Development of Myoelectric Prosthetic Hand based on Arduino IDE and Visual C# for Trans-radial Amputee in Indonesia

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***Abstract*— This paper presents a preliminary study on design and development of prosthetic hand controlled by electromyography (EMG) sensor for patients who suffered from trans-radial amputee. The system is made up of an embedded Arduino microcontroller equipped with Visual C# programming as graphical user interface (GUI). The prototype of the prosthetic hand has five grip modes i.e. hand open and close, hook finger movement, peace finger movement, pointing finger movement, and active thumb. The mechanism of prosthetic hand is designed with selected mode grip pattern, where each motion is triggered from muscle contraction that is acquired using EMG sensors. In addition, the input of EMG signal can be monitored from the graphs in GUI based on Visual C# programming. Each finger in the prosthetic hand prototype is driven by a linear actuator. The objective of this study is to design and develop a prototype of myoelectric hand based on EMG sensor and create a prosthetic hand grip pattern mode program.**

Keywords—electromyography, Arduino, prosthetic, graphical user interface

I. Introduction

Currently, the development of the technology is growing rapidly in almost all aspects such as health, education, defense, security etc. Myoelectric prosthetic hand or often we call bionic hand is one example of the latest technological developments in the field of health, especially in the biomedical field. This technology comes as the development of pre-existing technology, namely passive prosthetic hand technology or artificial hand that is used for hand amputation patients. User / wearer can drive the passive prosthetic hand by powering it using his/her body such us shoulder. Prosthetic hand is aimed to replace the lost of upper body parts due to amputation.

Amputation is a medical act of cutting either part or all parts of the body, which can include the fingers, hands, arms, legs etc. Amputation on the hands of a person's body greatly affect the productivity or capacity of the person in handling a job or doing activity of daily living (ADL). Deformity of the hands can be caused by amputation due to the work accident. Injury, deformity, or handicap can affect the hand function and quality of life of a person [1].

Prosthetic hand (artificial hand) becomes the main alternative for replacing the lost hand. Prosthetic hand can be divided in two types; body-powered and electrical motor powered prosthesis. Body-powered prosthetic hand is manually operated by utilizing the movement of certain body parts that are connected through cables or ropes. The movement of certain body part such as shoulder is be able to drive the prosthetic hand. While electric motor powered prosthetic hand is operated by the electric motor utilizing electricity signal from the remaining human hand in order to drive the prosthetic hand.

In this research, the myoelectric prosthetic hand technology is developed with the purpose as an option given besides passive prosthetic hand. The fundamental difference between myoelectric prosthetic hand and passive prosthetic hand technology is the inclusion of a series of programs that allow myoelectric prosthetic hand technology to perform movements that cannot be performed by passive prosthetic hand technology. The myoelectric prosthetic hand technology that is developed in this research will use Arduino microcontroller and C# programming. To control the myoelectric prosthetic hand, electromyography (EMG) sensor is employed in this research. Arduino microcontroller is utilized as a main computation for reading the muscle contraction via the EMG sensor and controlling the motion of linear actuators. The linear actuators are connected to the fingers by using four-bar linkage mechanism.

II. Myoelectric Prosthetic Hand Design

Prosthetic hand is an artificial human hand made with the aim to replace the lost of human hands for people who have upper limb amputations. Prosthetic hand basically has two functions that are as cosmetic tool and functional tool. Prosthetic hand as a cosmetic tool has a form resembling the original hand, but cannot function as the original hand [2]. While the prosthetic hand as a functional tool has the ability to perform basic human hand movements such as cylindrical, lateral, palmar, hook, tip, and spherical [3]. Anthropomorphic prosthetic hand has a high degree of resemblance with human hands and capable of performing activities such as human hands.

