A Two-channel Electromyogram-based Robotic Arm System: A Continuous Wireless Control using Simulated Hand Gesture Patterns

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Abstract

This research aims to conduct a simulation of the occurrence of electromyography signals in two groups of forearm muscles. Two switches were used to control the movement of the robotic arm to continuously mimic hand gestures. This project is developed from a simple robotic arm that has two movement directions for grasping objects with restricted size and shape. The goal of this research is to develop a robotic arm that can pick up and hold various objects with different sizes, shapes and weights. The robot arm should be able to perform four-hand gestures, including hand opening, object grabbing (using five and two fingers), and pointing with the index finger. The grasping pressure rate should be set automatically by wireless control to accommodate the handling of objects with different levels of sensitivity. Test results demonstrate that the robotic arm can handle various shapes and sizes of objects and perform the four-hand gestures with the continuous control similar to the human arm movement with an accuracy of 93 %. This research can be used as a guideline for applying actual electromyography signals to control artificial arms for disabled people in order to return them to live routinely with a good quality of life.

Keywords: *robotic arm, electromyography signals, wireless control*

1. Introduction

To apply a robotic arm with 4 human movement gestures mimicking human arm's functions, it is necessary to study the movement of human arms by specifically focusing on the hand and fingers that are control by the brain communicating through nerves in the form of electrical signals to muscles, allowing the forearms muscles to work (Mangukiya et al, 2017). As a result, this is the working of the hands and fingers as commanded by the brain (Elbagoury & Vladareanu, 2016). The forearm muscles that allow the hand and fingers to perform various postures consist of eight muscles, which are divided into two groups (Hernández, Vargas, & Rodríguez, online).

One is a group of Flexor muscles located in the front of the forearm, responsible for pulling in the fingers and wrist in the form of folding hands to clench a fist (Murillo & Moreno, 2016). Another is a group of Extensor muscles located in the back of the forearm, responsible for stretching the fingers and bending the wrist backward as shown in Figure 1.

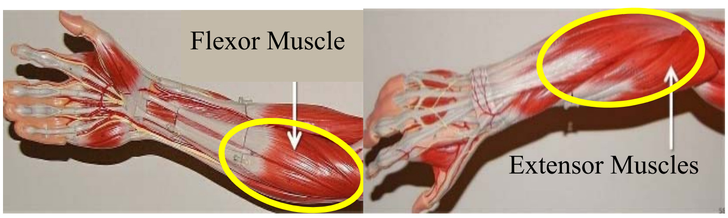


Figure 1 Flexor and Extensor Muscles
(Source: http://www.djibnet.com/photo/biol121)

EMG signals were generated by muscle contraction, the signals are characterized by two and three-phase waveforms, with an amplitude from 200 microvolts to 5 millivolts, a width of 5-15 milliseconds and 5 – 20 hertz (Robinson & Snyder-Mackler, 2008). The gesture of the muscle's contraction and loosening was converted into a binary code format, where logic "1" represents the contraction and logic "0" represents the loosening of muscle.

At present, there are many types of robotic arms developed to replace arm and hand lost. The robotic arm's movement requires a motor to drive. The servo motor is a type of motor with precise rotating angle control via pulse signal named Pulse Width Modulation (PWM), which control the pulse width input to the servo motor driver circuit in order to control the change in angle degree of the servo motor's shaft and to control the pulse frequency affecting the rotation speed of the servo motor as shown in Figure 2.

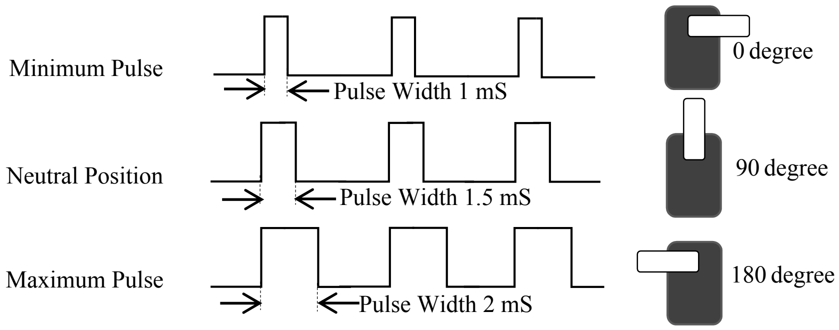


Figure 2 Pulse Width Modulation per the angle of the servo motor
(Source: https://www.servocity.com/how-does-a-servo-work)

