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Electromyography (EMG) Wireless System for Rehabilitation Process

Muhammad Aiman Suffian[1], Mohamad Nazib Adon[1]*

[1] *Department of Electrical Engineering, Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Batu Pahat, 86400, MALAYSIA*

*Corresponding Author: nazib@uthm.edu.my
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Abstract

Rehabilitation is a one of the critical processes for patients recovering from muscle-related conditions. However, current practices do not have an accurate or dependable system to track progress and parameters during recovery sessions, which automatically affects the efficiency and effectiveness of the rehabilitation process. Additionally, patients residing in rural areas face significant challenges in attending regular rehabilitation sessions at the hospitals or any rehabilitation centre, leading to lower attendance rates and potential gaps in recovery. This project focuses on developing a wireless Electromyography (EMG) system for rehabilitation purposes as it will track the patient progress. The methodology includes a main system responsible for continuous monitoring and data transmission using an ESP32 microcontroller, EMG sensors, LCD displays, and the Blynk IoT platform for real-time visualization. A sub-system is triggered when the push button is activated, initiating a 7-second measurement phase. During this phase, the system captures the highest EMG signal and its corresponding percentage, providing a detailed analysis of muscle activity. This modular approach ensures a smooth operation between real-time monitoring and targeted measurement processes. Results demonstrate the system ability to record muscle activity accurately, with Subject A (normal BMI) achieving a peak EMG value of 4095 bits and 100% contraction during testing. Signal verification showed that the recorded EMG signal pattern closely aligns with the M-wave characteristics identified in prior research, confirming its reliability and physiological relevance. The project concludes that the developed system is effective for rehabilitation applications and offers a foundation for future improvements, such as data analytics and cloud storage integration, to enhance its utility and accessibility.

1. Introduction

Overtime, telemedicine has revolutionized healthcare delivery by reducing barriers to seek treatment in person [1]. By encompassing wireless technologies, telemedicine has become even more advanced and opportunistic, allowing medical monitoring to be applied in multiple scenarios, including patients' houses [2]. Wearable physiological monitoring systems have played an important role in real-time health tracking and rehabilitation [1], which is urgently needed in the current situation. Such systems offer insights into patient physiological data that can provide tailored and effective healthcare interventions [3]. Electromyography (EMG)-driven interventions have taken these systems to another level, proving how EMG technology can improve

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rehabilitation device performance and results [4]. Additionally, platforms such as Blynk have been found to have a significant impact on home-based healthcare applications because they enable wireless communication, which facilitates the implementation of remote monitoring and the smooth transfer of information. This ability enables healthcare providers to respond in a short time and track patients more effectively [5]. A wireless solution using various available technologies combined with wearable sensors like EMG sensors can create an all-in-one remote patient monitoring system. The system allows doctors to monitor muscle activity and recovery of their patients remotely. This is where the combination of telemedicine, wireless communication, and wearable monitoring systems can be used to guide the development of an EMG-based wireless monitoring system. This project aims to translate these innovations to expand access and improve the quality of rehabilitation surveillance applied to patients' treatment of care, especially within the home.

2. Materials and Methods

Fig. 1 illustrates the block diagram of the Wireless EMG System, where the signal flow and interaction of the main components are represented. At the middle of this system is the Node-MCU ESP32, which is an adopted module used as a main controller to process data and communicate it. Muscle activity of the user picked up by the surface electrode, as an analog data, to the SEN-13027 EMG Module Sensor. This sensor brings the raw signals into readable format and, therefore, sends the processed muscle signals to the Node-MCU ESP32 for handling. The system then consists of a push button involved that acts as a user-triggered input for initiating a measurement process. This incoming input is interpreted by the Node-MCU ESP32, which processes the same data and manages the related outputs. The three main outputs of the processed data from the ESP32 are distributed to the Blynk Application, LEDs Indicator, and LCD Display. Data is provided through the integrated Wi-Fi module in the Blynk Application, enabling remote monitoring and control of the device using a cloud-based interface. Real-time EMG data, the highest recorded values, and the issuance of reset commands can be monitored remotely by the user. The green LEDs indicator intuitively displays the activity threshold feedback through 25%, 50%, 75%, and 100%, visually indicating muscle activity while the blue LED indicate the Wi-Fi connection status. Simultaneously, the LCD display allows for on-site usability through the provision of live EMG values and the status of the system in real time.

