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A Rehabilitation and Monitoring System for Upper Limb Stroke Based on The Combination of Mirror and Stationary Bicycle

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***Abstract*— The weakening of motor functions in individuals due to a stroke can impact daily life productivity, necessitating therapy or rehabilitation. One method for restoring the function of body parts, especially the upper limb affected by a stroke, is through mirror therapy on a bicycle. Mirror therapy provides visual stimulation to the brain, influencing the improvement of motor functions. To monitor the effectiveness and safety during therapy, a monitoring system is required to track progress and evaluate vital signs to prevent health issues arising from the exercise process. This research aims to design an integrated upper limb motor exercise system using a mirror therapy bicycle with a website to monitor the therapy process and evaluate the results. Observed parameters include heart rate, oxygen saturation, pedal rotations, and therapy duration. This is because the longer the duration and the more rotations of the static bicycle pedaled by post-stroke patients, the greater the likelihood of improving motor skills. Software reliability was tested for the website and data communication. The study involved 20 healthy subjects, analyzed statistically through descriptive statistics and normality tests using the Kolmogorov-Smirnov type. Then, data similarity was tested against a comparator using the Independent Sample T-Test. Heart rate (bpm) and oxygen saturation (SpO_2%) data from the sensor were normally distributed with a p-value $\geq$ 0.05. MQTT demonstrated optimal performance at QoS 0 with a throughput value of 604.8 bits/s, delay of 3.4 ms, jitter of 2.152 ms, and no packet loss.**

***Keywords*— Mirror and stationary bicycle; monitoring system; rehabilitation; stroke; therapy.**

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I. INTRODUCTION

Stroke is a condition that disrupts the motor nervous system. This occurs due to disturbances in the distribution of blood to the brain [1], [2]. Stroke has ranked third as the most dangerous disease after heart disease and cancer [3], [4]. According to the World Stroke Organization (WSO), stroke is the second-leading cause of death and the third-leading cause of mortality and disability worldwide [5]. Approximately 12.2 million people or more experience stroke each year. In individuals aged 25 and above, an estimated one in four of them will undergo a stroke annually. For those between the ages of 15 and 49, over 16% experience a stroke each year. In the age range below 70 years, more than 62% go through a stroke annually [6]. The data is a noteworthy fact for everyone to consider. It concludes that stroke is still a hazardous disease [7].

In general, stroke can lead to mortality and result in the weakening of motor functions in post-stroke patients [8]. Based on various studies, it is found that the disability rate in patients caused by stroke reaches 65%. Disability resulting from stroke involves cognitive function impairment. Cognitive function is a term used by experts to describe the brain's ability to process information. Cognitive functions include concentration, memory, written and verbal communication, awareness of body position in the surrounding environment, the ability to perform physical activities like eating, the capacity to execute executive functions such as problem-solving, as well as planning and considering situations [9]

The weakening of someone's motor functions due to a stroke can impact daily life productivity, hence necessitating therapy/rehabilitation. [10]. Several therapies can be undertaken by post-stroke patients, including therapy aimed at improving physical abilities, cognitive therapy, and alternative therapies such as massage, acupuncture, and the use of herbal remedies [11]. One method that can be employed to restore the function of body parts affected by a stroke is through mirror therapy cycling. This therapy combines mirror therapy with stationary cycle therapy [12]. Mirror therapy cycling provides visual stimulation to the brain, thereby influencing the improvement of motor functions. The combination of stationary cycle therapy with mirror therapy methods will result in an effective stroke rehabilitation process [13]. This therapy also trains the muscles to regain function gradually [14].

In the author's previous research, the implemented monitoring system could not provide measurable and remote monitoring. Therefore, the development of mirror therapy involves the Internet of Things (IoT) system. The IoT system can assist physiotherapists in monitoring post-stroke patients during therapy, either at the clinic or independently from a distance, without face-to-face interaction. This is necessary for greater efficiency, aiding patients, physiotherapists, and doctors in conducting therapy [15], [16].

The design of a mirror therapy monitoring website for post-stroke patients is a proposed innovation aimed at assisting and facilitating patients, physiotherapists, and doctors in the rehabilitation efforts for post-stroke patients. The therapy outcomes will be displayed on the website and can be accessed by physiotherapists and patients. These results can serve as evaluation materials for physiotherapists to observe the progress of post-stroke patients [17]. The data transmission system utilizes the Message Queue Telemetry Transport (MQTT) protocol because the data transmission system involves multiple sensor data and data computed by the microcontroller. The lightweight nature of the MQTT protocol contributes to the stability of the microcontroller in handling both data transmission and computation [18].

The observed parameters include heart rate, oxygen saturation, calorie expenditure, pedal rotations, and therapy duration. The duration and number of rotations on the stationary bicycle can enhance the therapy's effectiveness for post-stroke upper limb rehabilitation. It increases blood flow to the brain and improves blood circulation in the stroke-affected area. Furthermore, physical activity can stimulate the brain to generate neuroplasticity, the brain's ability to repair and reorganize disrupted nerve circuits due to a stroke. Thus, the longer the duration and the more rotations on the stationary bicycle performed by post-stroke patients, the greater the likelihood of improving movement abilities and daily activities in the upper limb. However, it should be done under the supervision and guidance of a therapy expert to minimize the risk of injury and ensure patient safety [19], [20], [21].

