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Research Article

Real-Time Individual Finger Movement of a Mecha TE Robotic Hand using Human Forearm sEMG Signals through Hardware-Software Communication

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Abstract: Electromyography (EMG) is a technique used to record the electrical activity of skeletal muscles. Through EMG, many signals can be obtained from the body, evaluated by signal processing, and then utilized in various applications. Currently, noninvasive EMG methods are being used to control some of the world's most advanced prosthetic devices, in addition to help in the field of robotic rehabilitation. This paper proposes a useful, low-cost method for controlling an individual finger movement of a robotic hand through the use of surface EMG (sEMG) signal acquisition from the human forearm. During this project, EMG signals were extracted from five muscles of the forearm via surface electrodes. These signals were amplified up to 4V maximum, filtered using second-order band pass filter of 20-1000 Hz, and rectified through a designed analog integrated circuits. Then the signals were converted to the digital form with the use of 10 bit analog-to-digital converter within the Arduino™microcontroller board. From here, the signals were implemented into a Simulink®model that used fast fourier transform (FFT), root mean square (RMS), and thresholding techniques to determine changes in the signal in order to generate Pulse-Width Modulation (PWM) for the five Futaba®S3114 micro servos of the Mecha TE™ Hand. After analysis of the data and project results, it was concluded that a method of using sEMG signal acquisition for robotic hand control in real time has been attained. Current setup can also be used with virtual hand control using Matlab 3D Animation toolbox.
Keywords: Electromyography, Filters, Microcontroller, Robotic Hand, Signal Processing, Simulink, Pulse-Width Modulation

INTRODUCTION

Prosthetics today are designed so that patients are better able to return to their previous lifestyle rather than to just provide the ability to perform simple tasks. With the latest advances in technology, prosthetics have become more realistic not only in appearance, but also in their ability to closely mimic the function of a natural limb. With the help of electromyography (EMG), a technique used for recording the electrical activity of skeletal muscles, prosthetic devices are now able to be better controlled. By the use of surface electrodes, EMG signals can be detected and the ion concentration of the muscles can be translated to an electric concentration so that it can be processed through various signal processing algorithms. In the case of prosthetics, this myoelectric technology utilizes the signals extracted from voluntary muscles in the residual limb to act as triggers that control electric motors within the device. The goal with many of these robotic prosthetics is to help in the area of rehabilitation. At this time, robotic prosthetics are used to improve dexterity, natural mobility, and sense of touch to missing or paralyzed limbs [1]. Other uses include providing robotically intelligent walkers in addition to wheelchairs for those suffering from lower limb joint conditions. Researchers have used electromyogram and electroencephalogram as an interface for virtual world control and teleoperation devices for the handicapped person [2-5]. It is even possible that robotic rehabilitation is capable of providing therapy at levels beyond that of a practitioner.

The electric activity of the muscle signal can be measured in sum at the surface of the skin as an EMG signal [6]. EMG signal is based on muscle contraction and relaxation. Its properties have been reviewed extensively [7]. This research project proposes an individual finger movement of the robotic hand using sEMG signals from human forearm using hardware-software communication. Five electrodes were placed on the five muscles chosen to control individual finger movement. The extensor ulnaris was chosen for thumb movement, the extensor digitorum was chosen to control the index finger, the flexor carpi radialis for the middle finger, the flexor digitorum superficialis for the ring finger, and the flexor carpi ulnaris was chosen for the pinky movement. Figure 1 shows the forearm muscles used in sEMG acquisition. The usual amplitude range of a sEMG signal is from 20 µV to 2 mV and the typical frequency range of a sEMG signal is from 20 Hz to 1000 Hz.

There were two integrated circuits (IC) used in analog circuit design, the TI LM741 operational amplifier and TI LM348 quadruple operational amplifier. The TI LM741 was useful because of its overload protection on the input and output. The TI LM348 is essentially a combination of four op amps assembled in one IC. The LM348 IC provides high gain and has other similar characteristics to the 741 op amp. Analog integrated circuit board was designed to amplify, filter and rectify sEMG signals from five muscles. Surface electrodes were used at same location to acquire better EMG signals, which showed in our previous study to acquire, record and analyze myoelectric signals from human forearm [8].

This paper further discusses the project which evaluated the circuit design and programming to control the Mecha TE Robotic Hand (Custom Entertainment Solutions) with sEMG signals via hardware-software communication using Arduino microcontroller and Simulink toolboxes.

