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EMG Controlled 3D Printed Bionic Hand

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Abstract

When muscle fibers contract, they generate electric signals by the exchange of ions across those fibers' membranes. These signals can be detected to control extremities and other organs after being applied to some processing, analyzing and filtering techniques. In this study, we aimed to design a 3D printed hand, which is easily adaptable to all amputees, with microcontroller-based control using EMG signals via open-source tools. All the mechanical parts were fabricated using an additive manufacturing method of 3D printing. The hand can move all fingers separately in an accurate way and it is fully controllable by a general-purpose microcontroller board. The design decreases the production period and cost of the prosthetic hand.

Keyword(s): 3D printing, EMG, Signal processing, Bionic hand.

Introduction

Electromyography (EMG) is an electro-diagnostic medicine technique for evaluating and recording the electrical activity produced by skeletal muscles [1]. When our muscle fibers contract, they generate electrical currents by exchanging ions across muscle fiber membranes. These generated signals are captured via electrodes connected to the skin surface or fibers directly. If EMG is recorded over the skin, then it is called as surface electromyography (sEMG). Since this type of EMG is non-invasive, it has more common use [2]. By the end of the 17th century, Galvani obtained direct evidence of a relationship between muscle contraction and electricity. He demonstrated that muscle contractions could be evoked by the discharge of static electricity [3, 4].

The EMG electrodes collect signals from different motor units. EMG signal analysis and detection are important not only in clinical diagnosis but also in different biomedical applications. Firing rates of Motor Unit Action Potentials (MUAPs) in EMG signals help us to diagnose neuromuscular disorders. The EMG signal can also be used to create an active application similar to prosthetics using appropriate algorithms and various signal processing hardware [6].

Because the average cost of a myoelectric hand is too high, which is the range between from $15,000 to $75,000 [5], we decided to study EMG-controlled and 3D-printed prosthetic hand in this study.

Materials and Methods

3D Hand Modeling and Designing

In this study, layer-by-layer our internal hand design was drawn by intelligent (CAD) program which is SolidWorks, we design the components accurately and separately each part alone to be suitable for the patient which are the hand body, proximal middle and distal phalanges of each the thumb, index, middle, ring and pinky fingers in addition to the motors, microcontroller and sensors bed, based on several concepts which are important in understanding individually the size, direction of motion, amputation site and angle, number of joints, actuators, weight and volume of the hand, age and sex of the patient, which current bionic hand designs do not do.

Next step was to design an elastic external hand cover using the 3D scanner, we used 3D3 HDI Advance Scanner, ABD that gave us the precise details of the normal human hand surface, and then some process was done on our 3d scanned hand to be extruded cut by (CAD) that allow us to insert the internal hand design to into. The last step in the modeling of the mechanic parts.

3D Printing

Assembling and handling the multiple 3D parts that represent components within a moving hand, we can say it is the testing of the whole hand before print it. The last step the designing our bionic hand is to decide which is the appropriate filament we should to fit and be closer to real hand; so we decided to use filament which is PLA and flexible PLA and print those materials under particular conditions like the temperature and the printing speed.

EMG Signal Processing

Electromyography (EMG) has defined as a function of time in terms of amplitude, frequency, and phase. EMG is an electrical current generated in muscles during contraction. The raw EMG signal is a voltage difference measured between recording electrodes. Since the raw EMG signal has positive and negative components we should ensure the raw signal does not average zero, this process can be done using the Rectification which is the translation of the raw EMG signal to a single polarity frequency [7].

Two types of signals' rectification refer to what happens to the EMG wave when it is processed, these types include full-length frequency and half-length. The full-length frequency was used in our EMG processing that adds the EMG signal below the baseline (usually negative polarity) to the signal above the baseline making a conditioned signal that is all positive, so full-wave rectification takes the absolute value of the signal array of data points as shown in Fig. 1 [8].

EMG Sensor and Microcontroller

The microcontroller was used to processes the signals by rectifying and summing. If the magnitude of the relevant sensor exceeds a predefined threshold value, a muscle impulse is said to have been detected on that channel [9].