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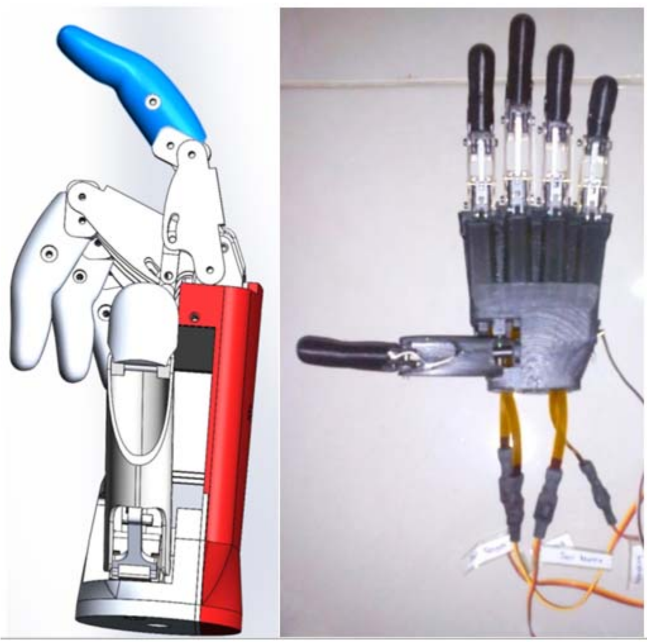
In this study, the prosthetic hand movement system was developed in the Arduino IDE software environment and the prosthetic hand control algorithm embedded on the Arduino Nano V3.0. This embedded system is developed to drive the prosthetic hand with the input from surface electromyography (sEMG) sensor. The sensor reads the muscle contraction of the user/wearer. The linear actuator used in this research is a linear motor Firgelli PQ12-R that was imported from Canada. The joint connection from linear actuator to the fingers is utilized four-bar linkage mechanism. The proposed myoelectric hand has five degrees of freedom (DOF). The design of the four-bar linkage mechanism has more challenging than the tendon-spring mechanism. Our previous research utilized tendon-spring mechanism for connecting the actuators and the fingers in the hand. Based on the previous research [4-6], the tendon spring mechanism can provide linear relationship from the actuator input to finger joint angle.

The design concept of the prosthetic hand prototype developed in this study is as an alternative device that can be used as a substitute for the hands of patients who have been amputated. The purposes of the proposed myoelectric hand are as follows:

a) Develop a prosthetic hand that can be used with amputation under below elbow (transradial amputation)
b) Input from the prosthetic hand movement comes from EMG sensor.
c) Can perform five different grip pattern modes such us open-close, hook, peace, indicate, and active thumb.
c) The resulted prosthetic hand weighs no more than 1 kg.
d) Portable and convenient to use.

Fig. 1 shows the proposed of myoelectric prosthetic hand based on 3D printing technology. In the finger design, DIP joint is fixed at 15^0. Index, middle, ring, and little fingers utilize four-bar linkage mechanism. The linkages are made of aluminum. The fingertips, and the palm of the hand are printed by using 3D printer. The other available prosthetic hands based on 3D print can be found in [7-13].



(a) (b)

Fig. 1. Proposed myoelectric prothetic hand. (a) 3D CAD design, (b) Resulted of the myoelectric hand prototype.

The myoelectric prosthetic hand prototype is designed to be driven by using sEMG sensor as an input control to drive the linear actuators. After the prototype of myoelectric prosthetic hand has been built, graphical user interface (GUI) was built for data acquisition, monitoring, and setting purposes. The developed GUI for the hand system is shown in Fig. 2. The GUI can be installed on the computer. The utilized toolbox and the character on the myoelectric hand system can be summarized as in Table I.

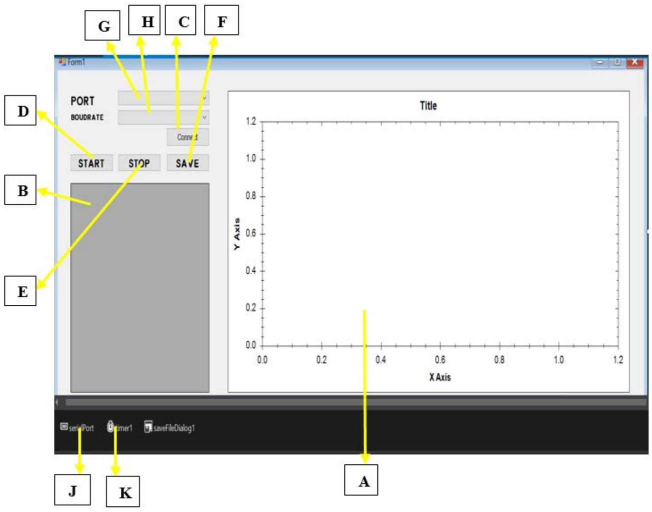


Fig. 2. Proposed graphical user interface in the myoelectric hand system.

