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Design of an Accessible, Powered Myoelectrically Controlled Hand Prosthesis

Osman Onur Akirmak [1], Çağdaş Tatar [1], Ziya Gökalp Altun [1], Yuriy Mishchenko [2]

[1] *Toros University, Bahcelievler 45, Mersin, Turkey*
[2] *Izmir University of Economics, Sakarya Cad 56, Izmir, Turkey*

Abstract **– In this paper we describe accessible myoelectric prosthetic hand design based on modification of existing mechanical prosthesis and off-the-shelf parts and components. Despite significant advances in myoelectric prosthetics, such existing devices remain out of reach of the majority of the patients needing them due to high costs and complexity. We describe a simple design that can be assembled based on existing or readily acquirable parts at approximately 1/100 of the cheapest commercially available alternative. Our design offers wrist disarticulation patients in developing countries an affordable myoelectric prosthesis with significant capacity for improving their quality of life.**

Keywords **– electromyography, sEMG, robotic prosthesis, bionic hand, neural prosthesis.**

1. Introduction

In recent years, myoelectric (EMG) prosthetics have attracted significant attention. Significant work has been done on such systems in research literature [1-9] as well as myoelectric prostheses are now available commercially on the market including i-Limb (Touch Bionics, UK), Michelangelo (Otto Bock Healthcare Product GmbH, Austria), Bebionic (Steeper Group, UK), and DEKA arm (Deka Integrated Solutions Corporation, USA). Unfortunately, the vast majority of such developments have been confined to advanced biomedical and robotics laboratories in main industrial countries, whereas the end designs are complex and extremely costly thanks to reliance on complex parts and advanced technologies. i-Limb prosthetic hand – one of such offerings sold commercially – comes with a price tag of 20,000 USD [10]. Despite a significant need existing in myoelectric prosthetics in developing countries, the above factors make it all but impossible for such patients to obtain a myoelectric prosthetic.

In this report, we describe a design for myoelectric hand prosthetic that is simple, inexpensive, and does not rely on advanced components or expertise. The design utilizes all off-the-shelf components and is based on alteration of conventional mechanical hand prosthesis to grant it bionic function. The simplicity, accessibility, and the absence of compulsory use of advanced parts make it possible for anyone to implement our design with limited resources, which can become a viable alternative for hand and arm amputees in developing countries for acquiring myoelectric powered prostheses, which have the potential to significantly improve their quality of life.

2. Materials and Methods

2.1. EMG signal sensing and acquisition system

Our design relies on an off the shelf surface electromyographic sensor based on ECG 3M Red Dot 2560 Ag/AgCl electrodes [11] and a simple signal electronic signal amplification and filtering circuit [12,13], which can be either acquired new – such as Grove EMG sensor from Seeed [14] – or assembled from basic electronics components such as INA106 instrumentation amplifier and active RC filters, following the detailed presentations that can be found elsewhere in the literature [15-17].

Electromyography (EMG) is a technique for sensing activity in the skeleton muscles of human body that develops during activation of those muscles. The principle of EMG sensing from the surface of the skin relies on placing electrodes next to target body muscles onto the skin surface [1]. In

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Corresponding author: Yuriy Mishchenko,
Izmir University of Economics, Izmir, Turkey
Email: yuriy.mishchenko@gmail.com

this work, we use the placement of electrodes identified by the end and the middle points of *flexor carpi radialis* and *palmaris longus* muscles involved in the flexion of middle finger, identified by the numbers 3 and 4 in Figure 2. [2]. These electrodes can be activated by a user upon contraction of his or her fist. Respectively, the two sensing electrodes are placed at the end and the mid-points of *carpi radialis* and *palmaris longus* muscles with the distance between them of approximately 1.5 cm, and measure the electric potential difference developing between these points upon fist contraction. A third, ground electrode is placed over the elbow of the same hand, over a bone, to provide a reference for the EMG signal to be used with the signal amplification and filtering circuit.

