ORIGINAL RESEARCH PAPER

Physiotherapy

"DEVELOPMENT OF A SMART PROSTHETIC ARM CONTROLLED BY EMG SENSORS AND AI"

KEY WORDS: Robotic arm, robotic prosthetic arm, arm amputation, artificial arm, AI controlled arm, advanced prosthetic arm.

Anuj Kabra

BPT, MPT (Orthopaedics), Certified McKenzie Therapist, Keller Oaks Healthcare Services, Keller (Texas, USA)

ABSTRACT

The increasing prevalence of limb loss, whether due to congenital disorders or traumatic events, has accelerated the demand for innovative and efficient prosthetic technologies. In response to this, the paper proposes an advanced prosthetic arm control system that integrates electromyography (EMG) sensors and artificial intelligence (AI) for seamless, user-driven motion. The system leverages the capability of EMG sensors to detect electrical signals from remaining muscle tissue, which are then transmitted to a Raspberry Pi Pico microcontroller for real-time processing. These signals are interpreted by a machine learning model, specifically TensorFlow Lite, to control the movement of the prosthetic arm's servo motors with high precision. This setup facilitates intuitive control, allowing users to execute complex gestures and actions with ease. The inclusion of AI not only increases the accuracy of motion predictions but also enables the system to adapt to the unique muscle signals of individual users, offering a more personalized experience. The results highlight the potential of combining bioelectric signal detection with machine learning to revolutionize prosthetic functionality, ultimately enhancing the autonomy and quality of life for users facing limb loss.

I. INTRODUCTION:

Around 15% of the global population faces some form of disability, one of the most challenging being the loss of a hand, whether due to congenital conditions or amputation. Living without a hand can create significant obstacles in daily life, impacting the ability to perform everyday tasks and reducing independence. To address this issue, this project focuses on the development of a prosthetic arm integrated with an electromyography (EMG) sensor. The EMG sensor offers a straightforward application process and is relatively comfortable for users. While there may be some minimal discomfort during its use, the benefits far outweigh the drawbacks. By utilizing the prosthetic arm, individuals who have lost a hand can regain the ability to perform many activities that were previously difficult or impossible. This innovation aims to significantly enhance the quality of life for users, restoring functionality and independence. The prosthetic arm, with its responsive control via the EMG sensor, allows users to interact with their environment and engage in tasks they would have been limited in performing, such as eating, writing, or grasping objects. The use of this technology not only offers physical benefits but also contributes to the psychological well-being of those affected, providing a sense of empowerment and improved social inclusion.

II. Project Overview:

A. Overall System Diagram

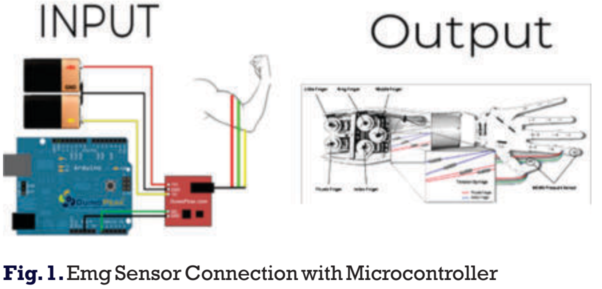


Fig. 1. Emg Sensor Connection with Microcontroller

The diagram above shows the connection of the EMG sensor with the microcontroller, the microcontroller shown in the diagram is Arduino Uno R3. However, the paper will be using the Raspberry Pi Pico for this for this project instead. The EMG Sensor output will be received using the analog input of the microcontroller. After this the paper would connect the microcontroller to control the motors of the arm to allow for movement base on the processed output. After that the values is passed on to an AI algorithm to be processed. Then the output of the algorithm is used to determine the action the Robotic Arm will make.

B. Hardware

1) Microcontroller

2) Raspberry Pi Pico: The Raspberry Pi Pico is a compact and adaptable microcontroller board, powered by the Raspberry Pi RP2040 chip. This microcontroller is equipped with a dual-core ARM Cortex-M0+ processor, capable of running at speeds of up to 133MHz, making it highly efficient for various embedded applications. It includes 256KB of RAM and 26 flexible GPIO pins, offering diverse connectivity and interaction possibilities. The board also features 2MB of QSPI Flash memory for storing program code and data, which ensures seamless performance in low-footprint environments.

