EVOLUTION IN ELECTRICAL AND ELECTRONIC ENGINEERING
e-ISSN: 2756-8458

EEEE

Vol. 7 No. 1 (2026) 172-181
https://publisher.uthm.edu.my/periodicals/index.php/eeee

# Design and Development of EMG Monitoring Based Human-Machine Interface Using Nextion Display

**Uswatun Khasanah Zakaria[1], Nur Anida Jumadi[1,2]***

[1] *Department of Electronic Engineering, Faculty of Electrical and Electronic Engineering Universiti Tun Hussein Onn Malaysia, 86400, Batu Pahat, Johor, MALAYSIA*
[2] *Advanced Medical Imaging and Optics (AdMedic), Universiti Tun Hussein Onn Malaysia, Batu Pahat, MALAYSIA*

*Corresponding Author: anida@uthm.edu.my
DOI: https://doi.org/10.30880/eeee.2026.07.01.023

### Article Info

Received: 12 February 2026
Accepted: 18 April 2026
Available online: 30 April 2026

### Keywords

Electromyography (EMG), Human-Machine Interface (HMI), Nextion Display, Real-Time Signal Visualization, Smart Healthcare Monitoring

### Abstract

Many rehabilitation devices use button-based interface that limit real-time feedback, accessibility and user interaction, reducing compliance and effectiveness in home-based monitoring. This project develops a user-friendly Human-Machine Interface (HMI) to replace buttons, creates a communication algorithm between a Nextion HMI display and microcontroller, and evaluates real-time system response. Methodology included hardware development using EMG sensor, a 3D-printed casing using Fusion 360, Canva-designed for GUI layouts, and UART implementation. EMG testing assessed the developed system under three muscle contraction with load. Average maximum amplitudes were 0.80 mV, 1.55 mV, and 2.68 mV respectively, confirming increased muscle activity. Higher EMG amplitudes appeared in overweight subjects, but underweight subjects also showed increased activity under load, indicating physiological variation beyond BMI affects activation. Results validate that the EMG system reliably records muscle activation patterns in real-time via web interface. While full real-time visualization was not implemented, the GUI integration shows future potential. This research confirms the HMI-based EMG monitoring system is user-friendly for smart rehabilitation. Future work will target full real-time integration, muscle fatigue analysis, and improved home-based usability.

## 1. Introduction

Rehabilitation for individuals with neuromuscular conditions like stroke, muscular dystrophy, diabetic neuropathy, and myopathies tends to be gradual and variable due to the absence of real-time monitoring of muscle activity and tailored feedback. Electromyography (EMG) is an established method for evaluating muscle function. EMG signals provide quantitative information on muscle activation and have been widely used to monitor muscle activity levels during rehabilitation and assistive device evaluation [1]. However, conventional EMG systems are frequently complex, costly, and restricted to clinical settings [2]. Many existing systems still rely on traditional control methods like physical button or remote interface which reduce usability and real-time interaction [3]. Also, many current systems continue to employ constrained, button-based interfaces that aren't suited for real-time feedback, accessibility, or user engagement [4]. These limitations may make it more difficult for users to comply and lower the effectiveness of home-based diagnostic equipment. The integration of Human-Machine Interface (HMI) systems in medical devices offers an opportunity to modernize the user experience by providing

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a more intuitive and interactive control mechanism [5]. Interactive graphical interfaces have been shown to improve accessibility, efficiency, and user comprehension by presenting complex data in centralized manner [6].

Therefore, it is essential to create a user-friendly Human-Machine Interface that combines EMG signal monitoring with engaging visual feedback, allowing both patients and therapists to monitor, comprehend, and enhance rehabilitation sessions. This kind of system would improve the accessibility, portability, and effectiveness of EMG-based rehabilitation and recovery, particularly for use at home and would be more natural for human perception, which improves engagement, response time and ease of interpretation compares to nonvisual control methods [7]-[9]. Real-time health monitoring systems are increasingly adopted in smart healthcare to enable continuous observation, timely feedback and remote decision making outside clinical setting [10]. Moreover, research emphasizes that usability in medical devices significantly influences patient engagement, safety, and decision-making. In keeping with modern technology developments and patient-cantered care paradigms, this can help enable more efficient and approachable healthcare solutions.

The primary objective of this study is to design and development of human-machine interface (HMI) for smart healthcare device which following several specific goals. The first goal is to develop a user-friendly interface (HMI) Display, replacing traditional button-based controls for better usability. The second goal is to develop an algorithm for processing communication between Nextion Human-Machine (HMI) Display and microcontroller. The final goal is to evaluate the feedback and response of the developed system in real time.

The implementation of the device focus on the design, development and evaluation of graphical interface for EMG monitoring system with Nextion HMI display. The scope of this study includes designing and developing a user-friendly graphical interface using Nextion Editor, using Arduino IDE to program the microcontroller and establish UART-based serial communication with the Nextion Display, and testing the effectiveness and response time of Human-Machine Interface (HMI) Display when receiving and processing inputs.

