Early Detection of Carpal Tunnel Syndrome: Design And Validation of A Rechargeable Electromyography Device For Monitoring Median Nerve Electrical Activity

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***Abstract*—Carpal tunnel syndrome (CTS) is one of the most common compression neuropathies that affects the upper extremity, manifesting through sensations like numbness, tingling, burning, or pain in the hands. The condition's gradual progression can lead to irreversible hand dysfunction if left unaddressed. Hence, its early detection is essential to take the necessary actions to slow or stop the syndrome's progression. This research aimed to design and develop a rechargeable early detection device for CTS that employs an EMG muscle sensor to measure the electrical activity of the muscle and validate the device's functionality through a sample program for the microcontroller, including assessing the output voltage of the components using a voltmeter, and by engaging medical experts to evaluate its efficacy in early detecting carpal tunnel syndrome. Sixty-two (62) participants were tested during the deployment of this device to determine whether their hands are healthy or susceptible to carpal tunnel syndrome. The readings from the device were compared to the medical professionals' impressions, resulting in a specificity of 0.84 and a sensitivity of 0.67. The device showed promising results, with an accuracy of 71% in determining the condition of an individual's hands.**

Keywords— Carpal tunnel syndrome (CTS), surface electromyography (sEMG), median nerve, nerve electrical activity, ESP8266, abductor pollicis brevis muscle, WebSocket

I. INTRODUCTION

Carpal tunnel syndrome (CTS) manifests when the median nerve, traveling from the forearm to the hand's palm, experiences compression or constriction at the wrist. The onset of symptoms typically occurs gradually, marked by frequent sensations of numbness or tingling in the fingers, particularly the thumb, index, and middle fingers. Individuals experiencing carpal tunnel syndrome (CTS) may express a feeling of their fingers being ineffectual and swollen, despite the absence of noticeable or significant swelling [1]. In 2017, within the realm of occupational injuries and diseases affecting the wrist and hand in the Philippines, there were a total of 7,458 reported cases. Among these, CTS accounted for 1,982 cases, reflecting a significant percentage of the overall instances. Specifically, CTS constituted approximately 26.6% of the documented wrist and hand occupational injuries and diseases during that period. This statistic underscores the noteworthy prevalence and impact of Carpal Tunnel Syndrome in the occupational health landscape of the Philippines in 2017 [2].

Amidst the prevalence of CTS, existing diagnostic methods often face limitations, particularly in terms of accessibility and portability. The integration of surface electromyography (sEMG) technology into a rechargeable device introduces a novel avenue for early detection, promising to redefine the landscape of CTS monitoring. Recognizing individuals who are at risk and instituting appropriate preventive measures is crucial to minimize the occurrence and impact of these conditions in a work environment. While milder instances of CTS can be effectively managed through localized steroid injections, cases of moderate to severe severity often necessitate surgical intervention for a definitive cure [4]. Consequently, the researchers are working towards creating and validating a rechargeable microcontroller-based device to identify the state of the median nerve through electromyography. In addition to evaluating the nerve's condition, the device will also ascertain the patient's vulnerability to CTS.

II. BACKGROUND OF THE PROBLEM

Carpal tunnel syndrome (CTS) ranks among the most prevalent neuropathies affecting the upper extremity, characterized by sensations such as numbness, tingling, burning, or pain in the hands. This condition arises from compression of the median nerve as it traverses the carpal tunnel. Occupations involving repetitive movements, frequent computer use, and exposure to vibrating equipment pose a heightened risk for developing CTS [4]. Diagnosis typically involves physical examinations, with electrodiagnostic testing and/or ultrasonography utilized to confirm findings in atypical cases [5]. If left untreated, CTS can progress gradually, potentially resulting in irreversible hand dysfunction. Hence, early detection is crucial to initiate appropriate interventions aimed at slowing or halting the syndrome's progression.

Surface electromyography (sEMG) has emerged as a promising technique for assessing muscle activity, offering valuable insights into myoelectric output [6]. By utilizing surface electrodes placed on the skin, sEMG allows for the study of how neural commands translate into muscle activation [7]. In recent research, sEMG is prevalent but underutilized as a valuable tool for physical medicine and rehabilitation. The traditional EMG equipment is regularly monitored by medical specialists, however, sEMG technique has not yet been effectively implemented in practical medical settings [8]. The traditional EMG equipment also lacks portability and accessibility to many individuals at risk due to its bulky structure and the power source it requires. It commonly employs a needle EMG which requires a needle electrode to be directly inserted into a muscle [9] which can cause discomfort to the patients.

