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Technical Report

NeuroEstimulator: A functional electrical stimulation prototype

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Abstract

This technical report presents a project dedicated to creating a prototype for myoelectric stimulation aimed at providing treatment to patients experiencing motor control loss due to central nervous system traumas or strokes. The project's primary objective is the detection and amplification of myoelectric signals for subsequent muscle stimulation, restricted to operate only in the forearm region, aiming to improve the long-term quality of life for these individuals.

Throughout the development of this device, we faced challenges inherent to the existing functional prototype, and in response to these issues, we propose a new and revised version of the current prototype, integrated with a mobile application and remote server, allowing for more precise treatment monitoring. This report provides an overview of the project and its development process.

1 Introduction

This project was developed for the Integration Workshop 3 subject of the Computer Engineering major at UTFPR Curitiba.

The pursuit of solutions in the field of motor rehabilitation has been a central focus in improving the quality of life for patients experiencing motor control loss due to central nervous system traumas or cerebrovascular events. This technical report presents a project dedicated to the design of a myoelectric stimulation prototype. Developed in collaboration with renowned institutions such as UTFPR, UEL (State University of Londrina/PR), and other entities, this project has as its primary objective creating a device capable of detecting and amplifying myoelectric signals. These signals are then utilized as triggers for muscular

stimulation using Functional Electrical Stimulation (FES), with the purpose of partially restoring the compromised motor function, aiming to promote a positive and enduring impact on the quality of life for these patients.

Throughout the development process of this device, several challenges were encountered, particularly in enhancing the existing functional prototype. Among these challenges, limitations in controlling electrical stimulation and insufficient treatment data storage stand out. In response to these issues, the project proposes a revised version of the initial prototype, integrated with a mobile application and a remote server. This update aims not only to overcome the identified gaps but also to provide more precise treatment monitoring, enabling efficient data storage, and allowing the responsible therapist to adjust the device parameters more consciously.

This technical report aims to detail the conception, development, and enhancement process of the myoelectric stimulation device, starting from the initial phase of research and component selection to the advanced stages of preliminary testing. The project seeks not only the functional efficacy of the device but also its practical applicability and safety for therapeutic use in a clinical environment. This report offers a comprehensive view of the project stages, outlining its potential positive impact on the field of motor rehabilitation.

1.1 Overview

The NeuroEstimulator represents a significant advancement in seeking solutions for functional electrical stimulation, serving not only as a treatment tool but also as an integrated system designed to capture crucial information inherent to the patients' treatment. Its primary goal is to acquire essential data for studies, analyses, and serve as a foundation for related research, aiming to continuously enhance the treatment's effectiveness. This fills the gap for FES stimulation devices capable of gathering treatment session information in an accessible and efficient manner. The device is intended to, in the first moment, be able to operate only on the forearm of a person, but can be extended, in future developments, to other body parts and muscles.

The operation of this system is based on a trigger that utilizes amplified signals from surface electromyography (sEMG) generated when the patient attempts to move a specific muscle. Upon detecting muscular activity, the system is triggered, activating an oscillatory circuit that generates FES stimulating pulses. These pulses are directed to facilitate muscle contraction and promote nerve activation in the affected area, aiming at rehabilitating the patient's long-term muscle control.

Furthermore, the NeuroEstimulator has the ability to capture and store crucial patient treatment information. It records parameters used to generate the pulse, trigger sensitivity, emergency interruptions, and the range of hand movement before and after each treatment session. This data is vital to provide the responsible therapist with detailed insights into the patient's treatment progres-

sion, allowing for a more precise analysis and enhancing personalized therapeutic direction.

The system's architecture consists of several key components:

- An embedded system responsible for detecting muscle sEMG signals, generating Functional Electrical Stimulation (FES) pulses, and measuring the range of motion.
- The REST API manages business rules, user control, authentication, and manipulates data related to treatment sessions and patient information. It coordinates and manages the functionalities offered to the mobile application and the embedded system.
- The database plays a crucial role in persisting treatment-generated information. It stores data from treatment session histories and patient details, ensuring the integrity and availability of data necessary for analysis and therapeutic monitoring.
- The mobile application serves as the graphical interface for therapists within the system, acting as an intermediary between the API and the embedded system. This allows therapists to configure patient treatments in a personalized manner, view relevant information, and efficiently interact with the system in a clinical context.

These modules and their relations to the system actors are succintly illustrated on Figure 1.

2 Project Specification

The project specification was separated into five main categories: Mechanical, Electronic, Firmware, Mobile App and Back-End requirements. The functional requirements for these categories are listed in, respectively, Sections 2.1, 2.2, 2.3,2.4 and 2.5.

2.1 Mechanical Functional Requirements

- MFR01 - The embedded system (circuit box) should have an On/Off button.
- MFR02 - The user should be able to remove the batteries for recharging.
- MFR03 - The circuit box should have a red LED indicating when the circuit is on.
- MFR04 - The circuit box should have a green LED indicating when a electric stimulation is occurring.