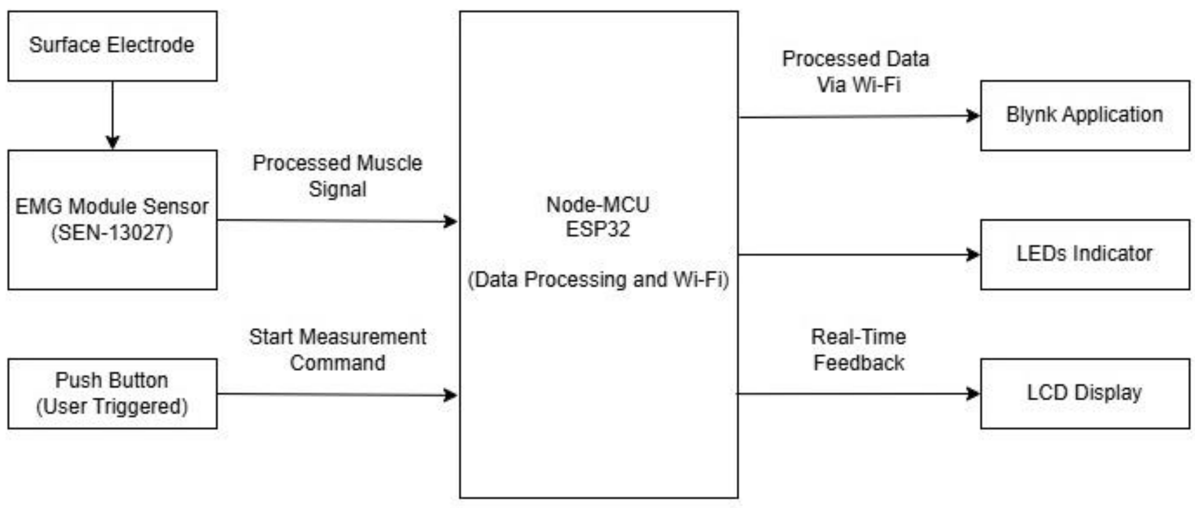


Fig. 1 *Block Diagram of EMG Wireless System*

Fig. 2 shows the system flowchart for RMG Wireless System. EMG Wireless System runs from initialization through real-time monitoring and storage of data to assist in rehabilitation. It initializes the ESP32 microcontroller and checks whether the EMG device is connected to the Wi-Fi. So, the Blue LED will indicate whether the EMG device is connected to the Wi-Fi. The muscle activity signals are collected as raw data by the EMG sensor and subsequently converted to readable signals by the ESP32 during operation. It displays the information through an LCD and delivers it to the Blynk platform to track it remotely. The Auto-rehab platform provides visual feedback through LEDs indicating 25%, 50%, 75%, and 100% completion thresholds, assisting users and therapists in adjusting rehabilitation based on performance. The system starts a 7-second measurement period, capturing peak EMG values when the user presses a button which will act as a sub-system. The output is then displayed on the LCD and uploaded to the Blynk platform to monitor progress. A reset button clears stored data between sessions and improves usability when multiple users and interactions are involved. The system comprises a combination of localized and remote interaction, increasing the efficiency of monitoring muscle activity and the patient's rehabilitation process. Comprising features such as real-time feedback, threshold indicators, and remote access, it supports rehabilitation exercises while ensuring effective therapy and data-driven outcomes.