Heart rate and blood oxygen levels can influence stroke therapy, especially physical therapy, to improve motor skills. Unstable heart rate can affect the heart's performance in pumping blood throughout the body, including the brain. Blood oxygen levels are also crucial to meet the oxygen needs of stroke-affected brain tissues. In stroke therapy, monitoring heart rate and blood oxygen levels can help assess therapy effectiveness and identify potential health issues that may arise during the therapy. Monitoring can also assist in determining whether the level of activity undertaken by stroke patients is appropriate, thereby enhancing therapy effectiveness and minimizing the risk of potential health issues during the therapy [22], [23], [24], [25], [26], [27]. Exercising with a hand bike can be beneficial for the recovery of upper limb function in post-stroke or spinal cord injury patients [28]. Therefore, the duration, number of rotations, heart rate, and oxygen levels must be observed and monitored to enhance the effectiveness of mirror therapy.

A stroke is a sudden emergency in the nervous system caused by the occlusion or hypoperfusion of blood vessels in the brain. If not promptly addressed, the death of brain cells can occur within a few minutes. This can lead to neurological disorders, disabilities, or even death. There are risk factors that can contribute to a stroke, both unmodifiable and modifiable. Unmodifiable risk factors include increasing age and male gender. Meanwhile, modifiable risk factors include high blood pressure, diabetes, and dyslipidemia. Lack of awareness of stroke risk factors, limited knowledge about stroke symptoms, and a lack of optimal care and adherence to therapy programs for stroke prevention are issues faced in stroke care in Indonesia. This impacts the stroke mortality rate [29], [30], [31], [32], [33].

In anatomical pathology, stroke can be distinguished into two types, namely ischemic stroke and hemorrhagic stroke. Ischemic stroke occurs when blood vessels in the brain are blocked, leading to partial or complete cessation of blood flow. Ischemic stroke is the most common type, accounting for approximately 80% of all stroke cases. Based on their causes, ischemic stroke can be divided into three types: thrombotic, embolic, and systemic hypoperfusion. Thrombotic ischemic stroke is caused by the formation of blood clots (thrombus) inside blood vessels, disrupting normal blood flow. An embolic stroke occurs when an artery is blocked by a blood clot from another body part. Systemic hypoperfusion is a type of ischemic stroke caused by a decrease in blood flow from the heart to the entire body due to irregular heart rhythm. Meanwhile, hemorrhagic stroke occurs when blood vessels rupture, causing blood to flow into brain tissue. This type has a lower percentage compared to ischemic stroke [34], [35], [36].

Several studies on instrumentation systems in monitoring IoT-based microcontrollers in mirror therapy have been extensively discussed. First, a study by Muhammad Arif and his team titled "The Influence of Mirror Therapy on Movement Abilities in Stroke Patients in the Working Area of Puskesmas Kumpulan Kabupaten Pasaman in 2018." Based on the researchers' hypothesis, stroke patients experience stiffness or movement limitations because of nerve damage. In this study, patients with impairments in the arm and leg were trained to perform movements using mirror techniques. By using the reflection of the healthy hand or foot, patients could gradually mimic the regular movements of that hand or foot. In this process, patients viewed the reflection of the healthy hand or foot through a mirror, transmitting information to the brain through vision to move the affected hand or foot like the healthy one. One limitation of this study is that the product was not equipped with a monitoring system to evaluate the patient's progress [37].

In the second study, by [38] revealed that mirror therapy has proven effective for all patients suffering from stroke with hemiparesis symptoms. Mirror therapy can be performed for 15-60 minutes, 3-5 times a week, for 2-6 weeks. When combined with other methods, mirror therapy can further enhance the motor strength of patients. Implementing mirror therapy can also alleviate pain in the patient's extremities. Stroke rehabilitation is a crucial component in assisting individuals who have experienced a stroke to achieve optimal functional levels and prevent future functional decline. The goal of rehabilitation is to enhance the physical and functional recovery of the patient. Physical recovery relies on intensive therapeutic exercises designed to improve the functions of stroke survivors. Through regular physical therapy exercises, stroke survivors can experience positive improvements in lower limb abilities, functional mobility (such as walking capabilities), and their overall quality of life [39].

Stroke patients undergoing home care without a home-based rehabilitation program have a higher risk of mortality compared to those following a home-based rehabilitation program, especially in the form of early discharge supported by a multidisciplinary team. This underscores the importance of home-based rehabilitation programs in enhancing patients' independence in daily activities and reducing their dependence on others in performing these activities. Moreover, a decline in activity levels in stroke patients can also increase the risk of mortality [40].

Monitoring is an activity conducted to observe and supervise the implementation process of a designed or created program. The primary objective of monitoring is to ensure that the program runs smoothly according to the established plan and to identify potential obstacles and seek solutions to overcome them. Through monitoring activities, it can be ensured that the processes align with the established procedures.

Techniques that can be used to achieve optimal results include flexion and extension movements in the elbow and wrist and pronation and supination in the forearm. Additionally, gripping and opposition movements in the upper extremities and crucial movements in the lower extremities include knee flexion and extension, dorsiflexion in the ankle, hip internal and external rotation, and toe movements. Combining mirror therapy with other methods can enhance the motor strength of patients. Implementing mirror therapy can also alleviate pain in the patient's extremities. One limitation of this study is that the product used was not equipped with a monitoring system to evaluate the progress of the patients [41].

In the third study by [42] utilized the max30100 sensor. The device used to display data is an OLED (Organic Light-Emitting Diode) screen measuring 128 x 64 pixels. Within this screen, some LEDs will light up according to the input program, forming images or text. The IoT platform used to display data on the web is ThingSpeak. The ThingSpeak website presents data as graphs illustrating readings collected by sensors over time. These graphs enable the storage and retrieval of data values for further analysis. ThingSpeak can be accessed anywhere and anytime if there is an internet connection. The results of heart rate measurements indicate a significant error, with an error rate of 6.67%. However, oxygen saturation and body temperature measurements show smaller errors, namely 1.19% and 0.3%, respectively. One limitation of this study is the improper placement of the heart rate sensor, leading to a considerable error rate.

