CENG424 Embedded Computer Systems
Project Report
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Project Title: Telepathy

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Abstract

This project explores the integration of neuroscience, embedded systems, and interactive technology to create an educational tool that demonstrates the practical applications of neural communication and control. Utilizing Electromyography (EMG), the electrical activity produced by skeletal muscles is captured to detect and interpret muscle movements. This data is processed using an Arduino microcontroller, which calculates a moving average of the EMG signals to determine muscle activation.

The processed EMG data is used to control an interactive parkour game displayed on a 16x2 LCD screen. When muscle activation is detected, the character in the parkour game jumps, providing a practical demonstration of bio-signal processing and real-time data communication. This hands-on project illustrates the potential of using simple muscle movements to interact with digital interfaces, making complex scientific concepts accessible and engaging through interactive learning environments.

The primary goal is to make complex concepts in neuroscience and embedded systems accessible to students and enthusiasts. By visualizing muscle activation and translating it into interactive control, the project aims to foster a deeper understanding of bio-engineering principles and inspire interest in the fields of neuroscience, biomedical engineering, and interactive technology. This project exemplifies how interdisciplinary approaches can be employed to create engaging educational experiences that bridge the gap between theoretical knowledge and practical application.Through this initiative, the project aims to ignite curiosity and encourage further exploration in the realm of human-machine interaction, showcasing the exciting possibilities that arise from the fusion of biological signals and digital technology.

1 Introduction

In recent years, the field of neural communication and control has witnessed significant advancements, driven by the convergence of neuroscience, bio-engineering, and embedded systems technology. Understanding and harnessing the electrical signals generated by skeletal muscles, known as Electromyography (EMG), has opened up new avenues for interactive and assistive technologies. This project aims to demonstrate the practical application of EMG in controlling digital interfaces, specifically by using muscle activation to interact with a parkour game displayed on a 16x2 LCD screen.
The core of this project involves capturing EMG signals using a sensor, processing these signals with an Arduino microcontroller, and directly using the processed data to control a game. The Arduino processes the EMG data to calculate a moving average and determines muscle activation, which is then used to make the character in the parkour game jump. This setup not only provides a tangible example of bio-signal processing but also highlights the potential for using simple, everyday muscle movements to interface with digital systems.

The objectives of this project are multifaceted:

- **Educational Engagement:** This project aims to make sophisticated scientific concepts in neuroscience and bio-engineering accessible to students and enthusiasts through hands-on learning experiences. By providing a practical demonstration of EMG signal processing and its applications, the project helps demystify complex topics, making them more approachable and understandable. The interactive nature of the project enhances engagement and retention, allowing learners to see real-world applications of theoretical concepts.
- **Practical Demonstration:** To showcase the practical applications of EMG in real-time control of digital interfaces. This project serves as a proof-of-concept for using muscle activation to control a simple game, highlighting the potential for similar approaches in more complex and varied applications. It demonstrates the feasibility of using low-cost, widely available components to achieve sophisticated control mechanisms, thereby lowering the barrier to entry for further experimentation and development in this field.
- **Interdisciplinary Integration:** This project illustrates the seamless integration of embedded systems, signal processing, and computer programming in creating interactive applications. It combines hardware and software components, requiring knowledge and skills from multiple disciplines. This interdisciplinary approach not only showcases the versatility and interconnectedness of different fields but also encourages collaboration and innovation by highlighting how various technologies can be combined to solve problems and create new possibilities.
- **Innovation Inspiration:**To inspire future developments in human-machine interaction and assistive technologies by demonstrating the potential of using biological signals for control purposes. This project acts as a catalyst for innovation, showing how biological data can be harnessed to create intuitive and responsive control systems. By exploring the practical applications of EMG signals, it encourages further research and development in related areas, such as prosthetics, rehabilitation devices, and interactive gaming, paving the way for breakthroughs that can significantly enhance quality of life.

