Two-Channel sEMG Controller for Electric Hand Gripper: Amputee Hand Training Device

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***Abstract*—This research aims to design and develop the two-channel surface electromyography (sEMG) control unit for an electric hand gripper, projected for amputee hand training device. The intention of this medical device is to use it before using the prosthetic hand. The amputee hand training device has developed based on the principle of physiology, biomedical electronics and microcontroller. The prototype consisted of three main units: signal detector and signal conditioning modules, signal control and processing components using the ATMEL 328 microcontroller, and the 2-Degrees of Freedom (DoF) electric hand gripper with DC servo motors. The performance testing was done by the users controlled the 2-DoF electric hand gripper using their sEMG signal. The functional assessment results showed that the success rate of grasping accuracy of the three main basic geometries were 93% of cylinder, 90% of cubic and 40% of egg. The success rate of the rotation of a wrist hand was 83%. Each calculation was calculated for 30 times in performing its specific function. The production cost of this medical device was around £165.**

***Index Terms*—robotic hand, surface electromyography, sEMG, myoelectric control, prosthetic hand, rehabilitation**

I. Introduction

There is a number of artificial hand and its control system. The surface electromyography (sEMG) is one of a well-known technique that used to control an artificial hand. The sEMG controller of simulated hand relied on the principle of the somatic motor, the voluntary nerve system innervates of skeletal muscle [1]. The source of electromyography (EMG) is generated by interneuron of the brain in the central nerve system, and led the action potential moved down to the motor neuron. Activates all muscle fibers of the motor unit, postsynaptic membrane is depolarized End-Plate Potential (EPP), and in the region in neuromuscular junction, so-called "end-plates". Signal spreads in both directions along the muscle fibers. As a result, this generated movement across cell membrane, and produced an electromagnetic field. EPP stimulation, it raised to 30-40mV of neurotransmitter released in both action potential and activation of myoelectric signal to muscle cell fiber contraction in human [2], [3].

The myoelectric prosthesis hand is controlled by sEMG signal. Therefore, electrical signal from the human brain can be regulated the myoelectric prosthesis hand function on the control device which is best known for effective result than the other techniques. Previous works have been done on constructing myoelectric hand, for example, the decent design and development of mechanical hand proposed to study myoelectric hand gripper [4]-[6]. In this work, we detected and used the sEMG signal, which is around 3-5mV and frequency ranged 20-1000Hz, in sEMG random energy. The detected signal is appropriated to the usage of sEMG control device of electric hand gripper for amputee hand training device. Thus, sEMG signal was obtained and noise was filtered for receiving a decent signal to control and drive the electric hand gripper.

This proposed system is the training device, intended for the hand amputation using myoelectric prosthetic hand, and was developed to assist in learning myoelectric control system and training the muscle isolation. The amputation teacher helped the amputees to operate and employ the amputee hand training device for practicing their arm muscle. This device might be easier than the previous techniques in rehabilitation training for amputee hand muscle isolation [7], [8]. Fig. 1 reveals the principle of sEMG controller for the robotic hand gripper [4], [5].

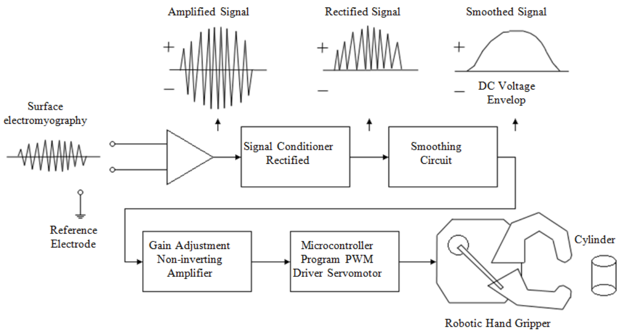

Figure 1. Principle of sEMG regulator for the robotic hand gripper.

The sEMG signals after rectification as the detected envelope (DC voltage envelop), which is used to trigger and drive the 2 DC servo motors of the robotic hand training device. However, the weak electrical signal can be generated an ineffective sEMG signal, that resulted to control and drive the myoelectric prosthetic hand.

II. Design and Development

This prototype was the 2 signal lines of the 2-channel surface electromyography to operate the 2-DoF electric hand gripper built up with the two servo motors. This is a

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medical instrument for training device before using myoelectric prosthetic hand. The block diagram is shown in Fig. 2, reveals the two-channel sEMG controller with sEMG detector and signal conditioning, composed of three main components: the smart detector box, sEMG electrodes and signal modulator.