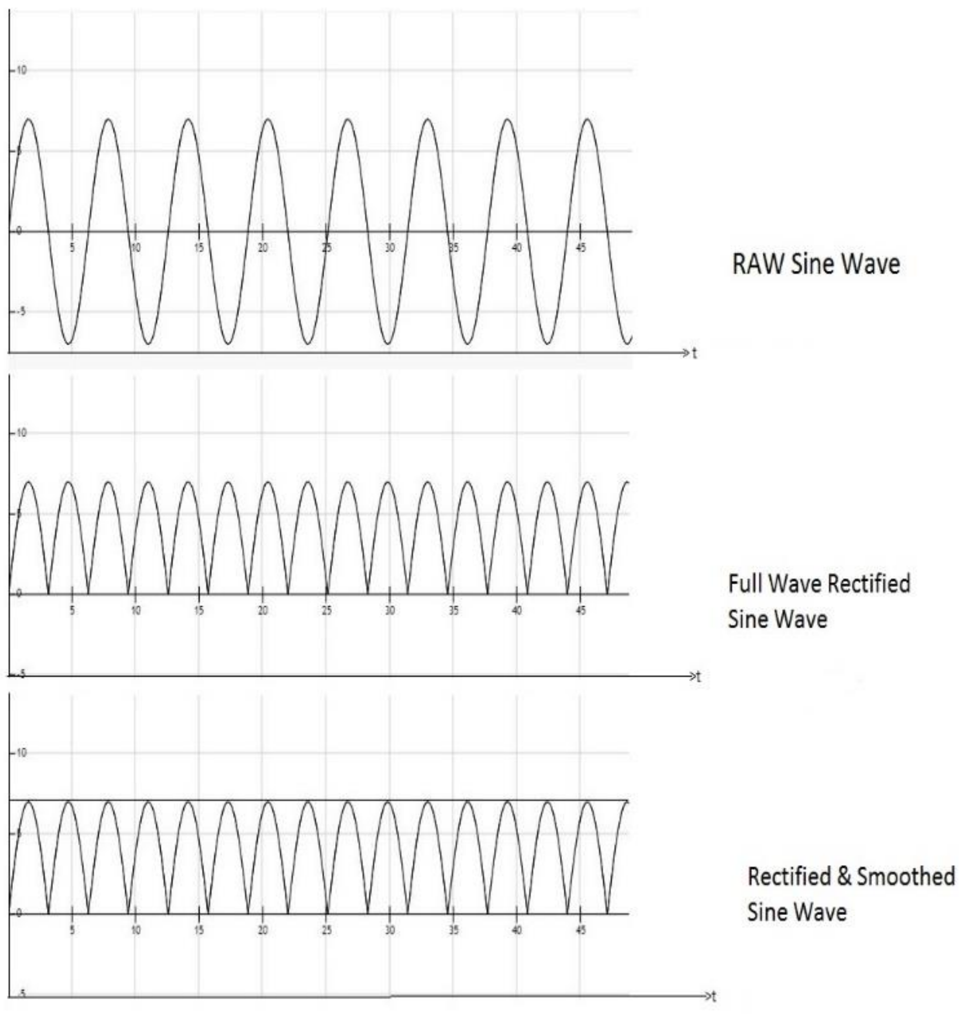

Figure 1. Full-wave rectification of a sinusoid.

An EMG sensor is used to amplify, rectify, smooth analog signals. The sensor consists of low-power JFET-input operational amplifiers to turn alternating signal into a direct voltage. Thus, this signal can be read by a microcontroller by using some additional common components of resistors and capacitors. A 109-line microcontroller code is written in C programming language to convert analog signals into numbers via an internal analog-to-digital converter (ADC).

This code controls five servo motors that are connected to both the fingers and the microcontroller. An extra servo motor is rotating with a max of 180 degrees. Thus, the hand contains six servo motors that control the five fingers separately and individually in addition to controlling the wrist motion.

Results

EMG signals were analyzed and rectified from normal hand using multi-channel sEMG. There are six different contractions of a human hand's muscles: the contraction of each thumb, index, middle, ring, and pinky fingers with the wrist (Fig. 2). Different EMG signal amplitudes due to different contraction forces.

