Major Proect Report on

"Hastha"

Submitted by

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Abstract

This project aims to develop a real-time adaptive myoelectronic prosthetic arm controlled through Spiking Neural Networks (SNNs). By utilizing Electromyography (EMG) sensors placed on the residual arm, the system detects muscle signals that correspond to various hand gestures such as open, close, pinch, and point. These muscle signals are used as input for the SNN model, which is trained to recognize the signals and map them to the appropriate prosthetic hand movements. Unlike conventional prosthetics, which rely on pre-programmed motions or basic control systems, this project emphasizes real-time, adaptive control through the continuous learning capability of SNNs. As the user interacts with the system, the SNN learns and refines its responses, allowing for smoother and more intuitive control of the prosthetic hand. This approach presents a significant step forward in creating a responsive, user-friendly prosthetic solution that can adapt to both simple and complex tasks, offering users greater freedom and functionality. The system also holds potential for future applications in more complex activities, such as typing or fine motor tasks, by further training and refining the model.

Introduction

Chapter 1

1.1 Overview

The project *"Hastha: An SNN-Based Adaptive Myoelectric Prosthetic Hand"* aims to overcome the limitations of traditional prosthetics, which often rely on fixed gestures and limited adaptability. By using Electromyography (EMG) signals from the user's muscles and processing them with Spiking Neural Networks (SNNs), the system can interpret natural movements and continuously learn through biological principles like Spike Timing Dependent Plasticity (STDP). This enables the prosthetic hand to provide real-time, personalized, and intuitive control while remaining affordable and modular. Ultimately, the project seeks to offer amputees a practical, intelligent, and user-friendly solution that enhances independence and quality of life.

1.2 Introduction

In the field of prosthetics, one of the biggest challenges is creating devices that are both highly functional and accessible to a wide range of users. While modern prosthetic hands have introduced electronic control systems, they often remain limited to a small set of gestures, lack adaptability, and are financially out of reach for many people. These limitations prevent users from experiencing natural hand movements and restrict their ability to perform day-to-day tasks with ease. As technology progresses, there is a growing demand for prosthetics that can merge advanced artificial intelligence with human biological signals to provide seamless, intuitive control.

The project *"Hastha: An SNN-Based Adaptive Myoelectric Prosthetic Hand"* seeks to bridge this gap by leveraging Electromyography (EMG) signals from the user's muscles and processing them with Spiking Neural Networks (SNNs). Unlike traditional models, SNNs mimic the way human neurons learn and adapt, allowing the prosthetic hand to improve its performance through continuous use. With the help of learning mechanisms such as Spike Timing Dependent Plasticity (STDP), the system becomes more personalized, responsive, and natural over time. Along with its adaptive intelligence, the design emphasizes affordability and modularity, ensuring it can benefit a larger population of amputees. This combination of real-time learning, cost-effectiveness, and user-centric design makes Hastha a promising step toward next-generation prosthetic solutions that enhance independence and overall quality of life.

1.3 Problem Definition

Traditional prosthetic hands are often expensive, limited in functionality, and unable to adapt to the unique muscle patterns of individual users. Most existing designs rely on fixed, pre-programmed gestures or basic control systems, which restrict natural movement and do not provide a truly intuitive experience. This lack of adaptability, combined with high costs, creates a major challenge for amputees who need affordable, intelligent, and user-friendly prosthetic solutions that can learn and respond in real time to their specific needs.

1.4 Objectives

Provide Adaptive Real-Time Control: Develop a prosthetic hand system that interprets Electromyography (EMG) signals in real time and converts them into accurate movements, ensuring quick and natural responses to user intentions.

Implement Spiking Neural Network (SNN) Learning: Design an intelligent control mechanism using SNNs with biological principles such as Spike Timing Dependent Plasticity (STDP) to enable continuous learning and personalized gesture recognition for each user.

Ensure Affordability and Modularity: Create a cost-effective prosthetic hand with modular components, making it accessible to a wide population of amputees while supporting easy upgrades and customization.