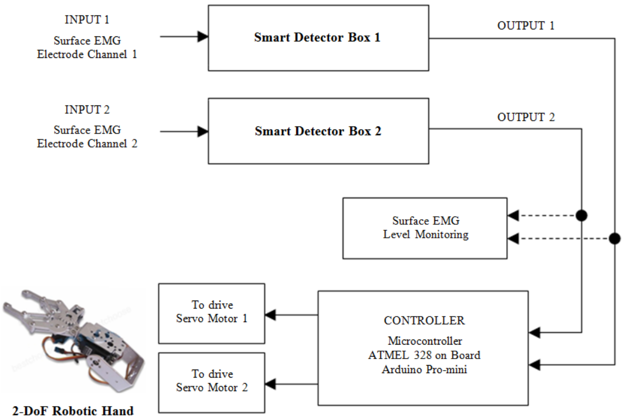


Figure 2. Block diagram of proposed research project.

A. Smart Detector Box

The smart detector box consisted of sEMG detector and signal modification. The dimension of the box was 43mm of width, 61mm of length and 40mm of height, with 3 holes for cable of 3 locations of sEMG electrodes. Each radius of the cable was fixed at 3mm. In the product design, CATIA V5, the computer-aided design software was used to design the box, and the plastic container of sEMG electrodes and the printed circuit board (PCB) was printed by using the MakerBot 3D printer. Inside of the smart detector box, it had the 2 PCBs: the PCB 1 and 2 are designed for signal conditioning and signal modulator modules, respectively. Fig. 3 shows the actual smart detector box that used in this project.

B. Signal Detector

The sEMG electrodes were the 2 inputs of surface electromyography contributed detectors from skeletal muscle, and these electrodes were modified from the disposable electrocardiogram (ECG) electrodes [3], [5], [9]. According to the modification technique of the sEMG active electrodes, we placed the electrode A and B with the distance configuration from A to B is roughly 20mm, and a ground electrode is reference signal was located at the middle of electrode A and B (see Fig. 3). This modification technique is satisfactorily detecting signal by an electrode placed near the activated muscle fibers. Consequently, the acquired signal waveform is in phrase of the Motor Unit Action Potential (MUAP) [2]. The MUAP is a signal from depolarization, and multiple fibers in a motor unit are simultaneously recorded sEMG signal associated with double electrodes and ground reference.

C. Signal Conditioning and Modulator

The signal conditioning and modulator composed of precision full-wave rectifier and non-inverting amplifier, as well as, the completed 2 circuit boards are shown in Fig. 3. There were obviously different 2 modules of the 2 PCBs; however, explanation of them was translated into the block diagram is relatively similar. The block diagram of the signal conditioning and modulator part illustrates in Fig. 4. The smart detector box incorporated with the SEMG detector, signal conditioning and signal modulator [10]. The module one was an active component with the biological amplifier using the INA128 and the operational amplifier (Op-Amp) LF353 is for low-pass and high-pass filters. In addition, the module two was a precision rectifier and a non-inverting amplifier using the Op-Amp LF353 and LF351, respectively. Hence, the final SEMG signals released from the smart detector box including PCB 1 at output 1 and PCB 2 at output 2, as shown in Fig. 4. Within the 2-DoF robotic hand training device, the signals at output 1 and 2 used to drive the 2 servo motors that integrated both functions were grasping basic items and rotating the wrist, respectively.

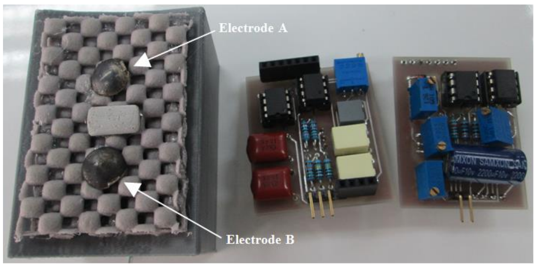


Figure 3. The detector of surface electromyography (left), signal conditioning module (middle), signal modulator module (right).

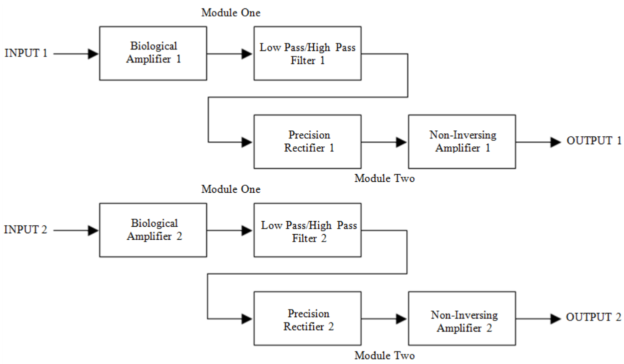


Figure 4. Block diagram of the smart detector box.

D. Integrated Signal Controller

The integrated signal controller employed the ATMEL 328 microcontroller to control the mechanical hand. This part connected with the smart detector box and the 2-DoF electric hand gripper. The ATMEL 328 microcontroller was a central component on the Arduino Pro Mini. Microcontroller was programmed to convert an analogue signal that received from the smart detector box into the 10-bits digital signal [11]. The digital signal was integrated to generate the outputs of the Pulse Width Modulation (PWM) for controlling and driving the 2 servo motors inside the 2-DoF electric hand gripper. Fig. 5 shows the microcontroller module.