III. OBJECTIVES

The general objective of this study is to develop a rechargeable electromyography device that assesses the median nerve's electrical activity for early detection of carpal tunnel syndrome. Specifically, this journal aims to:

1. Design a device that utilizes an EMG muscle sensor to detect the muscles' electrical activity for nerve condition analysis.

2. Validate the device's functionality through a sample program for the microcontroller, including assessing the output voltage of the components using a voltmeter, and by engaging medical experts to evaluate its efficacy in early detecting carpal tunnel syndrome.

IV. REVIEW OF RELATED LITERATURE AND STUDIES

A. Methods for Diagnosis of carpal tunnel syndrome

a. Electrodiagnostic testing

Electrodiagnostic testing involves measuring the electrical activity of muscles or nerves, which can indicate if they have been impacted by injuries or diseases. Although the tests are accurate, they can be uncomfortable or expensive for patients due to the main procedures involved, which are electromyography and nerve conduction studies. Yet, the goal of this research is to develop a device that is both precise in diagnosis and comfortable for the patient.

CTS is the prevailing form of nerve entrapment, and according to a study conducted by Werner and Andery, electrodiagnostic (EDX) techniques are a valid and reliable way to diagnose CTS. Abnormalities in the median nerve fibers within the carpal tunnel can be identified through EDX tests, which can confirm the diagnosis of CTS. The authors conclude that an EDX examination can provide confirmation of a clinical suspicion of CTS, which can be reassuring for both patients and physicians [10].

b. Electromyography

Electromyography is the process of recording the electrical signals within muscles. It has the ability to differentiate between muscle wasting and weakness caused by myopathy or neurogenic factors. Moreover, it can identify abnormalities like chronic denervation or fasciculations even in muscles that appear normal during a clinical assessment. During the EMG test, one or more small needles, or also called electrodes, are inserted through the skin into the muscle as shown in Figure 1 and Figure 2. These electrodes capture the electrical activity within the muscle, which is then displayed on an oscilloscope as waveforms. To facilitate detection, an audio-amplifier is utilized to enable auditory perception of the activity. The EMG test measures the electrical signals produced by the muscle at rest, during mild contraction, and during forceful contraction. Typically, muscles do not generate electrical signals when at rest. Following the insertion of an electrode, a brief period of activity can be observed on the oscilloscope; however, after that, no signal should be present. However,The primary drawback of EMG is the discomfort experienced during the needle examination [11].

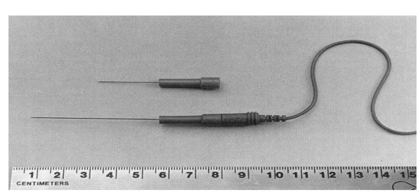

Figure 1: Monopolar needle electrodes used in electromyography [11]

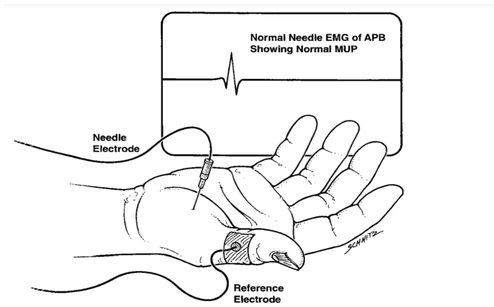

Figure 2: Placement of Electrodes and sample graph of Electromyogram [11]

c. Surface electromyography (sEMG) for detection of CTS

The electromyography interference pattern comprises motor unit action potentials (MUAPs) that reflect the electrical activity of motor units [12]. When an individual exhibits CTS, the physiological EMG pattern undergoes changes, resulting in diminished interference patterns [13]. In a study, multichannel surface electromyography was employed to detect muscle alterations in patients diagnosed with severe CTS. Two groups were examined to determine whether significant differences exist in EMG patterns between healthy and pathological groups. sEMG signals with alterations suggest a reduced number of motor recruitments, which is associated with reduced maximum voluntary contraction (MVC) in pathological groups. These findings indicate a defensive behavior from patients against painful movement. This study observed that sEMG interference patterns differ between healthy and severe CTS groups [14].