In the fourth study conducted by [43] reported that the measurement results from five participants were obtained. For this study, heart rate data was collected five times for the created device and five times for the comparison device, namely the pulse oximeter. Thus, the total data collected was 50. The study involved three male participants and two female participants. Participants of different genders were selected to obtain variations in heart rate values. Each participant's heart rate was measured five times. A limitation of this study is that only heart rate measurements were conducted, and other parameters were not involved.

In the fifth study conducted by [44] conducted a study on the developed device that successfully implemented remote monitoring through the Blynk application on IoT-based smartphones. Based on the test results, the device achieved an accuracy rate of 98.78% in oxygen saturation measurements, 95.12% in heart rate measurements, and 99.07% in body temperature measurements. The creation of a health monitoring system with indicators of body temperature, heart rate, and oxygen saturation based on the Internet of Things (IoT) was done using the serial communication method by connecting Arduino Uno with NodeMCU. This was done to ensure more accurate results. In this study, the sensor used was MAX30102. One limitation of this research is using applications that can add costs to development and maintenance. This could be a consideration, mainly if the development is carried out on multiple platforms, which would automatically increase costs.

The authors endeavor to research and enhance monitoring and sensor accuracy based on the previously outlined research studies and issues. These studies serve as references to create a new prototype. The proposed improvement involves utilizing the MAX30102 sensor with an average accuracy rate of 97%. This sensor has the advantage of measuring heart rate and oxygen saturation, which are highly relevant in health examinations to obtain more accurate information about an individual's health condition. The recorded data from the sensor will be transmitted to a website, and additionally, the generated output will be displayed through an LCD screen.

Based on several supporting studies, a system that can be concluded to be optimal for development is mirror therapy for stroke patients based on the Internet of Things (IoT). The communication system implemented in the IoT system is using the MQTT protocol. This protocol performs exceptionally well in data transmission for devices with limited power or bandwidth. The broker or server used in the MQTT protocol is cloud-based. Using a cloud-based broker is highly suitable because its reach has a broader value than a local network system.

The protocol system used for data exchange is MQTT. MQTT is a protocol that operates on top of TCP/IP and has a Machine-to-Machine (M2M) system. Essentially, the MQTT protocol is designed to be lightweight and power-efficient. The concept applied in the MQTT protocol is the use of publish/subscribe. MQTT is highly suitable for IoT devices in areas with limited internet network coverage. The MQTT protocol is ideal for mobile applications because it has a small data size and low power consumption [45].

Using the MQTT protocol as the communication system in embedded system applications has several advantages. Embedded system devices typically have various limitations, including network constraints. Network limitations may include limited bandwidth, high latency, volume constraints, and unstable connections. In addition to network limitations, there are constraints related to device aspects, such as limited memory, computing capabilities, and limited resources. The MQTT protocol is fundamentally designed to overcome all these limitations.

QoS, or Quality of Service, is a measurement of the quality in a network and is an effort to define the characteristics and properties of a service. The performance of a CPU network varies significantly, such as in QoS, which refers to the network's quality in providing better services. QoS aims to meet the different service needs of the same infrastructure. The MQTT protocol has several levels of Quality of Service (QoS). The offered QoS ranges from 0 to 2. In QoS 0, a message will be delivered once without regard to whether the client has acknowledged the message. In QoS 1, a message will be delivered at least once, ensuring that the client receives the message at least once. Throughput is the total number of successfully arrived packets observed within a specific time interval, divided by the duration of that time interval, as expressed by the equation (1):

$$Throughput = \frac{Number\ of\ Units\ Produced}{Time\ period} \quad (1)$$

whereas, Throughput is the total number of successfully arrived packets observed per unit of time of data transmission, the number of sent packets is the total size of the packets that have been sent, and the time of data transmission is the total observation time. Then, the parameter delay or commonly referred to as latency is the time it takes to process data transmission:

$$Delay = \frac{Time\ span}{Packet} \quad (2)$$

whereas the delay is the time delay during the transmission process, the Time span is the time range from the beginning of a transmission to the end, and Packet is the total number of packets received after the data transmission process. Then, the Jitter parameter is the variation in delay over a specific period, equation (3). A jitter can result in the loss of transmitted data. Data loss occurs primarily when the transmission is carried out at high speeds.

$$\text{Jitter} = \frac{Total\ Variation\ in\ Delay}{Total\ packets\ received} \quad (3)$$

Packet loss refers to the number of data packets lost per second, equation (4). In general, packet loss can be caused by several factors, including a decrease in signal quality in network media, corrupt packets that refuse to transmit data, and errors in network hardware.

$$Packet\ loss = \frac{sent\ data - received\ data}{Total\ Number\ of\ Packets\ Sent} \quad (4)$$

Packet loss refers to the number of packets lost per second. "Data sent" is the total amount of data transmitted, while "data received" is the total amount of data received.

II. Materials and Method

The therapy system is capable of monitoring post-stroke patients undergoing mirror therapy. The system can remotely monitor post-stroke patients engaged in therapy using a website named MIROCLE. Some measurements conducted include heart rate, oxygen saturation, calories, duration, and the number of pedal rotations. In Figure 1, the architecture of the system is illustrated.