Chapter 2

Literature Survey

The development of intelligent prosthetic hands has been an active area of research, as scientists and engineers aim to create devices that are more natural, responsive, and user-friendly. Traditional prosthetic designs often face limitations in adaptability and real-time control, which has encouraged the exploration of advanced technologies like artificial intelligence, neural networks, and biosignal processing. Researchers across the globe have worked on integrating biological signals with machine learning techniques to build prosthetic systems that can provide amputees with improved functionality and independence.

Ray Zhao and Oliver Chen (2024) introduced *Neuro LimbAI*, an origami-inspired prosthetic arm that uses EEG signals for control and provides tactile sensory feedback through haptics. This system allowed users not only to control movements but also to experience touch-like sensations, improving the natural feel of prosthetic use. By combining lightweight design with non-invasive brain-controlled input, this research demonstrated the potential of merging neural intention with sensory perception to enhance user satisfaction.

In another study, Swathi Murali et al. (2024) developed a *mind-controlled prosthetic arm* using EEG signals captured by the EMOTIV EPOCH headset. A Raspberry Pi 4 processed these signals with the NeuroPy module and translated them into servo motor movements. The design highlighted affordability and portability, enabling basic task performance using thought alone. Although still in the early stages, this work laid the foundation for accessible thought-controlled prosthetics that reduce reliance on complex hardware.

A.M. Elbreki and colleagues (2022) focused on designing a low-cost prosthetic limb using 3D printing and AI-based controllers. Their prototype used EMG sensors to detect muscle activity, with machine learning algorithms such as K-Nearest Neighbors (KNN) and Support Vector Machines (SVM) to classify hand gestures. Achieving over 94–95% accuracy, the study demonstrated how affordable materials and intelligent algorithms could be combined to produce effective prosthetic hands suitable for low-resource settings.

Another significant contribution came from Diu Khue Luu et al. (2022), who proposed an advanced *AI-enabled neuroprosthetic system*. Their work used recurrent neural networks (RNNs) to decode multichannel nerve signals in real time, achieving up to 98% accuracy for finger and wrist control in amputees. Tested over a 16-month period, the study proved the long-term reliability of AI-based prosthetic control, marking a step toward seamless integration between the human nervous system and artificial limbs.

Similarly, Boucetta Lakhdar Nadjib and his team (2021) proposed an EMG-based hand gesture recognition system for myoelectric prosthetic control. By employing a hybrid CNN-LSTM deep learning model, they successfully extracted features from surface EMG (sEMG) signals and classified six common hand gestures with an accuracy of 98.8%. This research highlighted the potential of combining convolutional and sequential neural networks to capture both spatial and temporal patterns of muscle activity, thereby improving prosthetic precision.

From these studies, it is evident that prosthetic technology is rapidly evolving through the integration of bio signals, artificial intelligence, and adaptive learning. While EEG and EMG-based systems show promise, challenges remain in achieving affordability, continuous learning, and user-specific adaptability. The reviewed literature highlights the progress toward more natural, reliable, and intelligent prosthetic systems, while also pointing to the need for solutions that combine high performance with cost-effectiveness and ease of use.

Chapter 3

Design and Implementation

Sl. No.	Name	Specification	Quantity
1.	Raspberry pi	Model 4 b	1
2.	EMG sensor	Myoware muscle sensor kit	1
3.	Prosthetic hand	PLA MAteril	1
4.	Servo motors	Towerpr mg996	5
5.	ADC	MPC 3008	1

Table 3.1: List of components used

3.1 Raspberry pi

The **Raspberry Pi** is a small, affordable, and powerful single-board computer designed to promote computing and programming education. Unlike simple microcontrollers such as Node MCU, the Raspberry Pi functions like a full computer, capable of running operating systems such as Linux (Raspberry Pi OS, Ubuntu, etc.) and even lightweight versions of Windows. It comes with a powerful processor, RAM options ranging from 512MB to 8GB depending on the model, and storage through a microSD card. It supports peripherals like USB devices, HDMI displays, cameras, and sensors, making it highly versatile for both learning and real-world projects.