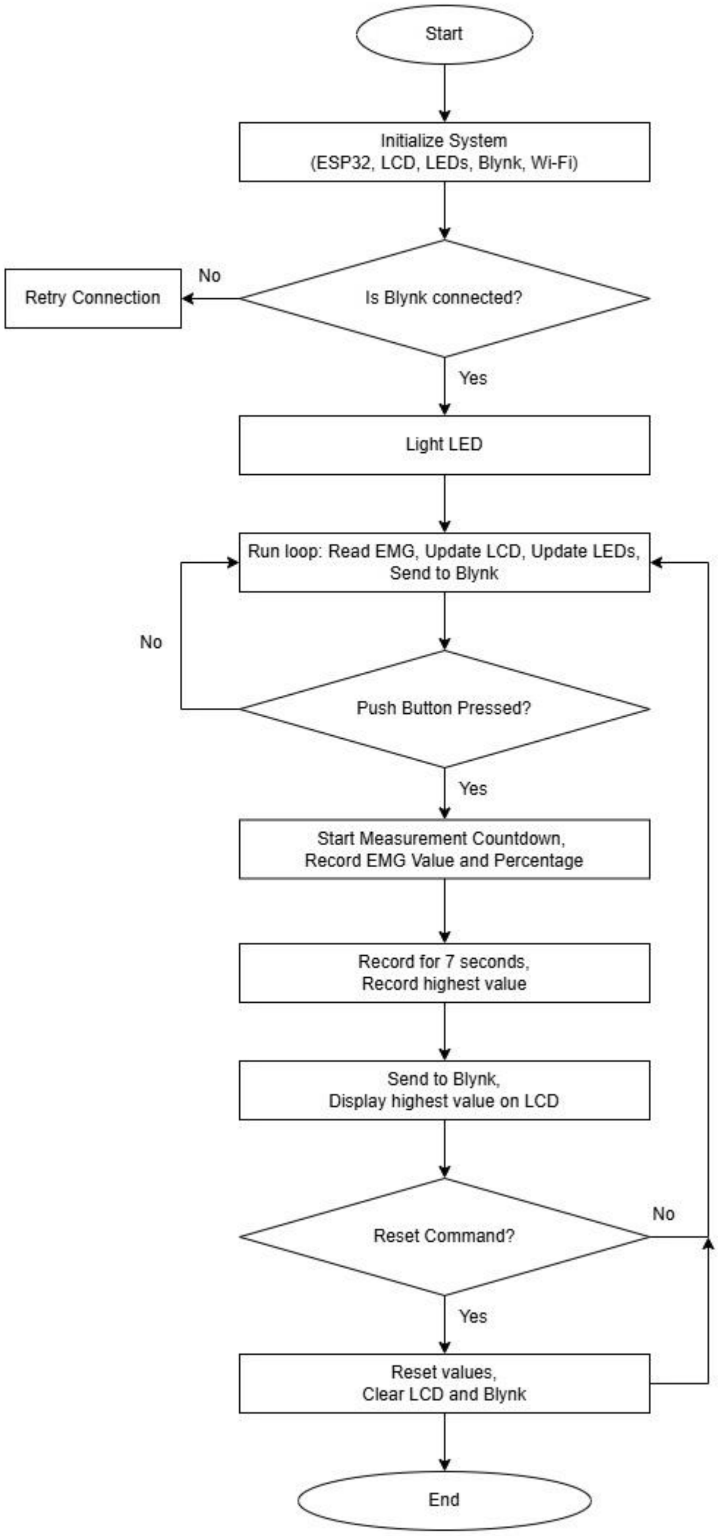


Fig. 2 *EMG Wireless System Flowchart*

2.1 Circuit Diagram

Wireless EMG System is a system that combines existing hardware and software to capture, process, and visualize EMG signals for use in rehabilitation. The hardware for this device includes an ESP32, EMG Sensor, push button, LEDs, 16x2 LCD, and a power supply connected to the ESP32 so that it can all function smoothly together. The EMG sensor uses GPIO34 (analog input) of the ESP32 to capture the signals generated by muscle activity. EMG Muscle sensor is connected with a pair of 9V batteries. Real-time feedback is provided via LCD with I2C communication on GPIO21 and GPIO22, and green LEDs act as EMG intensity thresholds are indicated at 25%, 50%, 75%, and 100% using LEDs). A blue LED indicates whether the device is connected to Wi-Fi. Interaction with the push button starts a sequence that records muscle activity data through EMG Muscle sensor for 7-seconds, and then processes it to obtain maximum values, returns it as the total muscle engagement of muscles for visual interpretation as a percentage. The data is processed by the ESP32 and is sent to the Blynk application over Wi-Fi, which allow both the users and therapist remotely. It allows real-time data acquisition, signal conversion, and visualization, and results are displayed on the LCD and the Blynk app. It has real-time values, peak EMG percentages, and signal plots that assist users in tracking them.l

