PROJECT REPORT

Analysis and Estimation of Human Intention Using Facial sEMG Signal for Wheelchair Automation

Author: JOYEL THOMAS

Institution: NSS COLLEGE OF ENGINEERING

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Abstract

This project focuses on the analysis and estimation of human intention using facial surface electromyography (sEMG) signals to control wheelchair automation. The primary problem addressed is the need for intuitive and non-invasive control mechanisms for wheelchair users, particularly those with severe mobility impairments. Traditional control systems often require substantial manual effort or are not user-friendly for individuals with limited motor functions.

The methodology involves designing an EMG sensor system using the TL084 operational amplifier (op-amp) IC to capture facial muscle activity. The EMG signals are then processed and fed into an L293D motor driver IC, which controls the rotation of a motor based on the detected signals. The system is calibrated to recognize specific facial muscle movements, translating them into corresponding motor actions. This setup enables users to control the direction and movement of the wheelchair through simple facial expressions.

Key findings from the project demonstrate that the EMG-based motor control system accurately interprets facial muscle signals to drive the motor, achieving reliable and responsive control of the wheelchair. The response time and accuracy of motor movements were tested and found to be satisfactory, indicating the system’s potential effectiveness in real-world applications.

In conclusion, the project successfully developed a prototype for wheelchair automation using facial sEMG signals, providing a promising solution for enhancing the mobility and autonomy of individuals with severe physical disabilities. Future work could involve refining the signal processing algorithms, improving user comfort with more advanced sensor placements, and conducting extensive user trials to further validate the system's usability and effectiveness.

Table of Contents

1. Introduction

1.1 Background

Assistive technologies are crucial for enhancing the quality of life for individuals with mobility impairments. These technologies provide solutions that allow people with physical disabilities to perform daily activities independently, improving their autonomy and overall well-being. For wheelchair users, assistive technologies can significantly enhance mobility, enabling them to navigate their environment more freely and participate in social, educational, and professional activities. The development and implementation of advanced assistive technologies can lead to increased accessibility and inclusion, reducing the dependence on caregivers and promoting a higher degree of independence.

Electromyography (EMG) signals are electrical activities produced by skeletal muscles during contraction. These signals can be detected using surface electrodes placed on the skin and are valuable in controlling assistive devices due to their responsiveness and precision. EMG signals provide a direct interface between the human body and machines, enabling intuitive control mechanisms. In the context of assistive devices, such as powered wheelchairs, EMG signals can be used to interpret the user's intentions through muscle movements. This capability allows for the development of control systems that respond to subtle muscle activities, providing a non-invasive and user-friendly way for individuals with severe physical impairments to operate these devices.

1.2 Problem Statement

Wheelchair users, especially those with severe mobility impairments, face numerous challenges in operating their wheelchairs. Traditional control systems, such as joystick controllers, may require fine motor skills that some users do not possess. Furthermore, these systems can be physically demanding and may not be suitable for individuals with limited upper body strength or coordination. There is a significant need for intuitive control systems that are easy to use and do not rely on complex physical actions. Such systems should be capable of interpreting simple and natural signals from the user, such as facial muscle movements, to ensure accessibility and ease of use.

1.3 Objectives

The primary objective of this project is to develop a facial sEMG-based control system for wheelchair automation. This system aims to:

- Capture and process facial EMG signals using a TL084 op-amp IC.
- Translate these signals into motor control commands using an L293D motor driver IC.
- Enable intuitive control of the wheelchair through specific facial muscle movements.
- Evaluate the system's performance in terms of accuracy, response time, and user comfort.

By achieving these objectives, the project seeks to provide a viable solution for enhancing the mobility and independence of individuals with severe physical disabilities.

1.4 Scope

This report is structured to provide a comprehensive overview of the project, detailing the development and evaluation of the facial sEMG-based wheelchair control system. The sections covered include:

- Introduction: Provides background information, problem statement, objectives, and scope of the project.

- Literature Review: Reviews existing research on EMG technology, facial EMG signals, and assistive technologies for wheelchair control.
- Methodology: Describes the system design, hardware and software components, data collection, signal processing, intention estimation, and control strategy.
- Implementation: Details the experimental setup, calibration procedures, testing protocols, and challenges encountered during implementation.
- Results: Presents data analysis, performance metrics, and key observations from the experiments.
- Conclusion: Summarizes the findings, contributions, and potential future work.
- References: Lists all the sources cited in the report.
- Appendices: Includes additional material such as schematics, code snippets, raw data, and supplementary information.

2. Literature Review

2.1 Overview of EMG Technology

Electromyography (EMG) is a technique used to evaluate and record the electrical activity produced by skeletal muscles. EMG signals are generated when muscle cells are electrically or neurologically activated. The process involves placing electrodes on the skin overlying a muscle or group of muscles. These electrodes detect the electrical potentials generated by muscle fibers' contractions and convert them into data that can be analyzed and interpreted.

