Capstone Project Proposal

Project Name: Nexus: AI for Bionic Arm

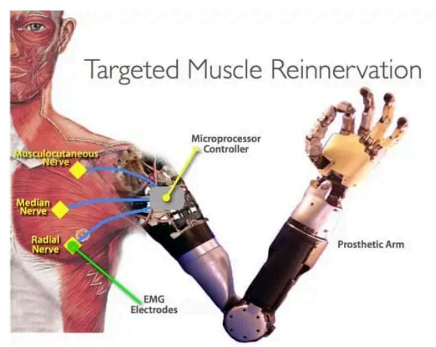
Student: Abhinav Maru

Area of Concentration: Project Management

Final Product: An AI model that can accurately predict finger movements using myography signals and enables individual finger movements.

1 PROJECT BACKGROUND

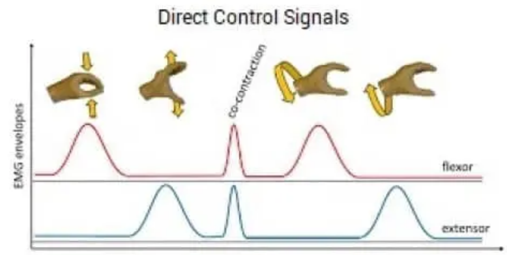
Many of us take our bodies for granted, and we do not give another thought to the arms and limbs and our second-nature control of them. However, there are many people that are not born without a fully developed limb and even more that had theirs amputated as a result of various circumstances. These individuals are not able to live the same kind of lives as the rest of us and often need to rely on other people or means to get by. Not only is their quality of life much lower because they aren't able to enjoy the same freedoms as the rest of us, but their confidence and self-esteem may take a hit as well due to not being able to take care of themselves.



Numerous medical prosthetics, bionics, and advances have been made for amputees. However, these solutions have a few key flaws. The core problem is improving the dexterity and usability of prosthetic limbs while reducing costs. Many prosthetics lack precision in movement or fail to respond accurately to user input, limiting their effectiveness in everyday tasks. The very precise solutions usually involve some kind of surgery or alternative control mechanisms that are very expensive with their limitations. The average prosthetic arm can cost anywhere between 10 thousand dollars and 100 thousand dollars. By incorporating AI, the goal is to predict the user's intent and adapt to the surroundings to create a more intuitive and functional prosthetic arm that adapts to the user's needs. I want the model to act as a middleman between the body and the bionic rather than simply mapping the raw EEG signals to the motors, which many products currently do.

I want to do this project because my grandfather suffered from a paralyzed leg and wasn't able to enjoy his life as freely as before. I want amputees to have the same quality of life as the rest of us and not feel bad because they aren't able to do something. As a result, in order to make bionics more accessible, it is important to introduce a low-cost solution that still has many of the benefits of other arms on the market. The success of this project would mean that a disabled person wouldn't need to break the bank or have complicated surgery done to get a bionic.

2 PROJECT SCOPE



This project would involve designing and implementing an AI-driven algorithm to improve the functionality of a prosthetic arm. This will involve only software development and testing for the AI for the pre-existing bionic prototype. The model will enhance motor control, grip precision, or responsiveness by processing sensor data, recognizing user intent, and delivering precise commands to the arm. The scope of the AI model will be confined to only being a predictive model and will not involve any reinforcement or generative AI models or techniques whatsoever. This would ensure that the minimum viable product can be achieved without too much extra work in designing a proper architecture, unlike the other approaches. Furthermore, the model needs to be able to simultaneously provide outputs for multiple motors. However, the input for the fingers only needs to be 1 dimensional, as the prosthetic arm itself is not currently capable of moving them left and right. The model also needs to meet the target metrics for reliability and accuracy, and I will gather and synthesize these metrics and adjust the model's parameters accordingly. The data used to train the model will come from pre-existing datasets of myo signals, which simply need to be processed to the format for training.