By achieving these objectives, the project aims to bridge the gap between theoretical knowledge and practical application, fostering a deeper understanding of the interplay between biological signals and digital technology. This initiative serves as a catalyst for curiosity and innovation in the overlapping fields of neuroscience, bio-engineering, and interactive technology, highlighting the exciting possibilities that arise from their integration.

2 Literature Review

The Telepathy project facilitates learning through interactive and fun activities for people interested in muscle activity and neuroscience. In the project, muscle activity from one participant is read and translated into a signal. The obtained signal is used to control a digital interface, demonstrating the educational potential of EMG technology. Several foundational studies and related works have informed the development of this project.

One of the foundational studies on controlling another person's muscles is conducted by Backyard Brains, known as the human-to-human interface. This work demonstrates how signals received with an EMG cable are transferred to another person using a TENS unit, allowing the arm of another person to be moved without that person's voluntary control. In the study, brain signals directed to hand muscles are read and transferred to another person's hand, causing involuntary movement. This work also utilizes a tool named muscle spikerbox to visualize and hear muscle vibrations. The equipment used in this project is relatively affordable, making it accessible for amateurs and high school students to learn Greg Gage (2009); Gage (2015). This research inspired the genesis of our project. However, due to limited equipment and the potential risks of transmitting signals to a person, our implementation focuses on educational demonstrations and controlling digital interfaces rather than direct human control.

Another study that involves controlling someone else's body via electrical muscle stimulation is bioSync. BioSync monitors the muscle activity of one person and replicates the movement in another person's arm, synchronizing muscle activities without visual or auditory feedback. This system can be used in interactive rehabilitation, sports training, and shared embodied experiences Nishida (2017). An advanced version of this system, known as Wired Muscle, coordinates the movements of both participants, making it applicable for learning musical instruments and sports requiring fast reactions Nishida (2017); Wilson (2017).

Recent work on integrating Arduino-based systems for interactive applications includes a project that creates a parkour game controlled by an Arduino and displayed on a 16x2 LCD screen. This project highlights the practical aspects of combining hardware and software to create engaging interactive experiences Mindhe (2021). Another project details the development of an LCD game using Arduino, showcasing the feasibility of using simple hardware components to create interactive digital games Brooks (2020).

The main difference between other works and Telepathy is that it simplifies the learning of muscle activity and neuroscience by making the process engaging and accessible through visual feedback. Unlike studies that focus on direct muscle control with complex setups, Telepathy uses real-time data visualizations to make abstract concepts tangible. Instead of transferring EMG signals to another person, Telepathy uses the signals to control a digital interface, ensuring a safe and controlled learning environment. By utilizing affordable and readily available components, the project is easy to replicate, making it accessible to students, educators, and hobbyists. This approach makes complex subjects approachable and enjoyable, emphasizing educational engagement through interactive methods.

3 Methodology

3.1 Project Planning and Research

The initial stage involved extensive research on Electromyography (EMG), Arduino microcontrollers, signal processing techniques, and game implementation using an LCD screen. Clear project objectives, targeted audiences, and educational goals were defined. A comprehensive project plan was developed, outlining tasks, timelines, and resources needed to ensure a structured approach and systematic execution.

3.2 Hardware Selection and Acquisition

EMG sensors, Arduino microcontrollers, and a 16x2 Arduino LCD screen suitable for capturing, processing, visualizing muscle signals, and displaying the parkour game were identified and procured. Ensuring the compatibility of these components with the project's objectives was crucial, focusing on their ability to function effectively within the designed framework.

3.3 Software Setup and Configuration

Necessary software tools for signal processing and game implementation were installed and configured. The team familiarized themselves with the software platforms and libraries required for effective implementation. For the Arduino, the Arduino IDE was used for programming. Key libraries included the LiquidCrystal library for interfacing with the 16x2 LCD screen.

3.4 Hardware Integration and Prototyping

The EMG sensors, along with the 16x2 LCD screen, two potentiometers, and a resistor, were integrated with the Arduino microcontroller, following manufacturer guidelines to develop prototype circuits that could effectively capture and process nerve signals. Thorough testing on these hardware components was conducted to ensure their functionality and reliability in simulated environments.