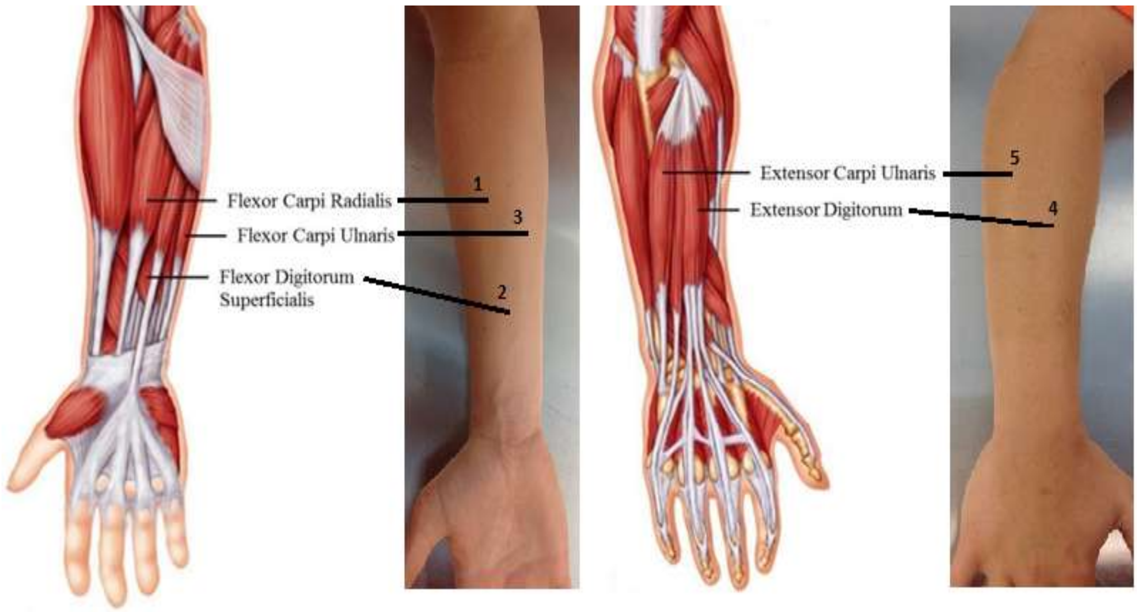

Fig-1. Forearm muscles used in sEMG acquisition (1) Flexor Carpi Radialis, (2) Flexor Digitorum Superficialis, (3) Flexor Carpi Ulnaris, (4) Extensor Digitorum and (5) Extensor Carpi Ulnaris

EXPERIMENTAL MATERIALS

A. Instrumentation Amplifier

An instrumentation amplifier was significant in obtaining a useable sEMG signal. The raw sEMG signal is obtained in mV and must be amplified in order to be functional in signal processing procedures. The amplifier was designed with a gain of 1000. In Figure 2, the original signal appears to be zero due to the difference in voltage when compared to the amplified output signal. The input signal has amplitude in mV compared to the output signal amplitude in V. Function generator used to test an electronic circuit using sine waveform.

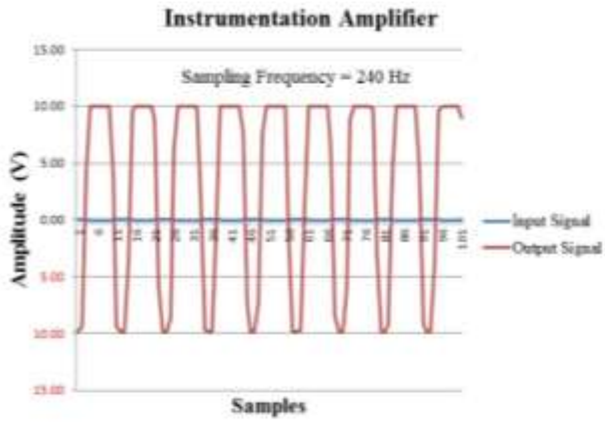

Fig- 2. Instrumentation amplifier input and output signals

B. Second-Order Band Pass Filter

Surface EMG signals contain a large amount of noise in the raw state. To rid the noise and obtain a clearer signal, frequencies must be eliminated. Ranges above 1000 Hz are considered noise in addition to frequencies below 20 Hz. The second order band pass filter was designed to eliminate the frequencies outside of this range. Figure 3 shows the input signal at a frequency of 30 Hz, as the frequency drops below 20 Hz the output signal approaches 0 Hz. As the frequency rises above 20 Hz the output signal is conserved. Similarly, as the frequency surpassed 1000 Hz the output signal approached 0 Hz.