By leveraging the Nextion HMI display and programming it via the Arduino IDE using UART communication, the study aims to develop an intuitive touchscreen interface that enhances usability, responsiveness, and data visualization. This innovation facilitates home-based rehabilitation by providing a more accessible, interactive, and effective healthcare solution for both patients and healthcare providers

## 2. Methodology

This project aims to create a smart healthcare device that can utilize a non-invasive physiological parameter using an intuitive Human-Machine Interface (HMI) to visualize surface electromyography (EMG) signals for rehabilitation objectives. The general block diagram of the EMG monitoring system is indicated in **Fig. 1.** EMG sensor reads the muscle signals and the ESP32 microcontroller interprets the signal. The processed information is then sent to the Nextion HMI display via serial UART.

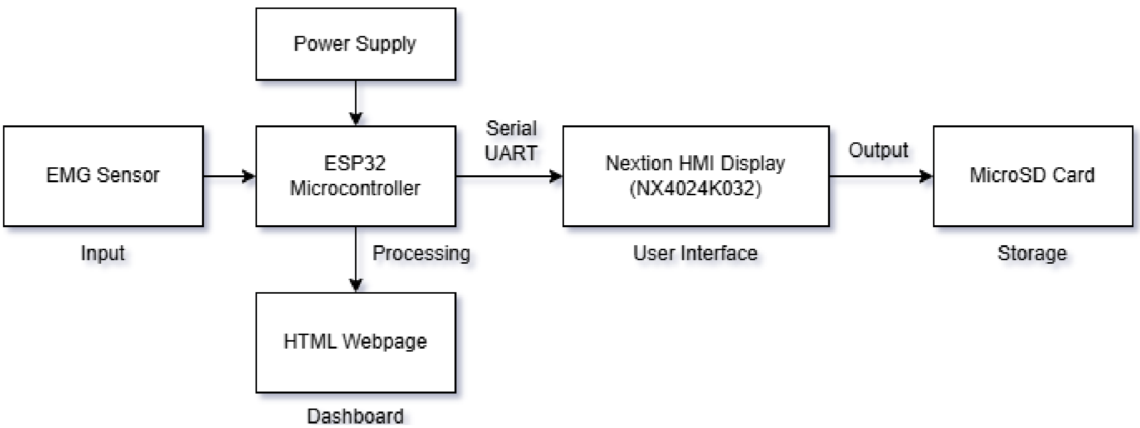



**Fig. 1** *Block diagram of the project*

The system flowchart represents the stages of acquisition of the EMG signal, its processing and calibration, as well as visualization of the data. The system will read repeatedly the EMG signals, process the data and display the output to the display interface. **Fig. 2** shows the system workflow of the HMI health monitoring interface layout.