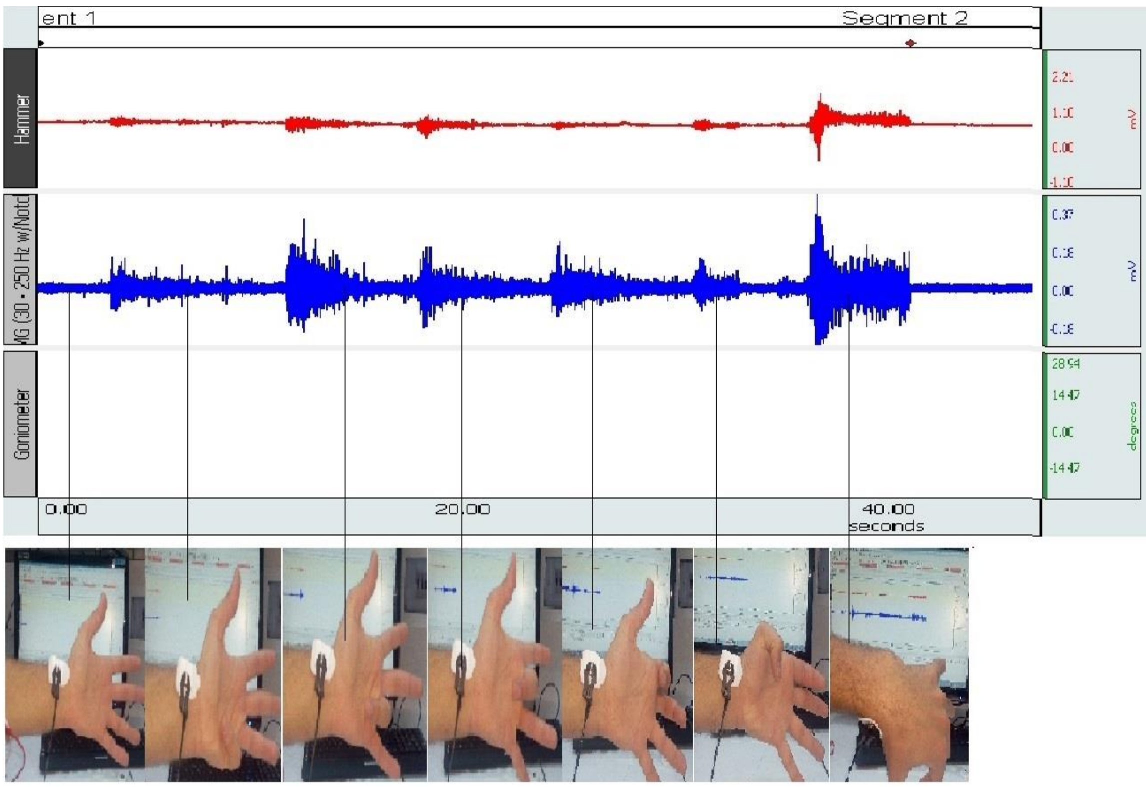

Figure 2: Different signal amplitude correspond to different forces of the contraction of the muscles in the each thumb, index, middle, ring and pinky fingers and the wrist.

These signals were rectified using a simple Matlab code (Fig. 3). Because the classifier implementation is not an issue of this study, we didn't implement a pattern recognition algorithm. The movement of any finger is decided by only the amplitude level of rectified EMG. These levels were determined for individuals separately by investigating the Matlab output.