A. Material

The max30102 sensor measures heart rate and oxygen saturation, while the IR sensor reads the number of pedal rotations when post-stroke patients undergo mirror therapy using the stationary bike. The RTC assesses the duration of the evaluation of the patient's progress. Other components utilize keyboard functionality for entering Wi-Fi and body weight. Body weight data is necessary to calculate the calories burned after therapy.

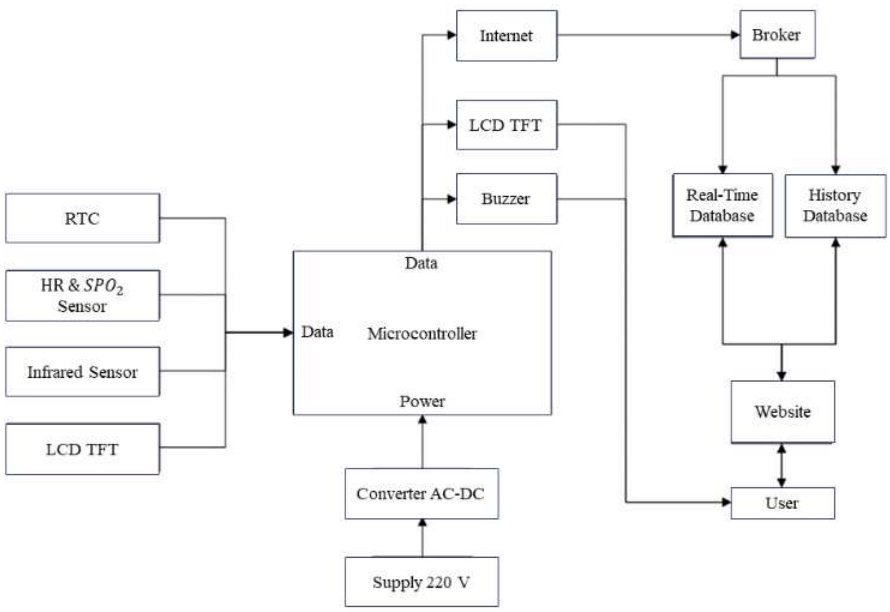

Fig. 1 Illustrates the full architecture of the system.

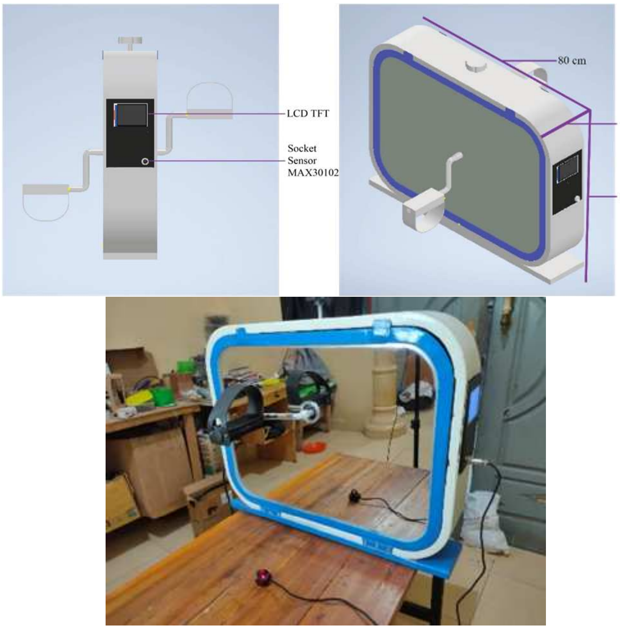

Fig. 2 Therapy Device Design Combining Mirror and Stationary Bike

The therapy results are then published on the website and can be accessed by physiotherapists and patients as part of the monitoring system. Additionally, therapy outcomes are directly displayed on the LCD. This device has several sensors for measuring post-stroke patients, as shown in Figure 1. The product framework utilizes stainless steel and glass, with pedals as the driving force in the pedaling process. Some components include infrared sensors, heart rate and oxygen saturation sensors, RTC, Keypad, and ESP32. The monitoring system has two methods: through the LCD on the product and via the website.

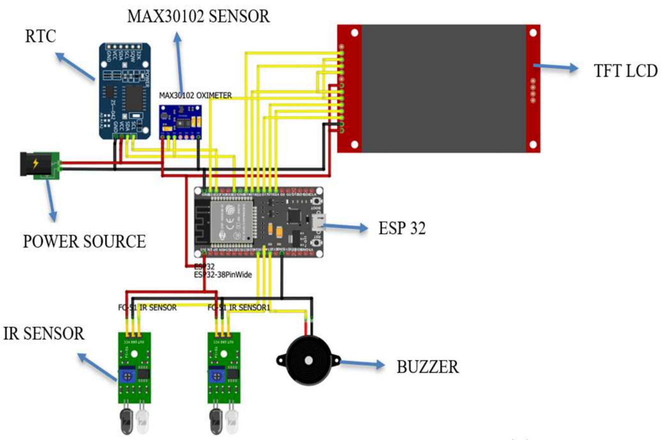

Fig. 3 Wiring diagram of the designed system

Figure 3 depicts the Wiring Diagram of the designed therapy and monitoring system. Implementing a buzzer in mirror therapy involves several components, including a microcontroller, a heart rate sensor, and the buzzer itself. The heart rate sensor measures the patient's heart rate during therapy, and the signal is sent to the microcontroller, which processes the signal. If the heart rate exceeds the predetermined value of 90 bpm, the microcontroller sends a signal to the buzzer to sound. Implementing a buzzer in mirror therapy can help ensure the safety of patients during therapy, especially for those with vulnerable health conditions.