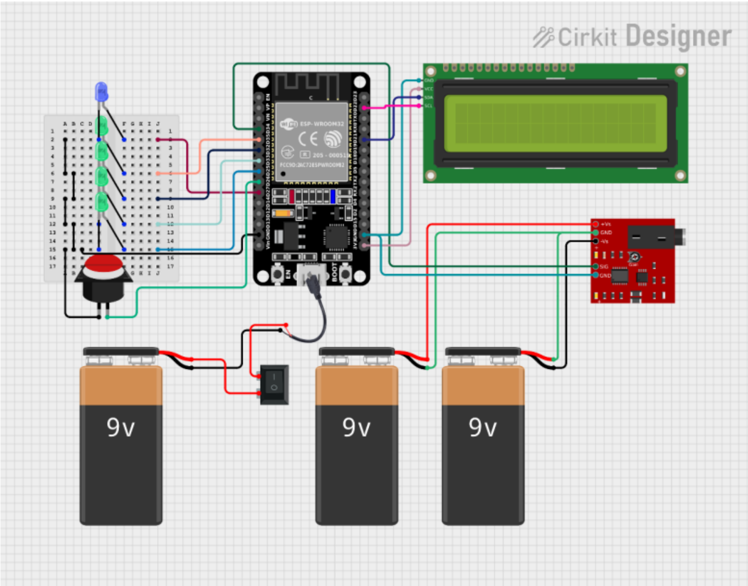
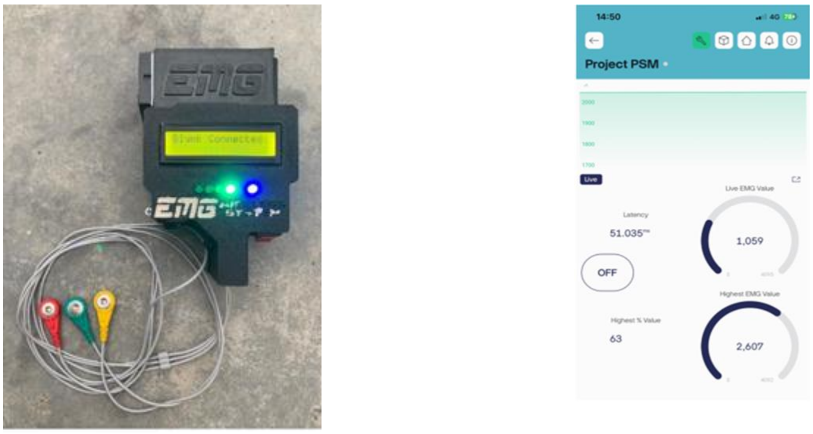


Fig. 3 *Circuit Diagram for EMG Wireless System*

3. Result and Discussion

3.1 Prototype

Fig. 4(a) illustrates the prototype of the Wireless EMG System developed for this project, showcasing its hardware integration for muscle activity data collection, processing, and transmission. The housing protects the electronic components from environmental factors while enhancing portability and ease of use, with a power switch and rechargeable battery for standalone operation. Lightweight and efficient, this hardware supports EMG measurements with precision, fulfilling rehabilitation objectives. Fig. 4(b) highlights the Blynk interface, which is integral to the system's software integration. It enables wireless real-time visualization and analysis of EMG data through an intuitive graphical interface. Circular gauges display live and maximum EMG values, providing immediate feedback on muscle activity during rehabilitation. Together, the hardware and software integrations form a fully wireless, user-centric solution for monitoring and analyzing muscle activity, meeting the project's precision, reliability, and usability goals in rehabilitation settings.