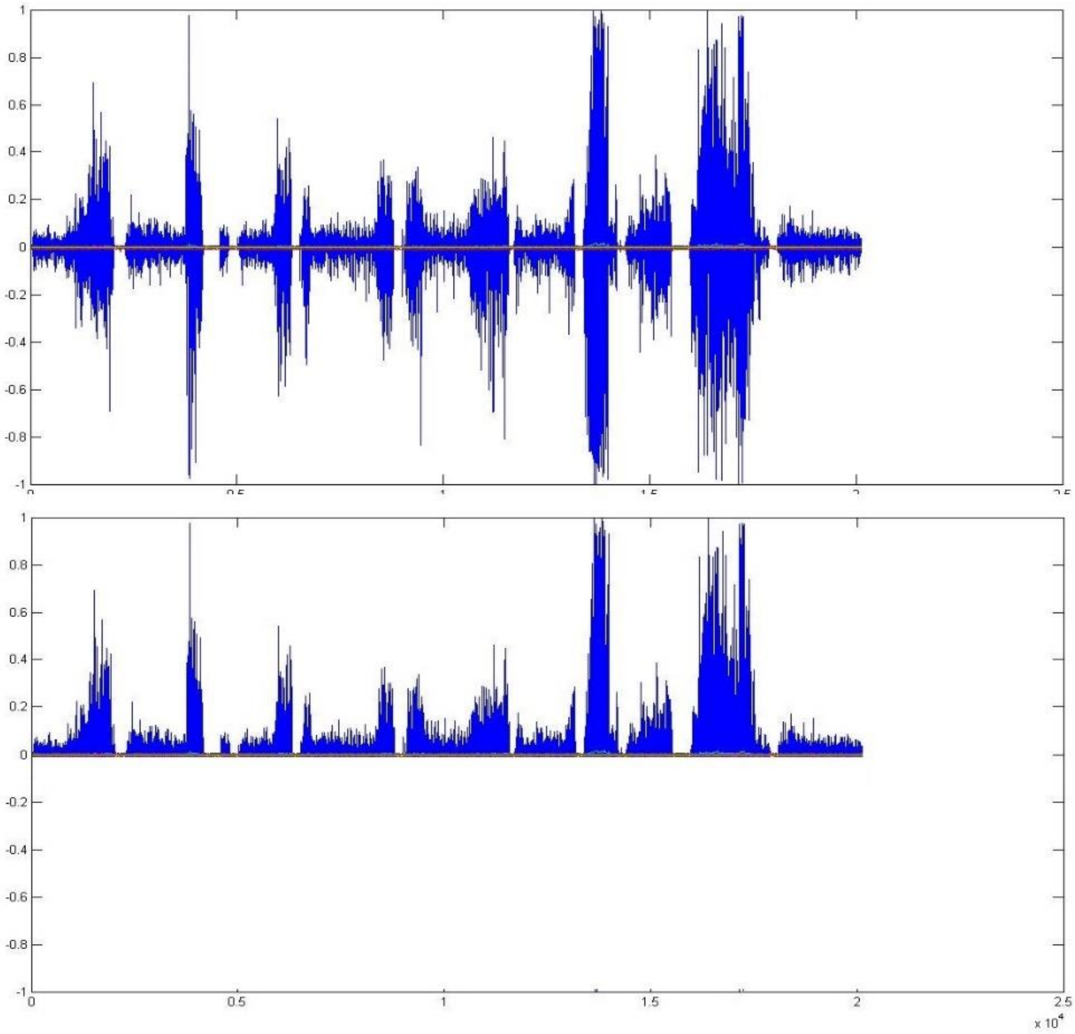

Figure 3: EMG signals are rectified using MATLAB

EMG electrodes were placed on forearm flexor/extensor (wide), extensor bundle (wide), flexor bundle (wide) placements. EMG signals were converted to digital numbers by microcontroller's analog-to-digital converter using a general-purpose EMG sensor. These signals were compared to predetermined levels (in Matlab); therefore, the corresponding motors were activated by the microcontroller. All movements were actuated correctly.

Discussion

Our bionic hand fits individual patients. By this study, the design may be easily adapted to the most appropriate hand by changing the size, the direction of motion, the amputation level, and the number of joints, actuator types, the weight, and the volume of the hand. By considering the age and the sex of the individual, the shape of the hand can be changed via a 3D design file itself and a 3D scanner. If an extra movement is requested or an existing movement is requested to change by the individual, the bionic hand can be re-programmed by the microcontroller, which controls the motors' functionality.

In this study, six servo motors have controlled separate five 3d designed fingers separately and individually in addition to controlling the wrist supination and pronation motion this allows to dynamically movement of the hand.

To find the right location of EMG electrodes on the skin is a bit challenging, which requires experience. In addition, when one of the finger movements occurs, we also noticed a slightly cross-talk inference among EMG channels.

In future trends, the bionic hand will have more dynamic movements like dorsiflexion, palmar flexion, radial abduction, and ulnar adduction motions or even have multi biological sensors like temperature, force, rough and smooth feelings, etc.

Conflict of Interest: The authors declare that they have no conflict of interest.
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