Equation 1 can be used to explain the function of the servo motor as follows:

$$\omega = \frac{K}{s(Ts+1)} v_a \qquad (1)$$

Where ω: angle of the motor rotation (rad/s)
V_a: input voltage (v)
K: constant

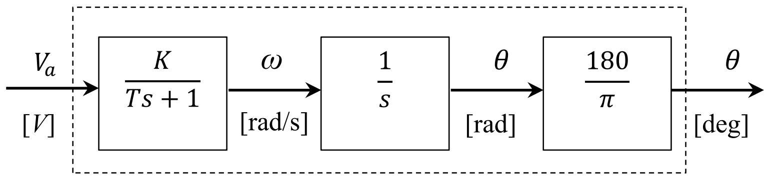


Figure 3 Controlling servo motor angle degree

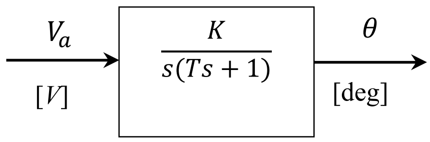


Figure 4 Transfer function of servo motor control

From Figure 3 and Figure 4, when input the pulse Width modulation signal into the servo motor, the pulse signal will be sent to the microprocessor inside the servo motor module. The average pulse width modulation, which is a voltage, will be processed in order to control the motor inside the servo motor, rotate and drive the servo motor shaft for angle change

The structure of a servo motor in Figure 5 consists of a direct current motor (DC Motor), a rotary axis driving the reduction gear, and a set of adjustable resistance driving gear. When the motor rotates, the gear will change the resistance in relation to the angle degree of rotation, from the minimum resistance, 0-degree angle, to the maximum resistance, 180-degree angle, as shown in Figure 6.

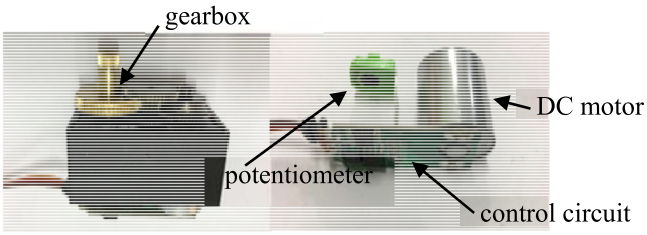


Figure 5 presents the structure of the servo motor

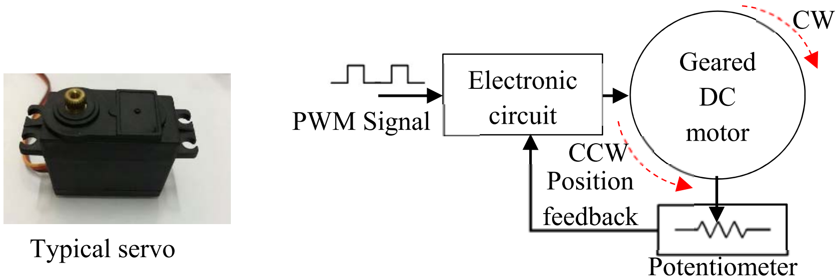


Figure 6 presents the operation of the servo motor
(Source: http://www.ermicro.com/blog/?p=771)

Nowadays, wireless communication is widely used, because of the ability to save the signal cable and more convenient operation. The Bluetooth communication module is a wireless data communication device that can be compatible with the microcontroller through Serial Communication with UART (Universal Asynchronous Receive Transmitters) using only 1 cable channel for wireless data transmission on the 2.4 GHz electromagnetic field using only 3.3 to 6 Volts direct voltage. Therefore, it is suitable to be used as a medium for data transmission to drive the servo motor for the robotic arm (Oskoei & Hu, 2007). The circuit connection model is shown in Figure 7.

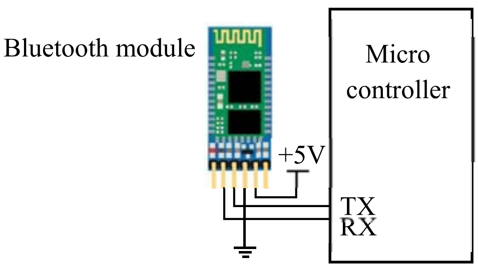


Figure 7 Bluetooth module

2. Objectives

This research aims to conduct a simulation of the occurrence of electromyography signals in 2 groups of forearm muscles by 2 switches to control and move a robotic arm continuously like the function of a human arm.