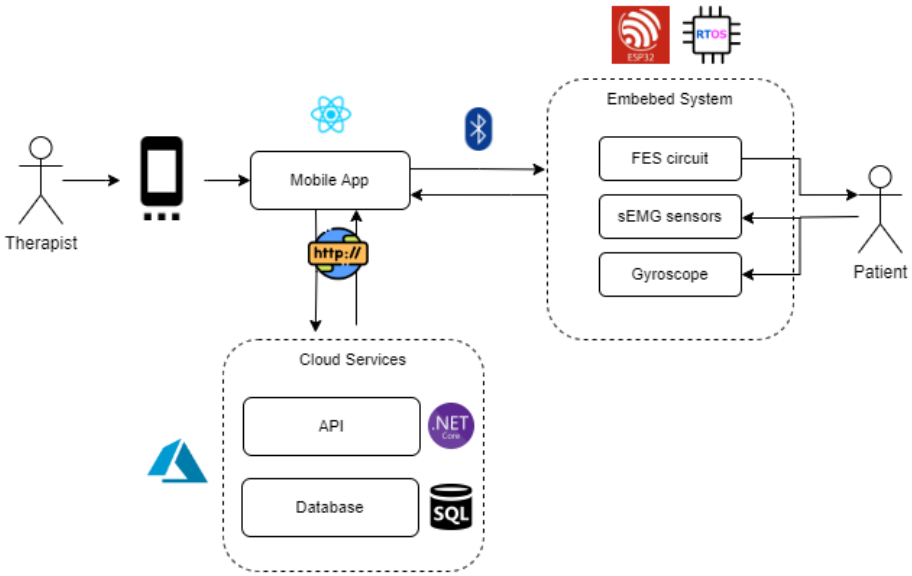


Figure 1: System architecture overview

- MFR05 - The patient wrist should be able to do a free extension movement.
- MFR06 - The circuit box should have a emergency stop button.
- MFR07 - The forearm support need to maintain the patients forearm fixed in position.
- MFR08 - The circuit box should have a yellow LED indicating when the patient tries to extend his wrist.
- MFR09 - The gyroscope must be fixed in the back of the patient's hand using a glove.

2.2 Electronic Functional Requirements

- HFR01 - The circuit board must have a Bluetooth module for communication.
- HFR02 - The output signal from the primary circuit of the board must be amplified to the final voltage of up to 127 Volts through a 1:10 transformer.
- HFR03 - The circuit must be able to acquire a sEMG signal from the patient by using sensors.
- HFR04 - The stimulation circuit must be turned off by a kill switch.

- HFR05 - The circuit must acquire sEMG signal at minimum 500 Hz.

2.3 Firmware Functional Requirements

- FFR01 - The firmware should be able to generate a signal which will be used by the hardware to create a FES signal.
  - FFR01.1 - The firmware should be able to control the pulse wave amplitude digitally.
  - FFR01.2 - The stimulation has to be adjustable between 30 Hz and 90 Hz and is referred as main frequency oscillation.
  - FFR01.3 - The stimulation duration should be adjustable between 1 seconds and 10 seconds.
  - FFR01.4 - The pulse width has to be adjustable between 100us and 1000us.
- FFR02 - The firmware should be able to sample the Surface Myoelectric Signal (MES) using Surface Electromyography.
  - FFR02.1 - The sample resolution should be at least 12 bits.
  - FFR02.2 - The triggering threshold must be adjustable and will be referred as activation difficulty.
- FFR03 - The firmware should able to measure the angular amplitude of the patient wrist extension when it receives the request to do so from the app.
- FFR04 - The device must communicate with the App via Bluetooth.

2.4 Mobile App Functional Requirements

- MAFR01 - The App must have a login screen with user authentication.
- MAFR02 - The App should have two distinct profiles: Heath Professional and Patient
- MAFR03 - The App shoud has a exclusive interface to the health professional
  - MAFR03.1 - The health professional should be able to create sessions for patients.
  - MAFR03.2 - The health professional should be able to register new patients.
  - MAFR03.3 - The health professional must be able to start a session via interface when connected to the patient device's microcontroller.

  - MAFR03.4 - The health professional should be able to allow/block the patient from starting the session.
  - MAFR03.5 - The patient treatment parameters should be able to be modified by the health professional interface.
  - MAFR03.6 - The health professional must be able to start the stimulation via interface when connected to the patient device's microcontroller for testing.
  - MAFR03.7 - The App must have a parameters screen that shows the patients current treatment adjustable values.
  - MAFR03.8 - The health professional should be able to see the patient previous sessions history data.

- MAFR04 - The App needs to communicate via Bluetooth with the microcontroller.
- MAFR05 - The session parameters defined by the health professional should be stored on the cloud.

2.5 Back-End Functional Requirements

- BEFR01 - The server should control user access via profiles
- BEFR02 - The server should store the patients data
  - BEFR02.1 - Personal data (Name, Id)
  - BEFR02.2 - Intervention Data(date, difficulty, contraction duration, sEMG amplitude and Wrist extension angular amplitude before and after the intervention)
- BEFR03 - The server should authenticate the user

3 Development

This section describes the project's development process, describing some technical details as well as some difficulties faced and how they were handled. Further details on the development progress can be obtained in the project's blog[1].

3.1 Mechanical Structure

The mechanical part of the project consists of three modules: the circuit box, which houses the electronic circuit; the support for the patient's forearm; and the glove, which is used as the support for the gyroscope responsible for measuring the wrist's range of motion.

3.1.1 Circuit Box

Initially, the plan was to 3D print the entire box; however, over time, this approach proved unfeasible due to a lack of accessible printing locations. Consequently, the decision was made to commission the production of an MDF (Medium-Density Fiberboard) box with the required measurements to accommodate the PCB and modules used for the operation of the embedded system. The external view of the developed circuit box is presented in Figure 2.