Surface electromyography complements nerve conduction studies (NCS) in patients with mild CTS by examining potential alterations in sEMG signals. Significant disparities exist in the root mean square (RMS) values of these signals, indicative of their amplitude, between the moderate-to-severe group and the control group. The RMS value, often chosen as a parameter, directly correlates with the level of physiological motor unit activity during contraction. These observed changes in RMS values among CTS patients suggest a reduction in motor unit recruitment [15].

d. Ultrasound

With the widespread adoption of high-resolution ultrasonography, ultrasonic examination has proven to be an effective diagnostic method for carpal tunnel syndrome. The key benefits of ultrasonography include its simplicity, speed, non-invasiveness, and cost-effectiveness. An additional advantage lies in the ability to observe tissue dynamics through real-time imaging. Recent studies indicate that ultrasonic examination can offer diagnostic accuracy comparable to nerve conduction studies in identifying carpal tunnel syndrome. Anticipations suggest a continual increase in the demand for ultrasound in routine medical care. Ultrasonography for carpal tunnel syndrome reveals an enlarged median nerve in the proximal carpal tunnel, thickening of the flexor retinaculum, and edema around flexor tendons in cross-sectional images. Moreover, the introduction of advanced technologies like ultrasonic elastography and speckle tracking enables the quantification of dynamics and material property changes in nerves, tendons, and their adjacent structures. This review outlines recent developments in the diagnosis of carpal tunnel syndrome using dynamic ultrasound images and explores its pathology [16].

B. Wireless Surface Electromyography

Advancements in technology over the past decade have enabled the automation of monitoring and recording fitness activities. Consumer electronics such as wearable devices and applications now offer activity trackers, which monitor and track various fitness parameters. These include metrics like distance covered through walking or running, heart rate, and calorie expenditure [17].

In a study, a compact and wireless noninvasive surface electromyography (EMG) measurement system was introduced. Existing EMG sensor systems are hindered by their bulky size and the need for wiring. Hence, this study prioritizes the creation of a smaller preamplifier and a wireless EMG measurement system. Such a compact and wire-free EMG measurement system with improved signal-to-noise ratio (SNR) holds promise for enhancing subject comfort and facilitating external prosthesis control [18].

V. METHODOLOGY

A. Materials and Specifications

a. Analog EMG Sensor

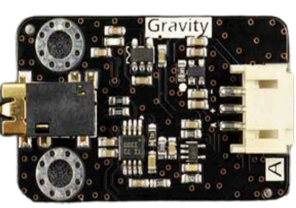

Figure 3: Analog EMG Sensor

The sensor detects surface electromyography (sEMG) signals, reflecting muscle and neural activities over the median nerve. It incorporates both a filtering and amplification circuit. The amplification circuit boosts minimal sEMG signals by 1000 times within a range of ±1.5mV and suppresses noise, mainly power frequency interference, through a combination of differential input and analog filtering. Signal strength correlates with muscle activity intensity. An analog EMG sensor enables noninvasive and convenient measurements, making it applicable in a CTS early detection device.

b. NodeMCU ESP8266

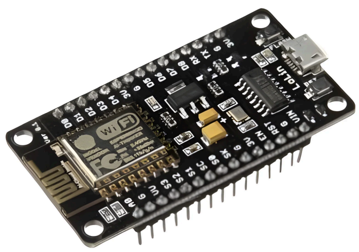

Figure 4: NodeMCU ESP8266

The ESP8266 microcontroller incorporates essential computer elements: CPU, RAM, networking (WiFi), and a modern operating system and SDK. This component fetches EMG data collected by the EMG sensor and transmits it to the network protocol for analysis.

c. 18650 Lithium-ion Battery

Figure 5: 18650 Lithium-ion Battery

The 18650 is a rechargeable lithium-ion battery with a nominal voltage of 3.7V and a capacity of 2200 mAh. It serves as the primary power source for the entire device, enabling its operation.

d. TP4056 Charging Module

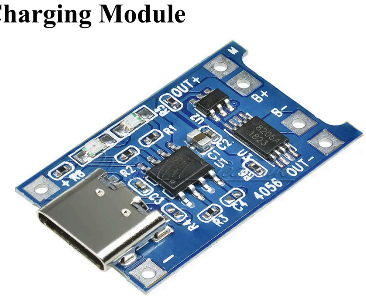

Figure 6: TP4056 Charging Module

This module charges the 18650 Lithium-ion battery using the constant-current/constant-voltage (CC/CV) charging method to prevent overcharging. It provides the necessary protection the battery requires and safely charges it to 4.2 V.

e. 7805 Voltage Regulator

Figure 7: 7805 Voltage Regulator

The 7805 voltage regulator is a positive voltage regulator that outputs 5V. It guarantees that the EMG sensor receives adequate input voltage to operate reliably.