3. Materials and Methods

3.1 The simulation of electromyography signals

for this research describes the function of electromyography signals by forearm muscles. According to the research, there are two groups of arms- muscles, Flexor group, and Extensor group (Day, S.2002). These two muscles work simultaneously in the opposite direction, which is also known as Antagonist. One muscle contract, while another muscle loosens. In addition, from the article on measuring electromyography signals via Myo Armband (Benalcázar et al, 2017), it is found that human arms can perform many gestures (Phinyomark, Khushaba & Scheme, 2018).

There are 4 gestures that have clear measured electromyography signals as follows:

Gesture 1. Open palm of the hand that loosens both Flexor and Extensor muscles at the same time.
Gesture 2. Fist clench that contracts both Flexor and Extensor muscles at the same time.
Gesture 3. Wrist bend inwards that contracts Flexor muscle and loosens Extensor muscle.
Gesture 4. Hand opening that loosens Flexor muscle and contracts Extensor muscles.

Therefore, the electromyography signals from these 2 muscles are used as a concept for the simulation of electromyography signals to control a robotic arm in this research (Guerrero et al, 2015).

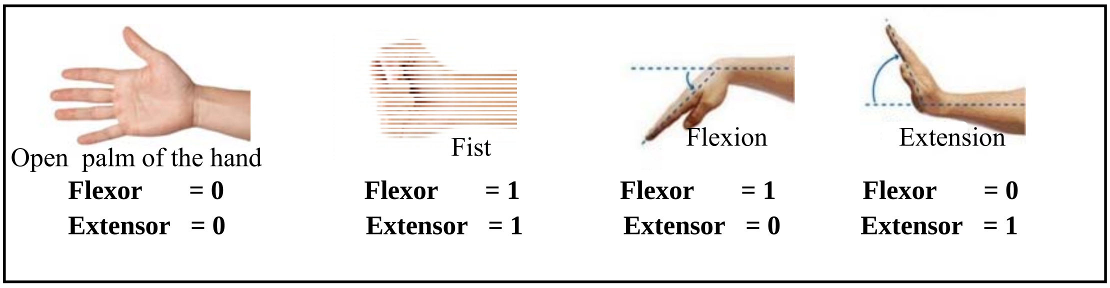


Figure 8 Binary code simulating the contraction and relaxation of the flexor and extensor muscles

From Figure 8, the comparison of the muscle's contraction and loosening from doing the 4 gestures is done by comparing a digital logic with Binary code format, where logic "1" represents the contraction of any muscle, logic "0" represents the loosening of any muscle.

Coding binary logic code 0 and logic code 1 by pressing the 2 switches according to the pattern of the electromyography signal from the 2 muscles, where Switch No. 1 (S1) represents Flexor muscle and Switch No. 2 (S2) represents the Extensor muscle. When a switch is pressed, there will be a digital logic signal "1" entering into the microcontroller. Meanwhile, when there is no pressed switch, a digital logic signal "0" will be entered into the microcontroller.

3.2 Gesture design for the robotic arm

This research aims to develop robot arms for the disabled. Therefore, there is a guideline for experimentation in accordance with the use of mimicking a human arm by designing the robotic arm to perform 4 hand gestures that humans use in daily life, including Gesture 1 for hand opening, gesture 2 for object grabbing using 5 fingers, gesture 3 for object grabbing using 2 fingers and gesture 4 for position pointing with an index finger (Villegas, 2017).

3.3 Mechanical design for the robotic arm

3.3.1 Robotic-arm mechanism

The robotic arm is driven by the servo motor. When the servo motor's shaft rotates, the nylon lines that are attached the shaft to the robotic fingers will be pulled, as a result, the fingers will bend inwards.

In contrast, when the servo motor's shaft rotates in an opposite direction, the nylon cord will be loosened, causing the robotic fingers to be stretched back to its original condition (Langevin, 2014).