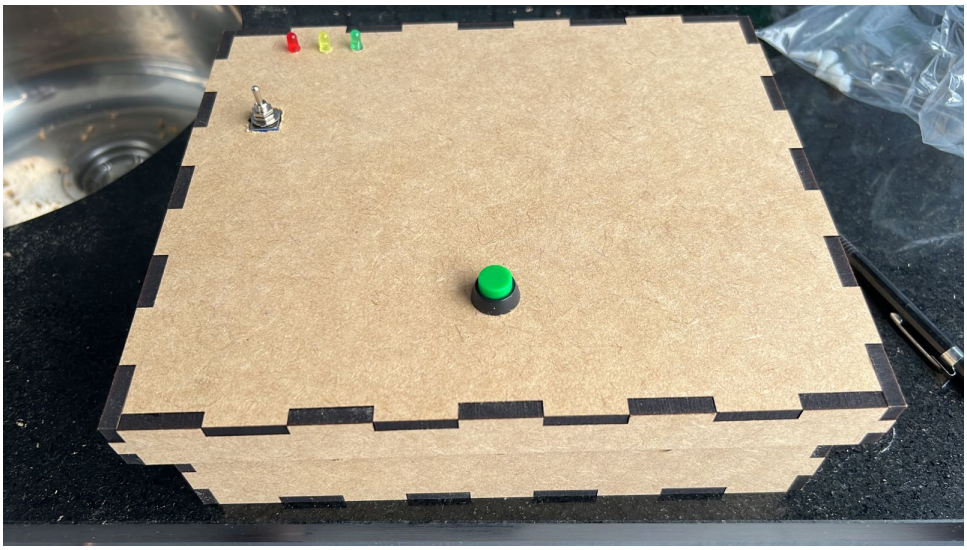


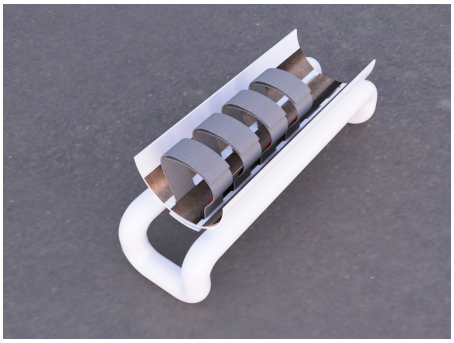
Figure 2: Circuit box

3.1.2 Forearm Support

The support for the patient's arm was initially designed using Fusion software[2]. After the design phase, the decision was made to construct the entire structure using PVC pipes. This support structure includes three foam-filled cushions aimed at providing additional comfort to the supported arm. Additionally, to secure the position of the five electrodes (three for capturing the sEMG signal and two for the FES signal), a method was developed involving the use of Velcro straps. The electrode cables are internally fixed by seams within these straps, allowing the therapist to adjust the electrode's position securely, preventing alterations by the patient.

3.1.3 Gyroscope Glove Support

To measure the range of motion that the patient can execute, the gyroscope needed to be attached to the patient's hand. Considering this requirement, a glove was designed in the Fusion program, featuring a holder where the gyro-

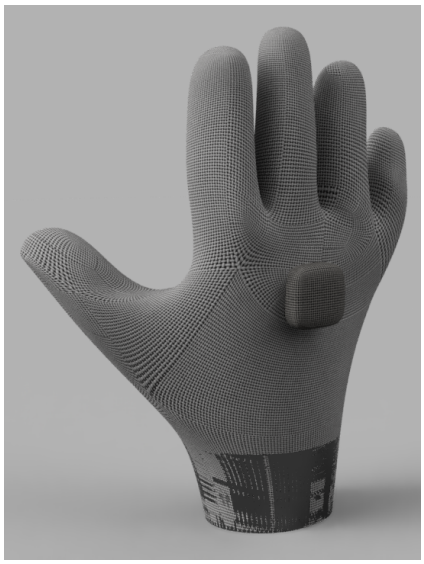


(a) Arm Support CAD Design

(b) Developed Arm Support

Figure 3: Arm support design and construction

scope should be placed, as depicted in the Figure 4. Subsequently, a glove compatible with the patient's hand was purchased, and this holder was sewn onto it.



(a) Gyroscope Support CAD Design

(b) Gyroscope Support sewn to the back of the glove (upper part)

Figure 4: Gyroscope support CAD design and construction

3.2 Hardware

3.2.1 Overview

The hardware of this project comprises components and modules interconnected on a printed circuit board, controlled by an ESP32 microcontroller[3]. Power is

sourced from two sets of batteries: one comprising a single 3.7V battery, and the other consisting of three 3.7V batteries connected in series, totaling 11.1V. The 11.1V supply is used to power the sEMG sensor through a 3.3V voltage regulator, as well as the part of the circuit responsible for stimulation. Conversely, the 3.7V set is regulated to 3.3V and powers the microcontroller and other circuit modules. This segregation of power sources was designed to ensure greater accuracy in sensor readings.