f. DC-DC Boost Converter

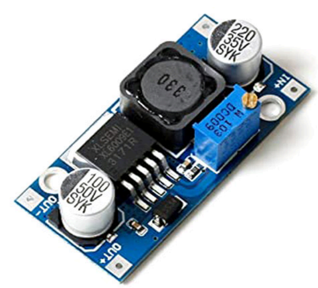

Figure 8: DC-DC Boost Converter

This module steps up the lower voltage supplied by the battery to a higher voltage capable of powering components in the device, such as the microcontroller and the EMG sensor. As the battery's nominal voltage is 3.7V, it needs to be stepped up to ensure proper operation of the device.

g. Disposable ECG Electrodes

Figure 9: Disposable ECG Electrodes

The disposable ECG electrodes have an adhesive that can stick to the patient's skin. The study used a solid gel Ag/AgCl sensor that can fit in the hands of individuals. The electrodes should be placed in a cool, dry place for storage. The electrodes must be put in the pouch with the open-end folded shut when not in use.

B. Hardware Design and Development

a. Schematic Diagram

The figure below is the schematic diagram of the MyoNerve device, which shows the interconnectivity of the components such as the ESP Microcontroller, EMG module, LM7805 Voltage Regulator, XL6009 DC-DC Buck Boost Module, TP4056 Module, battery level indicator, Lithium-Ion Battery, and switch.

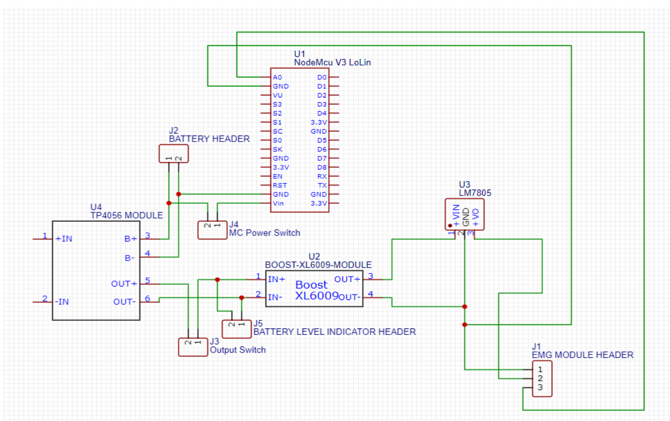

Figure 10: Schematic Diagram of MyoNerve Device

The EMG module is the vital component for EMG testing. The surface electrodes are placed based on the location of the median nerve then the EMG module will record the electrical activity of the muscle. The recorded data will then be transferred to the mobile application to proceed for data processing.

C. PCB Layout

The PCB layout is designed to contain and interconnect the following components such as the ESP8266, XL6009 Buck Booster, TP4056 Module, LM7805 Voltage Regulator, and Ceramic Capacitors. The J2, J3, J4, and J1 pin holes will be used to connect the Battery, Battery Switch, Microcontroller Switch, and EMG module respectively.

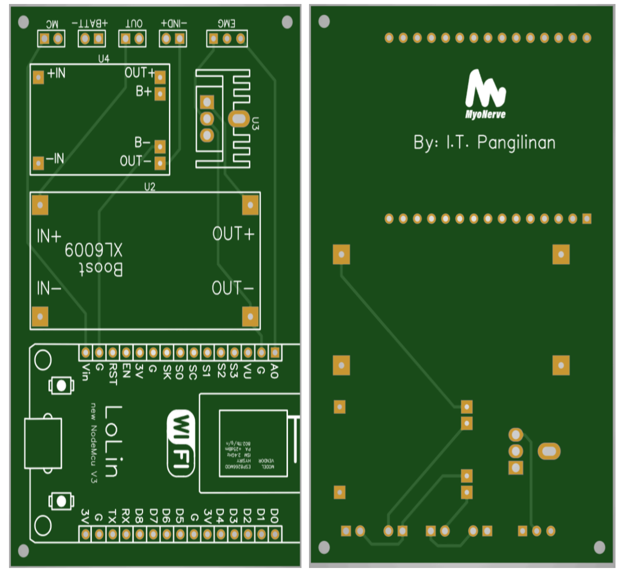

Figure 11: PCB Layout of MyoNerve Device

D. Chassis

The figure below illustrates the chassis design of MyoNerve, featuring specific dimensions (dimension). The design incorporated designated holes for the microUSB, charging, and EMG ports. Additionally, the switch had allocated openings, and the chassis was designed with ventilations on both sides to facilitate improved airflow. It helped prevent component malfunctioning caused by excessive heat.