B. Methods

As for the analysis technique used to test whether the sensor used works properly, it involves collecting heart rate data for each subject. Testing on healthy subjects used a pilot study research design with non-probability sampling, specifically purposive sampling. The required sample size at this stage is a minimum of 20 healthy individuals, with 5 trials for the created device and 5 trials for the comparison device, namely pulse oximetry. This allows for the accuracy of the sensor readings to be assessed. The subjects consist of 10 males and 10 females.

Subjects of different genders were selected to obtain varied heart rate values. The results were then compared with the pulse oximetry results, and their accuracy was calculated using Equation 5. The pulse oximeter used is the Choicemmed Pulse Oximeter, which can measure heart rates from 25 to 250 bpm. Medical professionals commonly use this device to assess the initial condition of patients when they arrive at healthcare facilities.

$$\%Accuracy = 100 - \left[\frac{Subtraction}{Commercial\ Tools}\right] \times 100\% \quad (5)$$

The difference results from the oximeter measurement subtracted from the max30102 measurement. Meanwhile, the Commercial Device refers to the measurement results using a standard oximeter. The obtained data will be tested with statistical analysis, including descriptive statistics and a normality test using the Kolmogorov-Smirnov type. Then, the data similarity will be tested against the comparator using the Independent Sample T Test.

Implementing the MQTT protocol requires a device capable of supporting and running smoothly. The device used is ESP-32, which supports and operates well with the MQTT protocol. The acquired data will be transmitted through ESP-32 to the database using the MQTT protocol. There are three sub-systems to be implemented, namely the instrumentation sub-system, communication subsystem, and monitoring subsystem. The Instrumentation System includes sensing to forward the data to the microcontroller. The power system used is also included in the instrumentation subsystem. After obtaining the data, the microcontroller is ready to flow through the communication subsystem with the MQTT protocol and is received by the backend system of the monitoring subsystem.

In the instrumentation subsystem, the components tested are the max30102 sensor, RTC, IR sensor, and LCD. For the max30102 sensor, the success indicator is when the sensor can detect and obtain heart rate and oxygen saturation data. The IR sensor's success indicator is when the sensor receives the number of pedal rotations. The RTC's success indicator is when the time displayed on the serial monitor matches the time on the laptop, and the parameter for RTC is time. Finally, there is testing for the OLED LCD, with the success indicator being if the LCDs characters according to what is input into the ESP32.

Instruments needed to implement the communication system include the implementation of the MQTT protocol on the MIROCLE product, such as a laptop and several software tools like Wireshark, Arduino IDE, and Visual Studio Code. Each selected software serves its purpose. Arduino IDE is used to manage the implementation of the MQTT protocol on the hardware. Visual Studio Code is used to implement the

MQTT protocol in the database. Wireshark is used for network analysis to find throughput, delay, jitter, and packet loss values. The last software used is MQTTX, which manages the broker and implements QoS. The analysis technique is based on relevant literature studies on MQTT protocol testing. The analysis technique also relies on data obtained through Wireshark software, which is then used to calculate throughput, packet loss, delay, and jitter.

The basic concept of the Message Queuing Telemetry Transport (MQTT) protocol is employed in network topology planning. Several components include 1 publisher, 1 broker, and 2 subscribers. The publisher consists of a microcontroller, namely ESP-32, which functions to send data obtained to the broker. The broker serves as an intermediary between the publisher and subscribers. There are 2 subscribers, each comprising a separate database. Each database has a distinct function: the monitoring database is used for real-time monitoring on the website, and the storage database stores the acquired data.

In the monitoring subsystem design, a website is utilized as the information system for the MIROCLE product. The website is intended to facilitate physiotherapists and patients in therapy sessions. The website can be accessed through smartphone, laptop, and computer browsers. The website design incorporates PHP programming language, Laravel framework, and MySQL database. The user interface on the website is developed using HTML, CSS, and Javascript programming languages. The MIROCLE website design is divided into two views: one for patients and the other for physiotherapists. Here is an explanation of the views on the website:

1) Patient Login Page: The login page is used to access the MIROCLE website. On this page, patients enter the username and password provided by the physiotherapist. Once the patient enters the username and password, they will access the MIROCLE website. The login page includes a password change menu if the patient wishes to update their password.

2) Patient Dashboard Page: The patient dashboard page is the initial display of the MIROCLE website. The dashboard page includes several sidebar menus, such as dashboard, graphs, profile, and log out. The dashboard header has a generate report menu, which functions to download therapy results after completion. The dashboard page shows real-time therapy results, including heart rate, therapy duration, oxygen saturation, pedal rotations, and burned calories. Additionally, the dashboard displays a graph showing the total number of patients undergoing therapy for one month. The right side of the body section contains the patient's biodata, including a photo, name, age, weight, gender, and medical history.

3) Patient Graph Page: The graph page displays the patient's therapy results. It shows various graphs, including heart rate, oxygen saturation, pedal rotations, and burned calories. The graph page illustrates improvements or declines during therapy sessions. The header of this page also includes a generated report menu for downloading a summary of the patient's therapy results.

4) Profile Page: In the patient's profile, they can input personal data such as name, age, weight, gender, and medical history. The patient can also change their profile photo at the top. The patient's biodata will be displayed on the dashboard menu.

5) Physiotherapist Login Page: The login page is used to access the MIROCLE website. Physiotherapists enter the registered username and password to access the MIROCLE website.

6) Physiotherapist Dashboard Page: The physiotherapist dashboard page is the initial display of the MIROCLE website. This page includes several sidebar menus, such as dashboard, patient data, patient input, therapy history, and log-out. The physiotherapist's name is displayed in the header section. The upper body section shows the total number of patients, the number of male patients, and the number of female patients. The dashboard page also displays the total number of patients undergoing therapy for one month as a graph.