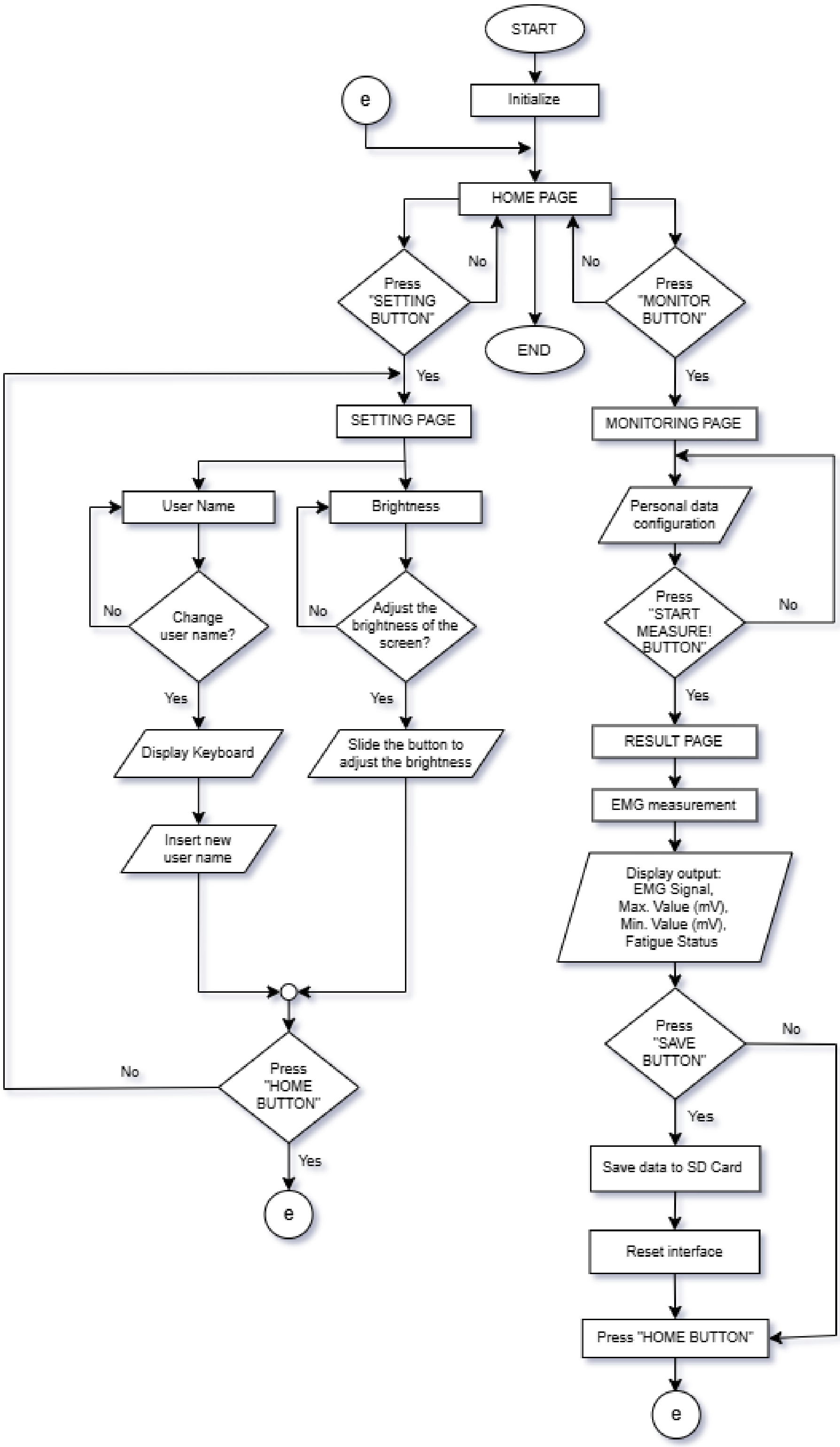



**Fig. 2** *System workflow of the human-machine interface layout*

## 2.1 Software Development

This section discusses about the software development of graphical user interface (GUI) design implementation using two stage which is Canva and Nextion Editor. The original GUI layout was designed using Canva to visualize the HMI layout in terms of structure, flow of navigation and screen arrangement. This was done to create a good readability, consistency as well as user friendly interaction prior to implementation in Nextion Editor. **Fig. 3** illustrated the Canva platform as a GUI development tool.

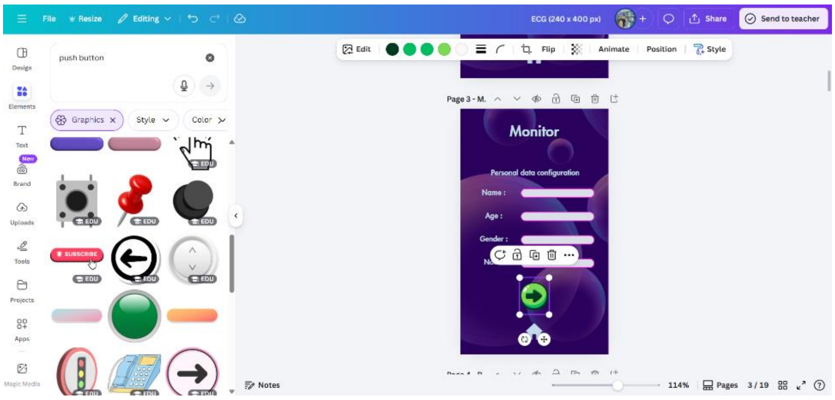



**Fig. 3** *Canva Platform as GUI Development Tool.*

The primary development environment for the GUI of the HMI display was the Nextion Editor. This specialized visual tool enables users to create, test, and program screen interactions especially for Nextion displays. This platform is available on the official Nextion website. In this project, the design of each GUI page was based on background images made in Canva. Using the drag-and-drop functionality of Nextion Editor, interface elements like buttons, text boxes, touch-sensitive areas, and variable displays were incorporated as displays in **Fig. 4**.

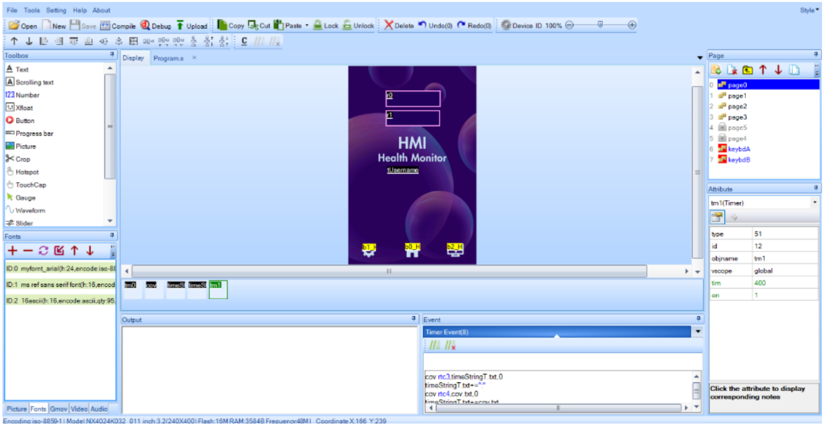



**Fig. 4** *Nextion Editor Platform as Main GUI Development Tool*

## 2.2 Hardware Implementation

The hardware platform will be comprised of Nextion HMI Enhanced display, EMG sensor and an ESP32 microcontroller as a main component in these studies. **Fig. 5** illustrates the circuit diagram of the whole system while the **Fig. 6** illustrates the 3D casing design using Autodesk Fusion 360 that would be printed in BambuLab A1 3D printer. The design was to be made more portable, secure the internal parts and add to their ease of use.