TABLE I. DEVELOPED GUI TOOLBOX FOR WIRELESS EMG MONITORING SYSTEM.

Character	Toolbox	Function
A	Zedgraph	To create a realtime signal graph from the EMG sensor
B	DataGridView	To display the signal number from the EMG sensor being monitored
C	Button (Connect)	To enable graphics
D	Button (START)	To begin the monitoring process
E	Button (STOP)	To stop the monitoring process
F	Button (SAVE)	To store the monitoring results in richtextbox
G	Combobox (PORTi)	To select a port
H	Combobox (BOUDRATE)	To select baudrate speed
J	Serial Port (Arduino)	To create a relationship between arduino Nano V3.0 microcontroller with C # programming language
K	Timer (Second)	To run the program work in realtime

The input used to drive the prosthetic hand comes from the EMG sensor signal. EMG sensor has an analog signal that is directly proportional to the muscle contraction of the human hand. The more the value of the muscle contraction is measured, the more the analog value outputs. This output voltage will go into the microcontroller and used to move the corresponding Firgelli linear actuator. Before developing the program of control algorithm on the myoelectric hand, the measured analog value of the prosthetic hand user should be known. The analog value recorded on the Arduino monitor via serial communication will be used as the reference value to create a boundary value which will be used to control the linear actuator. The linear actuator can be extended or retracted for flexion and extension motion on the prosthetic hand fingers. EMG sensor used are able to read and convert muscle contractions on the human hand. Control algorithm program written in Arduino IDE is uploaded to the microcontroller and then the EMG is connected to Arduino Nano V3.0 using Analog input pin to move the prototype of the prosthetic hand.

III. RESULT AND DISCUSSIONS

A. *Interface Hardware and Software*

In this study, the developed hardware system is myoelectric prosthetic hand that can be moved with EMG sensor, where the EMG sensor is placed on the remaining arm/hand of the patient. The muscle contraction is read by EMG sensor and then sent the acquired signal to the microcontroller using analog to digital converter (ADC). The acquired signal is processed by the microcontroller and sent the processed signal to the actuators in the prosthetic hand in the form of the PWM signal. The acquired signal is sent to the developed GUI via serial communication by using Bluetooth. The proposed interface of the myoelectric hand system is shown in Fig. 3.

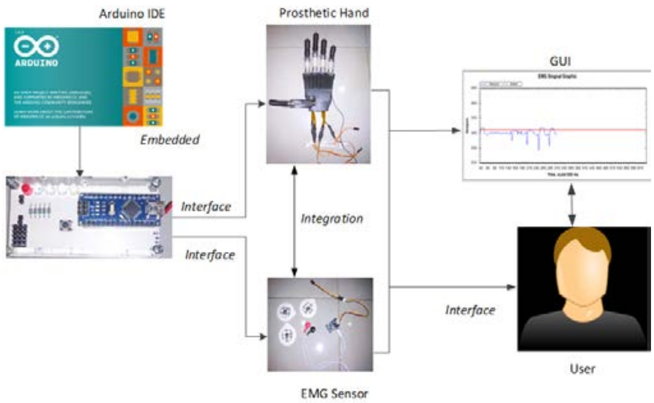


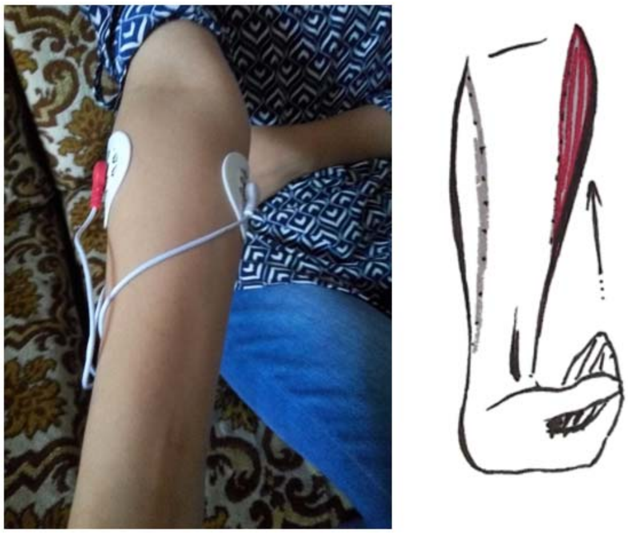
Fig. 3. Proposed interface in the myoelectric hand system