3.5 Implementation

The implementation involved using Arduino code to read, process, visualize, and use EMG signals for controlling a parkour game displayed on a 16x2 LCD screen.

3.5.1 Arduino Code:

The Arduino code reads EMG sensor values, processes the data to calculate a moving average, and visualizes the signals on a 16x2 Arduino LCD screen. Additionally, the code controls the parkour game displayed on the LCD screen based on muscle activation.

Steps:

- **Initialize Variables and Pin Setup:**
  - Define the analog pin for the EMG sensor (A0).
  - Initialize variables for storing EMG readings (emgValue), calculating moving average (readings, readIndex, total, average), and setting the activation threshold (threshold).
  - Define pins for the LCD screen (PIN_AUTOPLAY, PIN_READWRITE, PIN_CONTRAST) and initialize the LiquidCrystal library.
- **Setup Function:**
  - Initialize the LCD screen by defining the pins and setting the communication rate with lcd.begin(16, 2).
  - Create custom characters for the LCD screen to represent different elements of the parkour game, such as running and jumping sprites.
  - Initialize the readings array to zero and setup serial communication at 9600 baud rate.
- **Loop Function:**
  - **EMG Sensor Reading:**
    * Subtract the last reading from the total.
    * Read the current EMG sensor value using analogRead(emgPin).
    * Add the new reading to the readings array and update the total.
    * Advance to the next position in the array, wrapping around if necessary.
    * Calculate the moving average of the readings.
  - **Display EMG Value:**
    * Print the average EMG value to the serial monitor.
    * Display the average EMG value on the LCD screen.
  - **Muscle Activation Detection:**
    * Check if the average value exceeds the threshold to detect muscle activation.
    * If muscle activation is detected, update the game state to make the character jump. .
  - **Game Logic:**
    * Shift the terrain to the left to create a moving effect.
    * Generate new terrain blocks and update the character's position based on muscle activation.
      .
    * Check for collisions between the character and terrain blocks to determine if the game should end.
  - **Delay:**
    * Introduce a delay of 100ms before the next reading to ensure smooth gameplay and accurate signal processing.

  By following these steps, the implementation successfully integrates real-time EMG signal processing with interactive gameplay on an LCD screen, providing a tangible demonstration of how biological signals can control digital interfaces.

3.6 Communication Interface Setup

The communication interface setup is crucial for processing EMG data using the Arduino and displaying it on the 16x2 LCD screen to interact with the parkour game.

3.6.1 Components

- **Arduino Microcontroller:** An Arduino UNO board serves as the central processing unit. It receives EMG data and processes it for further analysis.

Figure 1: Arduino UNO

- **Electromyography (EMG) Sensor:** These sensors are attached to the skeletal muscles of the user. They detect electrical activity generated during muscle contractions or movements.