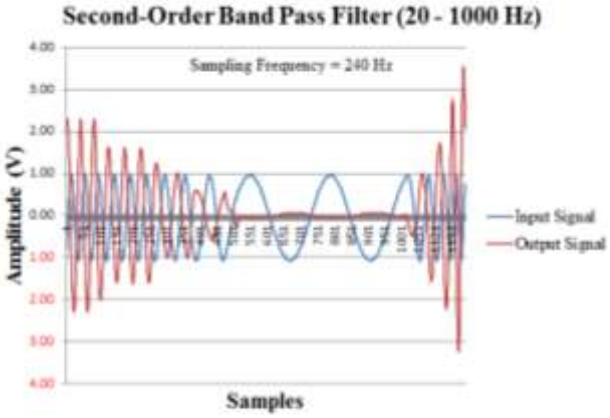

Fig-3: Band pass filter input and output signals

C. Full-wave Rectifier

A full-wave rectifier was applied in the design to convert the negative polarity of the signal into a positive polarity. The resulting all positive signal allowed for more data points to be kept and analyzed in the FFT implementation. Figure 4 displays the input versus output sine waveforms through the designed full-wave rectifier circuit.

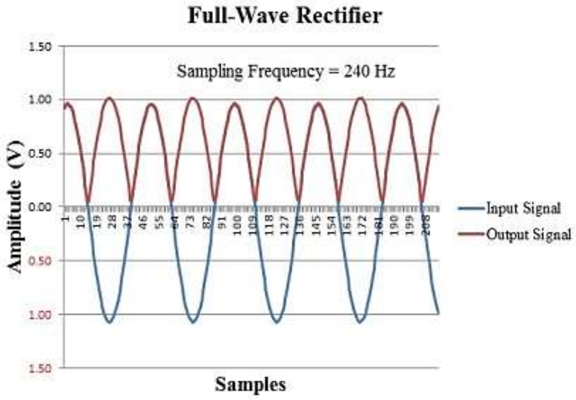

Fig-4:Full-wave rectifier input and output signals

D. Microcontroller

The Arduino™ Duemilanove, 8-bit microcontroller was used for this project. Figure 5 shows the microcontroller board equipped with an ATmega 328 IC, six 10-bit analog-to-digital converters, and 14 digital input/output pins with 6 Pulse Width Modulation (PWM) pins. The Arduino Input/output (I/O) Library is used to create a real time connection between Simulink and the Arduino board.

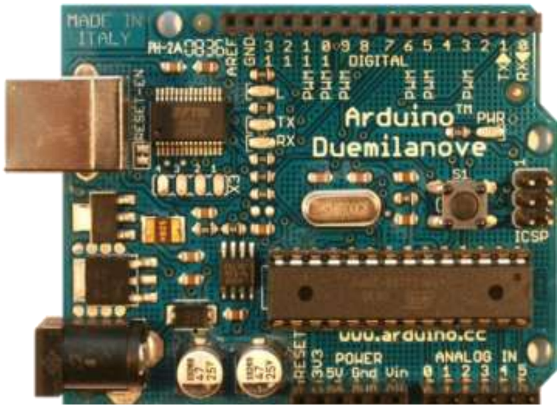

Fig- 5: Arduino Duemilanove A Tmega 328 microcontroller board

E. Simulink

The Simulink program is an environment which allows for the user to create block diagrams for simulating, analyzing, and designing systems for a variety of applications. The block libraries with Simulink are customizable for the user's needs and the program has the ability to integrate with MATLAB and all of its functions. Numerous toolboxes allow for the program to execute many different tasks. The Digital Signal Processing (DSP) System Toolbox™ and the Arduino I/O Library were applied to create the communication system between Simulink and the Arduino microcontroller. The DSP System Toolbox has blocks that can be used for filtering, FFT, and other DSP applications for creating real-time designs and processing streaming data.