The peripherals used in this project encompass an AD8232 module[4] adapted for sEMG signal reading through a modification in its low-pass filter, providing a tailored solution to meet the specific needs of the NeuroEstimulator as specified at the reference article [5]. Additionally, it includes an ADS1115[6] analog-to-digital converter, enabling precise acquisition of the muscular signal and measuring the amplitude used to feed the H-bridge. For visual indication within the system, three LEDs are employed: one indicating the connection status, another recognizing the occurrence of a trigger, and the third signaling the application of Functional Electrical Stimulation (FES). The device also integrates an emergency button, offering an immediate interruption option in critical situations. Furthermore, the digital potentiometer X9C104[7], whose output is connected to a voltage buffer constructed using the operational amplifier LM358[8], is noteworthy. The buffer's output feeds an L293D H-bridge[9] responsible for generating the pulse, which is sent to a 12V/127V transformer to achieve its final stimulation voltage.

The ESP32 microcontroller was chosen to manage the peripherals in this project due to its versatility and cost-effectiveness for the proposed application. Although the ESP32 has an integrated Bluetooth module, an external HC-06 module[10] was chosen to avoid the possibility of losing the microcontroller's input/output (I/O) when dealing with Bluetooth communication, which could occur when using the ESP32's internal module.

Figure 5 presents the complete schematic diagram of the electronic hardware developed, with its three sub-modules: ESP32 (microcontroller), Pulse Generation (with its digital potentiometer X9C104, H-Bridge L293D, and digital amplifier LM358), and Bluetooth module HC-06. The output of the Pulse Generation sub-system is sent to the transformer (TRANSF+ and -). In Figure 6, the connections between the sensors (through a 12 bit AD-Analog-to-Digital converter ADS1115), the batteries, and connectors to the gyroscope and sEMG sensor module are presented.

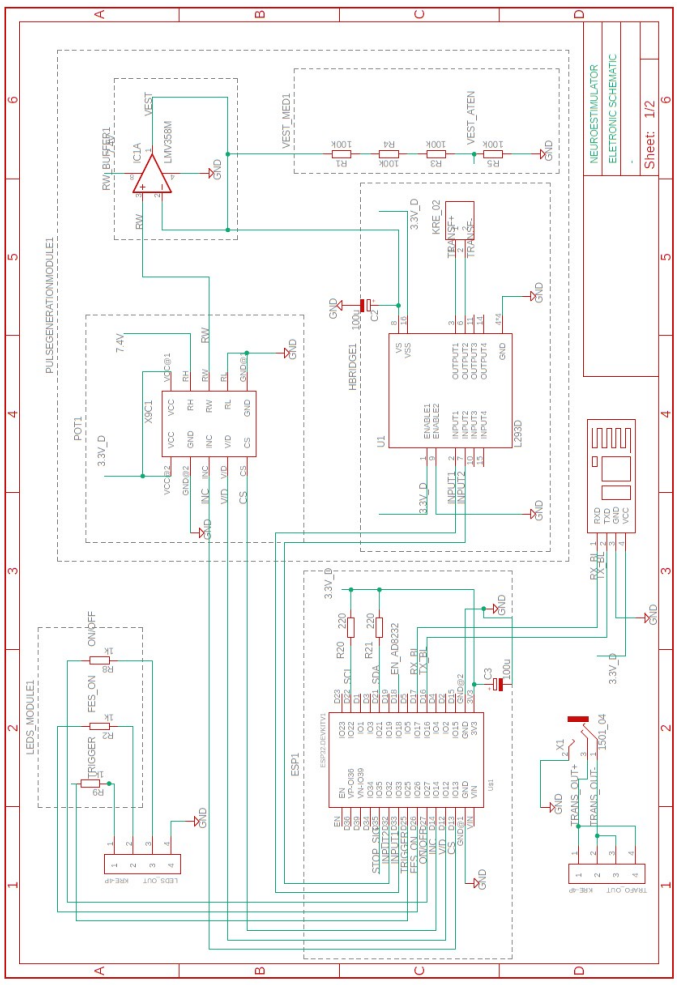


Figure 5: Circuit Schematic Page 1

3.2.2 PCB Build

The printed circuit board modeling was done using Fusion 360[2]. For the fabrication of the printed circuit board, Plan A was to utilize the Photoresist Method, involving the application of photosensitive ink onto the copper board, exposing it to ultraviolet light, and then developing it to define the areas that should be corroded. However, several issues arose with this method: the ink drying time was excessively long and incomplete; adjusting the exposure time of the ink to ultraviolet light, along with the concentration of the ink's developing solution, took time to find the right settings; the ink's developing process did not completely remove the ink in some parts as intended and started revealing areas that were not supposed to be removed. These setbacks caused significant delays, so Plan B was adopted: the Toner Transfer Method, which involves transferring the printed ink from paper directly onto the board using heat. This method was