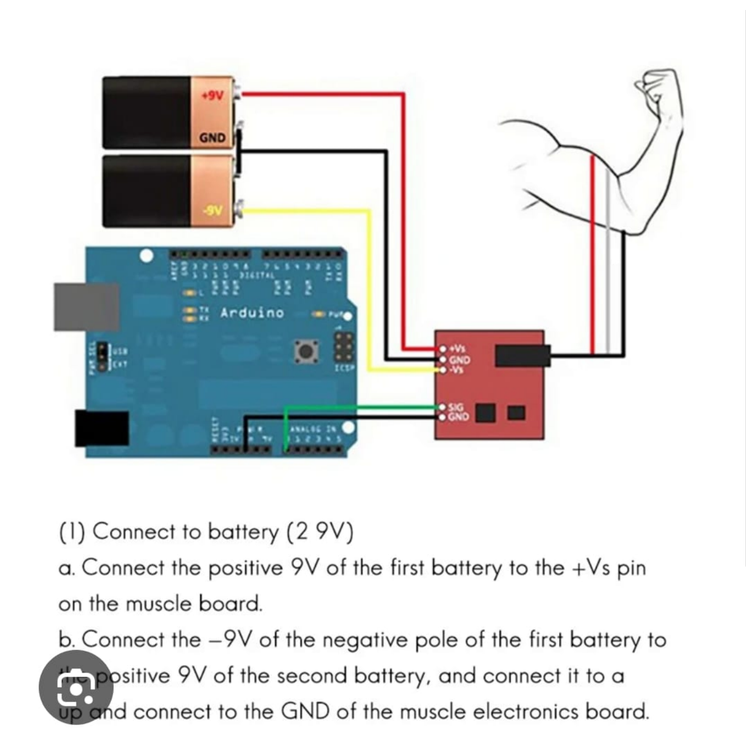

Figure 2: Structure of EMG Sensor Connection with Arduino

- **Data Transmission Lines:** Analog data flows from the EMG sensors to the Arduino Uno board.

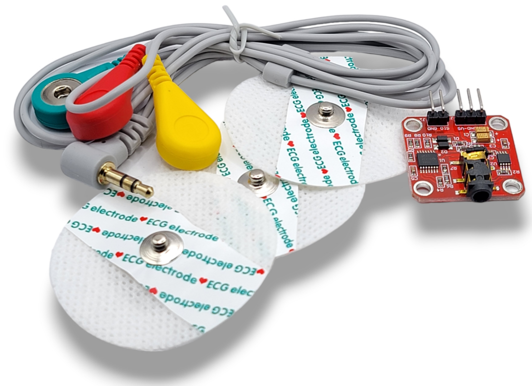

Figure 3: EMG Data Transmission Lines

- **9V Battery(3x):** Provides power to the system. One battery is used to power the Arduino Uno, ensuring it can process the EMG signals and control the LCD display. The other two batteries are used to power the EMG sensor, ensuring it can accurately detect and transmit muscle activity signals to the Arduino. The connection setup for these batteries is shown in Figure 1, illustrating how each component is powered effectively within the system.
- **16x2 Arduino LCD Screen:** Used to display the parkour game and visualize muscle activation signals in real-time.

Figure 4: 16x2 LCD Screen- 1602A

- **Electronics Breadboard:** Provides a platform for connecting and organizing the electronic components.

- **10k Potentiometers (2x):** Used to control the contrast and brightness of the LCD screen.
- **Jumpers:** Wires used for making connections between components on the breadboard.

3.7 Documentation and Reporting

Progress, methodologies, results and conclusions throughout the project have been documented using tools such as LaTeX and Google Docs and will continue to be documented as the project progresses. A comprehensive final project report was prepared, detailing each development stage and key findings. This documentation was aimed at facilitating knowledge sharing and enabling the replication of results by other researchers or educators.

4 Experimental Results

4.1 Experiment 1: Initial EMG Signal Acquisition and Processing

Setup: The initial experiment focused on acquiring and processing EMG signals from the human arm. The components used included:

- Electromyography (EMG) Sensor:
- Arduino Uno microcontroller
- EMG Data Transmission Lines
- 2 9V batteries for power
- Jumper wires

Procedure:

- **Data Transmission Lines Placement:**
  - Proper placement of the data transmission lines on the participant's arm was crucial. The lines were positioned at the midline of the muscle belly, between the innervation zone and the myotendon junction, to ensure accurate signal acquisition.
  - Different placements (innervation zone, midline offset, and myotendon junction) were tested to observe their effects on the signal quality .