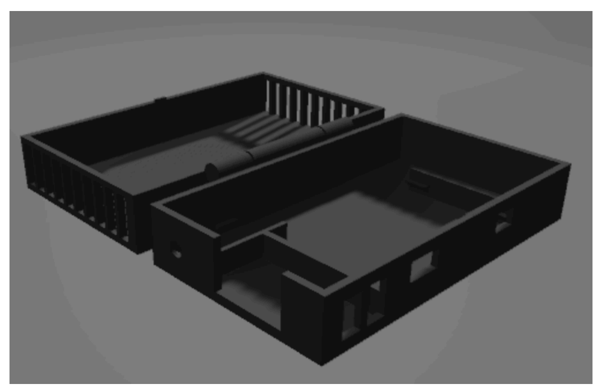

Figure 12: Chassis Design

The device incorporated a hinged lid for convenient opening and closing. Additionally, the device was divided into dedicated sections for the battery, microcontroller, and EMG muscle sensor units of MyoNerve.

E. Calibration

To enhance the precision of probe placement in the hands and obtain accurate readings from the muscle sensor, the researchers conducted calibration and fine-tuning of the electromyogram under the guidance of a licensed physical therapist.

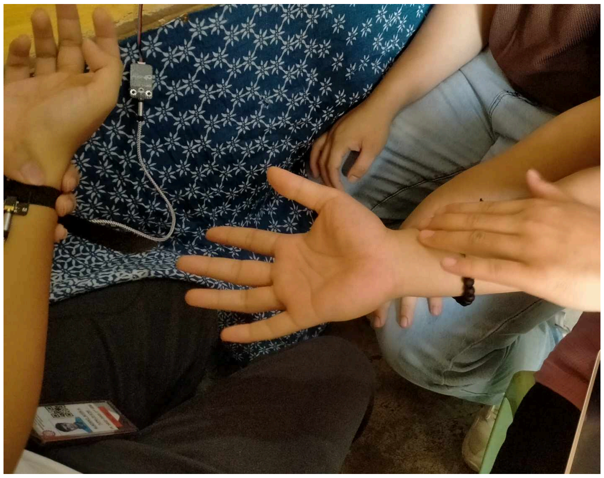

Figure 13: Calibration and Fine Tuning of probe placement with a Physical Therapist

During this process, the researchers identified specific routines that patients should perform to distinctly observe variations in graphs between a healthy and an unhealthy nerve. The physical therapist recommended various routines, ultimately selecting the thumb opposition and pinch test. Recording electrodes were strategically positioned on the muscle over the median nerve in the palm, with the ground electrode situated in the bony part of the wrist. The figures below illustrate the optimal probe placement for acquiring EMG data and observing the electrical activity of the muscle.

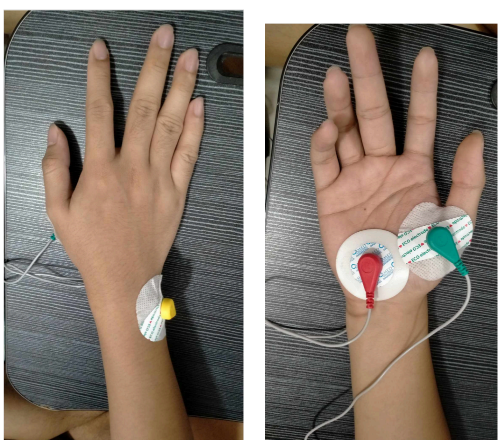

Figure 14: Optimal probe placement

The physical therapist recommended placing the surface electrode on the abductor pollicis brevis muscle, which is where the median nerve is situated. This is because carpal tunnel syndrome affects the median nerve and causes compression there. Therefore, a thumb routine was devised to collect data on the median nerve.

Moreover, the researchers conducted a meeting via Google Meet with an electromyographer, a medical professional who performs EMG tests. The researchers explained the study, and the electromyographer provided his feedback. He stated there is a similarity between gathering electromyogram data and conducting electromyography in hospitals. He also mentioned that the EMG sensor must collect data within a small range during the rest routine before testing the patient. Moreover, he suggested using an external stimulant and needle electrodes, similar to the nerve conduction tests. Lastly, a medical deployment protocol was evaluated (see appendix) to review the detailed procedure for conducting the test during the study deployment.