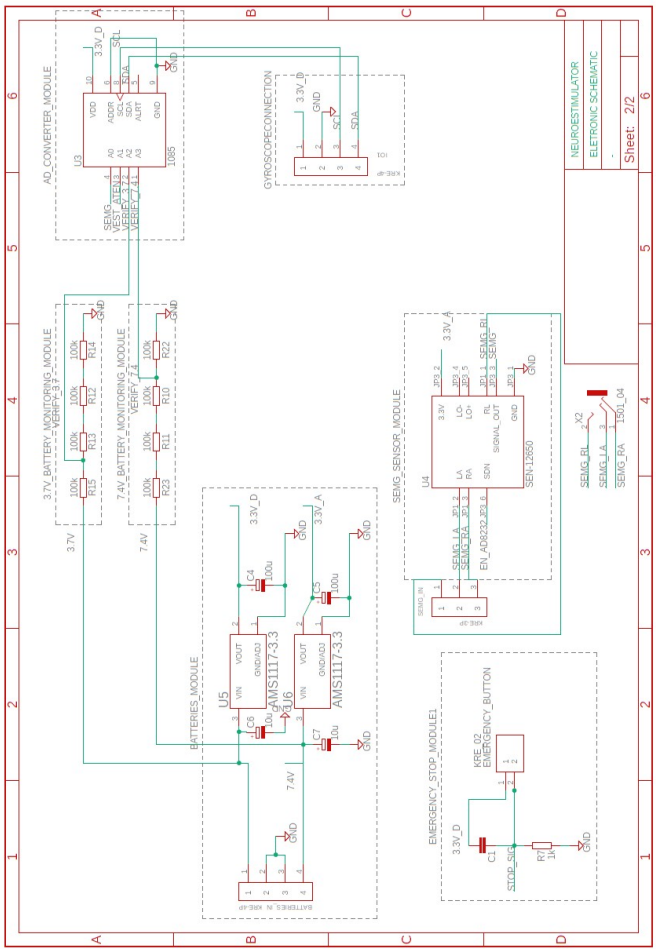


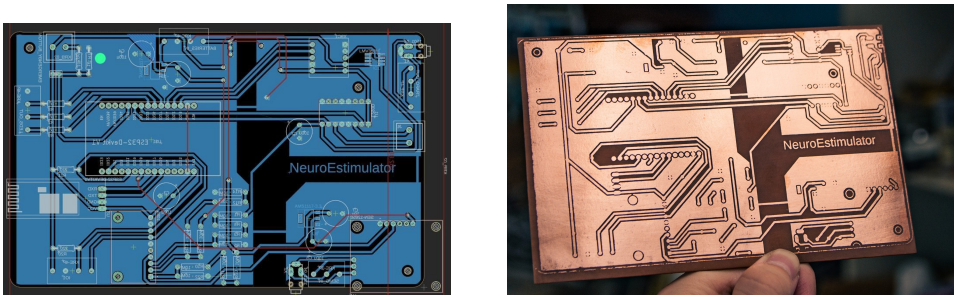
Figure 6: Circuit Schematic Page 2

successfully executed, and the board was then etched.

The board's holes for component soldering were created using a CNC drill. All components were individually tested before soldering. For more complex components like ICs and the ESP32, sockets were soldered to ease modifications and potential replacements. The final PCB is shown in Figure 7

3.3 Firmware

The firmware implementation was carried out using the PlatformIO [11] tool integrated into the Visual Studio environment, with the C++ programming language. The firmware architecture was structured modularly to facilitate maintenance and expandability. Additionally, the firmware architecture was planned to encompass Bluetooth communication and session functionalities through the



(a) PCB Design (b) PCB

Figure 7: PCB design and made

use of tools present in FreeRTOS [12], a real-time operating system running on the ESP32 [3]. A state diagram was created to visually represent the flow of operations and interaction between various system states.

To optimize system performance, a specific task was dedicated exclusively to receiving Bluetooth messages from the mobile application. This task ensures effective communication between the device and the application, vital for real-time configuration and adjustment of treatment parameters. In parallel, another task was assigned to manage session functionalities, such as reading sEMG signals, executing FES, and other session-related operations. The tasks for message reception and session management are also in different cores.

Regarding the range of hand extension movement, after gyroscopic calibration, measurements are processed to obtain accurate results. This process is essential to ensure accuracy in hand extension reading, aiding in the collection of treatment data for future processing.

In the context of sEMG signal reading, a complex strategy was adopted. The implementation of a timer ensures the periodic collection of samples, awakening a task dedicated to this function with high priority. This approach avoids code congestion, providing efficient and consistent sEMG signal reading. The timer-controlled periodicity is essential for the accuracy and reliability of measurements.

To control the voltage feeding the transformer used in stimulation, a digital potentiometer and an analog-to-digital converter were integrated. The process involves precise measurements made by the converter and adjustments to the potentiometer until the desired value is reached. This approach allows detailed control of voltage, essential for customizing each patient's treatment.

Additionally, the implementation of an interruption, serving as a response mechanism to emergency situations or to interrupt stimulation when necessary, plays a crucial role. This interruption interacts with the emergency button and stop messages received from the application, ensuring immediate and safe control of the system.

Regarding Functional Electrical Stimulation (FES), parameters are dynam-

ically updated via Bluetooth from the application. This communication allows real-time adjustments, including modification of the potentiometer voltage. Once all parameters are validated, FES is initiated, controlling the H-bridge. For a predetermined period, dependent on the parameters received from the application, the signal is maintained with positive voltage for a specific interval followed by negative voltage for the same period. Then, the signal is followed by zero volts (or the neutral condition). This cycle persists until the total stimulation time, as defined by the application, is achieved. This structured and integrated approach aims to optimize the effectiveness of the treatment provided by the NeuroEstimulator.

3.4 Software

The project software consists of two parts: the API and the Mobile App.

3.4.1 API

The API has the main goal of processing all the information that will be stored in the database, such as therapist data, patient data, and all conducted sessions. Furthermore, it is also used for authenticating therapists and patients within the Mobile App.

The API's development was carried out using the C# programming language [13] in conjunction with the .NET framework [14], strictly following the RESTful paradigm. Additionally, the Object-Relational Mapping (ORM) Entity Framework [15] was chosen, adopting the "code first" approach for designing the data model. This approach was chosen to proactively model the database, aligning the application logic with the database structure.