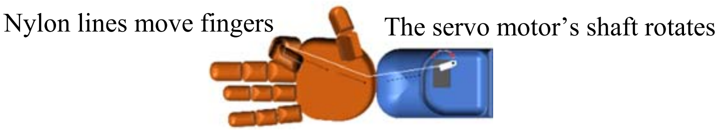


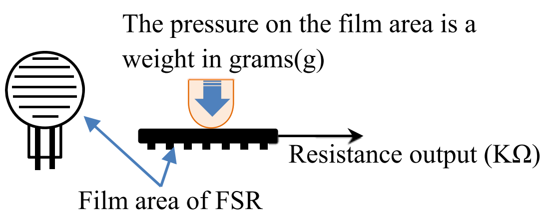
Figure 9 Robotic-arm mechanism

3.3.2 Digital control program and robotic arm control

This research applies the Arduino IDE as a computer application for the design and development of the robotic arm control program. The researcher applies Arduino nano microcontroller board with ATmega328 processor as a control device because of its small size, lightweight, and only 7 to 12 Volts required direct voltage, with a processing speed of 16 MHz, 14 digital interface supporting pins, and 8 analog interface supporting pins (Setiawan, 2016). 5 servo motors, MG996R module, are used to drive the 5 robotic arm's fingers since it requires high torque up to 11 kilograms per centimeter, and 4.5 – 6 Volts of direct voltage (Villegas, 2017). Control rotation with the pulse width modulation (PWM), in which the rotating angle of the motor shaft will change according to the pulse width (Villegas, 2017), causing the servo motor's shaft to rotate to the desired angle from 0-degree angle to 180-degree angle.

3.3.3 Feedback control system

In order to design a robotic arm to handle objects with fragile physical properties and at risk of breakage, it is necessary to design a system to measure the rate of force acting on an object. This research used force-sensing resistor (FSR) as a device for measuring the rate of force applied to an object while a robotic arm picks up an object (Stephens-Fripp et al, 2018). From the study of the work of FSR, it was found that the resistance value of the sensor will change when there was pressure on the film area of the sensor. In this study, the pressure on the film area is a weight in grams(g). The FSR acts as an electric resistor that changes with the force applied to the sensor (Cognolato et al, 2018). By default, if there was no force acting on the sensor (weight is 0 gram), the sensor's internal resistance was equal to 100 kΩ. Only when the force is applied to the sensor, the resistance value decreases according to the pressure applied to the sensor as shown in Figure 10.



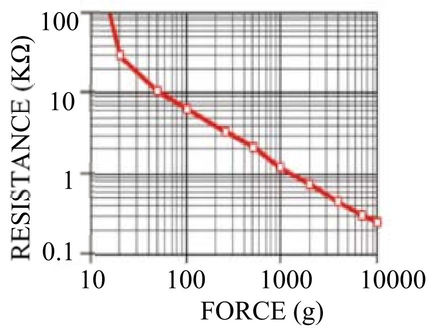


Figure 10 Variation of resistance (ohm) with force applied on the FSR
(Source: https://www.trossenrobotics.com/productdocs/2010-10-26-DataSheet-FSR402-Layout2.pdf)

From the characteristic of changing the internal resistance of the pressure sensor, it led to the circuit design as shown in Figure 11.

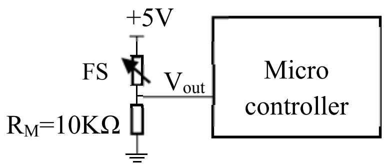


Figure 11 Pressure measuring circuit with FSR

The output voltage from the circuit will change if there was pressure on the sensor. In other words, when there was no pressure on the sensor, the output voltage is equal to 0 volts. But if there was pressure applied to the sensor, the output voltage will increase according to the weight of the applied pressure, with a maximum value of 5 volts. The output voltage could be calculated from Equation 2:

$$V_{out} = \frac{R_M \times V}{(R_M + R_{FSR})} \quad (2)$$

V_{out} = output voltage (V)
R_M = constant resistance (10KΩ)
V = constant direct current voltage (5V)
R_{FSR} = resistance value within the sensor that changes with the weight of the pressure (Ω)

In addition, the pressure could be specified in 3 levels, which are the lowest level, with a 0-300 grams force rate, an output voltage of 0-2.9 volts; moderate level, with a pressure rating of 301-600 grams, the output voltage was 2.9-3.5 volts and at the highest level, with a pressure rating of 601-1000 grams, the output voltage is 3.5-4.3 volts. It showed the pressure status with 3 color lamps, namely the lowest pressure level, displayed with green light bulbs. The medium pressure level was displayed with an orange lamp and the maximum pressure level was displayed with a red lamp with a robotic arm that stops immediately.

