**ELE 401 - GRADUATION PROJECT I TERM REPORT**

**Hacettepe Unıversity   
Department of Electrıcal and Electronıcs Engıneerıng**

**Project title:** Improvement of Myoelectric Underactuated Hand Prosthesis

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# **ABSTRACT**

This report presents the activities carried out as part of ELE 401 Graduation Project 1 at Hacettepe University's Department of Electrical and Electronics. The research was conducted during the summer term and aimed to improve the Myoelectric Underactuated Hand Prosthesis. The initial phase involved conducting general research to gain a better understanding of the project. Afterward, we identified challenges from previous prostheses and attempted to find solutions. Concurrently, we used a 3D printer to create components for the prosthetic hand, acquired necessary equipment, and initiated developing the required software.

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# **INTRODUCTION**

This report presents the important building blocks of a better design for which different fields have been studied and examined. After some discussion sessions, final decisions for each design units are made to improve the previous design. There are three main improvements that the project aims: EMG Signal Processing, Mechanical Control Mechanism and Sensors to provide feedback for certain tasks.

# **PROJECT DESCRIPTION**

The purpose of this project is to improve a mechanical design and EMG process algorithms that are the basis of a prosthetic hand. Within the scope of the project, some of the most important aspects of the prosthetic hand design will be improved. The high number of actuators used in the prosthetic hand, will be inefficient in terms of both the weight and power consumption of the device. For this reason, underactuated mechanical models, where the number of actuators is lower than the degree of freedom, are preferred in academic studies and industrial applications. The most common signal acquisition method in today's prosthetic hand control is to utilize EMG signals. Taking into account their functionality and ease of use, EMG controlled prosthetic devices have considerable advantages and a high potential of improvement. These prosthetic hands can be used by people suffering from limb loss after a brief training and adaptation period. This process does not require a medical procedure, since the same signals generated for the control of a healthy limb are being used, thus resulting in a natural control mechanism. In this study, predefined hand movements will be realized on an underactuated prosthetic hand by interpreting EMG signals.

# **ENGINEERING STANDARDS AND DESIGN CONSTRAINTS**

There are some basic criteria that a biomedical device should provide. The most important of which is that they should be safe and should not have a health-threatening factor. The standards related to these criteria are listed in the other section.

## **3.1. ENGINEERING STANDARDS**

ISO 13485 / 14971 / 14969 - Medical Devices Package:

The ISO 13485 / 14971 / 14969 - Medical Devices Package provides regulatory requirements for quality management medical device systems and incorporating and maintaining a risk management system associated with the use of medical devices. This package includes:

ISO 13485:2016

ISO13485:2016-Medicaldevices-Apracticalguide ISO 14971:2007

ISO/TR 14969:2004 Historical Document

*11073-20601-2008 - IEEE Health informatics – Personal health device communication – Part 20601: Application profile – Optimized exchange protocol:*

Within the context of the ISO/IEEE 11073 family of standards for device communication, this standard defines a common framework for making an abstract model of personal health data available in transport-independent transfer syntax required to establish logical connections between systems and to provide presentation capabilities and services needed to perform communication tasks. The protocol is optimized to personal health usage requirements and leverages commonly used methods and tools wherever possible.

## **3.2. DESIGN CONSTRAINTS**

1. Motion constraints of the underactuated hand must be determined.
2. Primary actuation concerning each movement and every subsequent passive actuations must be determined.
3. Size and power of the chosen servo motors must be suitable for the hand mechanics design.
4. Tendons must be properly incorporated into the underactuated structure.
5. Obtaining EMG signals from multiple electrodes.
6. Memory and processing capabilities to perform EMG signal classification.

# **BACKGROUND**

## **BACKGROUND ACQUIRED IN EARLIER COURSE WORK**

The foundational knowledge for this project was acquired through various undergraduate courses taken in the first three years of the program. The key courses that provide theoretical background for this project are:

### **4.1.1. Signals and Systems**

Understanding the concept of signals and systems is crucial for signal processing, particularly in the context of Electromyography (EMG) signals. The course covered topics like Fourier Transform and Laplace Transform, which aid in the analysis and manipulation of EMG signals.