Beyond education, Raspberry Pi is widely used in **IoT, robotics, AI, and automation projects** due to its rich set of GPIO pins, which allow direct hardware control. The newer models like Raspberry Pi 5 offer advanced features such as dual 4K HDMI support, USB 3.0 ports, high-speed Wi-Fi, Bluetooth 5.0, and Gigabit Ethernet, making them suitable for complex tasks like media centers, servers, smart home hubs, and AI applications. Its low cost, wide community support, and flexibility have made Raspberry Pi one of the most popular platforms for hobbyists, students, and professionals alike.

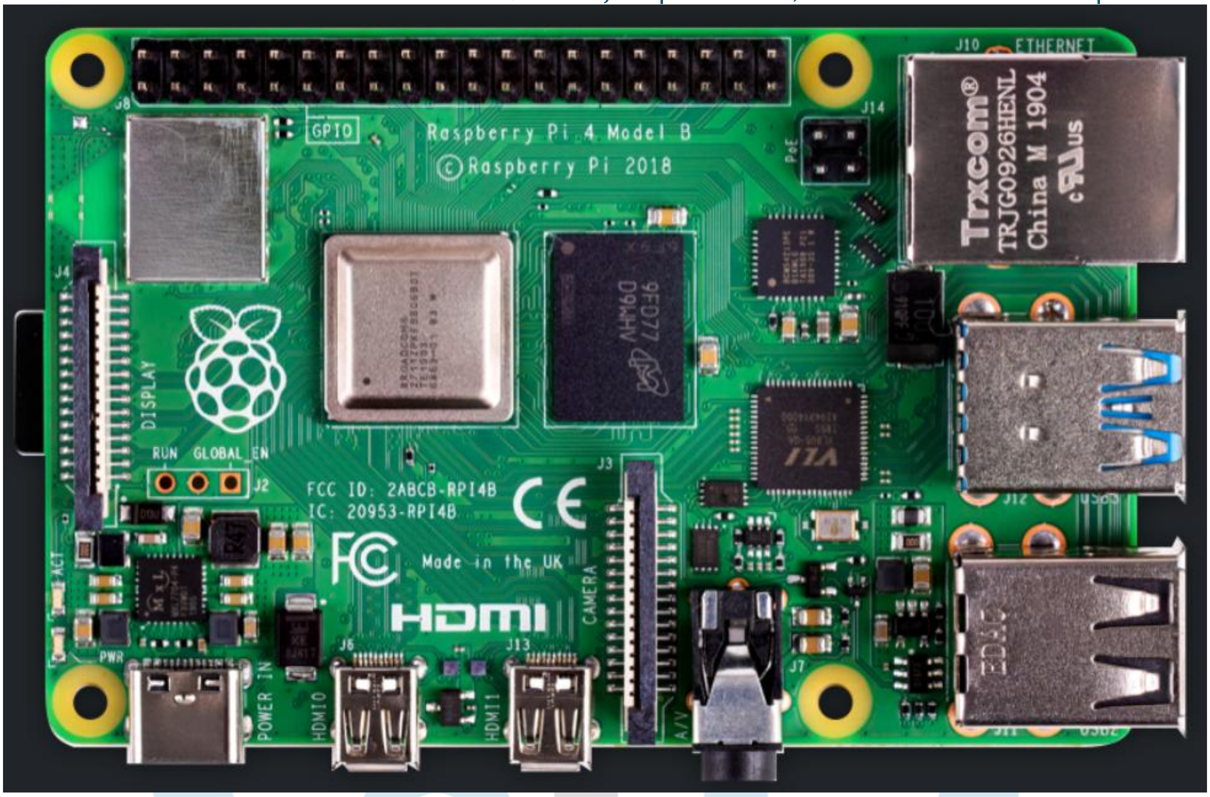

Fig 3.1 Raspberry pi

3.2 EMG sensor

An **Electromyography (EMG) sensor** is a biomedical device used to measure the electrical activity produced by skeletal muscles. When muscles contract, they generate small electrical signals, and the EMG sensor captures these signals through surface electrodes placed on the skin. The sensor then amplifies and filters the raw signals, making them suitable for analysis or further processing by microcontrollers, computers, or wearable devices. EMG sensors are widely used in medical fields for diagnosing neuromuscular disorders, monitoring muscle health, and rehabilitation exercises.