In biomedical applications, EMG signals are widely used for various purposes:

- Diagnostics: EMG is used to diagnose neuromuscular diseases, nerve disorders, and conditions affecting muscle function.
- Rehabilitation: EMG helps in the rehabilitation of patients by monitoring muscle activity and providing biofeedback during physical therapy.
- Prosthetics: EMG signals are used to control prosthetic limbs, enabling users to perform complex movements by contracting their remaining muscles.
- Research: EMG is utilized in research to study muscle function, fatigue, and coordination in different activities and conditions.

2.2 Facial EMG Signals

Facial EMG signals are generated by the muscles in the face, which are involved in expressions and movements. These signals can be used to detect human intentions based on specific muscle activities. For example, smiling, frowning, or raising eyebrows produce distinct EMG patterns that can be captured and analyzed.

The specifics of using facial EMG signals include:

- Electrode Placement: Electrodes are placed on key facial muscles such as the frontalis (forehead), orbicularis oculi (around the eyes), and zygomaticus major (cheek).
- Signal Processing: The raw EMG signals are processed through filtering and amplification to remove noise and enhance signal quality.
- Feature Extraction: Key features such as amplitude, frequency, and timing are extracted from the EMG signals to distinguish between different facial expressions.
- Intention Detection: The processed signals are mapped to predefined commands or intentions, enabling the control of devices such as a wheelchair based on facial expressions.

2.3 Assistive Technologies for Wheelchair Control

Existing assistive technologies for wheelchair control aim to provide users with enhanced mobility and independence. Common technologies include:

Joystick Control: Traditional wheelchairs are often equipped with joysticks for manual control. While effective for many users, they can be challenging for individuals with severe motor impairments.

Sip-and-Puff Systems: These systems use air pressure generated by inhaling or exhaling through a tube to control the wheelchair. However, they may be cumbersome and less intuitive.

Head Control Systems: Head movement is tracked using sensors or cameras to control the wheelchair. While providing hands-free operation, these systems can suffer from accuracy issues and may require extensive calibration.

Eye-Tracking Systems: These systems use eye movements to direct the wheelchair. They are highly dependent on precise calibration and can be affected by lighting conditions and user fatigue.

2.4 Gaps in Existing Research

Despite the advancements in assistive technologies, several gaps remain in the research and development of intuitive and non-invasive control systems:

- User Comfort: Many existing systems are not comfortable for long-term use or require intrusive hardware.
- Accuracy and Responsiveness: Some control systems lack the accuracy and responsiveness needed for reliable wheelchair navigation.
- Ease of Use: Technologies like sip-and-puff or eye-tracking systems may require significant training and calibration, making them less user-friendly.
- Affordability: High costs of advanced control systems can be a barrier for many users.

This project addresses these gaps by developing a facial EMG-based control system that:

- Provides Comfort: The use of surface electrodes is non-invasive and can be comfortably worn for extended periods.
- Ensures Accuracy and Responsiveness: By leveraging advanced signal processing techniques, the system offers precise control based on natural facial expressions.
- Enhances Ease of Use: The intuitive nature of using facial expressions for control reduces the learning curve and makes the system more accessible.
- Offers Cost-Effectiveness: The system can be developed at a relatively low cost, making it affordable for a broader range of users.

By addressing these critical areas, the project aims to provide a more effective and user-friendly solution for wheelchair automation, enhancing the quality of life for individuals with severe physical disabilities.

3. Methodology

The methodology section details the process and components used to develop the EMG-based motor control system for wheelchair automation. It covers the design, hardware, software, intention estimation, and control strategy.

3.1 System Design

The overall system design focuses on capturing and processing facial EMG signals to control motor rotation, thus automating wheelchair movement. The project utilizes EMG signals collected from facial muscles to estimate user intention. These signals are processed and translated into commands that control the motor's rotation.The system's architecture comprises three primary components:

1. EMG Sensor Array: Placed on the face to capture muscle activity.

2. Signal Processing Unit A microcontroller that processes the EMG signals.

3.Motor Control Unit: A motor driver circuit that controls motor rotation based on the processed EMG signals.

Incorporated Explanation:

"The project utilizes EMG signals collected from facial muscles to estimate user intention. These signals are then processed to control the rotation of a motor, which can be used to automate wheelchair movement."

3.2 Hardware Components

The hardware components include:

1. EMG Sensor Array: Sensors are placed on facial muscles to detect electrical activity.

2.TL084 Operational Amplifier IC: Used to amplify the weak EMG signals.