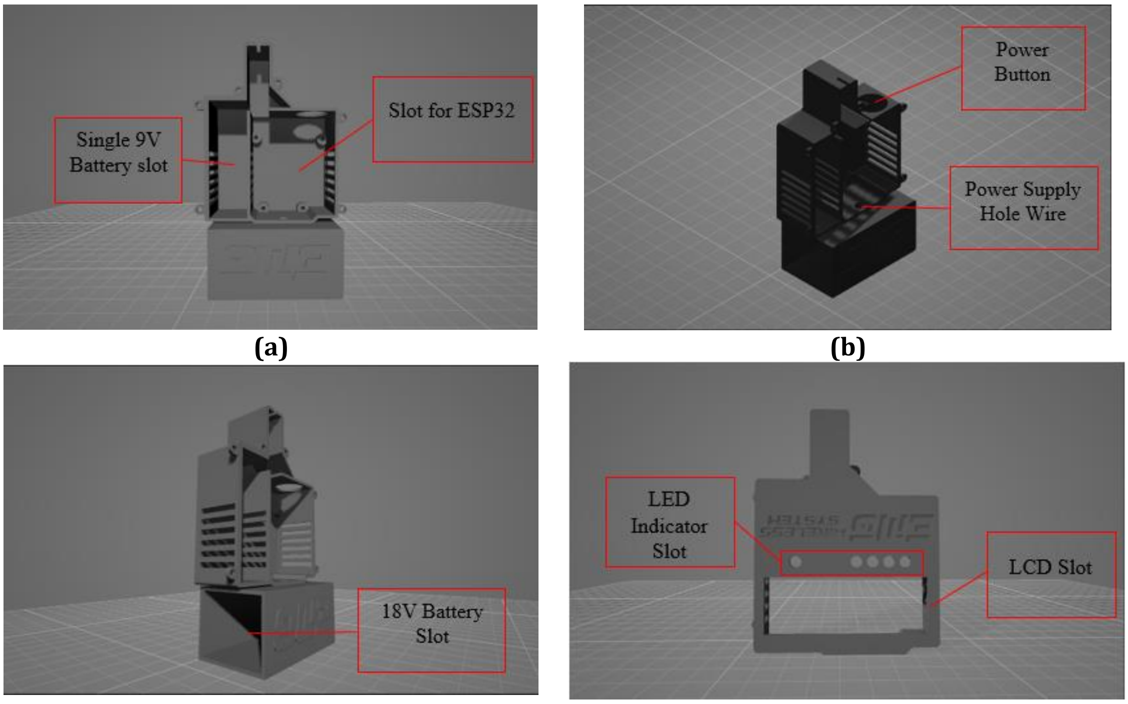


(a) (b)

Fig. 4 *(a) Hardware Integration (b) Software Integration*

3.2 3D-Printing

The 3D model, as shown in Fig. 5, demonstrates the detailed enclosure and structural design of the Wireless EMG System. This model was conceptualized in SolidWorks, a professional 3D CAD software, and fabricated using 3D printing technology with Acrylonitrile Butadiene Styrene (ABS) material. ABS was chosen for its durability, impact resistance, and suitability for functional prototypes, ensuring the device is lightweight, portable, and robust under working conditions.



(c) **(d)**

Fig. 5 *(a) Front-view, (b) Isometric right view, (c) Isometric left view, (d) Front interface*

The design includes the following key components:

- Front View in Fig. 5(a): The 9V battery slot is located at the bottom, providing a secure yet accessible placement for the primary power source. Next to it is the ESP32 microcontroller slot which ensures the stability and proper mounting, preventing movement during operation.
- Isometric right view in Fig. 5(b): This view highlights the power button for easy on and off functionality and a power supply hole for external connections. The placement ensures ergonomic access and organized wiring, contributing to a clutter-free appearance.

- Isometric left view in Fig. 5(c): An 18V battery slot powers the EMG sensor independently, ensuring stable and interference-free performance. This separation of power supplies for the microcontroller and EMG sensor enhances system reliability during operation.
- Front Interface in Fig. 5(d): The LED indicator slot accommodates LEDs for real-time status updates, such as power, connection, or processing activity. Below it, the LCD slot provides a visual interface for system parameters, operational status, and user prompts, improving usability and monitoring capabilities.

The modular design ensures precise dimensions and compatibility among components, enabling easy assembly and maintenance. The use of ABS material in 3D printing further enhances durability while maintaining a compact and lightweight structure. The prototype is optimized for functionality, portability, and user interaction, fulfilling the project's objectives of creating an efficient and reliable rehabilitation device.