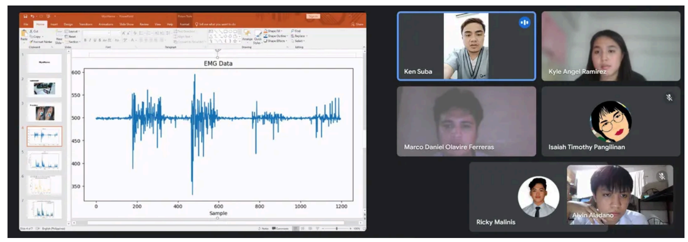

Figure 15: Consultation with Electromyographer in Reading the EMG Data

F. Experimental Setup

This device integrated hardware and software components to detect and monitor carpal tunnel syndrome through muscle electrical activity analysis.

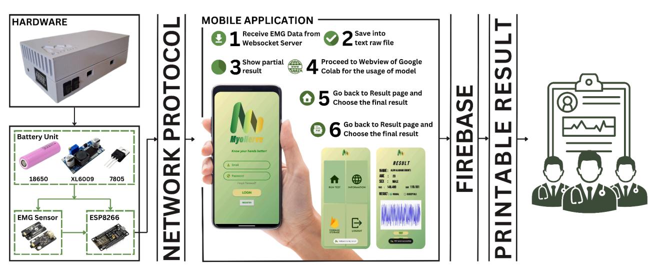

Figure 16: Overall System Architecture

The hardware included a switch, battery unit, and EMG module for capturing muscle electrical activity. The mobile application served as the user interface, receiving raw EMG data from the hardware via a network protocol. It employed a convolutional neural network model to analyze the data, displaying results for users.

Additionally, the mobile application generated graphical representations of EMG data that aided the users in interpreting muscle activity patterns and CTS symptoms. These graphical representations were accompanied by interpretations stored in a PDF format within the Firebase database, providing users comprehensive insights into their condition.

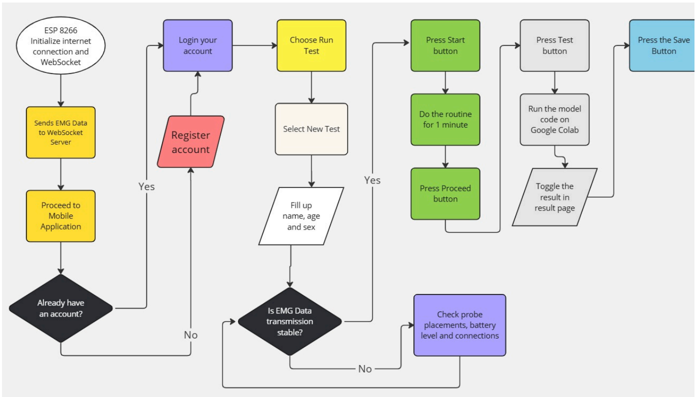

Figure 17: System Flowchart

The figure shows the step-by-step process, from initializing the ESP 8266 to transmitting EMG data over the WebSocket server. The user must create an account to access the mobile application's home screen. If the user still needs to create an account, there is a register button to create one. Log in to your account to access the site, then choose "Run Test" and "New Test" to begin testing a person. Before continuing the routine, the user must enter the required information and ensure the EMG data transfer is stable. Start the procedure, then go to the results page and change between "Normal" and "Susceptible" based on the model's findings on Google Colab. Pressing the save button will save the result as a PDF, and can be accessed and downloaded from "Firebase Storage" on the homepage.

G. Sensitivity and Specificity Analysis

Analyzing sensitivity and specificity plays a vital role in evaluating the diagnostic accuracy of a device. These metrics helped the researchers assess how well the device can correctly identify actual positive cases (sensitivity) and actual negative cases (specificity) compared to a reference standard or gold standard. A contingency table would arrange the data in a 2x2 format, a confusion matrix, or a classification table. This table would encompass the following categories:

- **True Positive (TP):** The test correctly identified a condition that is present according to the gold standard.
- **True Negative (TN):** The test correctly identified a condition not present according to the gold standard.
- **False Positive (FP):** The test incorrectly identified a condition not present according to the gold standard (Type I error).
- **False Negative (FN):** The test incorrectly identified a condition present according to the gold standard (Type II error).