3. Microcontroller: Processes the amplified EMG signals.

4. L293D Motor Driver: IC Drives the motor based on commands from the microcontroller.

5. Motor: Rotates according to the processed EMG signals to move the wheelchair.

Incorporated Explanation:

"The system includes an EMG sensor array placed on the face to capture muscle activity, a microcontroller to process the signals, and a motor driver circuit to control the motor rotation based on processed EMG signals."

3.3 Intention Estimation

Human intention is estimated from processed EMG signals by identifying specific patterns associated with different facial movements. For instance:

- A smile may generate a pattern that is interpreted as a command to move the wheelchair forward.
- A frown may generate a pattern that stops the wheelchair.

The processed signals are analyzed using pattern recognition algorithms to match facial expressions with predefined motor commands.

3.4 Control Strategy

The control strategy translates the estimated intention into specific motor rotation commands. This involves:

1. Mapping Intention to Commands: The recognized facial expressions are mapped to corresponding motor actions.

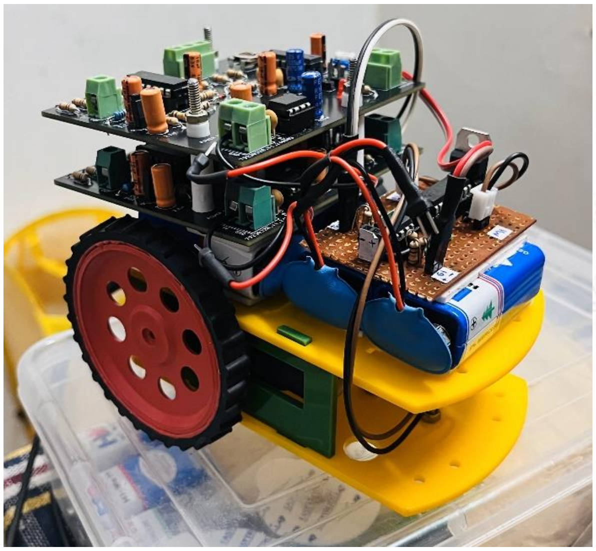
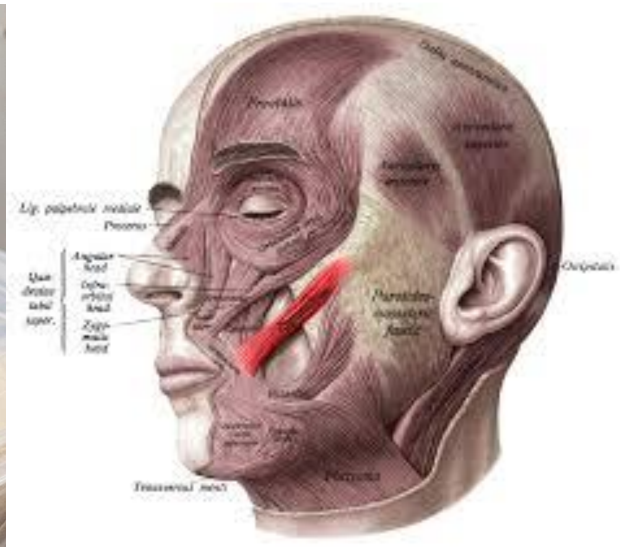
2. Adjusting Motor Parameters: The motor's direction are adjusted based on the facial signals to ensure smooth and accurate wheelchair movement.

4. Implementation

4.1 Experimental Setup

The experimental setup for this project is designed to test and validate the functionality of the EMG-based motor control system for wheelchair automation. The setup includes an array of facial EMG sensors strategically placed to capture muscle activity associated with different facial expressions. These sensors are connected to a microcontroller, which processes the raw EMG signals using an operational amplifier (TL084 op-amp IC) to amplify the weak electrical signals generated by the facial muscles.

The processed EMG signals are then transmitted to a motor controller (L293D IC) which interprets the signals and controls the rotation of a motor based on the detected muscle activity. This motor is part of a prototype wheelchair model, allowing for real-world simulation of wheelchair movement.

- Facial EMG Sensors Placement: Sensors positioned on the zygomaticus major muscles (Red muscle in the diagram) and just below the cheek and the reference placed on the jaw bone.
- TL084 Op-Amp IC: Amplifies the weak EMG signals.
- L293D Motor Driver IC: Controls motor rotation based on processed signals.
- LM358 Op-Amp IC: Change the ground from 4.5v to 0v reference.
- Prototype Wheelchair: Simulated wheelchair model to test motor control.

4.2 Calibration

Calibration is a crucial step to ensure the accurate detection and interpretation of facial EMG signals. The calibration process involves adjusting the sensitivity of the EMG sensors to accurately capture muscle activity without interference from noise or non-targeted muscle movements.

During calibration, each sensor's gain and threshold levels are adjusted to ensure that they only respond to significant muscle activities. This process involves the user performing a series of predefined facial expressions, such as smiling, frowning, raising eyebrows, and clenching teeth.