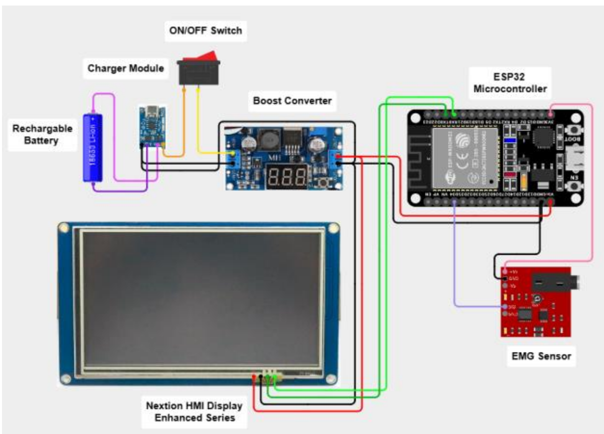



**Fig. 5** *Circuit Diagram with Main Component of This Project*

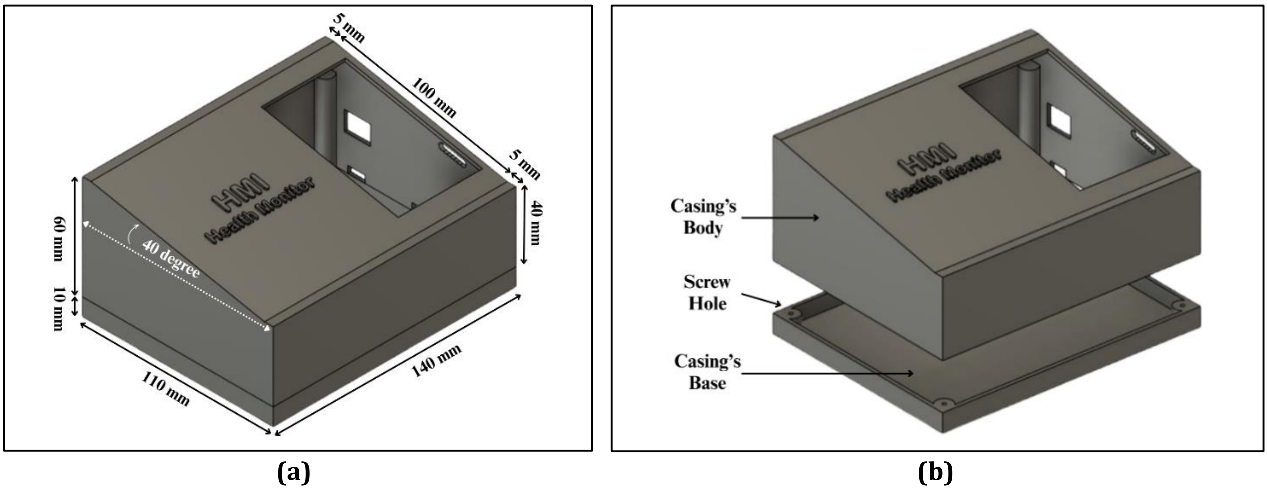



**Fig. 6** *3D Casing Design using Autodesk Fusion 360, (a) Final Design Dimensions, (b) Exploded View*

## 3. Results and Discussion

This section discussed the results obtained from these studies.

### 3.1 Prototype of Developed System

**Fig. 7** shows hardware set-up of the developed system prototype device outer and internal hardware arrangement. The prototype that has been developed is an EMG monitoring healthcare device that combines an ESP32 microcontroller, an EMG sensor, and a Nextion Enhanced HMI display to measure, process and display real-time EMGs. Circuit design and the components connection were initially tested using simulation to make sure that there was proper signal acquisition and consistent serial communication between the ESP32 and HMI display.