7) Patient Data Page: The patient data page contains patient biodata, including name, age, weight, gender, and medical history. Patients provide this data when they fill out the form on the patient data page.

8) Patient Input Page: This page is used to add new patients. On this page, physiotherapists can create a username and password for new patients.

9) Patient Therapy History Page: This page displays patients' therapy histories, including the patient's name, therapy date, therapy time, and duration of the therapy session. The data is recorded in the patient's therapy history each time a patient undergoes therapy.

10) Website Testing: The method used to test the website is the Black Box Method. Black box testing is a direct testing method that tests the functional aspects of the system to determine if it conforms to the design. In this testing, each program unit will be integrated and tested as a complete system to ensure that the system meets the specified requirements. The correctness of the tested software is evaluated based on the output generated from the given input data or conditions for the existing functions without inspecting and testing the source code. From the generated output, the program's ability to meet user needs can be measured, and any errors can be identified [46].

In Black Box Testing, testing is conducted based on application details such as the application interface, the functions within the application, and the alignment of function flows with the processes desired by the user. This black box testing tests an application's external appearance (interface) to ensure user-friendliness. Black box testing disregards control structures, focusing only on the domain information.

III. Result and Discussion

Testing on the Max30102 sensor was conducted by comparing the heart rate and oxygen saturation values obtained from the oximeter readings with the readings from the Max30102 sensor to determine its accuracy. The test involved 20 respondents, each undergoing therapy nine times for five minutes each.

In Table 1, Max sensor and oximeter data are typically distributed with a p-value ≥ 0.05, namely 0.200 ≥ 0.05. The data similarity test was performed using the Independent Sample T Test. H0 = No difference in the level of Max sensor measurements compared to the standard Oximeter, H1 = Different levels of Max sensor measurements compared to the standard Oximeter. Thus, based on the calculation results, the data has the same variance (Equal Variances Not Assumed) with a Levene's test for Equality of Variance value of 0.276 ≥ 0.05, meaning the data has the same variance. The p-value test is based on Sig 2-tailed, with a p-value of 0.098 ≥ 0.05, meaning H0 is accepted, indicating no difference in the level of Max sensor and standard Oximeter measurements; the average results of 20 subjects are shown in Figure 4.

TABLE I
RESULT OF NORMALITY TEST ON HR AND S_pO_2 DATA FROM MAX30102 SENSOR

	Kolmogorov-Smirnov			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
HR	0.099	40	0.200*	0.978	40	0.631
SpO_2	0.128	40	0.099	0.929	40	0.015

TABLE II
THE RESULTS OF THE INDEPENDENT SAMPLE T-TEST COMPARE EXPERIMENTAL AND CONTROL DATA

Group	F	Sig	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
HR*	1.221	0.276	1.697	38	0.098	4.625	2.7255
SpO2*	12.353	0.001	-3.796	38	<0.001	-0.91	0.2397

*Equal Variances Assumed

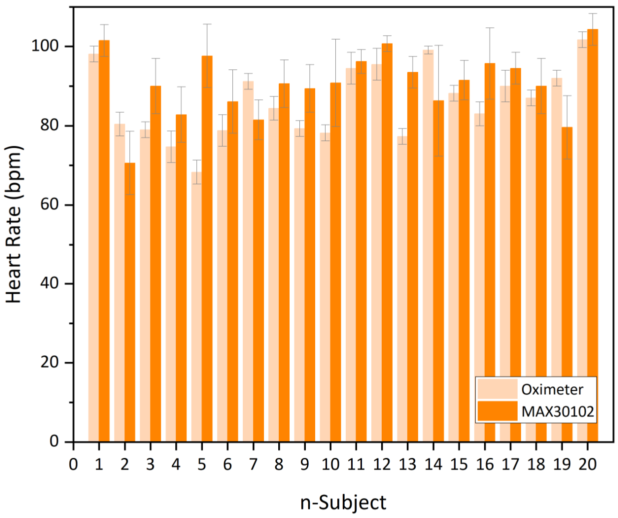

Fig. 4 Comparison Chart of MAX30102 Heart Rate (bpm) Measurement Results against Standard HR Data from the Oximeter.

In Table 2, Max sensor and oximeter data are normally distributed with a p-value of ≥ 0.05, 0.099 ≥ 0.05. Similarity testing was conducted using the Independent Sample T Test. H0 = No difference in the SpO2 (%) measurements between the Max sensor and standard oximeter, H1 = Different SpO2 (%) measurements between the Max sensor and standard Oximeter. Thus, based on the calculation results, the data has the same variance (Equal Variances Not Assumed) with a Levene's test for Equality of Variance value of 0.001 ≤ 0.05, meaning the data has different variances. Therefore, H0 is rejected, indicating a difference in the SpO_2 (%) measurements between the Max sensor and the standard Oximeter. The average results of 20 subjects are shown in Figure 5.

Several factors influence the difference in these values, such as the sensor's accuracy level and movement during SpO_2 measurements. Therefore, future improvements in accuracy and more in-depth testing are needed to enhance the similarity between the designed SpO_2 measurement system and the standard health measurement tool.

Several factors also affect the readings of the MAX30102 sensor, including the influence of external light interference, finger thickness, and imprecise finger positioning between the infrared light and the photodiode. Greater finger surface thickness causes more infrared light to penetrate, decreasing the intensity received by the photodiode, which can affect the accuracy of the sensor readings. Additionally, external light entering the sensor can also disrupt accurate readings.