B. *EMG signal acquisition*

In this research, EMG data collection was recorded using electrodes attached to the skin surface. This surface electrode only allows for a maximum of three uses, which is using adhesive type EMG. This electrode acquires the voltage generated by the user's muscle contraction. The magnitude of the EMG signal depends on various factors, such as placement on the hand, the type of electrode used, and the strength of the muscle contraction. The electrodes were placed on the arms with hand movements and positions as shown in Fig. 4. This study is intended to find position and movement that produce the best muscle contraction response.

Data acquisition or data collection was carried out on five subjects or study participants. They were male (one of whom was a subject with hand amputation) and one subject was female. Subjects have varied ages, three subjects have ages from 20 to 24 years at the time of data collection, one subject with transradial amputation has an age of over 35 years, while for female subject has an age of 22 years. Table II shows the list of subjects for EMG signal data acquisition.

In acquiring the muscle contraction signal, it used electromyography detector v1.1 and skin surface electrodes that use adhesive and cannot be reused or only one time usage. The data acquired by the microcontroller will be displayed on the monitoring GUI that was previously developed using Microsoft Visual Studio with C # language as shown in Fig. 2.



(a) (b)

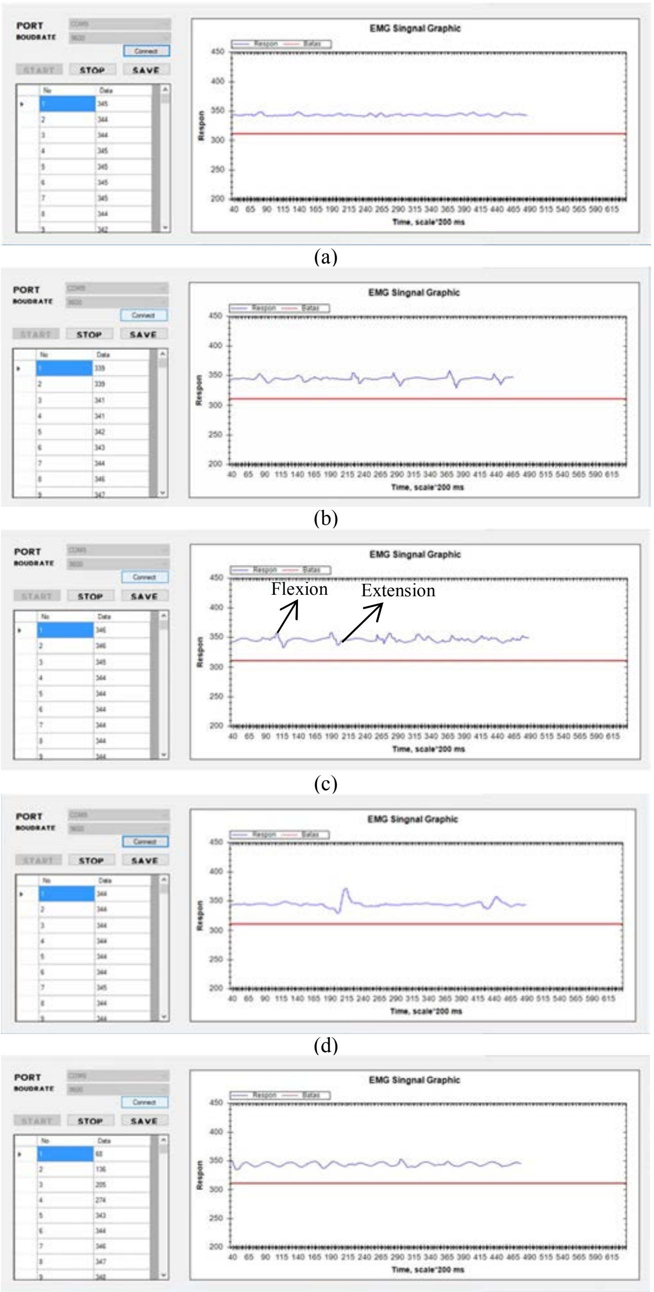
Fig. 4. Surface EMG placement. (a) on the arm below elbow, (b) flexion motion of the hand as a trigger to drive the myoelectric hand.