F. Robotic Hand

The robotic Mecha TE Hand is controlled through micro servos. Figure 6 shows the Mecha TE Hand that is equipped with five Futaba® S3114 micro servos that control the movement of each finger and the thumb. The hand is also equipped with a servo saver system that is used to prevent damage to the servos from overloading. Precaution has to be taken when supplying power to the hand in order to prevent damage to the servos; an excess of 5 V or more than 1 A to the servos, could cause damage.

Fig-6: Mecha TE Hand with Futaba S3114 micro servos

G. Biopotential Electrodes

The electrodes used in this project are the Duo-trode™ Electrodes from Myotronics shown in Figure 7. The small size and preset distance between centers allowed for better positioning and the elimination of cross talk from other muscles.

Fig-7: Biopotential Duo-trode™ Electrodes from Myotronics used in sEMG acquisition

EXPERIMENTAL METHODS

This project was dived into two tasks. The first task includes analog signal processing from human forearm and the second task includes hardware-software communication.

A. Experimental Setup

Surface EMG signals were amplified, filtered, and rectified through the designed circuit. Using predetermined values, a circuit board was created to satisfy the analog processing needs. Figure 8 displays the connection from human forearm muscles to designed analog circuit.

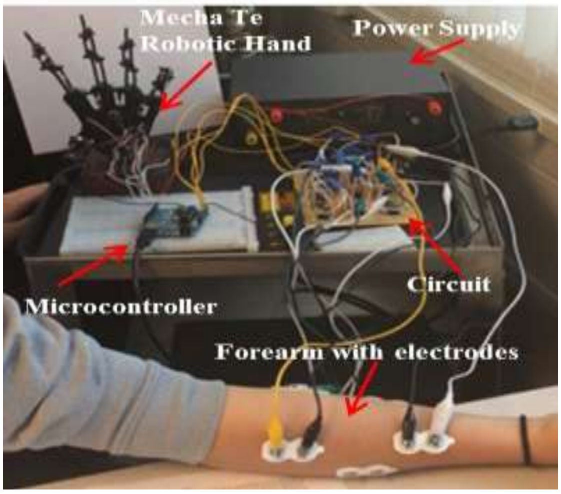

Fig-8: Experimental setup with microcontroller, electrodes, and robotic hand.

B. Hardware-Software Communication

The sEMG signals were first recorded and viewed in the computer using the DATAQ Instruments DI-149 data acquisition device. The muscle contractions of each finger movement were recorded over each electrode site with a sampling rate of 240 Hz and stored for later analysis. The Arduino microcontroller and the Simulink software were used in conjunction with each other to communicate between the circuit and the hand. The Arduino microcontroller converted the analog signal into a digital one through the 10 bit A/D converter in order for the signal to be properly used in the computer's digital environment. Using the Arduino I/O Library in Simulink, the connection between the microcontroller input and the computer was able to be made. Simulink model reads five A/D pins of Duemilanove microcontroller board in real time, process digital signals for decision making algorithm using signal processing and then sends the output back to the microcontroller to control the Mecha TE Hand through PWM.

RESULTS AND DISCUSSION

The signals were tested to determine if proper location was obtained. The best location for each electrode to control the individual finger was determined and the peaks can be seen in Figure 14. Through the use of Simulink, a control connection between the Arduino Duemilanove and Simulink could be made.

A. sEMG Signals from Analog Circuit

Surface EMG signals recorded using the DATAQ Instruments® DI-149 data acquisition device allowed for the selection of each electrode to be determined. The signal from each electrode site was compared with the movement of each finger and the best responses were chosen. Each of the signals controlled the corresponding finger on the Mecha TE Hand. Figures [9-13] show the peak voltages for each finger ranged from approximately 0.5-3.5 V after passing through the circuit.