This project would focus primarily on the AI and software components of a prosthetic arm, and will barely involve hardware modifications to the arm itself. Any significant design or hardware modifications will be outside of the scope of this project, meaning that I will need to use the arm version that I currently have. User testing is also part of the scope to ensure practical effectiveness. Assuming live testing of the arm is feasible, I will test if the arm can receive outputs for all degrees of freedom. However, if live testing is not feasible, then I will use or create some kind of simulation program in order to evaluate if the outputs of the model are accurate and make sense in the real-world context. Lastly, getting test subjects or real amputees will also be outside of the scope of this project as it would be difficult to manage communication along with the development of the model.

The successful creation of this AI would mean that the arm with more degrees of freedom (independent motions) than other low-cost arms, without any invasive procedures.

2.1 Goals and Objectives

Goals	Objectives
The model enhances the dexterity or the amount of gestures the arm can do.	1. The model is trained and mapped to 20 or more pre-configured gestures 2. The model also has individual & simultaneous control of fingers to allow variations and combinations of gestures.
The model is accurate, reliable, and has low latency	1. The model has an accuracy between 70-80% 2. Response time is between 5-10 seconds.
The model is trained in a reasonable time and is not computationally complex.	1. Find or curate a diverse dataset of forearm EEG's 2. The model takes less than a week at most to train.

2.2 Project Deliverables

Project Milestone	Date Estimate	Deliverable(s) Included
Milestone 1: Research Paper - Draft	11/15/2024	● Rough draft of the research paper on DL architectures for signal detection and classification, focusing mainly on implementation techniques and formatting the myo data to use with/ those techniques.
Milestone 2: Research Paper - Final	12/15/2024	● The final version of the research paper ● A comprehensive review of current signal detection architectures and preprocessing data. ● Start portfolio work
Sprint 1: Project Kickoff and Data Collection	01/15/2025	● Sourcing myo signal datasets for model training and identifying what gestures are in the data ○ Simple gestures used in everyday life ○ Finger extensions, opposition, wrist flexion, and pronation/supination ● Compilation of tools and environment setup for AI development ○ TensorFlow, VSCode, other Python packages ● Finish watching the GormAnalysis NumPy course on YT. ● Proposal revisions
Sprint 2: AI Model Design	01/27/2025	● Completed preprocessing of data ● Created training architecture ○ Includes input, hidden, and output layers ○ Output layer mapped to motor outputs. ○ Review and finalize model design ● Integrate model into C++ environment on Arduino
Sprint 3: Model Train-test Iteration 1	02/10/2025	● Run training of the model on the processed data ● Evaluation of early performance metrics (accuracy, loss, etc) ○ Evaluate performance: accuracy (<85%) and response time (between 5-10s) ● Test if the expected output is passed to motors based on the input ○ I.e Checking to see if myo signal input for the thumb results in the model passing the proper value and only to the thumb motor. ○ All 20 gestures are reproducible. ● Tune hyperparameters of the model based on evaluation. ● Progress report presentation & mentor evaluation of progress 2
Sprint 4: Model Train-test Iteration 2	02/26/2025	● Further training and testing of the model. ● Continue iterative tuning of model parameters for accuracy improvement

Project Milestone	Date Estimate	Deliverable(s) Included
Sprint 5: Model Train-test Iteration 3	03/11/2025	● Further training and testing of the model. ● Continue iterative tuning of model parameters for accuracy improvement. ● May involve architecture or parameter changes to minimize overfitting. ● Finish preliminary project portfolio
Sprint 6: Model Train-test Iteration 4	03/25/2025	● Final adjustments to the AI model ● Improved accuracy and real-time performance validation w/ arm. ● Evaluate performance: accuracy (<85%) and response time (between 5-10s) ● Test if the expected output is passed to motors based on the input ○ I.e Checking to see if myo signal input for the thumb results in the model passing the proper value and only to the thumb motor. ○ All 20 gestures are reproducible.
Sprint 7: Final Model Delivery	04/08/2025	● The final version of the AI model and a very basic command line interface. ○ On/off, metrics, and text display of the gesture. ● Comprehensive performance report with metrics on gesture accuracy, system latency, loss, training time, etc. ○ Multiple AI model performance & metric tests. ● Compile and finalize capstone project portfolio ● Start work on reflective essay due 4/16
Sprint 8: Project Wrap-up and Presentation	04/22/2025	● Final project presentation ● Submission of the complete project documentation and reflection on future improvements

3 PROJECT CONDITIONS

3.1 Project Assumptions

- My current computer has the computational resources for training the models quickly
- The actual prosthetic arm itself is in working condition
- I have the foundational knowledge to tackle the higher-order problems that may arise during model development.