### **4.1.2. Control Systems**

Control theory courses introduced the fundamentals of system modeling and control. These principles can be applied to understand the dynamics of a prosthetic hand, particularly in how it can be controlled using EMG signals.

### **4.1.3. Machine Learning and Data Science**

This course provided an introduction to machine learning algorithms, classification techniques, and data preprocessing. It laid the groundwork for understanding how to build and train a neural network model, as is done in this project.

### **4.1.4. Robotics and Mechatronics**

The course on robotics provided insights into actuators, sensors, and mechanical design, which are essential in developing the underactuated prosthetic hand.

### **4.1.5. Programming and Software Development**

Courses in programming languages like Python and using software tools such as TensorFlow were foundational in implementing the machine learning models and algorithms used in this project.

### **4.1.6. Fundamentals of Biomedical Engineering**

The fundamentals of biomedical engineering are crucial for developing underactuated prosthetic hands. These principles guide the design of ergonomic and efficient mechanisms that mimic natural hand movements. Knowledge in anatomy and signal processing helps in interpreting muscle signals for intuitive control. Understanding materials science ensures the creation of lightweight, durable, and biocompatible components. Human-centered design principles contribute to user-friendly interfaces, enhancing the overall functionality and usability of underactuated prosthetic hands.

## **BACKGROUND ACQUIRED THROUGH ADDITIONAL RESEARCH**

### **4.2.1. ADVANCED NEURAL NETWORK ARCHITECTURES**

Traditional neural network architectures may not be sufficient for complex EMG signal classification. Research in advanced architectures like Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) has shown promise in this domain (LeCun et al., 2015; Hochreiter & Schmidhuber, 1997).

### **4.2.2. UNDERACTUATED ROBOTICS**

While basic robotics courses provided an introduction to actuation and control, a deeper understanding of underactuated systems was needed. Academic papers and literature on underactuated robotics offer insights into the mechanics and control strategies for underactuated systems (Grizzle et al., 2014).

### **4.2.3. BIOMECHANICS AND HUMAN PHYSIOLOGY**

Understanding the physiology of human hands and their motion mechanics is crucial for designing a prosthetic hand that mimics natural movements. Research papers on biomechanics provided this understanding (Zatsiorsky & Latash, 2008).

### **4.2.4. TYPES OF SENSORS WHICH IS USED IN MYOELECTRIC HAND**

Electromyography (EMG) is an electrodiagnostic medical technique for evaluating and recording the electrical activity produced by skeletal muscles.[6] EMG is performed using an instrument called an electromyograph to produce a record called an electromyogram. An electromyograph detects the electric potential generated by muscle cells when these cells are electrically or neurologically activated.[7] The signals can be analyzed to detect medical abnormalities, activation level ,or recruitment order, or to analyze the biomechanics of human or animal movement.

Surface EMG assesses muscle function by recording muscle activity from the surface above the muscle on the skin. Surface electrodes are able to provide only a limited assessment of the muscle activity. Surface EMG can be recorded by a pair of electrodes or by a more complex array of multiple electrodes. More than one electrode is needed because EMG recordings display the potential difference (voltage difference) between two separate electrodes. Limitations of this approach are the fact that surface electrode recordings are restricted to superficial muscles, are influenced by the depth of the subcutaneous tissue at the site of the recording which can be highly variable depending of the weight of a patient, and cannot reliably discriminate between the discharges of adjacent muscles[8].

### **4.2.5. USES OF EMG ELECTRODES**

Electromyography (EMG) is usually done with wet electrodes. They are commonly made with Ag/AgCl (silver chloride). In this case, an interface with the skin is created with a gel. The problem with such electrodes is that the signal is affected by the way the electrodes are fixed over the skin and the use of gel. Besides, they irritate the skin and they are sensible to artifacts of movement and other interferences. In order to avoid these problems, dry electrodes with microneedles, which records the EMG signals, were manufactured. The micro needles pierced the stratum corneum of the skin. They improved the contact with the skin and avoided the interference caused by the dead cells. Besides, the application of a conductor gel and the preparation of the skin was not required. The micro needles were manufactured on a copper substratum with a laser beam. They were coated with gold, which is a biocompatible material. Although the size of the microneedles was very small, a good shape was obtained. The manufacturing process was carried out with a high precision and its repeatability was guaranteed. This manufacturing process is quick and cheap. The determination of the operation parameters of the dry electrodes was based on the contact impedance between the skin and the electrode. The performance of the proposed electrodes was compared with the performance of the commercial wet electrodes. The average impedance obtained were

6.5 and 9 kΩ for the wet and dry electrodes, respectively[13].