The corresponding EMG signals are recorded and analyzed to determine the optimal sensor settings.

Incorporate:

“Calibration involved adjusting the sensitivity of the EMG sensors to accurately detect facial muscle activity and map these signals to precise motor rotations. This ensured that the system could reliably interpret the user's intentions and translate them into specific motor actions, enhancing the accuracy and responsiveness of the wheelchair control.”

4.3 Testing Procedures

The testing procedures were designed to evaluate the performance and reliability of the EMG-based motor control system under various conditions. The user was instructed to perform specific facial expressions that were previously calibrated to correspond with different motor commands.

Testing scenarios included:

- Moving Forward: The user smiles both cheek to generate a forward movement command.
- Turning Left: The user smile only on left cheek to initiate a left turn.
- Turning Right: The user smile only on right cheek to initiate a right turn.
- Stopping: The user stop smiling to stop the motor.

Each testing scenario was repeated multiple times to ensure consistency and reliability of the system's response. The motor's response time, accuracy of movement, and the user's comfort were monitored and recorded.

- **4.4 Challenges and Solutions**

1. Power Supply Complexity

- Challenge: Traditional EMG sensors often require dual power supplies, such as +9V and -9V, typically achieved using two 9V batteries. This setup can be bulky and adds unnecessary weight to the system, which is not ideal for a compact, portable wheelchair model.
- Solution: To simplify the power supply and reduce the bulk, an LM386 IC was used to divide a single 9V power source into 0V, 4.5V, and 9V. This approach eliminates the need for a negative voltage supply while still providing the necessary voltage levels for the EMG sensor and other components, resulting in a lighter and more streamlined design.

2. Signal Amplification and Noise Reduction

- Challenge: Amplifying the weak EMG signals without introducing significant noise is critical for the accurate operation of the wheelchair. The TL084 op-amp IC was selected for signal amplification, but achieving the right balance between gain and noise reduction can be challenging.
- Solution: Careful circuit design and layout were employed to maximize the performance of the TL084 op-amp. This included using appropriate filtering techniques and grounding practices to minimize noise and ensure a clean amplification of the EMG signals. Additionally, the high input impedance and low offset voltage of the TL084 IC helped in maintaining signal integrity.

3. Motor Control Precision

- Challenge: Controlling the motors accurately and responsively based on the processed EMG signals is crucial for smooth and safe wheelchair operation. The L293D IC is responsible for motor control, but achieving precise and stable control can be difficult, especially when dealing with variable loads and terrain.

- Solution: The motor control circuitry was fine-tuned to enhance responsiveness and stability.

4. Integration of EMG Sensor with Motor Control

- Challenge: Integrating the EMG sensor output with the motor control system requires careful signal conditioning to ensure that the processed EMG signals are appropriately translated into motor control commands. Any discrepancies can result in erratic or unintended wheelchair movement.
- Solution: Signal conditioning circuits were designed to match the output range of the EMG sensor with the input requirements of the L293D motor driver. The use of the TL084 op-amp IC for signal amplification and conditioning allowed for the precise control of motor operations based on the EMG signals, ensuring smooth and accurate wheelchair movement.