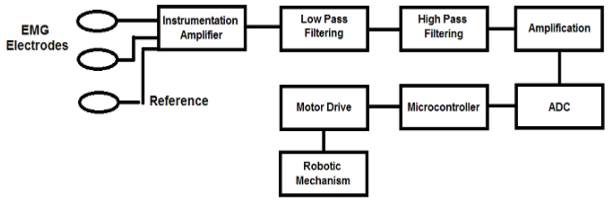

Figure 1. The overall block schema of the design of the myoelectric hand prosthetic in this work.

The signal from the sensing assembly is digitized by passing it onto a clone of Arduino Uno microcontroller via the ADC module of the microcontroller, and is then used by an embedded control software to direct a servo motor enacting the motions of the mechanical mechanism of the prosthetic hand, as will be described below.

Figure 2. Possible electrode locations for surface EMG measurements as related to hand movements. Locations 3 and 4 have been used in this work.

2.2. Muscle activation detection and embedded control software

The embedded control software is realized as s software on the base of Arduino Uno microcontroller clone in C programming language. The software implements a two stage signal processing strategy with a simple digital filter in direct form 1 applied first to the raw EMG signal in order to filter out slow signal variations otherwise affecting the prosthetic's performance (Figure 3.). Secondly, the software implements a simple 1 hidden-layer neural network to classify incoming signal into rest and target muscle activation states (Figure 4.).

The digital filter was designed by examining the EMG signal acquired from the sensor using a PC computer, by using the Filter Design and Analysis tool (FDAtool) in Matlab. During the examination, it had been observed that the raw EMG signal could contain contaminations in the form of low frequency variations at and below approximately 2-3 Hz, which significantly distorted the signal. Respectively, a high pass digital filter with cutoff frequency of 2 Hz was designed using FIR equiripple option in FDAtool in order to clean the EMG signal before passing it to a neural network classifier detecting the target muscle contraction waveforms.

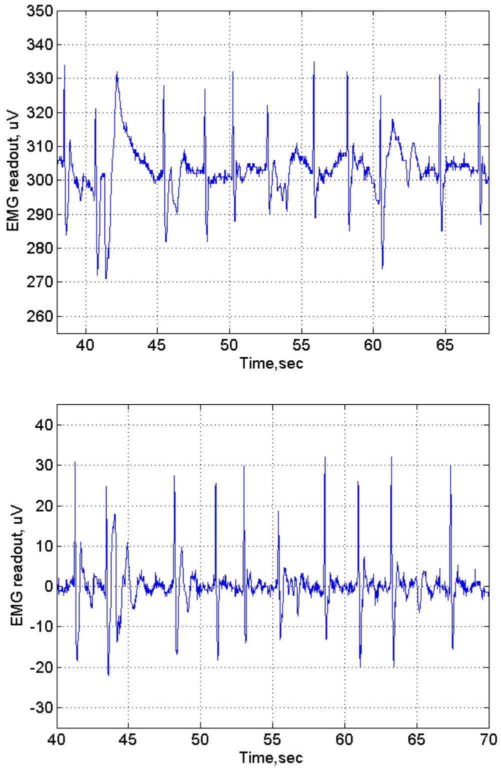

Figure 3. Example of the raw (top) and filtered (bottom) EMG signal as well as the waveforms associated with target muscles' activations.

To detect the muscle contraction waveforms, a one-hidden layer artificial neuronal network classifier was designed as described by

$$z = g\left(\sum_{j=1}^{5} \mathrm{h}_j \cdot g\left(\sum_{i=1}^{40} w_i s(t_i)\right)\right)$$

where $g(x) = 1/(1 - \exp(-x))$ is the sigmoid activation function, h_j and w_i are the neural network weights in the output and the hidden layer, and $s(t_i)$ is the waveform input produced from the raw EMG data by sampling the EMG signal at 40 control points uniformly distributed at 20 ms intervals over the most recent 800 ms part of the EMG signal.