Myoelectric signals were detected from each muscle using a linear array of 8 or 16 electrodes (silver bars 10 mm apart, 5 mm long, 1 mm diameter) in single differential configuration.

Electrodes were located along the length of the muscle with the bars of the electrode array perpendicular to the direction of the muscle fibres. This muscle fiber orientation assessment procedure includes: (a) to place the electrodes following anatomical information obtained from atlas, (b) to check the uniformity of subcutaneous tissue thickness with ultrasound device to determine muscle fiber direction in the median plane[15]

# **METHODS**

The methods which will be used in this project and the goals which will achieved in this project are listed below, (give alternatives before your decision)

* + Signal Acquisition
  + EMG signal classification.
  + Mechanical control.
  + Mechanical manufacture.

## **SIGNAL ACQUISITION METHOD FOR HAND PROSTHESIS**

Hand prosthesis control can be provided by EMG signals collected from the skin surface. This task can be performed by evaluating different Signal Processing and Artificial Intelligent Methods. One can use processed raw data and determining appropriate threshold levels. The other method may use features extracted from raw data in order to assess the intention for the hand activity.

### **METHODS OF SURFACE EMG(ELECTOMYOGRAPHY)**

EMG signals are obtained by measuring the electrical activity of the user's muscles by surface electrodes. The data which is collected from here contain necessary information about the movement of the muscles. Furterer topics will introduce to process how to EMG signals are extracted from skin.

#### Amplification & ANALOG FILTER

An instrumentation amplifier with gain 21 is implemented as preamplification system to acquire the differential EMG signal. To filter the frequency components that are not within the bandwidth of the EMG signal, a range from 20 Hz to 500 Hz, a high-pass filter with cut-off frequency 20 Hz and a low-pass filter with cut-off frequency 500 Hz in second order Sallen-Key configuration. An additional amplifier is used to eliminate DC offset and amplification with gain 20.

metin, diyagram, çizgi, yazı tipi içeren bir resim

Açıklama otomatik olarak oluşturuldu

MamSense sensor card provides EMG signal that is filtered and amplified to used. As indicated in Figure a. Figure b shows the response of the acquisition card.

devre, elektronik mühendisliği, elektronik donanım, elektronik bileşen içeren bir resim

Açıklama otomatik olarak oluşturuldumetin, çizgi, diyagram, öykü gelişim çizgisi; kumpas; grafiğini çıkarma içeren bir resim

Açıklama otomatik olarak oluşturuldu

#### Digital Filter

Due to the acquisition system being subject to the interference of electromagnetic noise induced by lamps or some other external device, and in order to digitally tune the response of the filter, the design of a digital notch filter is implemented to suppress a specific frequency component, which in this case is the AC power line noise at 50 Hz (or 60 Hz if you're located in North and South America).

The transfer function H(z) of a 2nd order notch filter can be expressed in the z-domain as:

## **METHOD OF EMG SIGNAL CLASSIFICATION**

There are various methods to classify a time-function signal in machine learning. In order to understand the performance of different methods for machine learning algorithms, different studies are examined. The first study is the Classification of EMG signals for multiple hand gestures based on a neural network [5]. The goal of this research is to distinguish between five different hand movements: resting hand, open hand, cylindrical grasp, lateral grasp, and wrist pronation and supination. The motivation behind this is to enable more natural grasping movements, which in turn will enhance the ability of the wrist to move in coordination with the object being grasped. In the study, The recorded EMG signals were extracted in the time and frequency domain using 50 samples per subject each of mean absolute value (MAV), root means square (RMS), median, and waveform length (WL) for further categorization. Backpropagation (BP) is a technique utilized by artificial neural networks (ANN) for classification. The network formed in the study is trained by providing it with input and target vectors. To improve the efficiency of the training process, the input feature vectors are normalized. Backpropagation uses the gradient of the performance function to adjust the weights and minimize the performance error. The ANN structure comprises three layers: an input layer, a hidden layer with a tan-sigmoid activation function, and a linear output layer. Each layer, except for the input layer, has a weight matrix, a bias term, and an output vector. The input weights (IW) are the weight matrices that connect to the inputs, while the layer weights (LW) are the weight matrices that come from the hidden layer outputs. By dividing the training input data, the Lavenberg-Marquardt technique, which is employed for backpropagation (BP), generalizes the network for overfitting. A total of 70% of the input data is used for training, 15% for validation, and 15% for testing. The pattern recognition and neural network structure are shown in Figure 1.