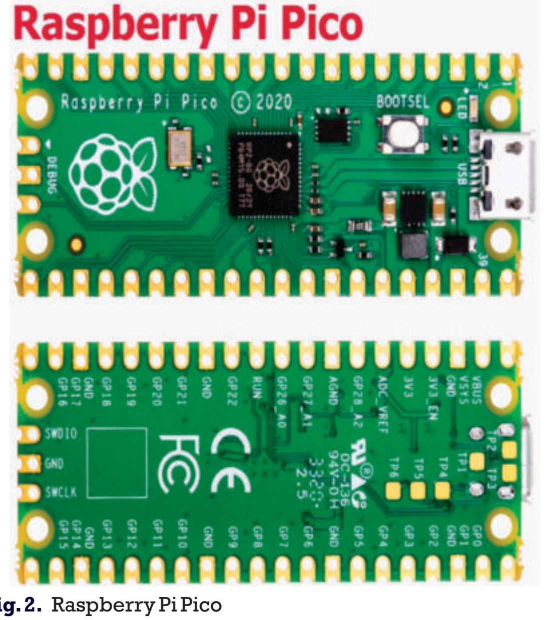


Fig. 2. Raspberry Pi Pico

the paper selected the Raspberry Pi Pico for the project due to its small form factor, combined with the powerful ARM Cortex-M0+ architecture. This processor's efficiency allows for the deployment of lightweight machine learning models, such as TensorFlow Lite, which is essential for the project's computational tasks.

3) EMG Sensors: The EMG sensor is one of the most important components of the project. It is used to measure the muscle activity in the arm. So that the paper can use the output of the EMG sensor along with an AI algorithm to be able to control the arm movements.

Fig. 3. EMG Sensor

4)Flex Sensors: A flex sensor is a ultra-thin high- sensitivity sensor that detect the amount of deflection or bending in one direction. When the sensor is flexed or bended across the sensing area, the resistance of the sensor increases causes the output voltage change, the greater the pressure, the greater the output voltage.

Fig. 4. Flex Sensors

5) Servo Motors: The servo motor is a rotational actuator, that can be control with high precision and efficiency. The servo motor will be used in controlling the movements of the arm. The servo motor will be controlled according to the prediction of the AI algorithm which will determine how each servo motor will move to perform an action according to the hand gesture of the user.

Fig. 5. Servo

6) Power Supply: Lithium-Ion (Li-Ion) Battery: The Lithium-Ion (Li-Ion) battery operates based on the movement of lithium ions between the positive and negative electrodes during the charging and discharging processes. When discharging, lithium ions travel from the anode to the cathode through the electrolyte, and the reverse occurs during charging. Li-Ion batteries are widely recognized for their high energy density, offering more power storage within a compact design compared to traditional rechargeable battery technologies. With a nominal voltage of 3.6V, they provide more voltage than many other battery types, which makes them ideal for applications demanding high power outputs, such as electric vehicles, portable electronics, and more. Another significant advantage of Li-Ion batteries is their minimal maintenance requirements. These batteries are designed to retain their capacity for a long period, but they benefit from proper charging practices, such as avoiding over- charging and deep discharges, to maximize their lifespan. Li- Ion batteries also feature integrated safety circuits to prevent damage from excessive current or temperature variations. Moreover, Li-Ion batteries are lightweight and have a low self-discharge rate, ensuring they can retain charge for longer periods when not in use. These properties make them the preferred power solution for a wide range of modern technological devices.

Table I Li-Po VS Li-Ion Battery

	Li-Po	**Li-Ion**
Name	Lithium-Polymer	Lithium-Ion
Voltage Range	3V to 4.2V	3V to 4.2V
Flexibility	High	Low
Costs	Slightly Expensive	Low
Capacity	2 times higher at same volume	Relatively Lower

7) Robot Arm: This is the design of the Robot Arm the paper purchased. The arm uses up to 6 servo motors to control each finger individually, with each finger's movement being regulated by the servo motor pulling a zip tie.