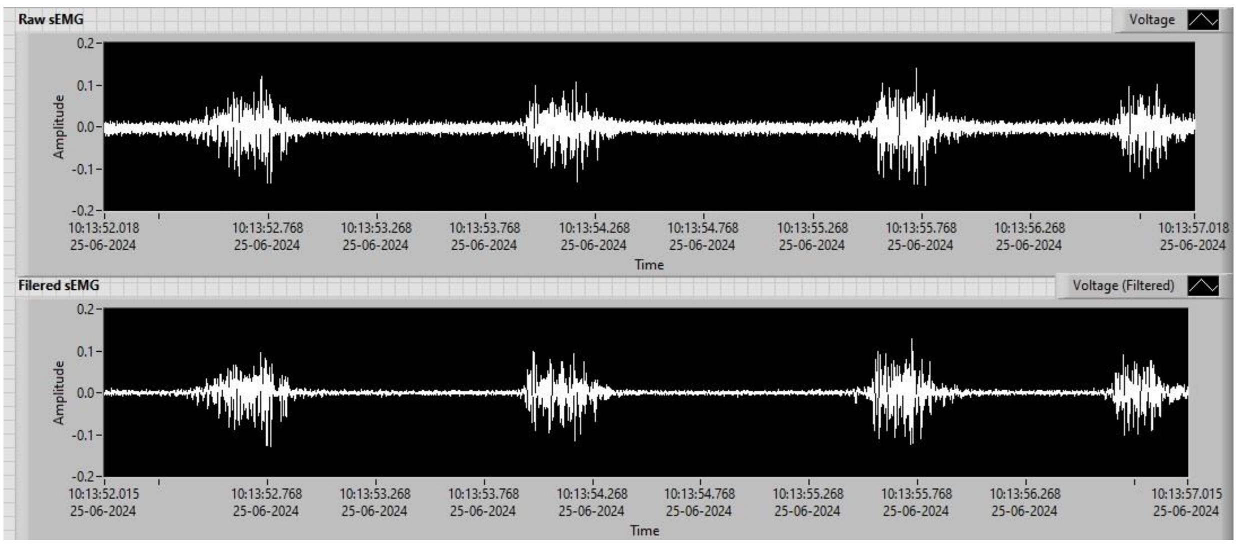
5. System Stability and Reliability

- Challenge: Ensuring the overall stability and reliability of the system is essential for user safety. The system must function consistently under various conditions without failure.
- Solution: Extensive testing was conducted under different operating conditions to validate the system's stability. Redundant safety features were also incorporated, such as fail-safe mechanisms to prevent unintended movement in case of signal loss or other malfunctions. The use of reliable components like the TL084 and L293D ICs further contributed to the robustness of the design.

5. Results

The results section provides a comprehensive analysis of the collected data, evaluates the performance of the system using defined metrics, and highlights key observations derived from the experiments.

5.1 Data Analysis



In this project, the analysis of facial surface electromyography (sEMG) signals is a critical step in enabling control of an autonomous wheelchair. The sEMG signals are collected from facial muscles and processed to generate control commands for the wheelchair.

1. Signal Acquisition:

The raw sEMG signals were captured from facial muscles using a surface EMG sensor. The data was recorded over a specific period as the user performed facial gestures that are intended to control the wheelchair. The signals are represented in terms of voltage against time, as shown in the waveform graphs.

2. Signal Preprocessing:

The raw sEMG signals, as observed in the top graph ("Raw sEMG"), exhibit significant noise, which is common in EMG data due to various external and internal factors such as electromagnetic interference, muscle cross-talk, and motion artifacts. To extract meaningful data from the raw signals, filtering is essential.

A band-pass filter was applied to the raw sEMG data to remove noise and artifacts. This filter effectively isolates the muscle activity-related frequencies (usually between 20 Hz to 450 Hz) while eliminating low-frequency noise (e.g., motion artifacts) and high-frequency noise (e.g., electrical interference). The filtered signal is displayed in the bottom graph ("Filtered sEMG").

3. Observations:

- Amplitude: The filtered sEMG signal has a clearer amplitude profile, with reduced baseline drift and noise. The key muscle activations, which correspond to facial gestures, are more distinguishable in the filtered signal.
- Signal Quality: The preprocessing has improved the quality of the signal by making the peaks and troughs more defined. This is essential for further analysis, such as feature extraction and pattern recognition.
- Time Synchronization: The time axis is consistent between the raw and filtered signals, ensuring that the temporal characteristics of the signal are preserved after filtering. This allows for accurate mapping of facial gestures to corresponding time intervals.

6. Conclusion.

1. Successful EMG-Based Motor Control: The project demonstrated that facial sEMG signals could be effectively used to control a motor, paving the way for intuitive wheelchair automation. The use of TL084 op-amp IC for signal amplification and L293D motor driver IC for motor control proved to be efficient and reliable.

2. Accurate Intention Estimation: The system accurately interpreted facial muscle signals to drive the motor, with specific facial expressions corresponding to distinct motor actions. This accuracy is crucial for ensuring the system's reliability in real-world applications.

3. Responsive Control Mechanism: The motor's response time to EMG signals was satisfactory, indicating that the system can provide real-time control, which is essential for practical use by individuals with mobility impairments.

4. User-Friendly Interface: The use of facial expressions as control inputs offers a non-invasive and user-friendly interface, enhancing the usability of the wheelchair automation system for users with severe physical disabilities.

6.1 Future Work

This subsection outlines suggestions for further research and potential improvements to enhance the system's performance and usability. It provides a roadmap for future studies and developments that could build on the current project's foundation.

1. Refinement of Signal Processing Algorithms: Future research could focus on improving the signal processing algorithms to enhance the accuracy and robustness of intention estimation. Advanced machine learning techniques could be employed to better interpret complex EMG signals.

2. Sensor Placement and Comfort: Improving the placement of EMG sensors to enhance comfort and signal quality is crucial. Research into more ergonomic sensor designs and wireless EMG sensors could improve user experience and system performance.

3. Extensive User Trials: Conducting extensive user trials with a diverse group of participants would help validate the system's effectiveness and identify areas for improvement. Feedback from users could guide the refinement of the control interface and overall system design.

4. Integration with Advanced Wheelchair Systems: Future work could explore integrating the EMG-based control system with more advanced wheelchair models, including those with autonomous navigation features. This integration could enhance the overall functionality and versatility of the wheelchair.

