BIONIC EVO: Prosthetic Arm

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***Abstract*—The primary objective of this project is to design and implement an advanced prosthetic human arm that helps amputees regain functionality. The aim is to create a prosthetic arm that closely mimics the capabilities of a real human arm, allowing users to perform a wide range of daily activities and regain a sense of independence.**

I. Customer Problem

AMPUTEES struggle with independence, work, and hobbies. They often feel dependent on family members and friends, relying on them to take care of them. In addition, they may forced to retire from work or switch careers entirely due to their amputation. It makes it harder for them to make a living, oftentimes relying on government aid for survival [1]. With this prosthetic arm, we aim to recreate a normal human arm, allowing amputees to regain independence, begin to perform daily tasks such as grooming, dressing, eating, etc. without assistance. They will also be able to work, and continue any hobbies they may have had to quit due to their medical circumstance, digging them out of the hole of their financial situation that the amputated arm may have put them in. Overall, the project aims to improve the overall quality of life of amputees, empowering them to pursue new hobbies and projects and leading them to live more fulfilling and active lives [2].

A. Stakeholders

- Graduate TA
  - Providing ample guidance, the graduate TAs assigned to the Bionic EVO team will issue valuable feedback to the project, which will refine the evolution of the device at each development stage.
- Amputees
  - Bionic EVO's primary end user. The success of Bionic EVO will benefit Amputees in terms of gaining mobility to enhance their daily lives. The needs and preferences of Amputees will correlate with what the deliverables will be for the prosthetic.
- Medical Professionals
  - Prescribing amputees' needs based on their physical conditions, medical professionals such as prosthetists and physical therapists can structure Binoic EVO's fit to clients, optimizing the prosthetic design based on ongoing support and care to concurrent amputees.
- Healthcare Professionals
  - Healthcare professionals such as occupational therapists and rehabilitation specialists can enable Bionic EVO to be effectively integrated into an amputee's daily functionality to regain complete individuality.
- Manufacturers/Suppliers
  - Responsible for producing and distributing the Bionic EVO product, these manufacturers and suppliers have the discreet input of providing concerns and feedback regarding the prosthetic's quality and supply chain logistics, ensuring the best transaction between developer and client.
- Research and Development Partners
  - Research and development partners, including academic institutions, research organizations or innovators in prosthetic technology, influence improving the design, functionality and performance of the Bionic EVO.
- Insurance Companies
  - Insurance companies, providing feedback on the financial aspect of the Bionic EVO prosthetic, evaluate the medical need for the product hence determining the coverage options in terms of insurance. The evaluations made by insurance companies will directly affect the accessibility of the prosthetic.
- Marketing/Sales Partners
  - Responsible for promoting the Bionic EVO product to target markets, marketing and sales partners have a direct contribution to the outreach and awareness associated with Bionic EVO.

B. Initial Requirements

- Functional
  - Weight
    - Full weight of the prosthetic must not exceed 5 pounds
  - Range of Motion
    - Must provide a minimum of 100 degrees of flexion and extension for each finger
    - Must provide a minimum of 180 degrees of rotation of the wrist
  - Grip Strength
    - Must exert a minimum grip strength of 20 Newtons (N)
- Technical
  - Arm's Mechanical components must withstand a minimum of 100 cycles of movement without failure

  - Arm must be able to withstand at least 450N of compressive force in all directions and at least 600N of tensile force
  - Fingers must be able to withstand at least 350N of tensile force and 200N of compressive force
  - Arm must be able to withstand 5V of shock
  - Arm must be IP64 (sweat & dust) resistant
- Safety Requirements:
  - The prosthetic arm should comply with electromagnetic compatibility (EMC) standards to prevent interference with other electronic devices and ensure user safety.
  - EMF Shielding

II. Principles

A. *Supervised Machine Learning and Statistical Modelling*

1) *Regression*

$$Y_i = f(X_i, \beta) + e_i \tag{1}$$

Eq. (1) Approximation for the equation of best fit (Regression Analysis)

$$TSS = \sum_{i=1}^{n} (y_i - \overline{y})^2 \tag{2}$$

Eq. (2) Sum of Squares Formula (Logistic Regression)