Fig. 6 illustrates the flowchart to program the microcontroller to function the 2-DoF robotic hand gripper. In addition, programming design represented on the microcontroller board: sEMG signal 1 and 2 (inputs) and PWM to drive the servo motor 1 and 2 (outputs), were the A01 and A02 pin ports and the 9 and 10 pin ports, respectively.

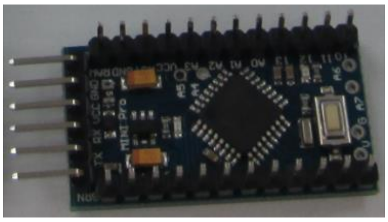


Figure 5. Microcontroller board.

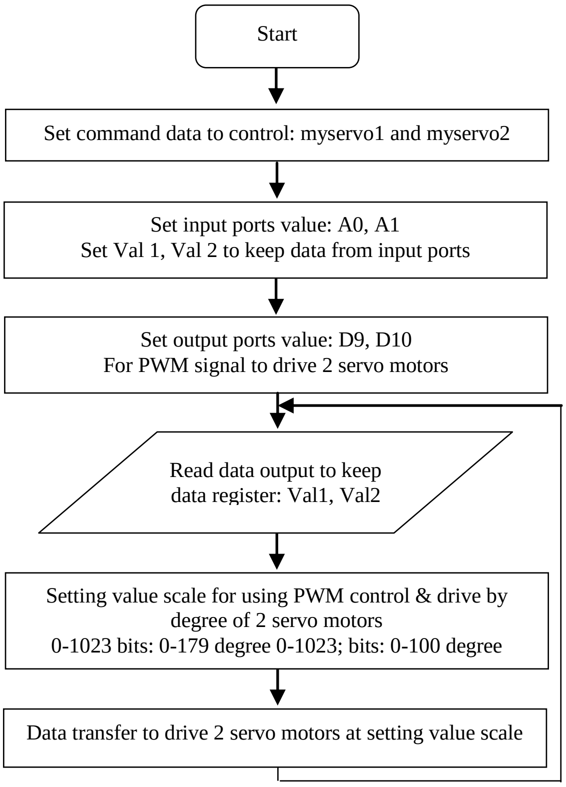


Figure 6. A flowchart shows the order in which the microcontroller is programmed.

Fig. 7 displays the amputee hand training device, the current development was a 2-fingers prototype, medical device designed for the hand amputation training purpose in practicing arm muscle isolation.

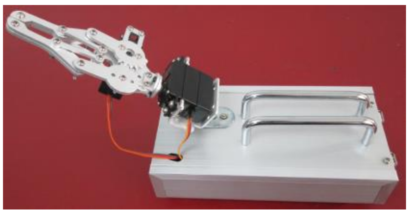


Figure 7. The 2-DoF robotic hand gripper proposed as the amputee hand training device.

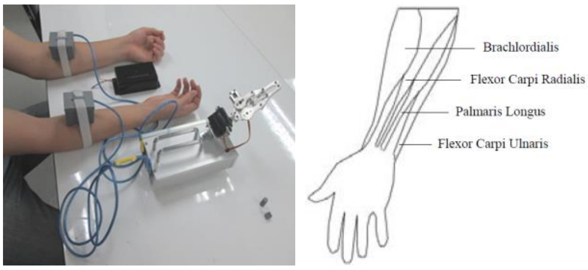
E. *Monitoring sEMG Signal Quality*

The notepad of 10-steps LED light bar was designed for SEMG signal monitoring, used to visualize the quality of detected sEMG signal from the smart detector box. The LM3914 was used as the comparator amplifier inside the notepad. Fig. 8 shows the notepad of sEMG signal monitoring, the red to green dots are the signal quality ranged from high to low levels of the signal detected. The acquired sEMG signal that demonstrated the LED level above the green dots is enough to drive the servo motor. However, if the obtained signal is within the green levels, so the smart detector box is needed to be checked and modified in section B and C for signal detecting and signal conditioning.

Figure 8. The notepad of 10-steps LED light bar for SEMG signal quality monitoring.

III. Test Procedure

The sEMG signal detector and modulator (the smart detector boxes) were placed on both arms of the volunteer as shown in Fig. 9(a). Fig. 9(b) reveals the muscle structures: Brachlordialis, Flexor Carpi Radialis, Palmaris Longus and Flexor Carpi Ulnaris. The group of these muscles is the locations to place the smart detector box for acquisition of sEMG signals. Fig. 10 shows the basic items are used in this experiment, cylinder shape with 1cm of diameter and 2cm of high, 1cm^3 of cubical shape, and the last object is an egg-shaped.