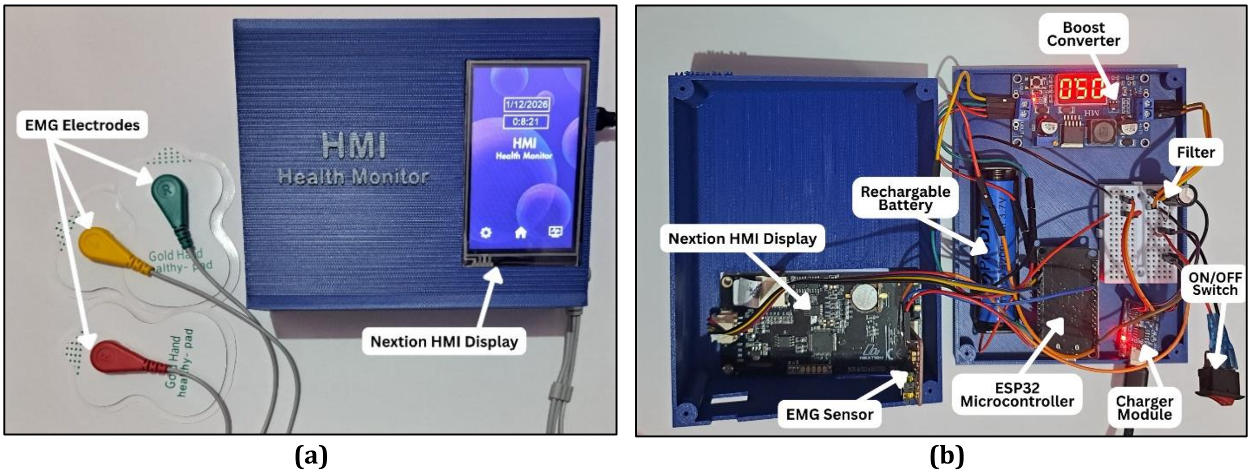



**Fig. 7** *Prototype of HMI Healthcare Device, (a) Device Outer Casing, (b) Internal Hardware Arrangement*

After a successful simulation, hardware connectivity was introduced to enable the EMG waveforms display, interaction with the system using touchscreen buttons, and personal data settings. The prototype casing had to be compatible with the parts so that it could be kept in place, yet it would be portable, work well and easily accessible thus making the device an appropriate candidate for the controlled human testing and additional system improvement.

### 3.2 Graphical User Interface Design

The initial phase of the Graphical User Interface (GUI) development used Canva as the design tool of choice to create visual organized and easy-to-use background design of the Nextion HMI touchscreen. The drag and drop feature of Canva as a wide range of visual components allowed it to provide individualized backgrounds on each HMI pages. **Fig. 8** illustrated the layouts that were designed systematically based on their functions such as the Home page, Setting page, Monitoring page and Result page.

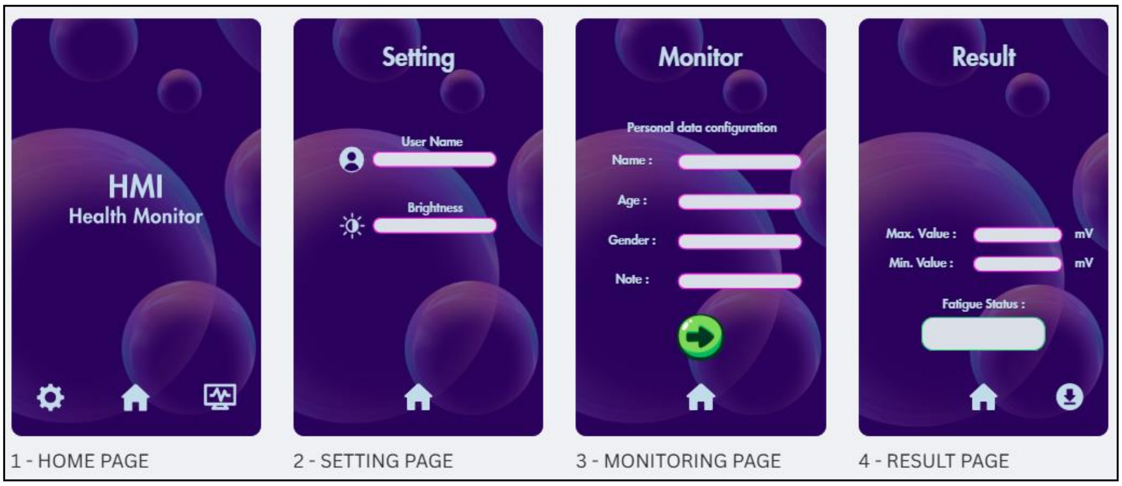



**Fig. 8** *GUI Background Design Using Canva*

The background pictures were properly scaled to fit the resolution and aspect ratio of the Nextion Enhanced HMI Display model NX4024K032 which 320x240 pixels. Once finished, the designs were exported as either in .jpg r .bmp and optimized to load effectively to the Nextion Editor without negatively impacting the system performance.