3.2 Project Risks

#	Risk	Likelihood	Project Impact-Mitigation Plan
1	Not enough computational resources	Medium	One possible option is to use cloud computing, specifically something like Google Collab. I am also considering buying a more powerful computer for myself, which would be useful for this as well. Lastly, I can reduce the amount of parameters at the expense of accuracy.
2	Bionic arm breaks	Low	Low risk as the arm is almost entirely unnecessary for testing the model. I can get the exact same information by using print statements for the outputs to see what motors are “activating”, there just won’t be any motors connected to the pins.
3	The dataset of myo signals might not be diverse	Medium	Proactively search for multiple datasets and consider curating synthetic data or generating additional samples through collaborations or open-source platforms. Allocate extra time for data preprocessing and augmentation.
4	The model may not achieve the desired accuracy	High	Iteratively test and tune the model during the training phases. Use alternative algorithms or hybrid approaches if the initial architecture underperforms. Allocate enough sprints for model optimization.
5	Overfitting the model	Low/medium	Implement regularization techniques and cross-validation, and ensure a diverse dataset to improve the model's ability to generalize.

3.3 Project Constraints

- The model is trained and created using Python, but it needs to be workable and processed in C++ in order to be compatible with Arduino’s circuit boards.
- Data limitations: the data across multiple datasets might not have a consistent format, or some of the data may not be high quality, which would necessitate a change in my approach later on.
- Computational power may be another restriction, as training a model can take a good amount of time and might lead to delays or changes in my approach.

4 Project Structure Approach

The project will be divided into 2-week sprints with defined objectives and deliverables. Progress will be evaluated at the end of each sprint to refine plans and adjust future objectives. The project will use a Kanban board to manage and visualize the workflow. The tasks will be divided into stages such as "To Do," "In Progress," "Review," and "Completed." This approach will allow flexibility, ensuring continuous progress without being tied to rigid deadlines for every task. Kanban's focus on limiting work in progress (WIP) ensures that I stay focused on one or two critical tasks at a time, reducing the risk of multitasking and improving efficiency. XP (Extreme Programming) practices will also be adopted to enhance the quality of the AI model. One key practice is Test-Driven Development (TDD), where tests are written before coding. I will be using a similar approach through Jupyter Notebooks, which allows compartmentalization of code and running blocks of code individually during runtime. Continuous Integration & Refactoring will be implemented to regularly integrate, optimize, and clean up code to maintain efficiency and scalability throughout the development process. Key dependencies include a proper Python environment to train an AI model, installation of Jupyter Notebooks, an internet connection, access to a mentor or other resources, and etc.

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5 MENTOR ASSISTANCE

My mentor can help with managing computational constraints by advising on efficient resource use, leveraging cloud platforms like AWS and GPUs for scaling tasks, and deploying AI models using services such as AWS S3, EC2, and Lambda. They can guide smart system design, integration of AI into IoT devices, and implementation of real-time data processing with AWS IoT or Kinesis. Additionally, they can support end-to-end application development, offering advice on coding best practices, frontend integration with tools like Angular or ReactJS, and building a scalable backend with Java and Spring Boot. Their expertise in project management, particularly using SCRUM, will help ensure structured development, thorough documentation, and efficient team collaboration.

6 APPROVALS

Prepared by	Abhinav Maru	10/22/2024 Date
Approved by	Mahender Reddy Gurram	10/22/2024 Date
	Lynne M. Norris	Date