3. DISCUSSION

This study aims to analyze the Post-Stroke ROM Measurement Tool with Black Box Boundary Value Analysis Testing. Has many features that can be accessed by three types of users, namely patients, doctors (therapists), and admins, patient features apart from being able to register can also record exercise movements moving the arms and fingers and is equipped with a chat menu (consultation) with the therapist (doctor) who handles it, besides In addition, there is an educational menu related to physical movement training patterns for stroke patients and foods that are good for consumption and prohibited for consumption by sufferers, so that it is hoped that this will increase the knowledge of stroke sufferers so that their disease does not get worse [5].

From the features provided, the therapist can view records of physical exercise regarding arm and finger movements, as well as heart rate and oxygen saturation conditions when the patient performs these exercises. This provides information about the patient's condition even without direct assistance from a therapist. Through recording the results of this exercise, the therapist or doctor can make further medical decisions through the application.

From the results of sensor flex output testing which aims to assess the curvature [8, 15-20] of stroke patients' fingers, the data is converted into Range of Motion (ROM) units.

Based on the results of finger movement testing, the data is converted into three forms of curvature which can make it easier for the therapist to understand the information provided by the tool. The three forms of curvature are flat pattern (0°), 450 bend, and 0° full bend, as shown in Table 3.

The drawbacks of this study include the results of flex sensor testing that do not match the theoretical resistance value. This is because, during testing, the resistance value of the flex sensor is affected by the load due to a connection with an external resistor in the circuit design.

However, in this value, there is no difference because the conversion is done on the ADC value so that the measured value is the resistance value on the device when used by the patient and external factors such as the external resistor value used as a pull-down to reduce analog data noise and bounce.

In addition, in the telemonitoring application for stroke patients, the drawback lies in the dependence on an internet connection which causes additional costs to be carried to carry out its functions, however, to overcome this, this tool is divided into 2 modes namely online and offline, offline mode will display values directly on the tool so that it will make it easier for patients to practice physiotherapy at home.

Measuring muscle strength when using this tool also cannot be measured accurately, so it needs further development, in the sense that the measurements in the design of this tool are still limited to flexion of the fingers so there is a need for additional extensions and rotations for improvement in physiotherapy.

Furthermore, this research also has the potential to be developed in terms of motion visualization integrated with virtual reality technology. This can improve the services provided to stroke patients by providing a more interactive visual experience.

4. CONCLUSIONS

The conclusions that can be drawn from this research are: the proposed physiotherapy telemonitoring systems for post stroke patients can serve as an innovation in physiotherapy rehabilitation exercise at home which is easy to use. With the various features provided and the underlying urgency, this system has the potential to be widely applied with the possibility of future development. Telemonitoring applications developed using Android Studio display a user-friendly interface. The application also connects with a doctor or therapist, enabling real-time remote monitoring. Patients can make consultations through the chat feature available in this application. The use of flex sensors to measure the curvature of the fingers involves converting the data into three conditions, namely straight (0°-11°), bent (11°-46°), and fully flexed (46°-90°). The design in this study is used in the condition of post-stroke patients as a form of flexion physiotherapy exercise on the fingers of the hand according to the value of range of motion in health.

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