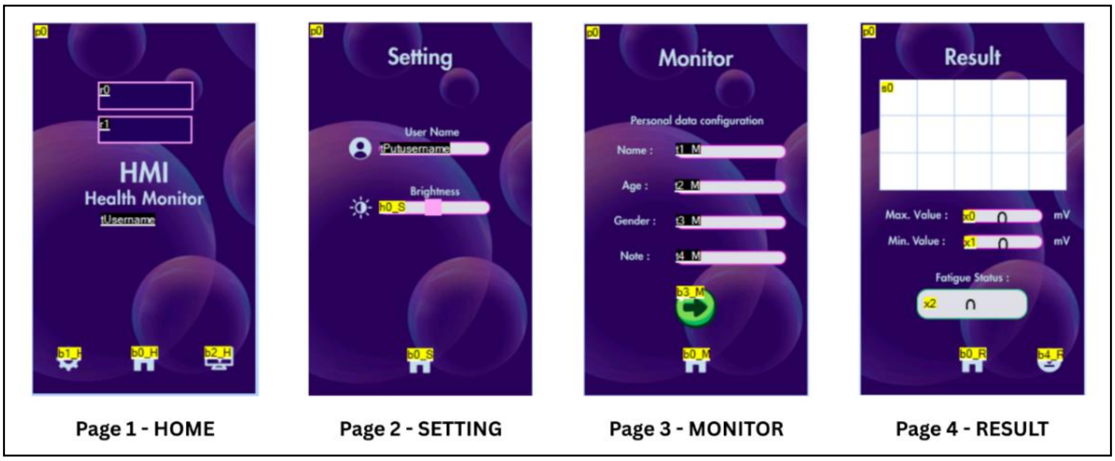



**Fig. 9** *GUI Implementation Using Nextion Editor*

**Fig. 9** shows the results of the element attribution for each page such as navigation, data display and user interface (GUI) implementation by the Nextion Editor. The designed interface pages were integrated well into the Nextion HMI display and interactive elements in the form of buttons, text field and waveform displays were configured to the requirements of the system.

## 3.3 Performance Evaluation

This section evaluates the performance of graphical user interface (GUI) that implemented on the Nextion Enhanced HMI display during the real-time operation. The study focusses on critical performance elements, such as touch response accuracy, page transition speed and real-time EMG waveform updates that directly affect user interaction and system usability.

**Table 1** summarizes the expected performance of the GUI during real-time operation based on the evaluation parameters discussed. The table presents an overview of the GUI responsiveness and display performance, serving as a qualitive assessment of the HMI functionality in developing the smart HMI healthcare device for EMG monitoring system.

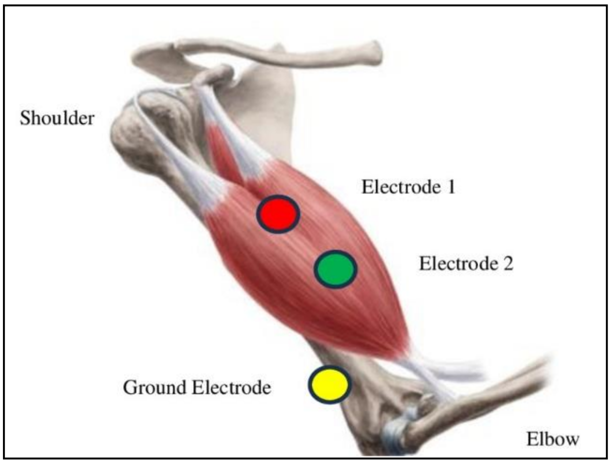
**Table 1**: *Evaluation Expect of GUI Performance During Real Operation*

| Evaluation Aspect | Observation | Status |
|---|---|---|
| Touch Response | Immediate | Medium |
| Page Transition Speed | Immediate | Medium |
| Waveform Update | Real-time | - |
| Readability | Clear | Good |

In general, the Nextion display performed well regarding touch sensitivity, clarity, and the successful execution of various functions throughout this project. However, there are some complexities of handling high-frequency EMG data and rendering waveforms through serial communication and the Nextion library on the ESP32 platform. The system's failure to send continuous EMG values prevented the waveform components from updating in real-time. Thus, the real-time visualization of EMG waveforms was not possible within the project's timeframe and requires further improvements in future development.

## 3.4 Web Server and Subject's Testing

This section presents the performance evaluation of the EMG monitoring device based on the testing on human subjects. The evaluation aims to determine the functionality, reliability and accurateness of the developed system in the acquisition and reproduction of real-time EMG signals. The testing was performed where EMG data were recorded and examined to ensure the system has the capability of displaying EMG waveforms, maximum and minimum voltage value in millivolts and the identification of important waveform patterns trough the HTML webpage as a dashboard display.