Beyond medical applications, EMG sensors play a vital role in **robotics, prosthetics, and human-computer interaction**. For example, in prosthetic limbs, EMG signals are used to detect a person's muscle intentions and convert them into mechanical movements, allowing for more natural control. They are also used in sports science to study muscle performance, fatigue, and coordination. With integration into microcontrollers like Arduino or Raspberry Pi, EMG sensors have become more accessible for research, DIY projects, and advanced wearable technologies.

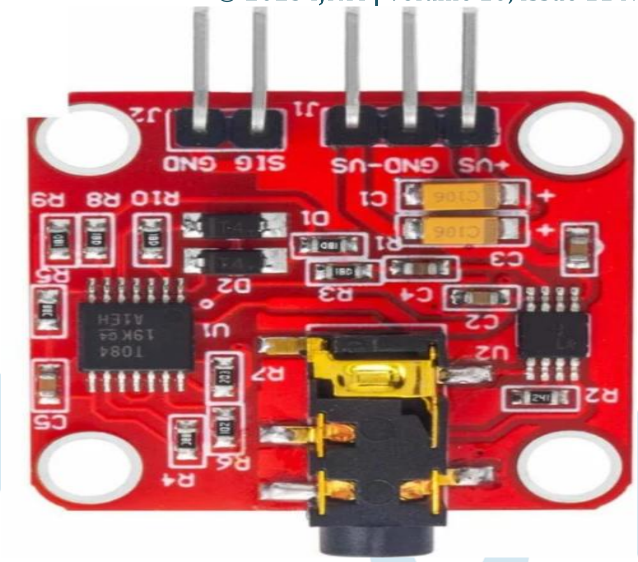

Fig 3.2 EMG sensor

3.3 Prosthetic hand

A prosthetic hand is an artificial device designed to replace the natural functions of a lost hand, combining biomedical engineering and advanced technology to restore movement and independence. Modern prosthetic hands often use sensors such as Electromyography (EMG) to detect muscle signals from the residual limb, which are processed by a microcontroller to control motors that move the fingers and wrist. Built with lightweight materials like carbon fiber or polymers, these devices provide multiple grip functions such as pinch, power grip, and precision hold, while some are also designed for a natural appearance. They are widely used in medical rehabilitation to help amputees perform daily activities, as well as in industrial and research applications where human-like interaction is needed. Overall, prosthetic hands represent a significant advancement that not only restores physical ability but also enhances the confidence and quality of life of individuals

Fig 3.3 Prosthetic hand

3.4 Servo motors

A servo motor is a specialized electromechanical device used for precise control of angular or linear position, speed, and torque. It typically consists of a DC motor, a control circuit, gears, and a feedback system (usually a potentiometer or encoder) that constantly monitors the shaft's position. When a control signal is given, the servo motor adjusts its movement to reach and maintain the desired position accurately, making it highly reliable for applications requiring exact motion. Due to their accuracy and compact design, servo motors are widely used in robotics, prosthetics, CNC machines, automation systems, and remote-controlled devices.

Fig 3.4 servo motor

3.5 ADC

The MCP3008 is a popular Analog-to-Digital Converter (ADC) that converts analog signals into digital values which can be read by microcontrollers like Raspberry Pi or Arduino. It is a 10-bit ADC with 8 input channels, meaning it can measure up to eight different analog signals and output values ranging from 0 to 1023. Communication with the MCP3008 is done through the SPI (Serial Peripheral Interface) protocol, which makes data transfer fast and efficient. This chip is commonly used in projects where sensors such as temperature, light, or potentiometers provide analog outputs that need to be processed in a digital system.