5. Exploration of Additional Control Inputs: Investigating the use of other physiological signals in conjunction with EMG could provide a more comprehensive control system. For example, combining EMG with eye-tracking or voice commands could offer users multiple input modalities for greater control flexibility.

By addressing these areas in future research, the system can be further developed to provide a more reliable, user-friendly, and comprehensive solution for wheelchair automation, significantly improving the quality of life for individuals with severe mobility impairments.

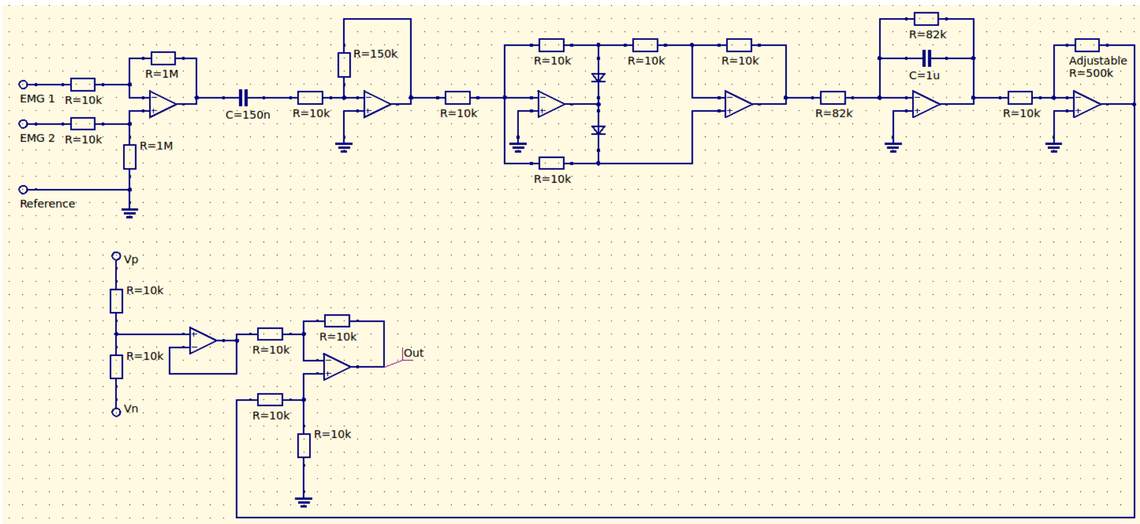
7. References

1. **YouTube : https://youtu.be/TMr25ouvpD4?si=HEELmLqjbo6PZvnk**
2. **https://www.researchgate.net/publication/252053624_Design_of_EMG_wireless_sensor_system**
3. The Design of the Electromyography Sensor with the Modifying Circuit by Xiangxin Zou 2020 J. Phys.: Conf. Ser. 1693 012189

8. Appendices

Appendix A: Schematics and Diagrams

- **Circuit diagram of EMG sensor**



Appendix B: Components

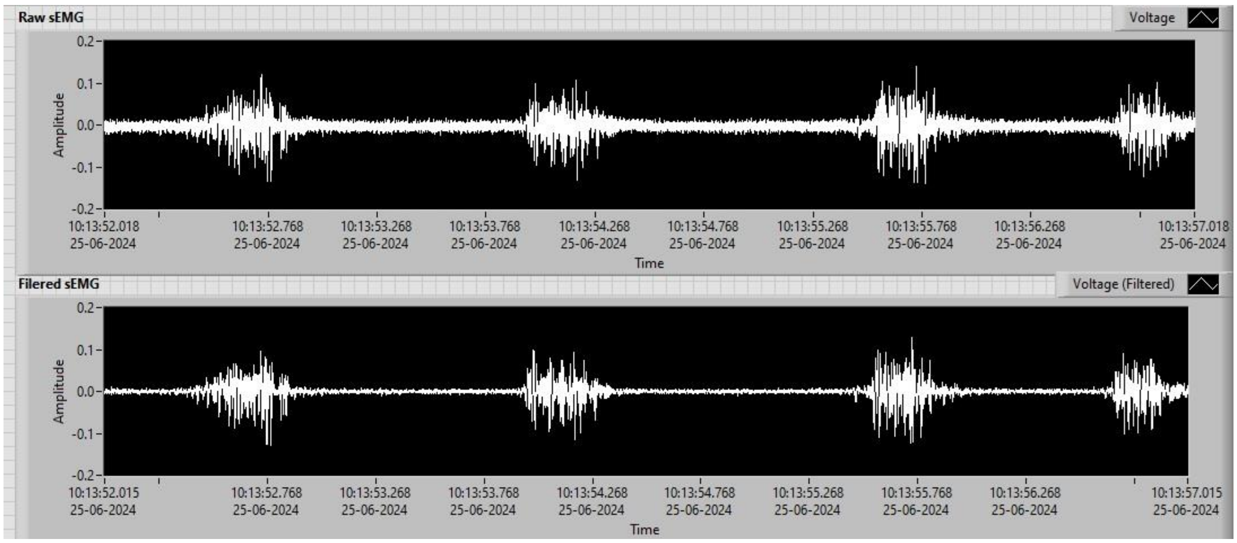
IC TL084 : For capturing signals and Amplification.