3.3 Verifying EMG Signal

The graph in Fig. 6 provides a muscle state which gives insight into real-time visualization of muscle activity as it illustrates the interplay between muscle relaxation (indicated by yellow brackets) and contraction (indicated by red brackets). Each peak and relaxation represent the natural rhythm of muscle engagement, where moments of contraction are characterized by sharp rises in the signal, reflecting heightened electrical activity as the muscle exerts force. Conversely, periods of relaxation display lower signal amplitudes, highlighting the muscles return to a resting state. This dynamic representation effectively captures the transitions between contraction and relaxation, offering a clear picture of how muscles respond and recover during movement. The consistent alternation of these phases underscores the balance between effort and rest. The peaks may reveal aspects of the muscle response's strength, efficiency and coordination depending on how sharp, frequent and variable they are. This kind of visualization is efficient in dulling the intricacy associated with the conduct of muscles, such tinnitus helps one understand how the body functions in reaction to multi-quality aspects for clinical rehab and performance tracking in athletes to scientific study, helping to span data across nerves and open up pathways to gain insight over muscle arrangements, the correlation to growth, and implications on performance.

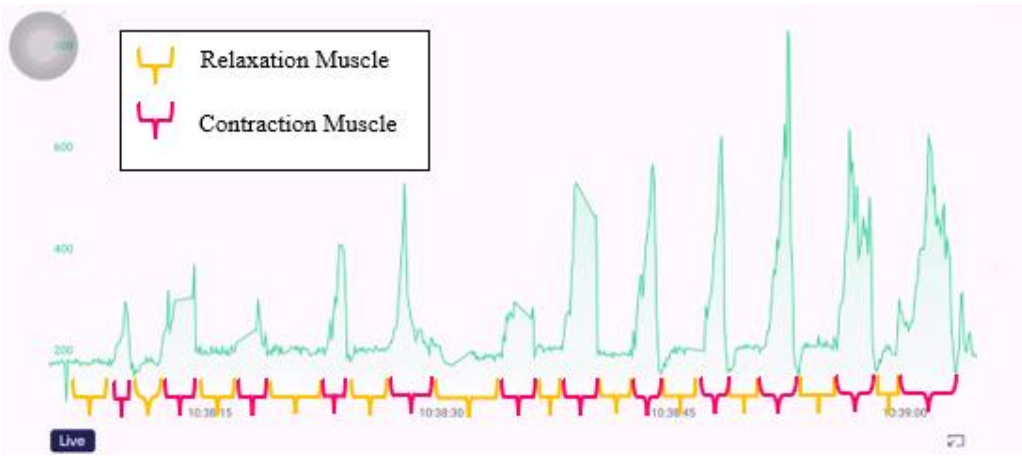
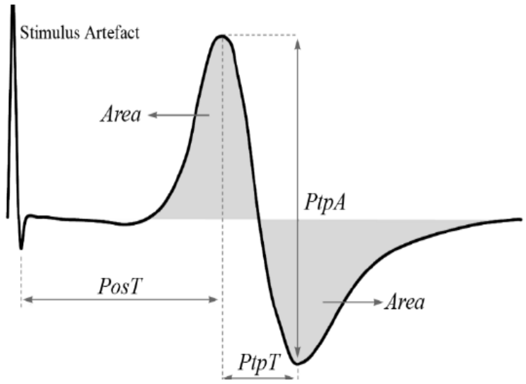
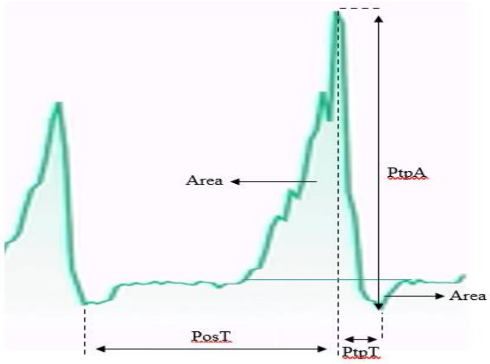


Fig. 6 *Muscle State*

The reliability of the EMG signal captured using the Blynk application, as shown in 7(b), was validated by comparing it with the standard M-wave from previous research (Fig. 7(a)). The reference M-wave exhibits key features such as a stimulus artifact, positive and negative peak amplitudes (PtpA and PtpT), and positive time (PosT), which reflects the intensity and duration of muscle response. The EMG signal from this study closely resembles the M-wave, with similar PtpA, PtpT, PosT, and waveform areas under the curve. This similarity confirms that the captured signal accurately represents the physiological response of muscles to stimulation. The validation demonstrates that the developed system reliably records EMG signals, supporting its application in rehabilitation.