**ekran görüntüsü, diyagram, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu**

Figure 1. The Neural Network Structure [5]

In the result section of the study, it is observed that The test accuracy and train accuracy of hidden neuron 1 is 40%, while those of hidden neuron 2 are 20%. Both hidden neurons 3 and 4 yielded results of 53.33%. The test and train accuracy for hidden neuron 5 is 66.67%. Test and train accuracy for hidden neuron 6 is 73.33%. The test accuracy and train accuracy in hidden neuron 7 are both 100%, demonstrating that this layer has the highest accuracy. Test and train accuracy for the eighth hidden layer is 60%. Nine and ten, the final hidden neurons, both produced 80% of the results. As a conclusion, it can be concluded that the average accuracy rate is also 80% when cross-validations are finished. We can draw the conclusion that the classifier in the MATLAB software, utilizing the Neural Network toolbox, is capable of successfully training and testing the EMG signals for the hand gesture with a high accuracy value.

The second investigation under review is titled "EMG-Based Control of Individual Fingers of a Robotic Hand" and was published in the Journal of Electromyography and Robotics [6]. The primary objective of this research is to employ electromyography (EMG) to enhance the control mechanisms for individual digits of a robotic appendage. Data for the study were collected from the broadest part of the forearms of 10 human subjects using an eight-channel surface electromyography system. The specific digits of interest in the study were the thumb, index, middle, ring, and little fingers.

For feature extraction and classification, a variety of metrics were utilized, including Standard Deviation (STD), Root Mean Square (RMS), Waveform Length (WL), and Willison Amplitude. Each electrode provided data for ten different features, resulting in an aggregate of 80 features utilized for the study.

The study conducted an exhaustive evaluation of four distinct classification algorithms to ascertain the most reliable, accurate, and computationally efficient among them. The algorithms evaluated were Linear Discriminant Analysis (LDA), K-Nearest Neighbors (KNN), Support Vector Machine (SVM), and Deep Neural Network (DNN).

The findings of the study revealed that the Deep Neural Network (DNN) model outperformed the other classifiers, achieving an average accuracy of approximately 95% in offline tests and around 92% in real-time data tests. However, it is noteworthy to mention that all the classification algorithms employed in the study managed to attain an accuracy level exceeding 90% in offline evaluations.

The test results for each classification method are shown in Figure 2.

metin, ekran görüntüsü, yazı tipi, çizgi içeren bir resim

Açıklama otomatik olarak oluşturuldu

Figure 2. Classification Result Comparison [6]

## **METHOD of MECHANıCAL MANUFACTURE**

The method chosen for the preliminary design is 3D printing with articulated joints. This choice is based on the InMoov project, which utilizes 3D printed parts for creating a robotic hand and forearm. The reasoning behind this choice is the ease of customization, rapid prototyping, and the ability to create complex geometries that would be difficult with traditional manufacturing methods.

**Components**

* **Fingers**: Thumb, Index, Majeure, RingFinger, Auriculaire (Pinky)
* **Wrist Parts**: Wristlarge, Wristsmall
* **Additional Parts**: topsurface, coverfinger, robpart2-5, ElbowShaftGear
* **Servo Motors**: For actuation

**Flow Chart**

1. **3D Print Calibration**: Print a CALIBRATOR to ensure parts fit.
2. **Part Printing**: Print all the parts with specific infill and wall thickness settings.
3. **Assembly**: Assemble the parts using bolts and screws.
4. **Servo Integration**: Integrate servo motors into the design.
5. **Tendon Routing**: Use braided fishing line for tendons.
6. **Sensor Integration**: Optional step for adding touch sensors to fingertips.
7. **Testing**: Test the assembled hand for range of motion and actuation.