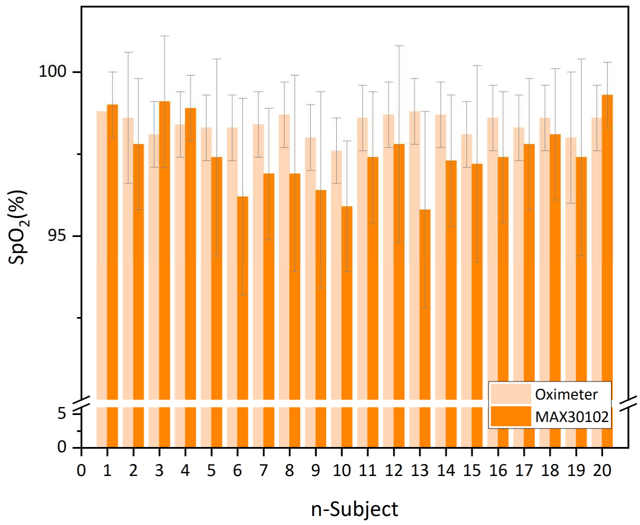

Fig. 5 Comparison Chart of MAX30102 SpO_2 Measurement Results against Standard Oximeter.

Table 3 presents the test results for each QoS. This testing is highly beneficial for analyzing the performance of each Quality of Service (QoS) to be examined in the MQTT protocol. The testing implementation involves sending 1000 packets or messages per second. In each QoS test, evaluation is conducted based on throughput, delay, jitter, and packet loss parameters. The QoS test results for each parameter will be compared, and the QoS with the most optimal parameters will be adopted for the system.

TABLE III
THE COMPARISON OF PARAMETERS BETWEEN QOS 0, QOS 1, AND QOS 2

No	Parameter	Value		
		QoS 0	QoS 1	QoS 2
1	Throughput	604,8 bit/s	619.2 bit/s	602.4 bit/s
2	Delay	3,4 ms	5,9 ms	34,5 ms
3	Jitter	2,152 ms	3,483 ms	24,113ms
4	Packet loss	0%	0%	3%

The comparison of parameters between QoS 0, QoS 1, and QoS 2 is presented in Table 3. This comparative analysis evaluates the performance distinctions among the three

Quality of Service (QoS) levels in the MQTT protocol. The assessment includes key parameters such as throughput, delay, jitter, and packet loss, with the goal of identifying the most suitable QoS level for integration into the system. Throughput is the amount of data successfully transmitted from source to destination within a specific time unit. To understand the influence of Quality of Service (QoS) on throughput, testing is conducted using three different QoS levels. Determining the most optimal QoS in terms of throughput performance, QoS level 1 becomes the most suitable choice due to its highest throughput value among the three QoS levels. The factors affecting the magnitude of the throughput value include the quality of the network being used during the testing. The throughput values generated from each QoS level will be recorded using Wireshark application as an analysis tool.

Testing the delay parameter is one of the crucial aspects examined in this research. The test results indicate that QoS level 0 has a lower delay value, specifically 3.4 ms. Meanwhile, QoS level 1 has a delay value of 5.9 ms, and QoS level 2 has the highest delay value, reaching 34.5 ms. The testing results reveal that the QoS levels affect the delay value in packet delivery over the internet using the MQTT protocol. QoS level 2 has the largest delay, while QoS level 0 has a smaller delay compared to the other QoS levels.

Subsequent testing focused on the jitter parameter. From the test results, it was found that at QoS level 0, the jitter magnitude is 2,152 ms. Then, at QoS level 1, the jitter value reaches 3,483 ms. Finally, at QoS level 2, there is jitter recorded with a value of 24,113 ms. Several factors can influence these differences, including the complexity and importance level of each QoS level in maintaining service quality. At lower QoS levels, the jitter value tends to be lower because the primary focus is on signal stability, consistent data delivery, and the transmission process. Meanwhile, the jitter value can be higher at higher QoS levels due to increased complexity in the data delivery process. In this study, the optimal jitter value can balance signal stability and service responsiveness. Thus, the jitter value at QoS level 0, precisely 2,152 ms, can be considered the most optimal compared to the other QoS levels.

The next test was conducted to analyze packet loss, a failure in data packet delivery. Based on the test results using the Wireshark application, it was found that QoS level 0 has a packet loss value of 0%, while QoS level 1 also has a packet loss value of 0%. However, for QoS level 2, there is an increase in packet loss by 3%. At the QoS level, the higher percentage is caused by the elapsed waiting time. Thus, packet delivery failures occur because the communication process involves more processes. This process results in a higher packet loss quantity at QoS level 2 than other QoS levels. Based on the test results, it can be concluded that in monitoring post-stroke mirror therapy, MQTT shows optimal performance at QoS level 0 with a throughput value of 604.8 bit/s, delay of 3.4 ms, jitter of 2,152 ms, and no packet loss. QoS level 1 is between QoS 0 and QoS 2 with a throughput of 619.2 bit/s, delay of 5.9 ms, jitter of 3,483 ms, and no packet loss. QoS 2 has the lowest performance with a throughput of 602.4 bit/s, delay of 34.5 ms, jitter of 24,113 ms, and a packet loss of 3%.