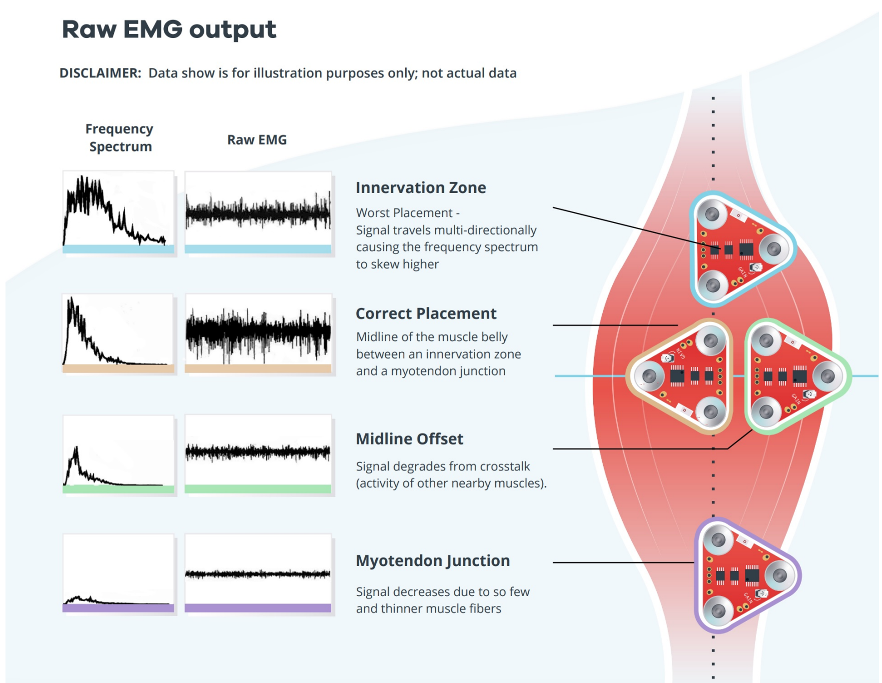

Figure 5: Emg Data Transmission Lines Placement:

- **Initial Signal Acquisition:**
  - The EMG sensor detected muscle activity and transmitted raw signals to the Arduino Uno.
  - An initial Arduino code was written to read the raw sensor values and print them to the serial monitor.
- **Signal Processing:**
  - The raw data initially showed high levels of noise and variability, which made it difficult to distinguish between muscle contraction and relaxation phases.
  - To address this, signal processing techniques were applied, including noise reduction through filtering and calculating a moving average of the readings.
  - Threshold values for muscle activation were adjusted to improve detection accuracy.
- **Results Visualization:**
  - The processed signals were displayed on Arduino IDE, providing a visual representation of muscle activity.
  - To address this, signal processing techniques were applied, including noise reduction through filtering and calculating a moving average of the readings.

Importance of Sensor Placement: Proper sensor placement significantly impacts the quality of the EMG signals. The best results were obtained when the sensor was placed at the midline of the muscle belly. Placing the sensor too close to the innervation zone or myotendon junction resulted in higher noise levels and less accurate readings. Figure 5 illustrates the effects of different placements on the signal quality.

Results: The experiment successfully captured and processed muscle signals, with the moving average displayed on the LCD screen. Initial readings showed significant noise, but after applying filtering and adjusting thresholds, the signals became clearer and more distinguishable. The importance of correct sensor placement was highlighted, as improper placement resulted in degraded signal quality.

4.2 Experiment 2: Parkour Game Integration

Setup: The primary objective of this experiment was to control a parkour game displayed on the 16x2 LCD screen using muscle activation signals. The setup included:

- All components from previous experiments:
  - Electromyography (EMG) Sensor:
  - Arduino Uno microcontroller
  - EMG Data Transmission Lines
  - 2 9V batteries for power
  - Jumper wires
- Custom-designed parkour game code integrated into the Arduino sketch

Procedure:

- Code Integration:
  - The parkour game code was integrated into the existing Arduino sketch. This involved defining custom characters for the game elements (such as the character and terrain) using the LiquidCrystal library.
- Game Logic Development:
  - The game logic was designed to interpret muscle activation (detected by the EMG sensor) as a command to make the game character jump.
  - Terrain and character sprites were created as custom characters and displayed on the LCD screen.
- Signal Processing and Game Control:
  - The Arduino code continuously read the EMG sensor values, processed the data to calculate a moving average, and determined muscle activation based on a predefined threshold.
  - When muscle activation was detected, the game character was programmed to jump, simulating an interactive game control mechanism.
- Threshold Adjustment::
  - Initial Observations: The predefined threshold for muscle activation was either too high or too low, causing either unresponsive or overly sensitive game controls.