Regression relates an independent variable to a dependent variable. It can be done by pretraining an equation of best fit as seen in eq. (1) using data given independent and dependent variables [3]. The sum of squares formula seen in eq. (2) allows the model to be trained by calculating the deviation of data from an equation of best fit. Calculating the variance of the data set from its mean gives a value that determines how well a modeled equation fits the given dataset thus, allowing the equation to be changed to improve the accuracy of the predicted data. Reducing the sum of squares means the model is more accurate than a model with a higher sum of squares. It is useful in determining whether a line of best fit is more accurate than a polynomial or exponential equation of best fit. Using eq. (1, 2) will allow the program to determine potential outliers in the EMG readings. It can be used to smooth out any arm movements and interpret any readings. Using muscle activity reading from the EMG sensors and modelling it to an equation where the position is the dependent variable and the readings are the independent variable, allows the position vector to be mapped such that the intended position can be determined.

B. *Classification*

Classification is a supervised machine learning model that is pre-trained with training data and can predict and label a set of data [4]. Classification can be used to determine actions and gestures that the robotic arm should make. Given the EMG readings, the arm may decide to grasp an object or it may decide to wave, which can be determined using the classification machine learning model.

1) *Random Forests and Decision Trees*

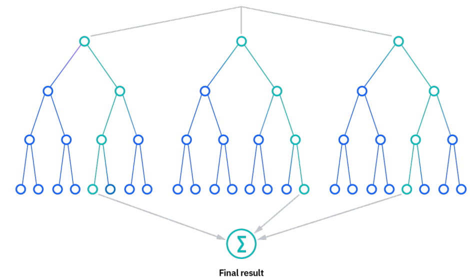

Fig. 1. A visual representation of random forests in [5, Fig. 1].

Fig. 1. is a visual representation of a decision tree used in random forests and decision trees. Initially, the random forests are divided into three subcategories which are manually defined. Decision trees are then split based on simple questions, leading to two branches: a ”Yes” branch and an ”Other” branch. This process is repeated recursively, creating subsets of data that lead to more accurate results. Fig. 1. also highlights that random forests use feature bagging and relevant questions to prevent ”overfitting” and produce more realistic predictions. Algorithms such as the Gini impurity, information gain, and mean squared error can be used to evaluate the quality of the trees, and trees are typically trained using the CART algorithm as described in [5]. Random forests use decision trees and feature bagging which are used to create a forest of uncorrelated decision trees. The major difference between decision trees and random forests is that random forests use all possible feature splits to determine an answer while random forests only use relevant questions [5]. This prevents the model from being ”overfitted” with data that only produces a correct answer while training but cannot produce answers correlated to real-world data. In this case, random forests can be used to determine what gestures the arm should make. It may determine readings from the EMG sensors and shake its hand or it may decide to make a fist.

2) *Support Vector Machines / Multiclass Classification*

$$z = w_0 + \sum_{i=1}^{\infty} w_i \vec{x}_i \tag{3}$$

Eq. (3) A hyperplane equation where w represents scalar multiples of vector x.

$$^{maximize}\alpha \sum_{i=1}^{n} \alpha_i - \frac{1}{2} \sum_{i=1}^{n} \sum_{j=1}^{n} \alpha_i \alpha_j y_i y_j K(X_i^T \cdot X_j) \tag{4}$$

Eq. (4) An equation representing the kernel trick to get the dot product of two vectors, [6, eq. (15)].