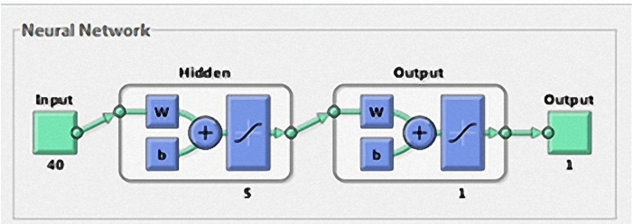

Figure 4. The diagram showing the layout of the artificial neural network used for detection of muscle activation waveforms in the EMG signal.

The neural network was trained by using the Neural Network design tool in Matlab and a 2 minute fragment of EMG data obtained while user was continuously contracting the target muscles at a rate of approximately one contraction per 2 seconds. An activation threshold of 0.999 was set for the neural network after the training, in order to minimize the rate of false positive errors while retaining most of the true responses. The final accuracy of the neural network with respect to the detection of muscle activations was calculated to be 94%.

Upon the detection of muscle activations, the embedded software activated the servo motor in the mechanical subsystem of the prosthetic hand in a manner related to the current state of the mechanical hand, which could be “open” and “closed” and was maintained by the software, so that the motor moved in alternate positions alternating between “open” and “closed” prosthesis’s states as controlled by the user contracting the target muscles.

2.3. Implementation of the mechanical prosthetic mechanism

We implemented the mechanical subsystem of our prosthetic by modifying an existing mechanical hand prosthesis Otto Bock (Otto Bock Healthcare Product GmbH, Austria), which is a commercially available, movable prosthesis that can be activated mechanically by pulling a pull-cord by the user. Together with internal springs that allowed the prosthesis to perform grab-and-hold motions and hold objects as activated by the user manually operating the cord with the other hand.

We modified the said prosthesis by removing the pull-cord and internal springs and replacing them with an EMG controlled servo motor mounted at the centre of the finger joint as shown in Figure 5. The assembly was then covered with the original cosmetic glove. The motorized prosthetic was then controlled by activations of the *flexor carpi radialis* and/or *palmaris longus* muscles in lower arm such as triggered by closing the user’s hand. In response, the prosthetic executed alternately hand-open and hand-close motions, allowing the user to grab and hold objects just as the original prosthetic did but now controlled entirely by the myoelectric signal.

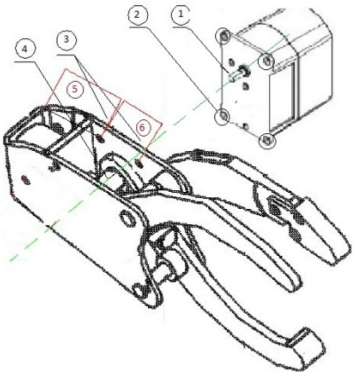

Figure 5. The drawing of the modified non-motorized Otto Bock hand prosthesis designed in this work. Numbers indicate: 1. The rod of the servo motor. 2-3. Fitting screws. 4. The rod place bracket. 5. The forearm-prosthetic connection area. 6. The fitting screw mounting holes.

3. Results

In this work we develop a design for powered myoelectric hand prosthetic based on modification of an existing conventional mechanical prosthesis. The modification involved replacing the internal springs and mechanical pull-cord with servo motors and electronic EMG activation circuit.

Overall, the altered design matched very closely the original mechanical prosthesis in terms of form, functionality, usability, effectiveness, and non-obtrusiveness. The entire motorized assembly could be covered using the original cosmetic glove and used with the original prosthetic socket, in place of the original prosthesis. In that respect, modified motorized prosthetic was a close to one-to-one copy of the original unit and could be used entirely in its place, now driven by the EMG control signal.

The modifications resulted in slight increase in the total weight of the modified prosthesis due to added sensing circuit, Arduino, and servo motor. These modifications added approximately 100 gram to the weight of the original prosthesis. Together with the weight of the original prosthesis’s mechanism of approximately 450 gram, that resulted in the total new weight of about 550 gram, perfectly compatible with the original unit. In terms of the usability of the original unit, these alterations resulted in nearly no changes.