(a) (b)

Figure 9. The test procedure of the research project, (a) the experimental setup (b) the group of hand muscles.

Figure 10. The basic objects for an assessment of the grasping function.

The hand amputation must practice using this device for at least 60 minutes, and adjust the sEMG signal before the test begin with detection of the great signal quality (above the green bar, see in Fig. 8). Besides, the test of myoelectric prosthesis hand function was included 2 states. In the first state, the amputee used the training device to grasp the basic items (see in Fig. 10) for 30 times. The test criterion is that the object is grasped and holding it for at least 3 seconds, and then released the holding item and suddenly grasp the item again. In the second state, the amputee used the training device to rotate the hand wrist for 30 times. In addition, the test criterion is that the 2-DoF electric hand gripper must rotate as a minimum of 90° degrees then relax the muscles to release the rotation of the robotic hand. Therefore, the amputee used the training device, and absolutely accepted these criteria in both conditions, and this means that the amputee was successfully trained with this research project.

IV. Results

The 2-dof robotic hand and its 2 main functions are grasping basic objects and performing the wrist rotation. The hand amputee training device was tested with the user attached the smart detector boxes on his arm skin (in the condition that surface electromyography is detected), a completed control system is fully connected with the 2-DoF robotic hand, and ready to perform the 2 main functions.

TABLE I. The Functional Test of the 2-DoF Robotic Hand

Frequency	Grasping Objects			Rotating Wrist
	Cylinder	Cubic	Egg	
1	Yes	Yes	No	Yes
2	Yes	Yes	No	Yes
3	Yes	Yes	No	No
4	Yes	Yes	Yes	Yes
5	No	Yes	Yes	Yes
6	Yes	Yes	No	Yes
7	Yes	No	Yes	No
8	Yes	Yes	Yes	Yes
9	Yes	Yes	No	Yes
10	No	Yes	No	Yes
11	Yes	Yes	Yes	Yes
12	Yes	Yes	Yes	No
13	Yes	Yes	No	Yes
14	Yes	Yes	No	Yes
15	Yes	Yes	Yes	Yes
16	Yes	No	No	Yes
17	Yes	Yes	No	Yes
18	Yes	Yes	Yes	Yes
19	Yes	Yes	No	Yes
20	Yes	Yes	Yes	Yes
21	Yes	Yes	No	Yes
22	Yes	Yes	Yes	Yes
23	Yes	Yes	No	Yes
24	Yes	Yes	No	Yes
25	Yes	Yes	No	No
26	Yes	Yes	Yes	No
27	Yes	Yes	No	Yes
28	Yes	Yes	Yes	Yes
29	Yes	Yes	No	Yes
30	Yes	No	No	Yes
Success in Total	28	27	12	25
Success Rate (%)	93	90	40	83

Note: ‘Yes’ is successful grasp; ‘No’ is unsuccessful grasp

Cylinder, cubic and egg were considered as the three standard objects, and used to evaluate the 2-DoF robotic hand. These items were a fundamental geometry, that appropriate to estimate the grasping function. The results of a functional assessment showed that the success rate of grasping function and rotating the wrist hand were 93% of cylinder, 90% of cubic, 40% of egg, and 83% of the wrist rotation. Besides, these calculations were computes based on 30 times in performance of its specific function, as shown in Table I.

Table I represents the achievement of the volunteer practicing the 2-DoF robotic hand; at this time, this device is a 2-fingers prototype. It has found that during the test procedure, a user is very difficult to grasp an egg using the current development.

V. Conclusion

This research presented 2-Degrees of Freedom robotic hand gripper, designed to use as a medical device. This system is intended for rehabilitation training, and the hand amputations have to use this training device to isolate their arm muscle before using the prosthetic hand. This is a low-cost medical device, consisted of 3 major components: the smart detector box to detect the surface electromyography, the integrated signal control device with microcontroller and the 2-DoF robotic hand gripper (2-fingers model). The two main functions of this device are grasping objects and rotating the wrist hand.

The volunteer used this device by following the instructions in the test procedure. The results showed that the success rate of the grasping function was 93% of cylinder, 90% of cubic and 40% of egg, and rotating the wrist hand was 83%. The success rate was calculated based on 30 times in performance. It is found that in this first prototype, the sEMG signal detector within the smart detector box was reasonably to acquire the decent signal to drive the servo motors; however, it was a fixed gain, designed for the specific hand amputee. As a result, another hand amputee is needed to recalculate the proper gain to function the training device.

Future work includes improvement of the smart detector box to be able to work automatically with a range of hand amputees, and the expansion of the training device with 3-fingers prototype. In the second model of this device would be enabled to employ the better performance in grasping an egg-shaped, and perhaps rapidly progress the arm muscle isolation.

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