Support vector machines use vectors to split up datasets to classify them. As shown in Fig. 2. a hyperplane is used to divide clusters of data. The hyperplane is optimal when it maximizes the distance between any point stated by [8]. As described in [7], training data is given to the machine in vectors and fed to the algorithm to train the model. Any new data can also be fed to the model which will output a

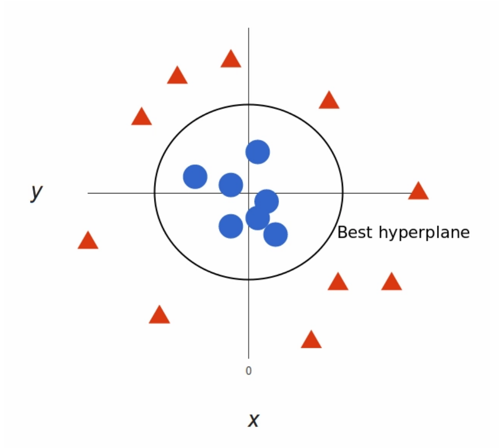

Fig. 2. A visual representation of how a hyperplane is used to divide points to classify data, [7, Fig. 4].

classification of the data. Robotic arms can incorporate SVMs and eq. (3, 4) with regression analysis to find a vector equation used to classify the data. This will help it determine gestures, and classify the EMG signals. It will also help with anomaly detection, user intent prediction, and adaptive control. The EMG signals can be input into the machine as vector equations and the algorithm can output different classifications such as anomalies and classified gestures.

C. Mathematical Modelling

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau) d\tau + K_d \frac{d}{dt} e(t) \tag{5}$$

Eq. (3) PID Control equation where K_p, K_i, K_d are PID constants, respectively [9, eq. (1)].

Proportional control is used to adjust to motor error measured. A higher K_p will help the variable reach the set point faster as described in [9]. Too high of a value will result in oscillations and the variable will always have static error. Integral control is used to address the static error in proportional control. An adequately set P and I value will allow the motor control to converge with the set point [10]. The derivative tune is used as a multiplier based on the ROC of the change of error. It dampens the effect of the error, making the motor less jittery by minimizing the over-adjustment of the correction factor. In this project, PID control can be used on numerous motors to smooth out motor control and reduce ”jittering” when the motor is in motion. With a typical arm, the arm must be able to move smoothly and stay in one place. PID control can be used to artificially replicate this function.

Electromyography (EMG) sensors will be used in this project to measure the muscle activity of an area. When detecting the activity, a lot of variance is introduced which influences the fidelity of the signal. Signal distortion and the signal-to-noise ratio contribute to the readings thus EMG signal processing is needed to reduce the signal error. Raw EMG data provides valuable information in a useless form. Different algorithms such as wavelet analysis, auto-regressive

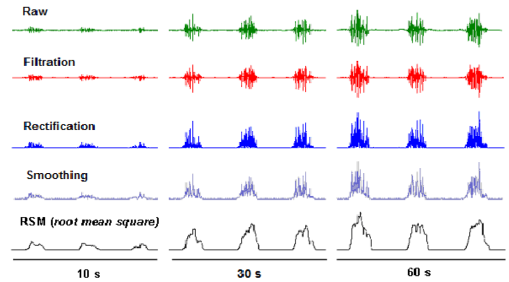

Fig. 3. depicts the recommended method for EMG signal processing, in [11, Fig. 2].

models, artificial intelligence, and higher order statistics must be used to parse this data [2, 11]. This project will use neural networks, artificial intelligence, auto-regressive models, and statistics to process the raw EMG data. It will allow the arm to replicate the intended movement of the user acting as a method of input to the program where the motors will be the output.

III. Conclusion

All aspects considered, this project proposal for Bionic EVO represents a pioneering effort within the field of prosthetic technology, with an underlying goal of enabling complete independence for amputees, where key stakeholders who will contribute their expertise for the project's success have been identified. Bionic EVO's approach combines supervised machine learning, statistical modelling, classification algorithms, and mathematical modelling to generate a prosthetic that accurately mimics human functionality. With a fully committed team backed by an experienced set of stakeholders, we as the Bionic EVO team are poised to create an effective design that is innovative in concurrent prosthetic technology. We are eager to see the journey ahead of the project, and the positive impact we expect to achieve.

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