Additionally, the documentation of the API endpoints was created through integration with Swagger[16], a tool that provides a systematic and standardized approach to documentation, offering an intuitive interface for visualizing and testing these endpoints.

The developed API utilizes SQL Server [17] as the database management system. The choice of SQL Server was based on its widespread acceptance and use within the community, along with its ease of integration with the .NET framework.

Both the database and the API are hosted on Azure [18], Microsoft's cloud service. The API was hosted on Azure App Services, while the database was provisioned on Azure SQL Server. Both services offer easy integration with the environment provided by .NET. Figure 8 shows an entity-relationship diagram of all data acquired and stored by the system.

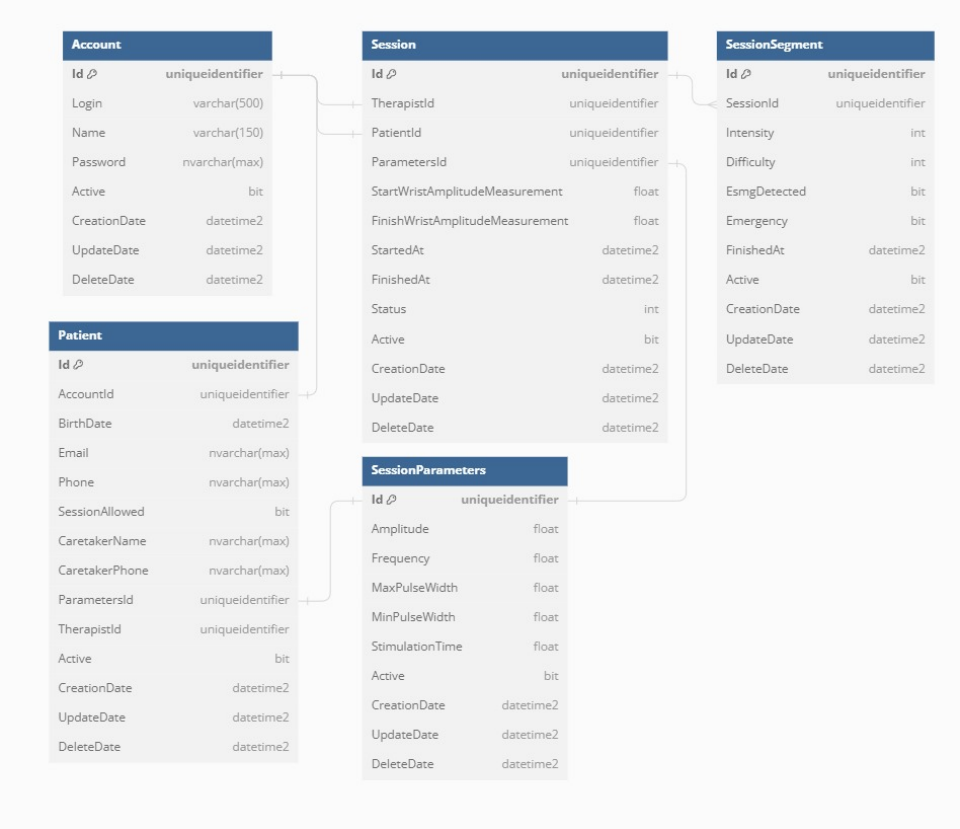


Figure 8: Entity Relationship Diagram

3.4.2 Mobile App

The mobile application plays a fundamental role as a communication interface between the therapist, the API, and the embedded system. Its primary functionality includes receiving information from the embedded system via Bluetooth connection, sending commands to it, and transmitting this data to the API via HTTP requests. Additionally, the app provides a graphical interface for therapists to configure patient treatments in a personalized manner. Furthermore, it allows the creation, management, and visualization of patient session histories.

The development of the application was carried out using the TypeScript [19] programming language, in conjunction with the React and ReactNative [20] frameworks. This choice was based on the previous experience of some team members and the widespread acceptance and use of these technologies within the community. The app was designed with a focus on the Android platform, and the possibility of portability to iOS was not extensively explored due to the more restrictive nature of development within Apple's ecosystem.

Communication with the API is facilitated by the Axios library [21], while Bluetooth communication is carried out through the react-native-bluetooth-

classic library [22]. These tools were strategically selected to ensure efficiency in data transmission between the app and external systems, providing a stable and reliable interaction during the therapeutic process. Figures 9 to 11 present the user interface developed for the app.