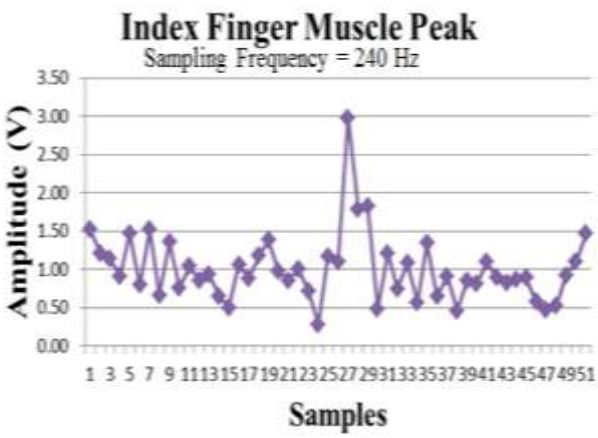

Fig-9: Index finger muscle peak waveform at 240 Hz sampling frequency

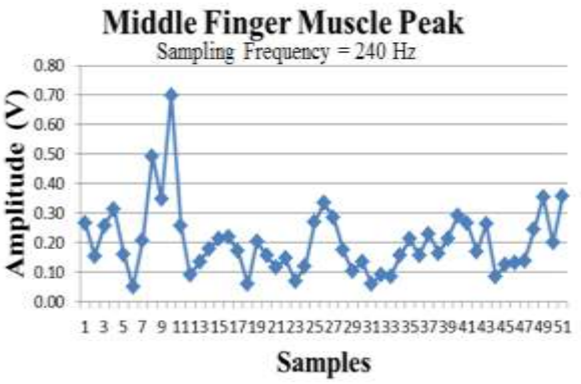

Fig-10: Middle finger muscle peak waveform at 240 Hz sampling frequency

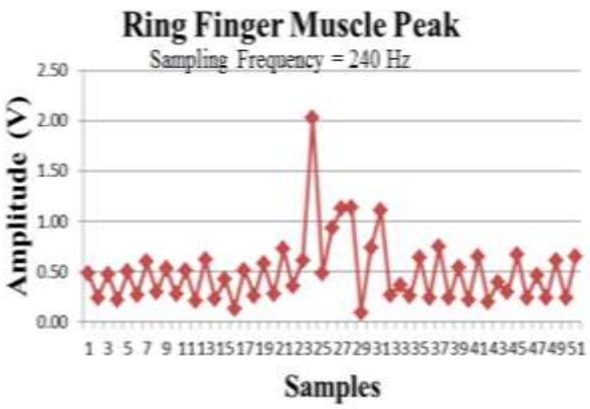

Fig- 11.Ring finger muscle peak waveform at 240 Hz sampling frequency

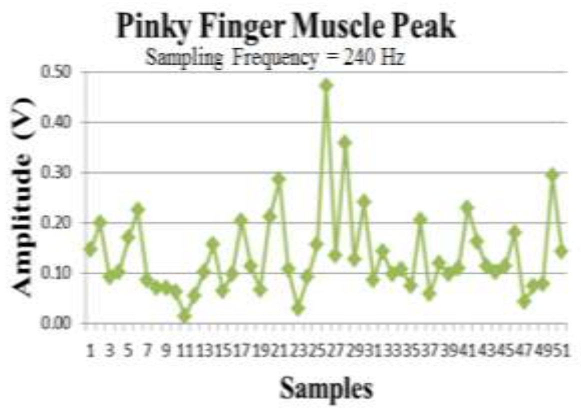

Fig-12.Pinky finger muscle peak waveform at 240 Hz sampling frequency

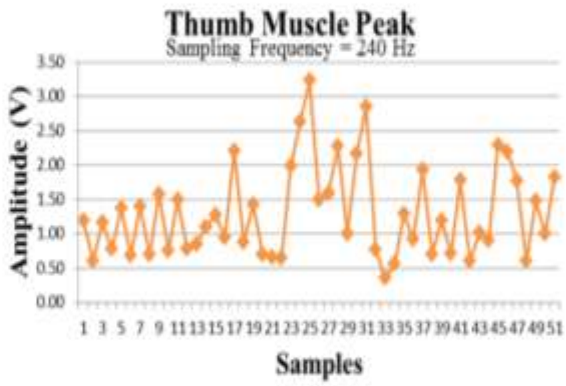

Fig-13:Thumb muscle peak waveform at 240 Hz sampling frequency

sEMG signals form all five muscles were recorded at 240 Hz sampling frequency for results only. Figure 14 shows successful amplification, filteration and rectification of the sEMG signals from human forearm. Actual control of Mecha TE robotic hand uses five 10 bit ADC to convert analog signals into digital in the range of 0-1023.