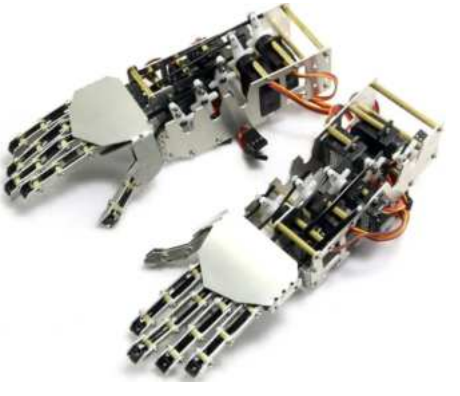


Fig. 6. Robot Arm

C. Software

1) **Arduino IDE:** Arduino IDE is an Integrated Development Environment that is use for uploading programs and communication to Arduino Boards or other supported micro- controllers and microprocessors. For this project the paper plan on using the Arduino IDE's serial plotter to visualize the output pattern from the EMG Sensor before using TensorFlow to train the data.
2) **Visual Studio Code:** Visual Studio Code (VS Code) is a highly versatile source code editor that offers powerful features such as integrated debugging, task automation, and version control support. It stands out for its lightweight nature while maintaining an extensive set of capabilities tailored for efficient development. Additionally, VS Code provides a robust extension marketplace, enabling users to personalize their development environment. These extensions can enhance the editor's functionality, supporting a wide range of languages, tools, and frameworks. For this project, the paper will leverage Visual Studio Code as the primary development environment, utilizing the Pico SDK alongside TensorFlow Lite for C++ integration. These tools will help streamline the development process, allowing for efficient coding, debugging, and model optimization.
3) **Pico SDK:** The Pico SDK or Raspberry Pi Pico SDK allows developers to write programs to the Raspberry Pi Pico

using C, C++, or Assembly Language. By providing headers, libraries, and build system necessary for it. The paper plan on using the Pico SDK in this project because the official TensorFlow lite library does not support the Raspberry Pi Pico board in Arduino. Hence, the paper have to use C++ in order to use TensorFlow lite with it .

4) **Tensorflow Lite (TinyML):** TensorFlow Lite also called TinyML is a AI Framework designed for microcontrollers or devices with minimal memory. It is written in C++and requires a 32-bit platform. With TensorFlow Lite the paper can use it to train the input from the EMG Sensors and predict the action of the arm making the control of robotic arm easier.

III. Activities And Progress

A. Issues and Challenges:

1. **TensorFlow Compatibility Issues:** The Raspberry Pi Pico the necessary specs to run the TensorFlow Lite. However, there is no official library for running TensorFlow Lite. The model can be train using TensorFlow in PC and convert to TensorFlow Lite for the microcontrollers later .
2. **Costs of 3D Printing:** Currently the paper are planning on 3D printing the Robotic Arm, however the paper haven't design it or haven't found any model the paper can use to estimate the cost yet so the paper aren't sure of the price. From questing the friends using PCBway website, it can get a bit pricy if there are lots of part and uses strong material.

B. Activity and Progress:

1) **Flowchart:**

Fig. 7. Flowchart

2) **Sensor Values:** As shown in the Fig.8, the paper were able to connect the emg with the oscilloscope and use the power supply in the lab to provide 5 positive and negative voltage to power the EMG sensor. The sensor uses three electrodes pad that is stick to the arm in order to get a single input. When the hand is closed the signal increases and when the hand is opened/relaxed the signal becomes still almost flat.

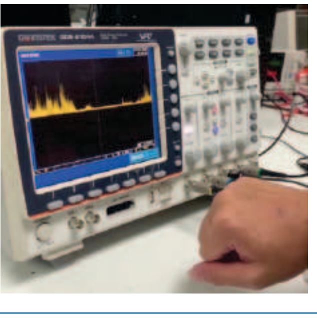


Fig. 8. Output of EMG Sensor

3) **Smoothing the Signals:** As the paper can see in Fig. 9 the output given by the sensor is not really smooth, and could be hard to work with. So in order to fix it the paper will be applying a filter to help smoothen the curve and make it easier to work with. The paper has decided to use the second order low pass filter in order to smoothen the curve. The filter was able to smoothen the curve when compared to the original unfiltered signal. However, the filter introduced a slight delay.