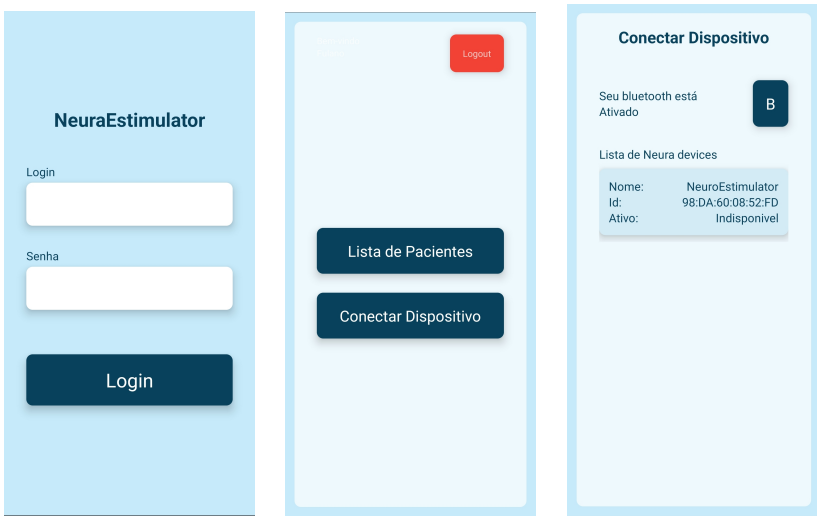


Figure 9: Initial screens

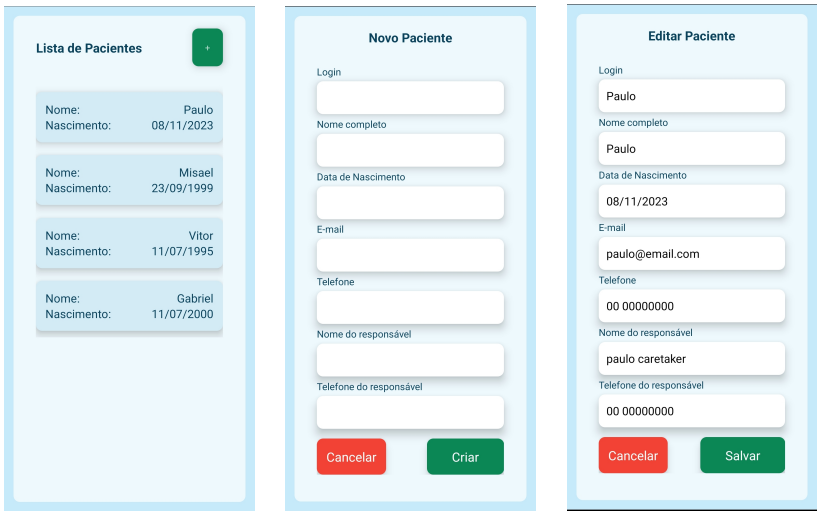


Figure 10: Screens to list, insert and edit patient

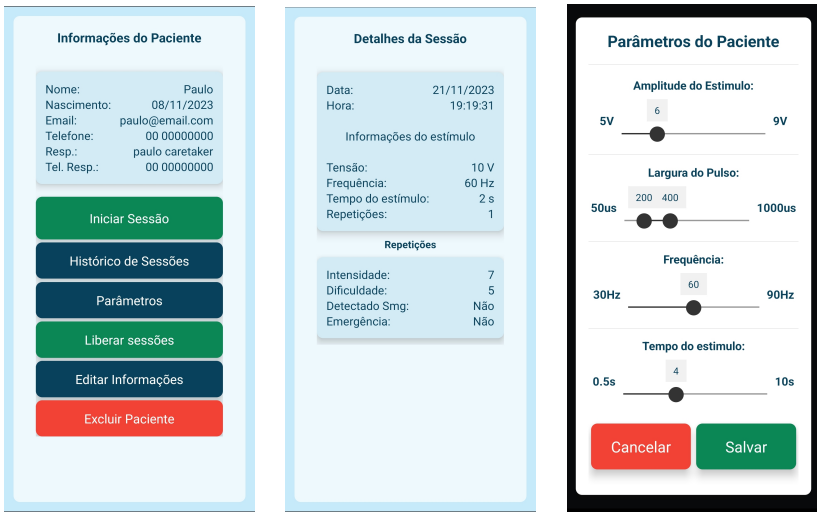


Figure 11: Screens to view patient info, session details and set FES parameters

4 Results

Our team has successfully met the initial requirements and concluded the development phase of the NeuroStimulator project, resulting in the creation of a functional tool that can be used in the context of physiotherapy routines research.

4.1 Budget

The initial budget projection for the project amounted to R$1388,94. However, upon completion, the actual expenditure totaled R$995,15, as shown in Table 1. This reduction in costs can be attributed to the decision to domestically manufacture the PCB instead of buying it from a factory, as initially planned. Additionally, the cost was further decreased by opting for the construction of the circuit box using MDF instead of utilizing 3D printing. These strategic choices not only contributed to significant savings but also demonstrated a practical and cost-effective approach to project implementation.

4.2 Schedule

Table 2 illustrates the estimated and actual hours invested in various phases of the project. The Electronics and Integration phases exhibit significant disparities between the estimated and worked hours due to problems that were faced during those developments mentioned in the conclusion section. These discrepancies point to a heightened impact on these stages due to encountered challenges during their development. Overall, the total estimated hours for the entire project amount to 448.2 hours, while the actual worked hours tally up to