  - Solution: Conducted multiple trials to find the optimal threshold level that balanced sensitivity and specificity.
  - Outcome: Established an appropriate threshold that accurately detected genuine muscle contractions, ensuring reliable game control.

Results: By addressing these scenarios, the project was able to fine-tune the system for better performance and reliability. The successful implementation of the parkour game on the LCD screen with EMG control highlights the potential for using bio-signals in interactive applications, offering a compelling educational tool that bridges the gap between theoretical knowledge and practical application.

4.3 Experiment 3: Integration with 16x2 LCD Screen

Setup: The primary objective of this experiment was to control a parkour game displayed on the 16x2 LCD screen using muscle activation signals. The setup included:

- All components from previous experiments:
  - Electromyography (EMG) Sensor:
  - Arduino Uno
  - EMG Data Transmission Lines
  - 3 9V batteries for power(one for the Arduino Uno and two for the EMG sensor)
  - Resistors and potentiometers for signal conditioning
  - 16x2 LCD screen
- Custom-designed parkour game code integrated into the Arduino sketch

Procedure:

- Integration of Game Code:
  - The parkour game code was integrated into the existing Arduino sketch. This involved adding the game logic, which interprets muscle activation (detected by the EMG sensor) as a command to make the game character jump.
- LCD Display Configuration:
  - Custom characters were created using the LiquidCrystal library to represent different game elements such as the running and jumping sprites. The LCD screen was configured to display the terrain and character sprites in real-time.
- Game Logic Implementation:
  - The game logic was designed to update the terrain and character positions based on the EMG signal. When muscle activation is detected, the character jumps. The game continues to run, creating a continuous parkour challenge on the LCD screen.
- Initial Response Delay:
  - Initial Observations: There was a noticeable delay in the character's jump response after muscle activation.
  - Solution: Optimized the Arduino code to ensure faster processing of the EMG signals and immediate update of the game state.
  - Outcome: : Achieved almost real-time response, enhancing the gameplay experience.

Results: By addressing these scenarios, the project successfully demonstrated the integration of EMG signal processing with an interactive digital application. This experiment highlighted the potential of using bio-signals for real-time control in educational and recreational applications, showcasing the innovative possibilities of merging neuroscience with embedded systems technology.

5 Conclusions and Future Works

5.1 Conclusion

The project has significantly advanced the educational application of neuroscience, engineering, and embedded systems technology by leveraging Electromyography (EMG) integrated with Arduino microcontrollers. This project demonstrates how complex scientific concepts can be made accessible and engaging through interactive learning environments. It effectively demystifies neural communication and muscle control, broadening interest and understanding among non-academic audiences.

Furthermore, the project showcases the practicality of using affordable, accessible technology in education, serving as a model for future initiatives that aim to democratize science education and stimulate further innovation in the fields of neuroscience and bioengineering. By providing real-time visualization of muscle activity and translating these signals into interactive digital controls for a parkour game on an LCD screen, the project has bridged the gap between theoretical knowledge and practical application. This fosters a deeper appreciation of the interdisciplinary nature of modern scientific and technological advancements.

5.2 Future Works

5.2.1 Enhanced Signal Processing Algorithms:

Future iterations of this project will focus on developing more sophisticated signal processing algorithms to improve the accuracy and reliability of muscle signal interpretation. Advanced techniques such as adaptive filtering, machine learning-based classification, and real-time noise reduction will be explored. These enhancements aim to minimize signal artifacts and increase the fidelity of muscle activity translations, thereby enabling more precise and responsive control mechanisms for the parkour game displayed on the LCD screen.