TABLE II. STUDY PARTICIPANTS INVOLVED IN THIS STUDY

Subject	Gender	Age	Hand condition
S1	Male	35	Transradial amputee
S2	Male	24	Healthy
S3	Male	21	Healthy
S4	Male	22	Healthy
S5	Female	22	Healthy

The results of the EMG acquisition signal with five study participants are displayed as shown in Fig. 5. The measurements start from subject 1 through subject 5 based on the position of the EMG electrode placement as shown in the Fig. 4. Flexion and extension movement on the user's hand is conducted with a measurement time of 20-40 seconds. The acquired sEMG signal is then sent to the GUI via serial communication by using Bluetooth. The acquired EMG signal that is sent to the GUI is in the form of analog to digital converter (ADC) value.

Based on the results of the measurements as shown in Fig. 5, the flexion and extension of the hand signal can be read by the sEMG sensor. The placement of the surface EMG electrodes on the arm as in Fig. 4 can detect flexion or extension movements in the user's hand. Based on the results in Fig. 5, study participant with transradial amputation gives the lowest amplitude of flexion and extension signal. Therefore, before the transradial amputee can utilize the myoelectric prosthetic hand perfectly, the remaining hand need to be trained and rehabilitated.



(a) (b) (c) (d) (e)

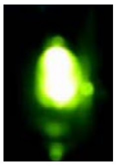
Fig. 5. Acquired EMG signals on five study purticiants. (a) Subject 1, (b) Subject 2, (c) Subject 3, (d) Subject 4, (e) Subject 5.

C. *Experimental Results*

Motion testing without grasping the object is conducted to find out the five motion modes can run according to the desired motion. There are five grip modes that have been developed on the proposed prosthetic hand, the movements that have been made are open - close, hook, peace, pointing, and active thumb. These modes will be explained in Table III as follows.

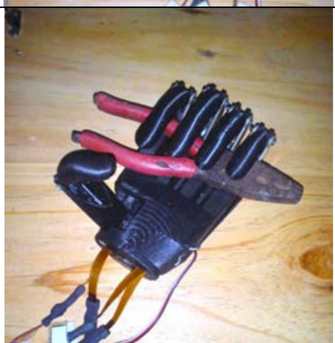
Table III shows the first mode with a red LED indicator that can move the hand open and hand close which is expected to replace the grip function, the second mode with the orange LED indicator can do hook motion which is expected to replace the function of holding objects in a vertical position like a bag . The third mode of movement is peace with a green indicator that is expected to replace the function of the hand under certain conditions. The fourth mode with a blue indicator can indicate the index which is expected to replace the function of showing something or typing the keyboard, then the fifth mode with a white indicator with active thumb motion which is expected to replace the handshake function.

TABLE III. STUDY PARTICIPANTS INVOLVED IN THIS STUDY

Mode	LED colour	Hand posture
Open – Close		
Hook		
Peace		
Pointing		
Active thumb		

Object grasping motion test is conducted to find out the grip mode that has been developed can work properly and can withstand the given load. Table IV shows the objects that can be taken and held by myoelectric hand on grasping object test. Based on the test result, the proposed myoelectric hand can stably grasp objects such us cylinder, tennis ball, pliers, smartphone, and marker pen.

TABLE IV. OBJECT GRASPING TEST

Object	**Grasping result**
Cylinder	
Tennis ball	
Pliers	
Smartphone	
Marker pen	

IV. CONCLUSION

In this study, a myoelectric prosthetic hand has been developed using four-bar linkage mechanism. The GUI for monitoring, and setting the hand system has been built in visual C#. Five grip patterns that have been developed are open - close, hook, peace, pointing, and active thumb. Based on the test results using single channel surface EMG signal input, the proposed myoelectric hand can be stably grasp objects such as cylinder, tennis ball, pliers, smartphones, and marker pens.

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