Table 1: Budget

Name	**Qty.**	**Un. Cost**	**Shipping**	**Cost**
Heart Rate Monitor - AD8232	2	R$ 44,80	R$ 34,31	R$ 123,31
Transformer 6V+6V 200mA - 110/220V AC	1	R$ 23,21	R$ 00,00	R$ 23,21
Gyroscope 3-Axis - MPU6050	2	R$ 11,48	R$ 00,00	R$ 22,96
Bluetooth Module Hc-06	1	R$ 34,86	R$ 00,00	R$ 34,86
Digital potenciometer - X9c104	2	R$ 32,80	R$ 00,00	R$ 65,60
SMD Components	7	R$ 01,00	R$ 00,00	R$ 07,00
Rechargeable Battery 3.7V 18650 12800 mAh Li-ion Top	4	R$ 18,00	R$ 00,00	R$ 72,00
3.7V Battery Holder for 2 Batteries	1	R$ 11,80	R$ 00,00	R$ 11,80
Dual 3.7V Battery Charger	1	R$ 27,80	R$ 00,00	R$ 27,80
operational amplifier - CI LM 358	4	R$ 00,99	R$ 00,00	R$ 03,96
H-Bridge - CI L 293 D	4	R$ 19,77	R$ 08,90	R$ 87,98
sEMG Electrodes (50 units)	1	R$ 19,25	R$ 00,00	R$ 19,25
FES Electrodes (4 units)	1	R$ 24,90	R$ 00,00	R$ 24,90
Hydrochloric Acid	1	R$ 20,00	R$ 00,00	R$ 20,00
Photosensitive Paint Kit	1	R$ 60,00	R$ 00,00	R$ 60,00
Hydrogen Peroxide	1	R$ 14,75	R$ 00,00	R$ 14,75
Velcro 20 mm (2 m)	1	R$ 03,90	R$ 00,00	R$ 03,90
Velcro 25 mm (2 m)	2	R$ 04,50	R$ 00,00	R$ 09,00
Filler Fiber 100	0,5	R$ 08,20	R$ 00,00	R$ 04,10
Screws and related	1	R$ 04,00	R$ 00,00	R$ 04,00
Drill	1	R$ 05,00	R$ 00,00	R$ 05,00
PVC Pipe and PVC connections	1	R$ 14,00	R$ 00,00	R$ 14,00
Sodium Carbonate (1 kg)	1	R$ 25,00	R$ 00,00	R$ 25,00
Paint roller	1	R$ 04,30	R$ 00,00	R$ 04,30
operational amplifier - Lvm 358 smd	10	R$ 03,00	R$ 15,00	R$ 45,00
Voltage Regulator - AMS1117 smd	10	R$ 01,90	R$ 15,00	R$ 34,00
PCB prints	4	R$ 05,00	R$ 00,00	R$ 20,00
Transparency sheets	5	R$ 02,90	R$ 00,00	R$ 14,50
Photographic paper	1	R$ 01,00	R$ 00,00	R$ 01,00
PCB drill	2	R$ 08,00	R$ 00,00	R$ 16,00
Uber PCB's transparency delivery	1	R$ 11,90	R$ 00,00	R$ 11,90
MDF Box	1	R$ 30,00	R$ 00,00	R$ 30,00
Extra components	1	R$ 30,00	R$ 00,00	R$ 60,00
Total			$ 73,21	R$ 921,94

741.15 hours, reflecting a noteworthy 65.15% difference between the estimated and worked hours. This highlights the importance of ongoing project monitoring and adjustment to ensure accurate planning and resource allocation.

Table 2: Schedule

Phase	**Estimated hours**	**Worked hours**	**Diference (%)**
Initial research	14	14	0
Electronics	130,5	238,4	82,68
Mechanical	57,3	51,38	-10,33
Firmware	52,45	84,1	60,34
Software	115,6	128,61	11,25
Integration	78,35	224,66	186,73
Total	**448,2**	**741,15**	**65,15**

5 Conclusions and Future Work

5.1 Conclusions

With the development of the NeuroStimulator project, a wealth of knowledge was gained on managing and executing an extensive project within a team. The process involved overcoming technical and interpersonal challenges, highlighting the critical importance of meticulous, realistic, and flexible planning before initiating development. Effective communication, team focus, and a harmonious working environment emerged as pivotal factors for project success. However, it is crucial to address challenges faced during the Electronics and Integration phases. These stages exhibited notable disparities between estimated and worked hours due to unanticipated complexities. In Electronics, issues arose in the confection of the PCB, requiring additional effort to resolve. The Integration phase encountered unforeseen obstacles in coordinating the various components while making a great use of the tools provided by the FreeRTOs system, leading to adjustments in the timeline and increased hours worked. These challenges underscore the importance of adaptability during project development. In the end, the NeuroStimulator project was delivered successfully as initially planned. The journey not only honed technical skills but also provided valuable insights into navigating the complexities of collaborative projects. These acquired skills extend beyond the completion of the academic course, proving instrumental in addressing the challenges of future professional engagements in a world where projects are increasingly sophisticated and collaborative.

5.2 Future Work

The NeuroStimulator project opens up fascinating prospects for potential future work, aiming to enhance and expand its functionalities.

- Miniaturization: Explore techniques to make the device more compact and portable, providing greater convenience for users.
- Battery Monitoring and Recharging: Implement a battery monitoring system in the prototype to offer users real-time information on the charge status. Additionally, explore the feasibility of integrating a recharging mechanism into the device.
- Development of a Web App: Create a complementary web application to facilitate remote configuration of the NeuroStimulator, allowing healthcare professionals to adjust parameters and monitor patient progress more conveniently.
- Advanced Data Analysis: Expand the capabilities of analyzing collected data, using more advanced algorithms to extract meaningful insights. This may include correlations between stimulation patterns and patient responses.
- Collection of New Data: Explore the collection of new data relevant to the research context, perhaps adding other sensors, such as additional biometric information or data related to the user's environment. This expansion can enrich research possibilities.
- Design Improvement: Invest in aesthetic and ergonomic improvements in the device's design, seeking a more user-friendly and discreet approach, contributing to a more positive user experience.

These suggestions represent just a few of the many possible directions for enhancing the NeuroStimulator. The ongoing development of the project provides a versatile platform to advance the understanding of myoelectric stimulation and its impact on motor rehabilitation [23].

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