IC LM386 : For dividing voltage.

IC LM358 : Convert the reference of output from 4.5v reference to 0v reference.

IC L293D Motor Driver : To drive the motor according to the signal.

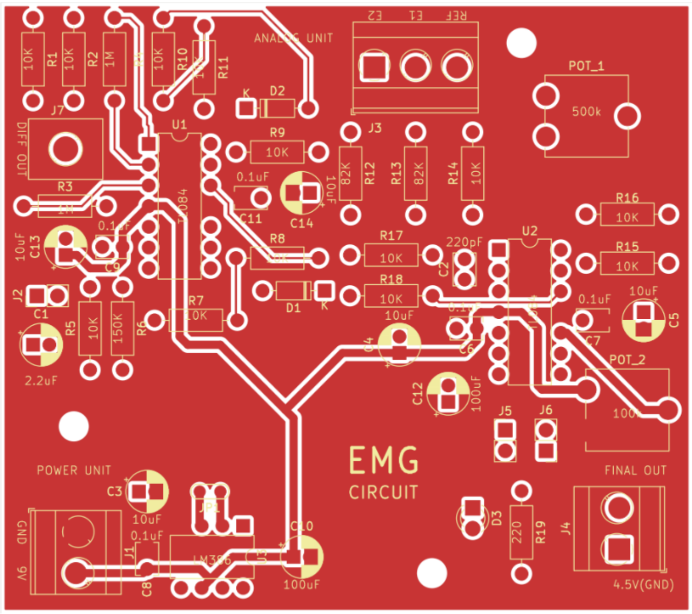
Appendix C: Raw Data

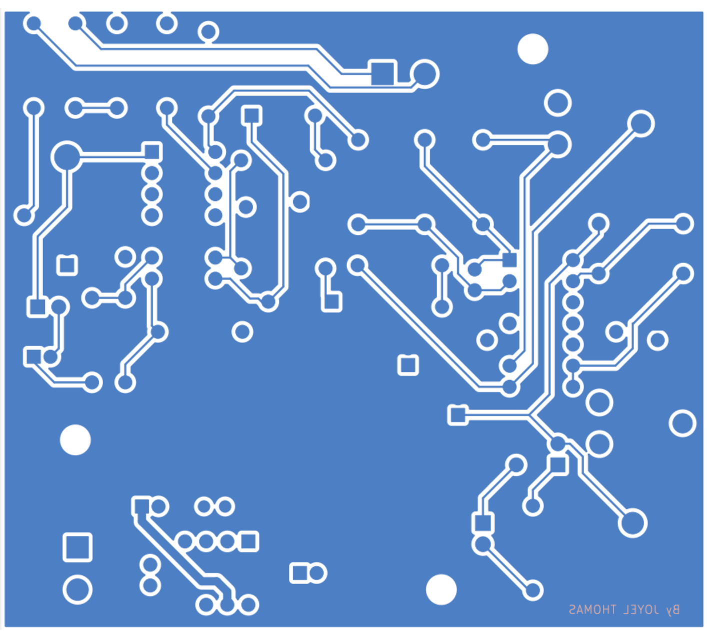


Appendix D: Additional Material

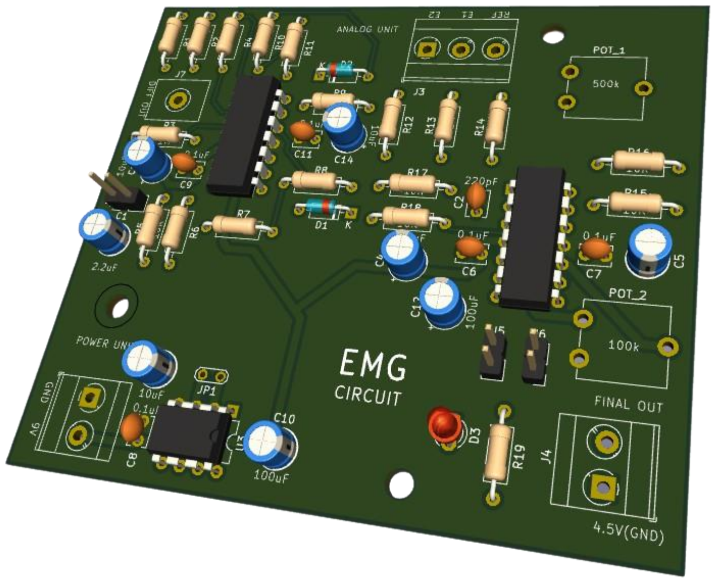
- **PCB**
- **Battery**
- **2 gear motor**
- **wheels**