**(a)**

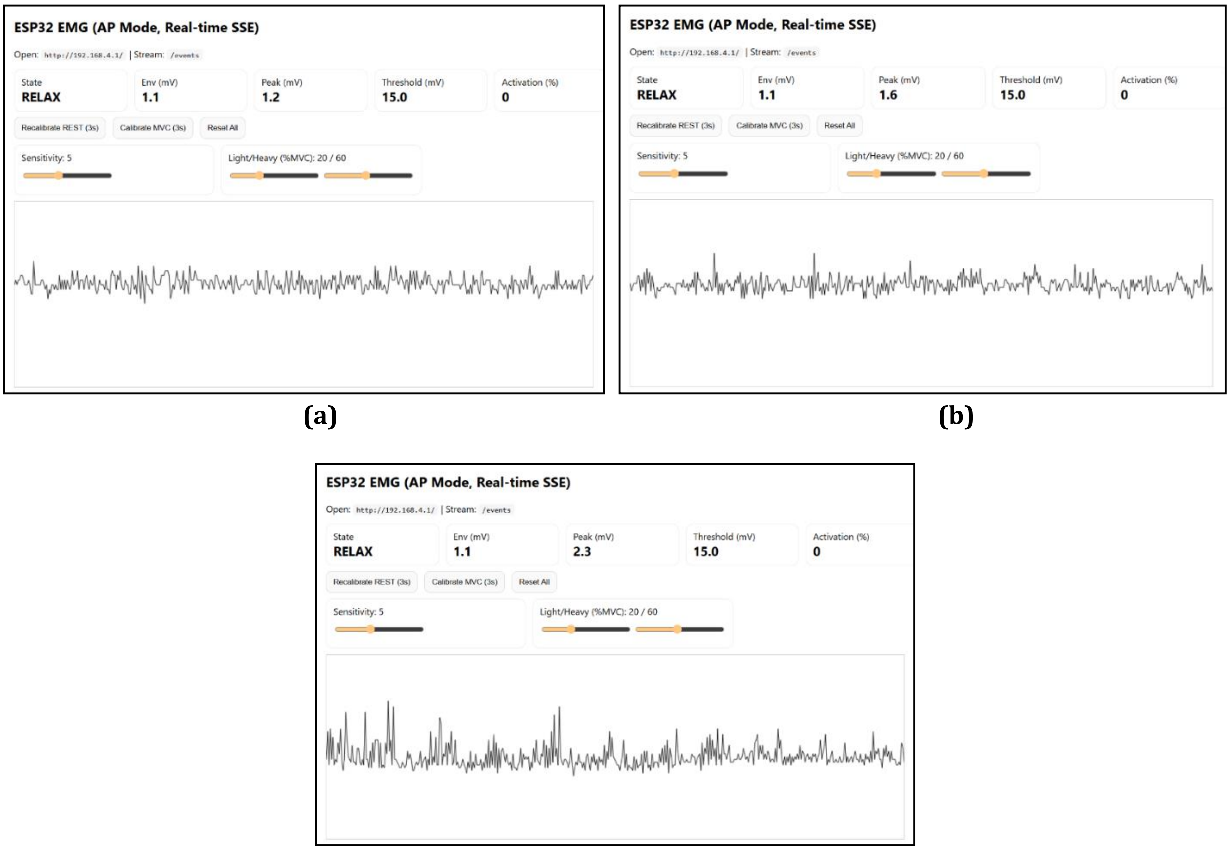
**(b)**

**Fig. 10** *(a) Electrodes Placement for Bicep Muscle Testing, (b) Example of Subject A Undergoing The Experiment*

**Fig. 10** shows the electrodes placement for testing on subject and the example of the testing that have been conducted during three different conditions which is during relaxation (straight upper hand), during contraction of the muscle (bent upper hand), and during contraction with dumbbell exercise (using 2kg load).

## 3.5 Data Analysis Based on Comparative Result

Several tests were carried out in order to get the EMG waveforms based on the different muscle contraction levels. The test was done on three levels of muscle contraction which is relaxation, contraction and contraction with load. Under the relaxed state, low amplitude EMG waves were recorded which were muscle activity at the baseline, and the peak value in millivolt rising progressively during the contraction state and become higher during contraction level with load. As we can see from **Fig. 11**, illustrates the displayed result of testing on Subject A during each condition on the web server HTTP dashboard which shows the higher the level of contraction, the higher was the amplitude of the EMG signal and the density of its activity in real-time.




**(a)** **(b)**

**(c)**

**Fig. 11** *Display Result for Subject A during,*
*(a) Relaxation, (b) Contraction, (c) Contraction with Load.*

The display results of subject A in **Fig. 11** show with little EMG amplitude at relaxation (1.2mV), moderate changes during contraction (1.6mV), and large changes in peak values during dumbbell exercise (2.3mV). The comparative analysis was conducted using EMG data collected from multiple subjects during controlled muscle activation tasks. Here are the comparative findings as illustrated in **Table 2,** outlining important parameters of the EMG observed in subject A to Subject H.

According to the comparison table, the difference in the amplitude of EMG signal and activation patterns in various subjects was noticed. These variations are anticipated because of personal factors in the form of muscle strength and the BMI status of each subject. Regardless of these differences, all subjects show definite responses of EMG signal in contraction and relaxation phases of muscles, which suggests that the EMG acquisition and processing system was reliable.

It is also revealed in the results that the web0based visualization system could consistently provide real-time EMG data of all subjects in real-time. This supports the validity of the web server method of web monitoring and validation of the behaviors of EMG signals when using the web to test a subject. The fact that signal trends are consistent across subjects also lends credence to the ability of the system to record meaningful signal data of muscle activity.

Comprehensively, the comparative analysis confirms that the designed EMG monitoring system can be able to obtain, process and present the EMG signals of various users in real-time through a web-based system. Though the data were not stored in the Nextion HMI display yet, the results obtained are a solid basis of further implementation of real-time EMG visualization and sophisticated analysis, including the muscle fatigue data. Due to the threshold being set at 15mV, but the EMG signals during dumbbell exercise remained relatively low meaning that the muscle activation may not have been strong or prolonged enough to induce measurable fatigue.