Sensitivity was the percentage of TP subjects with the disease in the whole group of participants with the disease, usually given as TP/(TP + FN). Sensitivity calculated the likelihood that individuals with the illness would get a positive test result. Therefore, it concerns a test's capacity to identify illness. However, specificity was the percentage of disease-free subjects with a negative test result out of the total number of disease-free subjects: TN/(TN + FP). Specificity quantified the likelihood of obtaining a negative test result in a healthy individual. It concerns a diagnostic procedure's capacity to identify the healthy.

VI. RESULTS AND DISCUSSION

A. Project Technical Description

MyoNerve is a rechargeable electromyography device designed to detect early symptoms of carpal tunnel syndrome through supervised machine learning integrated into its accompanying mobile application for result presentation and analysis. It measures 148x50x86 mm and features a rectangular chassis with multiple ports and compartments housing the sensor, battery unit, and main board.

Figure 18: MyoNerve device (left); Log-in page of mobile application (right)

The parts of this device include the following:

1. **Main chassis:** This houses the electronics and sensor.
2. **Electrode lead wire:** This wire connects the EMG sensor to the three electrodes (two recording electrodes and one ground electrode).
3. **Mobile application:** This contains the machine learning model for the analysis of EMG data, and it is responsible for data presentation and the generation of PDF results.

Each part significantly captures, transmits, analyzes, and interprets EMG data to generate recommendations. These recommendations can serve as a reference for individuals to decide whether to take measures to halt the progression of the condition.

B. Development of a Rechargeable Microcontroller-Based Device for EMG Signal Detection of Median Nerve Activity

Table 1: Specifications of the MyoNerve Device

Dimensions	148x50x86 mm
Input Supply Voltage	4.5~6.0 V
Wireless Standard	802.11 b/g/n
Frequency range	2.4 GHz - 2.5 GHz (2400M-2483.5M)
Battery Capacity	3300 mAh
Charging Port	USB Type-C
Microcontroller Port	Micro USB

MyoNerve is a compact device that houses the EMG muscle sensor and the main circuit board, which is responsible for capturing and transmitting data on the electrical activity of muscles over the median nerve. The table above summarizes the device's specifications, measuring 148x50x68 mm.

MyoNerve operates within an input voltage range of approximately 4.5~6.0 V. It leverages the 2.4 GHz band, offering an extended range and a usable speed of 50-70 Mbps, making it an ideal choice for wireless connectivity. It supports the 802.11 b/g/n standards, ensuring compatibility with a wide range of Wi-Fi networks.

Equipped with a rechargeable battery boasting a capacity of 3300 mAh, the device can deliver 3300 milliamps per hour before recharging. Charging is facilitated through a USB Type-C port, while a micro-USB connection powers and interfaces with the microcontroller.

Table 2: Computed Load Capacity

Device	**Voltage**	**Current**
EMG Sensor	5V	20mA
NodeMCU ESP8266	3.7V	800mA
XL6009 DC-DC Boost Converter	5V	18mA
		I_T = 20mA + 800mA + 18mA I_T = **838mA**

Computed Battery Life

Battery Life = Battery Capacity / Load Capacity = 3300mAh/838mA

Battery Life = **3.93 hours**

The provided data outlines the voltage and current requirements of two devices—an EMG sensor and a NodeMCU ESP8266—and the computed battery life based on a given battery capacity. The EMG sensor operates at 5V with a current draw of 20mA, while the NodeMCU ESP8266 requires 3.7V and consumes 800mA. The total load current is calculated as 820mA. With a battery capacity of 3300mAh, the estimated battery life is approximately 4.02 hours. However, upon testing, the device can last up to six (6) hours with continual use. It can still transmit data to the network protocol and perform its function, which is a good indicator since it can be used longer than expected.