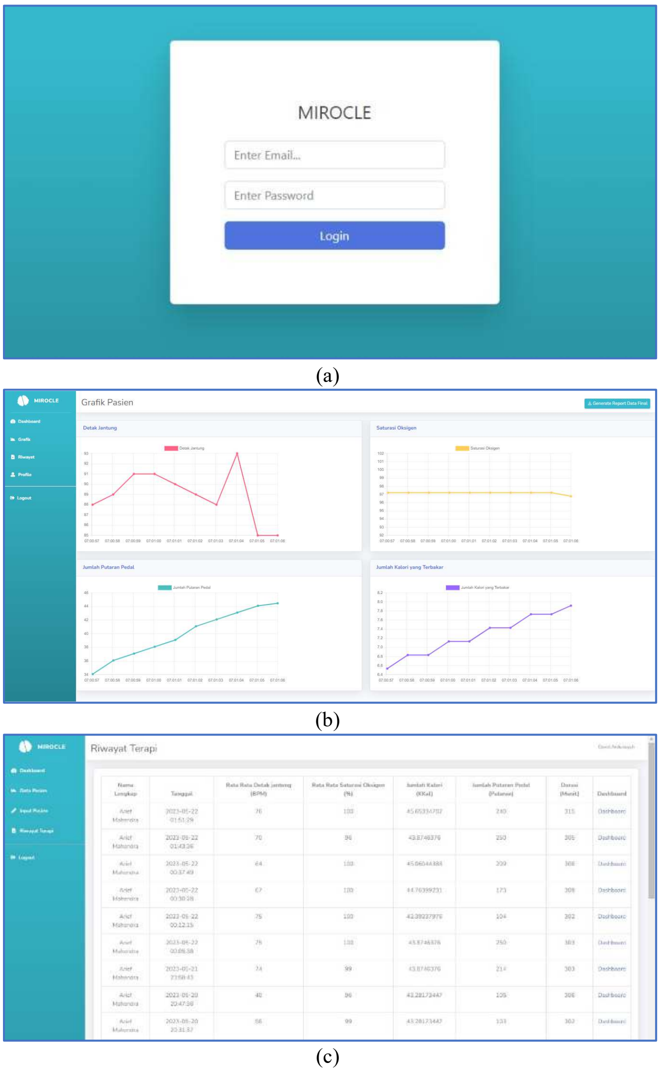

Fig. 6 Interface Display of the Therapy Monitoring Website: (a) login page, (b) patient graph page, and (c) therapy history page.

The first interface testing is on the login system, where patients and physiotherapists must enter the appropriate username and password to access the MIROCLE website. Two tests were conducted, including testing on the patient's website and testing on the physiotherapist's website. G Figure 6 displays three views on the therapy results monitoring website. In the patient website testing, users must enter the username and password registered by the physiotherapist. After entering the correct username and password, the patient will be directed to the patient dashboard. Upon entering the MIROCLE website, patients must fill in their biodata first. Several tests were conducted on the patient's website, such as checking whether the dashboard menu can display real-time therapy results.

The patient's profile and the total number of patients undergoing therapy each month are displayed on the dashboard page. Testing was also conducted on the patient dashboard to see if therapy results could be downloaded through the generate report feature in the final data. The therapy results can be downloaded in the form of an Excel file. In the graph menu, testing was conducted to see if the graph could display real-time therapy results. Another test was conducted on the patient profile page to see if the added biodata could be displayed in the patient dashboard menu. The last feature tested on the patient website is the logout menu; if the patient presses the logout feature, it checks whether they can exit the MIROCLE website.

Physiotherapists will enter the MIROCLE website page using the username and password registered in the MIROCLE tool. Physiotherapists will be redirected to the dashboard menu; testing on the dashboard menu checks whether it can display the total number of patients. Next, in the patient input menu, it is checked whether the biodata entered by the patient is saved on the patient data page. Further testing is done in the patient input menu; physiotherapists will add an account if a new patient wants to use the MIROCLE tool. Physiotherapists can also delete patient accounts through the delete patient feature. On the physiotherapist's website, they can view the therapy history of patients. In this therapy history, physiotherapists can also see in real-time if the patient is currently undergoing therapy. The last testing feature is the logout feature, checking whether physiotherapists can exit the MIROCLE website by pressing the logout feature. Several tests have been conducted, and all features function properly.

The combination of stationary cycling therapy with mirror therapy methods results in an effective stroke rehabilitation process. This integrated approach enhances the recovery of motor functions in stroke patients by providing both physical exercise and visual stimulation, leading to improved outcomes.

IV. Conclusion

The accuracy of the MAX30102 and IR sensors in the mirror therapy monitoring system has been evaluated. The MAX30102 sensor accurately measures heart rate and oxygen saturation, although factors like finger thickness, external light, and sensor positioning can affect accuracy. Therapy results for post-stroke patients are displayed in real-time on the MIROCLE website, developed with HTML, CSS, and JavaScript, offering an informative and user-friendly interface. The mirror therapy monitoring website has been tested for performance, verifying functionality and reliability in displaying real-time data. Test results show the MIROCLE website effectively monitors the progress of post-stroke patients in rehabilitation.

In IoT-based post-stroke mirror therapy monitoring, MQTT performs optimally at QoS level 0 with a throughput of 604.8 bits/s, a delay of 3.4 ms, jitter of 2.152 ms, and no packet loss. QoS level 1 has slightly lower performance, while QoS level 2 has the lowest performance and a packet loss of 3%. Testing confirms that MQTT at QoS 0 successfully transmits consistent, valid JSON-formatted messages, demonstrating the effectiveness of the mirror therapy monitoring system. Therefore, this system is accurate and safe, making it suitable for training actual stroke patients. Its high accuracy in measuring heart rate and oxygen saturation, along with real-time and informative data display, ensures precise and accurate monitoring. The reliable data transmission via the MQTT protocol guarantees consistent and valid data, crucial for the safety and effectiveness of stroke therapy. Thus, this system can be effectively used in clinical settings to aid stroke patient recovery through well-monitored mirror therapy.

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