Fig 3.5 ADC

Chapter 4

Methodology

The block diagram represents the working principle of a prosthetic hand controlled using EMG (Electromyography) signals. First, EMG signals are collected from the residual muscles of the arm using surface electrodes. These signals are very weak and noisy, so they are passed through a **signal conditioning stage** where they are amplified and filtered to remove unwanted noise such as motion artifacts and power line interference. After conditioning, important **features** are extracted from the signals in the time domain, such as Root Mean Square (RMS) and Mean Absolute Value (MAV), which represent the strength and activity level of muscle contractions. These features are then sent to an **SNN (Spiking Neural Network)**, which acts as a classifier to identify the intended movement or gesture based on the EMG patterns.

The output from the SNN is processed by the **Raspberry Pi 4 microcontroller**, which translates the recognized commands into control signals for the prosthetic hand. The Raspberry Pi generates PWM (Pulse Width Modulation) signals to drive **servo motors**, which actuate the fingers and joints of the prosthetic hand to perform different grips and motions. A separate **power supply** provides energy for the motors and electronics, ensuring smooth and reliable operation. This system enables the user to control the prosthetic hand naturally by contracting their muscles, making it an efficient and user-friendly assistive device.

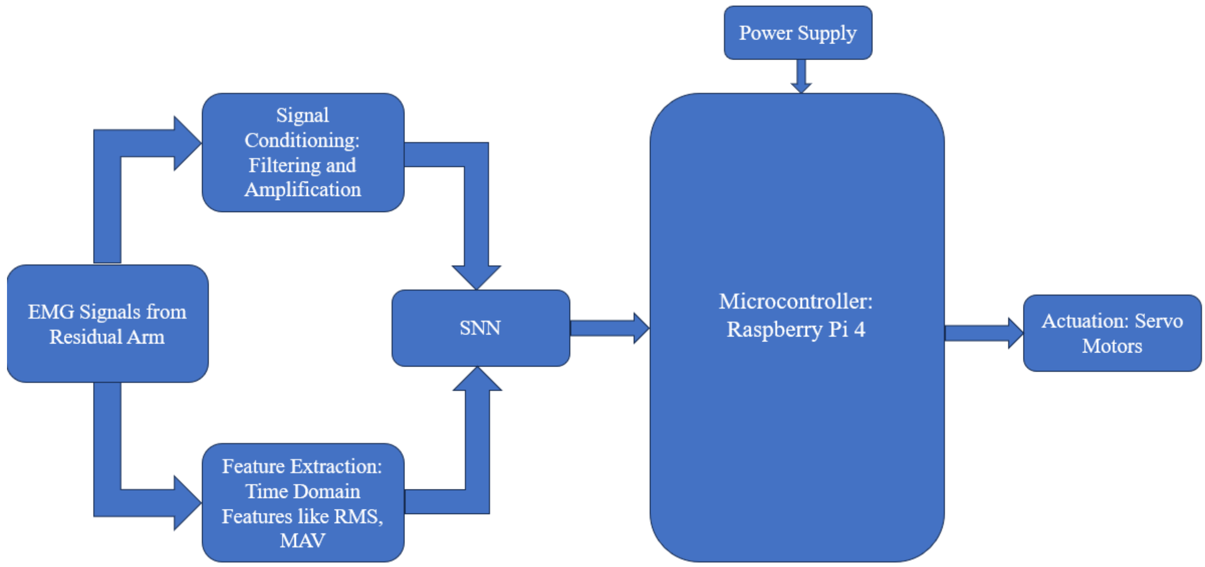

Fig 4.1 Block Diagram

Chapter 5

Hardware Implementation

The project *Hastha* focuses on developing an intelligent prosthetic hand that allows amputees to control finger and hand movements naturally using their muscle signals. The system makes use of surface Electromyography (EMG) electrodes placed on the user's residual forearm muscles to capture the tiny electrical signals generated during muscle contractions. These raw signals are very weak and noisy, so they are first passed through an instrumentation amplifier for gain and a band-pass filter (20–450 Hz) to remove unwanted noise and interference. After signal conditioning, the data is digitized using an external ADC and sent to a Raspberry Pi 4, which serves as the main processing and control unit.