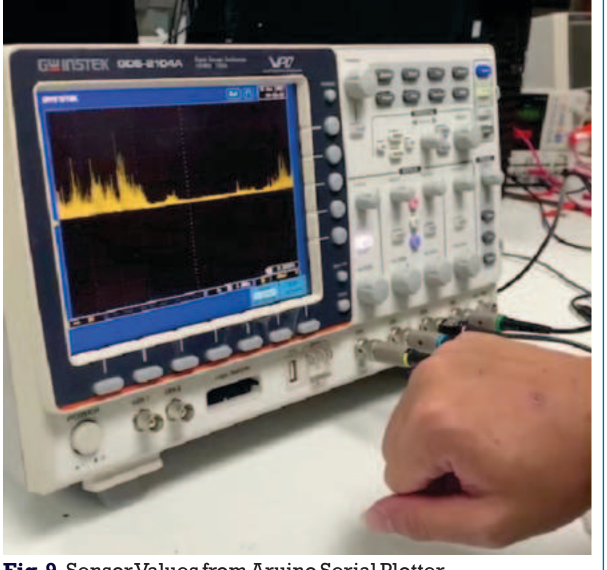
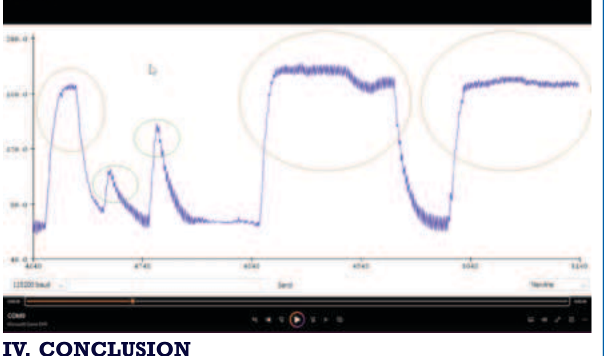


Fig. 9. Sensor Values from Aruino Serial Plotter.

4) **AI Training:**

Data Preparation: For the data preparation the paper will be using MATLAB to visualize what the data for open and close is. The paper will be dividing the recorded data into training data and testing data. 80% of the recorded data will be used for training data and 20% of it will be used for testing data. The recorded data will be from 30-40 people; each person will each open and close their hand for 1 minute. Here is the histogram of the recorded data for open and close hand



IV. CONCLUSION

The smart robot arm project based on the EMG sensor is a project that can help improve the lives of disabled person or amputees. As it allows them to be able to control their arm or missing parts again. This can also be implemented to other projects such as a remote surgery robot that require precise hand movement, or in industrial environment when testing chemicals without going near it. Currently the project is at its early stages and minor changes may occur in the future.

REFERENCES

[1] World Health Organization, "Disability and health," WHO Fact Sheets, Nov. 2021. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/disability-and-health

[2] United Nations, "Fact sheet on persons with disabilities," United Nations Department of Economic and Social Affairs, 2021. [Online]. Available: https://www.un.org/development/desa/disabilities/r esources/ factsheet-

on-persons-with-disabilities.html

[3] D. Farina et al., "The extraction of neural information from the surface EMG for the control of upper-limb prostheses: Emerging avenues and challenges," IEEE Transactions on Neural Systems and Reha- bilitation Engineering, vol. 22, no. 4, pp. 797-809, July 2014. doi: 10.1109/TNSRE.2014.2305111.

[4] S. S. Rautaray and A. Agrawal, "Vision based hand gesture recogni- tion for human computer interaction: A survey," Artificial Intelligence Review, vol. 43, pp. 1-54, Jan. 2015. doi: 10.1007/s10462-012-9356-9.

[5] A. Manthiram, "A reflection on lithium-ion battery cathode chem- istry," Nature Communications, vol. 11, no. 1550, Mar. 2020. doi: 10.1038/s41467-020-15355-0.

[6] E. Upton, "Raspberry Pi Pico: Specifications and Features," The MagPi Magazine, Jan. 2021. [On- line].Available:https://magpi.raspberrypi.com/ articles/ raspberry-pi-pico-microcontroller-specifications-features-and-rp2040.