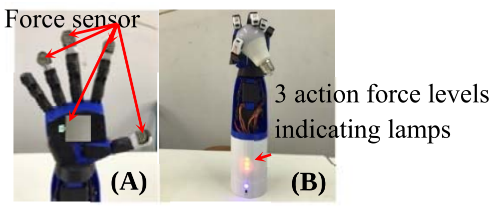


Figure 12 (A) Installation of force sensors in the robotic arm's fingertips and the palm area
(B) Action force status notification

3.4 Gesture control of the robotic arm

This research designs the robot arm to be able to perform 4 gestures by pressing the switch.

Gesture 1, hand opening, is a normal gesture when there is no pressed switch.

Gesture 2, object grabbing using 5 fingers, is controlled by pressing and holding S1 button. The robotic arm will move smoothly and continuously at a speed of 30 rounds per minute. The S1 button can be pressed until all 5 fingers grab and hold an object firmly, and released the S1 button to stop the order, making the robotic arm to hold the same position. To release the object, press the S2 button once, and the robotic arm will return to the hand opening gesture.

Gesture 3, object grabbing using 2 fingers, is controlled by pressing and holding S2 button. The robotic arm will move smoothly and continuously at a speed of 30 rounds per minute. The S2 button can be pressed until both 2 fingers firmly grab or hold the object, and released the S2 button to stop the order, making the robotic arm to hold the same position. To release the object, press the S1 button once, and the robotic arm will return to the hand opening gesture.

Gesture 4, position pointing with an index finger, is controlled by pressing S1 button and S2 button at once. All 4 fingers, except the index finger, will be folded, leaving only the index finger for pointing. To cancel the action, press S1 button once, and the robotic arm will return to the hand opening gesture.

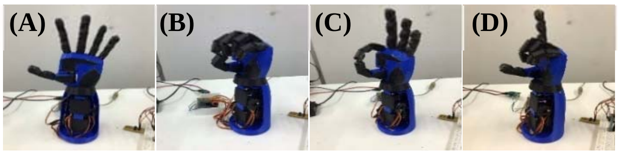


Figure 13 (A) Hand opening gesture (B) Object grabbing gesture using 5 fingers (C) Object grabbing gesture using 2 fingers (D) Position pointing gesture with an index finger

4. Results and Discussion

From the experiment to control the robotic arm to grab 9 kinds of commonly found objects in human life with different sizes and shapes. This experiment that is just a primary test with slight weight objects less than 500 grams the objects are shown in Figure 14.

Figure 14 Objects for pick up experiment

Table 1 Record of the results of the robotic arm's grabbing control with 3 different diameters of cylindrical objects by 5 times repeated grabbing test for each object type

Object grabbing using 5fingers	Ø5 cm.	Ø 6 cm.	Ø8 cm.	Accuracy
Cylinder	100%	100%	100%	100%

The result found that the robotic arm can handle all cylindrical objects, accounting for 100 percent. The design of the robotic arm's physical structure system supports the function to handle cylindrical objects with diameters from 2 cm to 10 cm.

Table 2 Record of the results of the robotic arm's grabbing control with 3 different diameters of round shaped objects by 5 times repeated grabbing test for each object type

Object grabbing using 5 fingers	Ø4 cm.	Ø 7 cm.	Ø9 cm.	Accuracy
Sphere	100%	100%	100%	100%

The result found that the robotic arm can handle all round objects, accounting for 100 percent. The design of the robotic arm's physical structure system supports the function to handle round-shaped objects with diameters from 2 cm to 10 cm.

Table 3 Record of the results of the robotic arm's grabbing control with 3 different sizes of cubical objects by 5 times repeated grabbing test for each object type

Object grabbing using 5fingers	W x H 2.5x2.5 cm.	W x H 4x3 cm.	W x H 10 x 5 cm.	Accuracy
Cube	100%	100%	100%	93%

The result found that the robotic arm can handle cubical objects, accounting for 93 percent. The design of the robotic arm's physical structure system supports the function to handle round-shaped objects with size from width 2.5 cm. and high 2.5 cm. to width 10 cm. and high 10 cm.

5. Conclusion

This study focuses on the simulation of electromyography signals by two muscles to continuously control a robotic arm to mimics the gesture of human arm wirelessles. The experiment showed that the robotic arm's gesture can perform the four-hand gestures with continuous control similar to the human arm movement with an accuracy of 93 %. The result can be further applied to the development of a robotic arm for the disabled who lost hands and arm since the study used switches as a simulation device to drive the robotic arm's servo motor, which can be applied with electromyography signals to control robotic arm instead of pressing switches.

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