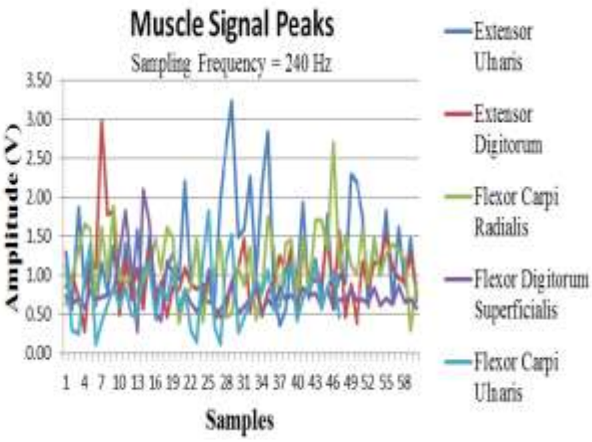

Fig-14: Signal peaks of each muscle using the DATAQ® DI-149.

B. Decision Making Algorithm

Arduino Duemilanove microcontroller board used with Simulink model in real time using Arduino-Simulink library, which allows Simulink model to acquire signals from ADC, perform signal processing using Simulink toolboxes and generate PWM signal for the micro servos of the Mecha TE Robotic Hand. The designed Simulink model uses FFT, root mean square (RMS), and Thresholding techniques to make a decision algorithm to generate PWM signal for the Mecha TE Robotic Hand, showed in figure 15.

The input from the Arduino was in the range of 0-1023, the range was based on the 10-bit A/D converter resolution. This digital signal was transferred to the Simulink model. The increase in voltages, resulting from amplification, allowed for the difference between the resting and peak portions of the signals to become approximately 2 V depending on the position.

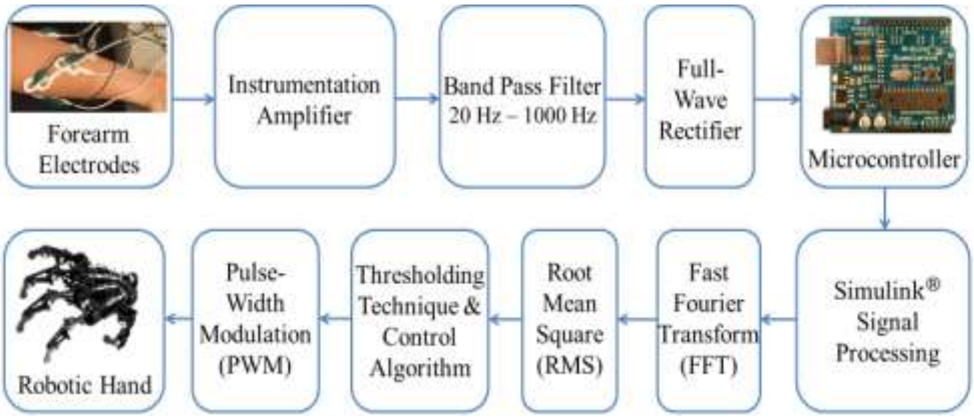

Fig-15: Project flowchart depicting each step of the project. Acquiring the signal, processing the signal, microcontroller implementation, Simulink processing, and the final output of robotic hand movement

FFT was implemented to convert the sEMG signals from time domain to frequency domain. The magnitudes of the signal at different frequencies are averaged over specified intervals. The average represents the power spectrum at the different frequencies. This output can then be utilized in the RMS block.

The RMS method was used to determine the threshold values for each signal input. The RMS is the root mean square of a predetermined set of discrete values. The magnitude of the FFT output was split up into regions to be evaluated. The result was a signal that had a continuous movement with a larger range of values. The increase in the range allowed for different thresholds to be applied in the model. The different thresholds gave not only a better range of motion, but also a movement that was more fluid and not as pulsated.

The use of the magnitude from the FFT, along with the increased range from RMS, allowed for the robotic hand movement to be closely mimicked from the forearm. The ability to control each finger of the robotic hand is an advantage to increasing the realistic movement of prosthetic hands. The use of the FFT and RMS are practical methods that can be continued to be improved.

CONCLUSION AND FUTURE WORK

Utilizing sEMG signal processing and Simulink-Arduino programming, the muscles of the forearm were successfully used to control a robotic hand. Simulink signal processing toolbox and Arduino library were used to generate PWM for the servo motors of the Mecha TE Robotic hand. The future work includes implementation of neural network and force measurements to obtain a more stable, fluid movement of the robotic hand. Also, the implementation of a speed control variable into the design will help to create a better imitated movement.

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