5.2.2 Integration with Additional Educational Content:

There is significant potential to integrate this technology with other scientific and educational content, creating more comprehensive and multidisciplinary learning modules. For instance, combining real-time physiological data with virtual reality environments could provide immersive learning experiences that enhance understanding of complex biological processes. Such integrations could cover a wide range of topics, from human physiology and biomechanics to robotics and interactive media, offering students a holistic view of how these diverse fields interconnect.

5.2.3 Expansion to Assistive Technologies

Building on the project's foundation, future work could extend into the development of assistive technologies for individuals with disabilities. By refining the EMG signal processing and control interfaces, the project could contribute to creating more intuitive and effective prosthetic devices or rehabilitation tools. This expansion would not only advance the project's educational impact but also demonstrate its potential for real-world applications that improve quality of life.

In conclusion, the "Telepathy" project lays a robust foundation for innovative educational tools that blend neuroscience, engineering, and technology. With continued development and expansion, it holds the promise of not only enhancing science education but also contributing to broader technological advancements and societal benefits.

6 Weekly Schedule/Project Plan

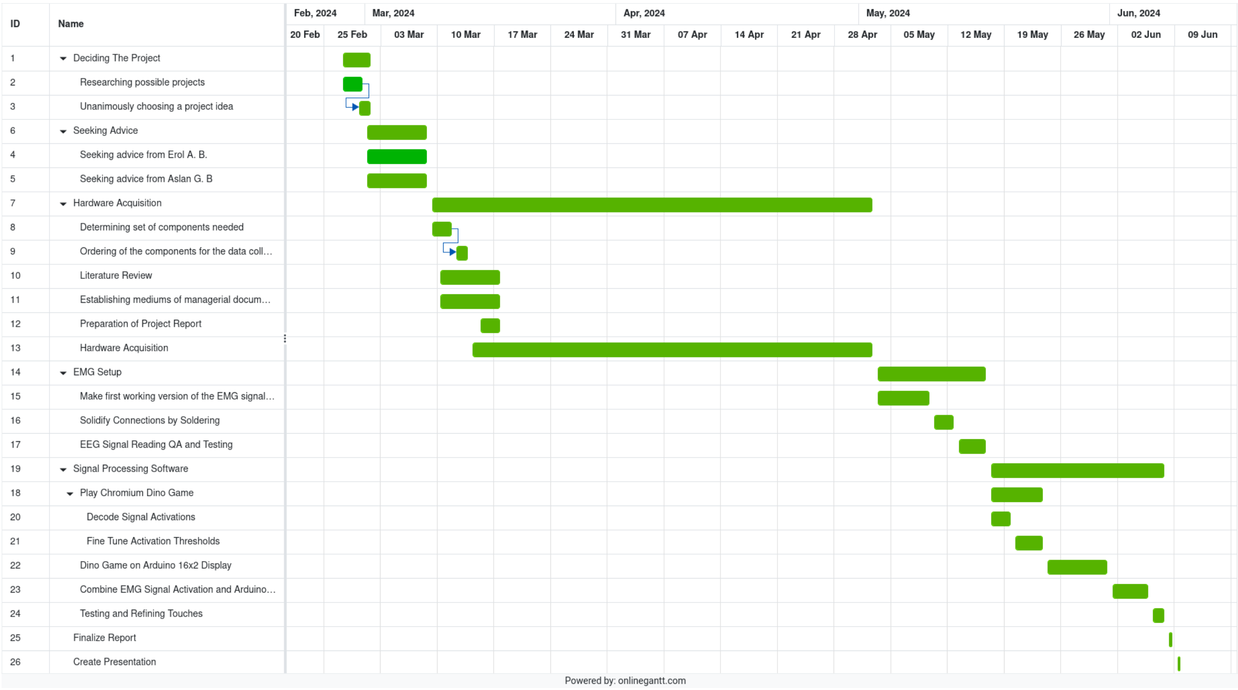

Figure 6: GANNT Chart. Link for bigger view

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