(a)



(b)

Fig. 7 *(a) The general representation of M-wave and some of the commonly extracted parameters [6], (b)EMG muscle signal from the Blynk Application*

3.4 Muscle Test

3.4.1 Muscle Contraction Test

The analysis describes the bicep muscle, one of the primary targets for strengthening in rehabilitation. Detailed data from six subjects measuring relaxation muscle values, maximum EMG, contraction percentages, and latency are found in Table 1. These metrics give deep insights into muscle health and how the neuromuscular system reacts against across various BMI.

Subject A (Normal BMI) shows 315.8 bits average value of relaxation, with the highest EMG value: 3004.2 bits. The subject contracted to 72.8% on average (latency: 102 ms), with Test 3 reaching a peak EMG of 4095 bits and 100% contraction.

Subject B (Normal BMI) showed an average relaxation value of 314.2 bits and a maximum EMG of 2224.6 bits. The average contraction was 53.8%, with latency at 275.4 ms. Test 5 demonstrated significant improvement, with an EMG of 3166 bits and a contraction of 77%, suggesting adaptability and potential for progression.

Subject C (Normal BMI) demonstrated consistent performance with an average relaxation value of 301.2 bits, maximum EMG of 2575.2 bits, and average contraction of 62.6% with a latency of 106 ms. The subject peak at 77% contraction, aligning with expectations for normal BMI individuals.

Subject D (Obese BMI) recorded an average relaxation value of 316.4 bits and maximum EMG of 2102.8 bits. The average contraction percentage was 51%, with latency at 118 ms. Although Test 1 showed an EMG peak of 2689 bits, subsequent tests revealed reduced values, likely due to muscle fatigue and the limitations associated with a higher BMI.

Subject E (Normal BMI) achieved an average relaxation value of 305 bits and maximum EMG of 2786.6 bits. The average contraction was 67.8%, with a latency of 56.8 ms. Test 1 recorded a peak EMG of 3582 bits with 87% contraction efficiency, demonstrating superior neuromuscular coordination.

Subject F (Obese BMI): Displayed an average relaxation value of 327.4 bits and maximum EMG of 3121.6 bits. Despite being in the obese category, the subject achieved an average contraction of 75.8% and a latency of 64.8 ms. Notably, Test 4 recorded a peak EMG of 4092 bits with 100% contraction, indicating variability within the obese group.

The results indicate that normal BMI subjects consistently outperform obese individuals in terms of EMG values, contraction strength, and latency. However, individual differences within each BMI group highlight the importance of personalized rehabilitation strategies. These findings contribute to understanding the relationship between BMI and muscle function, forming a foundation for future research and tailored rehabilitation protocols.

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Table 1 *Cumulative data for full contraction of the biceps muscle*

Subject	BMI Category	Test No.	Relaxation Muscle Value (Bit)	Highest EMG Value (Bit)	Highest Percentage (%)	Latency (ms)
A	Normal	1	330	2161	52	50
		2	321	2715	66	60
		3	298	4095	100	80
		4	333	2944	71	120
		5	297	3106	75	200
Average (Subject A)			315.8	3004.2	72.80	102
B	Normal	1	289	1509	36	100
		2	330	1211	29	100
		3	313	2101	51	327
		4	312	3136	76	400
		5	327	3166	77	450
Average (Subject B)			314.2	2224.6	53.8	275.4
C	Normal	1	321	2705	66	41
		2	299	2846	69	79
		3	288	2475	60	104
		4	291	1680	41	130
		5	307	3170	77	176
Average (Subject C)			301.2	2575.2	62.6	106
D	Obese	1	302	2689	65	35
		2	317	2309	56	74
		3	324	1707	41	113
		4	319	1866	45	174
		5	320	1943	48	194
Average (Subject D)			316.4	2102.8	51	118
E	Normal	1	299	3582	87	42
		2	300	3482	85	50
		3	334	3371	82	57
		4	298	1968	48	65
		5	294	1530	37	70
Average (Subject E)			305	2786.6	67.8	56.8
F	Obese	1	323	3681	89	40
		2	332	2445	59	53
		3	342	2785	68	60
		4	299	4092	100	81
		5	341	2605	63	90
Average (Subject F)			327.4	3121.6	75.8	64.8