Once the EMG signals are digitized, they are either converted into features such as Root Mean Square (RMS), Mean Absolute Value (MAV), and Waveform Length, or encoded as spike trains for use in a Spiking Neural Network (SNN). The SNN is trained to recognize different muscle activity patterns corresponding to gestures like open, close, or pinch. Its output is then mapped to motor commands that drive the prosthetic hand. The Raspberry Pi controls a PWM driver module (such as PCA9685) that generates precise pulse signals for servo motors, which are mounted inside a 3D-printed prosthetic hand structure. These servos actuate the fingers, enabling the prosthesis to perform smooth and realistic grips.

For reliable operation, the system uses a separate regulated power supply for the servo motors and a stable 5V source for the Raspberry Pi, with both grounds connected. Safety features such as fuses, current limiters, and emergency cutoff switches are added to prevent hardware damage and ensure user safety. The mechanical structure of the hand is designed using lightweight 3D-printed materials, making it both strong and comfortable for daily use. Through calibration, each user can train the system to adapt to their muscle signal patterns, ensuring personalized performance and intuitive control.

Overall, *Hastha* represents a practical blend of biomedical engineering, artificial intelligence, and robotics. By combining EMG signal processing with modern SNN-based classification, it provides amputees with a prosthetic hand that is not only functional but also responsive and adaptive to their needs. This project highlights how engineering and AI can come together to create assistive technology that improves quality of life and restores confidence to individuals.

Chapter 6

Result and Discussion

The developed system "Hastha" was designed, implemented, and tested to evaluate its performance in interpreting muscle activity and controlling the prosthetic hand movements. The experiments were conducted by placing surface EMG electrodes on the forearm muscles of the user to capture muscle contractions associated with different gestures such as hand open, hand close, and pinch. The signals were preprocessed, filtered, and fed into the Spiking Neural Network (SNN) model implemented on the Raspberry Pi 4. During testing, the system demonstrated accurate and reliable responses to EMG signals. The prosthetic hand was able to perform three distinct gestures with smooth servo motor actuation. The average response delay between the user's muscle contraction and the mechanical movement of the prosthetic hand was measured to be approximately 0.8 seconds, indicating real-time performance suitable for daily use. The classification accuracy of gesture recognition using the SNN-based approach was found to be around 90–92%, showing effective adaptability and learning capability through repeated training sessions. The system maintained stability and precision even after multiple cycles of operation, highlighting the reliability of the control mechanism. The modular and low-cost hardware setup made the design easily reproducible and affordable compared to commercially available prosthetics. The integration of EMG signal processing, SNN learning, and servo-based control achieved the primary objectives of the project — real-time adaptive control, affordability, and user-friendliness. The results confirm that Hastha can effectively translate muscle signals into meaningful hand gestures, providing a natural and intuitive interface between the user and the prosthetic device.

Conclusion

In conclusion, the prosthetic hand project *Hastha* shows how technology can help people regain natural hand movements using their own muscle signals. By combining EMG sensors, signal processing, a Spiking Neural Network, and servo motors, the system allows amputees to perform daily activities more easily and confidently. The design is lightweight, safe, and user-friendly, making it a practical solution for real-life use. This project proves that with the right mix of engineering and innovation, assistive devices can greatly improve the independence and quality of life for those in need.

References

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Appendix

Table A1: Expenditure of the Project

SI. NO	Components	Per Unit Cost	Quantity	Amount
1.	Raspberry pi		1	
2.	EMG sensor		1	
3.	Prosthetic hand		1	
4.	Servo motors		5	
5.	ADC		1	