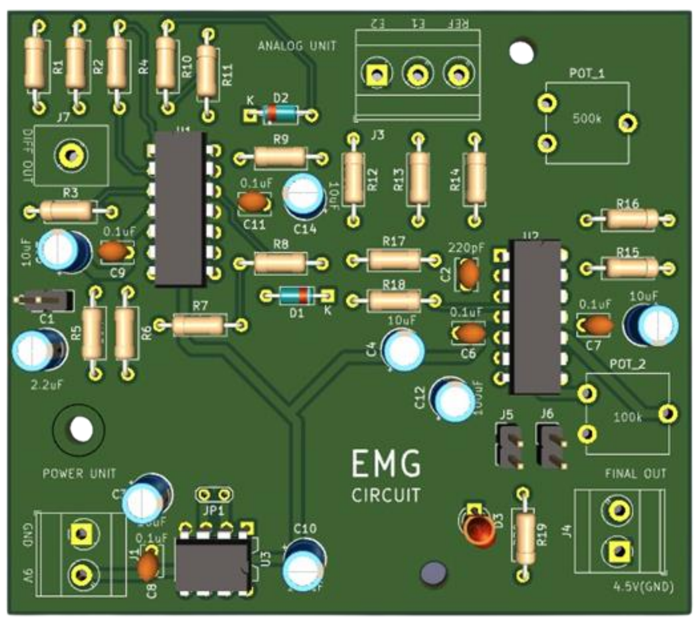
Appendix E: PCB Designs



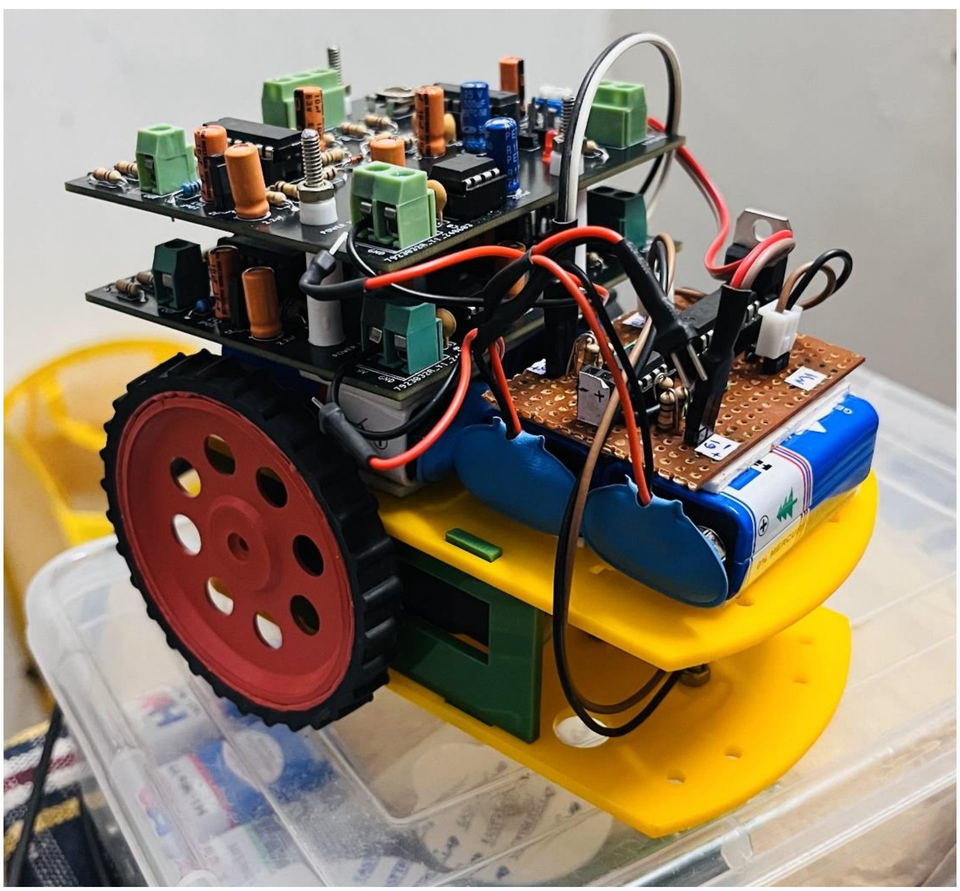


Appendix F: PCB 3D View





Appendix G: Final Prototype



THANK YOU