C. WebSocket as Network Protocol

The network protocol used for the connection between the hardware and mobile application is WebSocket which is a two-way communication protocol that is appropriate to use for real time transmission of data since it directly receives and sends the data from its server. It receives the data that ESP 8266 transmits to its server then sends the data to the mobile app.

```
#include <Arduino.h>
#include <ESP8266WiFi.h>
#include <ESP8266WiFiMulti.h>
#include <WebSocketsServer_Generic.h>
#include <Hash.h>

const char *ssid = "MyoNerve2k24";
const char *password = "CarpalTunnel123";
const int webSocketPort = 81;

ESP8266WiFiMulti WiFiMulti;

WebSocketsServer webSocket = WebSocketsServer(81);

const int analogInPin = A0;

void webSocketEvent(uint8_t num, WStype_t type, uint8_t
*payload, size_t length)
{

  (void)length;
  switch (type)
  {
  case WStype_DISCONNECTED:
    Serial.printf("[%u] Disconnected!\n", num);
    break;

  case WStype_CONNECTED:
  {
    IPAddress ip = webSocket.remoteIP(num);
    Serial.printf("[%u] Connected from %d.%d.%d.%d url:
%s\n", num, ip[0], ip[1], ip[2], ip[3], payload);
    webSocket.sendTXT(num, "Connected");
  }
  break;

  case WStype_TEXT:
    Serial.printf("[%u] get Text: %s\n", num, payload);

    break;

  case WStype_BIN:
    Serial.printf("[%u] get binary length: %u\n", num,
length);
    hexdump(payload, length);

    break;

  default:
    break;
  }
}

void setup()
{
  Serial.begin(115200);

  IPAddress staticIP(192, 168, 137, 143); // desired static
IP address
  IPAddress gateway(192, 168, 137, 1);    // router's IP
address
  IPAddress subnet(255, 255, 255, 0);     // subnet mask

  Serial.println("Setting static IP configuration...");
  Serial.print("Static IP: ");
  Serial.println(staticIP);
  Serial.print("Gateway: ");
  Serial.println(gateway);
  Serial.print("Subnet: ");
  Serial.println(subnet);

  WiFi.config(staticIP, gateway, subnet);
```

Figure 19: ESP 8266 code for establishing WebSocket Server

The figure above shows the codes used to connect ESP 8266 to a network which enables it to create a specific WebSocket server on a static IP address. This static IP address allows the mobile application to access the data received on the WebSocket server that was transmitted from the ESP 8266 and use it to create important processes on the app.

D. **Wireless Transmission of EMG Data using ESP8266 for Network Integration**

Table 3: Transfer rate of EMG Data from ESP8266 to the Network Protocol

Speed	**Data Rate**	**Total EMG Data / min**
Below Optimal (0 to 9.99 Mbps)	1-8 data per second	60 - 480 EMG Data
Optimal (10Mbps+)	9-10 data per second	540 - 600 EMG Data

The total number of EMG data transferred to the WebSocket Server depends on the transfer rate, which is influenced by the speed of the internet connection—whether slow, moderate, or fast. Testing required 600 EMG data points to accurately draw analysis from it. Hence, a fast internet connection is essential to obtain the necessary amount of data within a minute.

E. **Diagnostic Accuracy Test**

Table 4: Contingency Table of Test Results Used to Calculate Sensitivity and Specificity

		Physical Therapist Impression		
		Positive (+)	Negative (-)	Total
Test Result	Positive (+)	27	29	56
	Negative (-)	5	58	63
	Total	32	87	119

*Sensitivity = 23/30 = 0.843, specificity = 64/85 = 0.6667

The table above presents the numbers of true positives, false positives, true negatives, and false negatives accumulated from the deployment data. From this data, the device's sensitivity is calculated to be 84%, indicating that it correctly identifies 84% of individuals susceptible to carpal tunnel syndrome. Similarly, the device's specificity is calculated to be 67%, indicating its accuracy in identifying individuals who do not exhibit early symptoms of CTS.

VII. CONCLUSIONS AND RECOMMENDATIONS

This study designed and built a rechargeable device with a microcontroller and analog electromyogram (EMG) sensor for detecting median nerve electrical activity. This device can last up to 6 hours if used continuously. This device combines compact design, precise muscle activity monitoring, reliable wireless connectivity, and long-lasting battery life. It is a potentially valuable tool for medical professionals and researchers in muscle activity monitoring and early detection. Moreover, the researchers developed an ESP8266 program to retrieve data from the EMG sensor and transmit it to a network protocol. The efficiency and accuracy of EMG data analysis are contingent upon a fast internet connection, which enables the timely transfer of a sufficient amount of data for meaningful insights. During the deployment phase, the device demonstrated an accuracy rate of 71%, indicating that most of its results align with the observations made by physical therapists regarding early symptoms related to carpal tunnel syndrome.

To enhance the robustness of the study, the researchers propose several recommendations:

1. To make the device more compact, utilize a microcomputer such as Raspberry Pi that can connect to the internet, support the implementation of GUI, and ensure the seamless processing of EMG data.
2. Consider using sensory nerve action potential (SNAP) to provide more sensitive and accurate results for muscle activity over the median nerve. Then, Nerve conduction studies (NCV) can be utilized to more sensitively predict early carpal tunnel syndrome in an individual.
3. Implement simultaneous hand testing to shorten the duration and generate results promptly.

VIII. REFERENCES

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