**Table 2** *Comparative Result on Subject's Testing*

| Subject | Age | Gender | BMI Status | Subject's Conditions | Voltage Value of EMG (mV) | | Fatigue Status |
|---|---|---|---|---|---|---|---|
| | | | | | Env. | Max. | |
| **A** | 24 | Male | Over-weight | Relaxation | 1.1 | 1.2 | Normal |
| | | | | Contraction | 1.1 | 1.6 | Normal |
| | | | | Dumbbell Exercise | 1.1 | 2.3 | Normal |
| **B** | 24 | Male | Normal | Relaxation | 0.6 | 0.7 | Normal |
| | | | | Contraction | 0.9 | 1.0 | Normal |
| | | | | Dumbbell Exercise | 1.3 | 1.7 | Normal |
| **C** | 25 | Male | Over-weight | Relaxation | 0.9 | 0.7 | Normal |
| | | | | Contraction | 1.0 | 1.3 | Normal |
| | | | | Dumbbell Exercise | 1.5 | 1.7 | Normal |
| **D** | 24 | Male | Normal | Relaxation | 0.8 | 1.0 | Normal |
| | | | | Contraction | 0.9 | 1.5 | Normal |
| | | | | Dumbbell Exercise | 1.0 | 1.8 | Normal |
| **E** | 24 | Female | Normal | Relaxation | 0.7 | 0.8 | Normal |
| | | | | Contraction | 0.7 | 1.4 | Normal |
| | | | | Dumbbell Exercise | 1.1 | 4.2 | Normal |
| **F** | 24 | Female | Normal | Relaxation | 0.5 | 0.8 | Normal |
| | | | | Contraction | 0.7 | 1.8 | Normal |
| | | | | Dumbbell Exercise | 0.8 | 3.3 | Normal |
| **G** | 24 | Female | Normal | Relaxation | 0.6 | 0.8 | Normal |
| | | | | Contraction | 1.7 | 1.8 | Normal |
| | | | | Dumbbell Exercise | 1.1 | 3.2 | Normal |
| **H** | 24 | Female | Under-weight | Relaxation | 0.3 | 0.6 | Normal |
| | | | | Contraction | 0.5 | 2.0 | Normal |
| | | | | Dumbbell Exercise | 0.8 | 3.2 | Normal |

### 3.6 Further Discussion Reflected to Actual Project Outcome

The primary drawback of this project was that it was not possible to show real-time information of EMG waveform data on the Nextion HMI display despite the successful design of the GUI layout, variables, and event configurations in the Nextion Editor. The logic of communication between ESP32 microcontroller, EMG sensor and Nextion display was programmed in the Arduino IDE. Nevertheless, there were constant problems with the Nextion library, especially in the declaration and manipulation of elements of buttons, text fields, sliders, and waveform objects. All these repetitive compilation and communication errors did not allow the ESP32 to transfer EMG data to the Nextion display correctly and, as a result, no real-time EMG signals appeared on the interface.

This is assumed to have been predetermined by compatibility and communication limitations between the ESP32 platform and the chosen Nextion library, and the need to transmit data to the serial and vice versa. The extensive debugging and optimization could not be completed due to the common re-appearing errors and the limited project timeframe. Consequently, real-time visualization of EMG data to the Nextion display was not possible, but the GUI framework was successfully created and can be used in the future.

The other weakness was that muscle fatigue status analysis could not be implemented in the project time. Fatigue detection using EMG technique needs organized experimental procedures, sustained contractions of the muscle, and adequate data recording through time to note variation in signal amplitude and frequency attributes. Alas, the intended fatigue experiments were not done because of unforeseen damage to the EMG sensors and the lack of time to replace the sensors and conduct ethical preparation. As a result, the fatigue analysis was not part of the final implementation and can be suggested as a future work, where it is possible to control the testing conditions with longer exercise duration, heavier load resistance with continuous muscles contraction tests and use credible hardware to improve the usage of the system in rehabilitation and healthcare monitoring.

## 4. Conclusion

This project managed to create a Nextion-based HMI system of an EMG smart healthcare monitoring system. Although real-time visualization of the EMG waves was realized with the help of a web server interface, full integration with the Nextion display was not realized within the frame of the project. However, the developed HMI has a good future application of real-time EMG monitoring system. The subsequent research should be aimed at upgrading the communication between the microcontroller and the Nextion Display, providing real-time visualization of waveforms and carrying out orderly muscle fatigue monitoring experiments with specific procedures.

## Acknowledgement

This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through TIER1 (vot Q545).

## Conflict of Interest

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

## Author Contribution

*The authors confirm sole responsibility for the following:* ***study conception and design:*** *Uswatun Khasanah Zakaria and Nur Anida Jumadi;* ***data collection:*** *Uswatun Khasanah Zakaria;* ***analysis and interpretation of results:*** *Uswatun Khasanah Zakaria;* ***paper writing and revision:*** *Uswatun Khasanah Zakaria and Nur Anida Jumadi. All authors reviewed the results and approved the final of the manuscript.*

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