**Parameters**

* **Infill Percentage**: Determines the density of the 3D printed parts.
* **Wall Thickness**: Thickness of the outer shell of the 3D printed parts.
* **Servo Type**: Type of servo motors used for actuation.
* **Tendon Material**: Material used for the tendons (e.g., braided fishing line).

**Design Choices**

* **Finger Design**: Choice between simple and double-actuated thumb.
* **Sensor Integration**: Option to include touch sensors in the fingertips.
* **Tendon Routing**: Choice of routing tendons through the middle or side holes in the wrist.
* **Cover Options**: Choice to include covers for aesthetics and functionality.

Additional Notes

* **Material**: The material used for 3D printing can be either ABS or PLA.
* **Glue**: Acetone for ABS and Epoxy for PLA.
* **Bolts and Screws**: Various sizes are used for assembly, and some can be 3D printed.

This design is based on the [InMoov hand and forearm project](https://inmoov.fr/hand-and-forarm/), which provides a comprehensive guide for 3D printing and assembling a robotic hand and forearm. The project includes a list of parts needed, printing settings, and assembly instructions, making it a robust foundation for our preliminary design.

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# **PRELIMINARY DESIGN**

The preliminary design consists of four parts. These are the sensor part, signal classification part, mechanical part, and controller part. In the sensor part, EMG signals are obtained from the forearm by using electrodes. Electrodes collect EMG in addition to information from skin surfaces like ECG. To reach the EMG signal, analog filters will be used. Not only the problem is other signals, EMG signal power is also quite low and it must be amplified. We will use the MamSens sensor board to handle these situations. To improve signal quality, a digital notch filter will be used to eliminate power line noise and we get a pure EMG signal. In the classification part, for each hand position, eight-channel EMG signals will be recorded in the database. To improve accuracy, we will get signals from different people. Our AI model will be trained by using that database then the model will be embedded in the controller. In the controller part, the controller will get EMG signals from channels and feed the AI model as a result it decides the hand movement. According to decision-related actuators activated and hand gestures will be imitated. This program will be run in RTOS to perform multi-processing. RTOS will allow us to synchronise multi servos and perform other tasks simultaneously Mechanical parts 3D drawings obtained from inMoov and they will be 3D-printed by using PLA.

**metin, ekran görüntüsü, diyagram, paralel içeren bir resim

Açıklama otomatik olarak oluşturuldu**

# **TEAM WORK**

Teamwork is an extremely important element for a project. During our project work, our supervisor gave various research and study topics. Some research and development was done by each project member. During the term, all of the group members worked together on every part of the project, and all of the members worked on special topics. Barış Büyükyılmaz had researched EMG signals and processing, electrodes, and types, dry electrodes, and instrumentation amplifiers. Hasan Can Sert has worked on general research on prosthetic hands, 3D printers and hand design, and signal classification. Oğulcan Uğuroğlu had investigated motors and drivers, underactuated mechanism, mechanical design improvement, hand design issues.

# **COMMENTS AND CONCLUSIONS**

In the context of the ELE401 Graduation Project 1, our team embarked on a series of research methods aimed at rectifying the shortcomings identified in previous studies. Our objective was to devise effective solutions to these issues. Through a careful evaluation process, we identified the most suitable research methods, taking into consideration their feasibility and potential outcomes. As a result of these efforts, we formulated a comprehensive roadmap that will guide us through the subsequent ELE402 Graduation Project 2.

Throughout this phase, our focus was on identifying the mechanical and electronic components essential for the project's success. We also made informed decisions about the specific models that would need to be created using the 3D printer. Additionally, we conducted thorough investigations into prior research, uncovering gaps that needed to be addressed and extracting valuable insights that would inform our project.

As we approached the end of the term, we finalized our selection of the motor type and model that would best suit our project requirements. Leveraging the capabilities of a 3D printer, we successfully fabricated a prototype of the hand model we had designed. The process also involved careful consideration of the types and models of sensors that would seamlessly integrate into our project. To ensure the smooth progress of our work, we compiled a detailed list of items to be purchased. Simultaneously, we initiated preliminary preparations for the subsequent ELE402 Graduation Project 2, ensuring a strong foundation for the continuation of our research and development efforts.

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