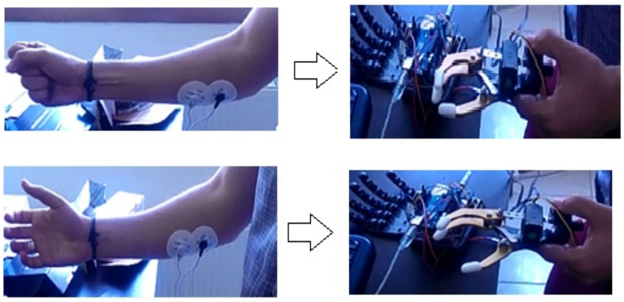

Figure 6. The modified prosthesis (right) and the EMG-controlled activation of the modified prosthesis (left).

The Hitec HS-311 servo motor used to animate the mechanical hand mechanism generated a maximum torque of 3.5 kg-cm, which was less than the force produced by the original springs that we removed. We tested the effect of this change on the usability of the new prosthetic with respect to the original grab-and-hold action that the original unit performed. The above torque produced by the servo motor was found to be sufficient to hold objects of up to 0.5 kg, adequate for daily tasks. A more powerful servo motor can also be installed in the described design if a more heavy duty prosthetic is required.

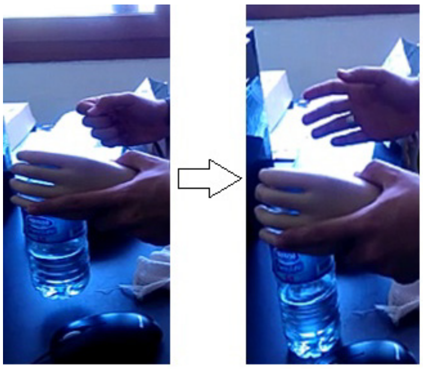

Figure 7. The modified prosthetic was able to grab and hold objects up to 0.5 kg in weight controlled by EMG activation.

Currently in the market, four myoelectric hand/arm prosthetic offerings are available. These are iLimb, Michelangelo, BeBionic, and DEKA Arm [18]. Most of these products are similar in design and features, and focus on providing a complex hand actuator which, nevertheless, is still activated via single EMG sensor and resolves a single muscle activation, exactly as in our design. The cost of such prosthetics, however, is immeasurably greater than ours. The cheapest of the commercial myoelectric prosthetics (Touch Bionic's iLimb) costs close to 20,000 USD. The design described in this work has been implemented for under 350 USD, where 50-100 USD had been spent on electronics parts and 250 USD was the cost of the original conventional Otto Bock prosthesis. Nevertheless, our prosthetic design provides the same EMG activation capacity as the significantly more expensive existing units and fulfils the most essential grab-and-hold function required by most wrist amputees. With the total costs in the range of 1-2% of the cheapest comparable alternative, our design presents a significant advance over the current state of affairs. Even though commercial prosthetics offer advanced sets of functions such as multiple grab positions which can be changed via smartphone application or manually, considering that taking and carrying objects is the main function required by wrist amputees, the simplicity and dramatically reduced total cost of our design – in 1-2% of the cheapest alternative – is an enormous advantage for wrist amputee users who desire to take advantage of myoelectric prosthetic technology over existing commercial units.

4. Conclusion

In this work we describe a design for a powered myoelectric hand prosthetic produced by modifying an existing mechanically activated prosthesis. The proposed design is simple and robust, and can be implemented with minimal resources and expertise. The design uses only readily available, off-the-shelf parts and can be implemented at a total cost of less than 2% of the cheapest alternative, which together with the most important holding-capability successfully fulfilled by the design offers feasible alternative for wrist amputees in developing countries who desire to take advantage of powered myoelectric prosthetic technology, which has substantial potential to improve the quality of life of such amputees.

Acknowledgements

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