3.4.2 Measured Muscle Value Based on Angle of Arm Bends

Table 2 summarizes the EMG readings of biceps muscle activity at various arm angles (0°, 45°, 90°, 135°, and Full°) over ten tests, with averages calculated for each angle. The results provide insights into muscle activation, and influenced by physiological differences, sensor placement, and muscle mechanics.

- 0° (Fully Extended): Values range from 267 bits (Test 9) to 361 bits (Tests 1 and 3), with an average of 311.2 bits. Variability reflects resting muscle tone, minor involuntary movements, and sensor alignment. Higher readings indicate increased baseline muscle tone, while lower values suggest relaxed states or alignment issues.

- 45° (Initial Contraction): Values span from 257 bits (Test 8) to 432 bits (Test 4), with an average of 329 bits. This angle marks the onset of muscle engagement. Higher values suggest effective sensor placement or stronger contractions, while lower values may indicate weak muscle activation or sensor errors.
- 90° (Peak Contraction): Readings range from 257 bits (Test 4) to 410 bits (Test 9), with an average of 305.5 bits. Despite being a key angle for biceps contraction, the average is lower, potentially due to muscle fatigue or coordination differences. Test 9 shows the strongest contraction, while Test 4 reflects poor activation.
- 135° (Near Maximum Contraction): Values range from 289 bits (Test 4) to 439 bits (Test 1), averaging 308.7 bits. This phase indicates shared effort between biceps and other muscles. Higher values suggest strong biceps engagement, while lower values reflect weaker triceps support or fatigue.
- Full° (Fully Flexed): Readings range from 302 bits (Test 10) to 705 bits (Test 1), with an average of 414.4 bits. This angle shows the highest average, requiring maximum muscle activation. Variability reflects differences in strength, endurance, and sensor placement, with Test 1 demonstrating peak performance and Test 10 indicating fatigue or sensor misalignment.

The data reveal a progressive increase in muscle engagement from 0° to Full°, with biomechanical transitions at 90° and 135° due to force distribution between muscles. Variability highlights the need for improved sensor placement and participant consistency. These findings provide valuable insights into biceps muscle behaviour during elbow flexion, informing rehabilitation strategies and standardized EMG protocols.

Table 2 *Measured muscle based on angle of arm bends*

Test No.	Measured Angle (Arm Bend for Biceps Muscle Angle)				
	0º	45º	90º	135º	Fullº
1	361	329	300	439	705
2	277	317	299	317	407
3	361	409	306	327	314
4	332	432	257	289	353
5	301	382	283	309	530
6	283	290	321	309	421
7	279	319	298	294	391
8	336	257	261	344	339
9	267	273	410	404	382
10	315	282	320	355	302
Average	311.2	329.0	305.5	308.7	414.4

4. Conclusion

This project successfully designed a wireless EMG system for rehabilitation that had its goals achieved. It helps in muscle activity monitoring, provides real-time feedback, and operates in a user-friendly manner for rehabilitation patients. Through the integration of an EMG sensor, LCD display, wireless connection with the Blynk platform, and LED indicators, the system was able to accurately capture and display muscle contraction data on the LCD as well as represent the contraction through the LED indicators, achieving the objective of this project, which was to have a functional wireless EMG monitoring system.

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Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

Author Contribution

The authors confirm their contributions to the paper as follows: study conception and design: Muhammad Aiman Suffian, Mohamad Nazib Adon; ***data collection:*** *Muhammad Aiman Suffian;* ***analysis and interpretation of results:*** *Muhammad Aiman Suffian;* ***draft manuscript preparation:*** *Muhammad Aiman Suffian, Mohamad Nazib Adon. All authors reviewed the results and approved the final version of the manuscript.*

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