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Development of 3D Printed Prosthetic Arm for Transradial Amputees

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Abstract

Artificial limbs often called as prosthetics are unique devices required for the amputees to lead daily life and regain functions of missing limbs by performing daily life activities. This project proposes a method of development of artificial limb for transradial amputees with 3D printing technology and electromyography as control mechanism. The main objectives of this paper include the process to design a transradial artificial limb via 3D printing technology to enhance the appearance of the prosthetics as the 3D printing technology has the capability to produce structures with various stages. The project also aims to develop transradial artificial limb with microcontroller and EMG sensors to improve the control mechanism. The proposed method will integrate the use of dry electrodes compared to the available methods for Electromyography Signals Acquisition. The EMG sensors accuracy analysed by integrating the data obtained from various body types subjects to prove the accuracy of the sensors which justifies the third objective of the process to analyse the EMG Sensing parameter of the transradial artificial limb. The emphasis of this project is to develop a prosthetic arm prototype that can be improved further for the usage of daily basis.

Keywords: *Artificial Limbs, 3D printed prosthetics, Electromyography, Bionic*.

1. Introduction

Amputation is a clinical procedure of surgically removing partial or entire limbs of the patients due to reasons such as Congenital, Trauma and diseases. The upper limb amputation is divided into 7 sub categories [1]. This paper focuses more on Transradial amputation as it limits the amputee's movement in activities such as picking eating and Grabbing [2]. Diabetes Mellitus is by far the most common cause of amputation in Malaysia, with a percentage of 70 per cent based on the studies conducted [3]. The prosthetics usage among the Malaysian amputees are in low state with 58 percentages [3]. The prosthetics are divided into 3 categories, which are Passive, Body Powered and Myoelectric [4]. Amputees need artificial limbs to function in daily life and carry out a variety of tasks but a high cost makes it difficult to afford [5]. It is also common for people to feel they need prosthetics because they want to improve their appearance and confidence [6]. The available artificial arms such as body powered prosthetics and myoelectric consist of complicated control mechanisms which makes it difficult for amputed people to learn and understand, which makes it ineffective [7].

2. Literature Review

2.1. Additive Manufacturing

Additive Manufacturing, often called 3D printing, has been a crucial part of upper limb prostheses due to its availability characteristics and less wastage in manufacturing [8]. A few key benefits of additive manufacturing compared to traditional manufacturing [9] are cost, speed, quality and innovation. Additive manufacturing also offers the platform to repair components to the latest design instantly compared to traditional methods requiring tooling. The tooling method consumes more time and costs more than additive manufacturing [9]. Additive Manufacturing has been tested on prosthetics by several studies to identify its effectiveness. As per studies, only three of the eighteen prostheses failed during the follow-up time of 5 weeks [10]. It was reported that the failure occurred due to fused deposition modelling techniques, which weakened the prosthesis structure. To summarize, additive manufacturing is the best option to develop prosthetics for amputees due to its cost, design flexibility, and automation.

2.2. Prosthetic Design

The design should meet several requirements that need to be fulfilled to develop an operational prototype successfully. There are two types of requirements: relaxed and complete [11]. Relaxed requirements are the method of prototyping the design with some trade-off limitations from the actual design. The complete requirements approach is about developing a prototype similar to the final design. The design of the prosthetic arm should consist of five fingers, palm attachment, forearm attachment and a compartment for the electronic components based on the project's requirements [12]. The design should maintain functional movement of the fingers to achieve the desired movements, similar to the human hand [13]. The functional movement is core related to the degree of freedom of fingers. There are six degrees of freedom for the translation and rotation of the palm [14]. There are four degrees of freedom for four fingers: the index finger, middle finger, ring finger and little finger. The TPU and PLA materials will be used in the prototype as The TPU material is the flexible material comparatively with PLA [15]. It is most suitable for usage in the printing of fingers and PLA is the most suitable for the forearm parts due to its rigidity.

2.3. Control Mechanism

Electromyography is one of the core components of the Myoelectric control mechanism method. The electromyography methods enable reading the muscle activation of skeletal muscles in the amputee's targeted muscle group. Muscle movements begin in the brain; muscle movement triggering begins in the motor cortex, where a series of action potentials send signals to the spinal cord [16]. The most common was to obtain EMG signals is through Gel electrodes. The problem with the gel electrodes is that they will produce cross-talk and distortion in the obtained signal as the gel starts to dry out. This issue will disrupt the control mechanism of the prostheses. The dry electrodes are proposed as the alternative solution for obtaining reliable EMG signals [18]. The dry electrodes do not need any form of gel to boost their conductivity and signal acquisition of muscle. To summarise, Electromyography method is proposed as the control system of this proposed project which incorporates dry electrodes for better signal acquisitions.

3. Methodology

3.1. Electronic Components

3.2.1. Arduino Nano

One of the most widely used devices for prototyping is Arduino. The main advantages of this device are its cost and support for firmware &libraries. The Arduino Nano is embedded in this project due to its compact form factor and 12 digital input terminals. It also has energy-saving features and a higher clock speed [20].

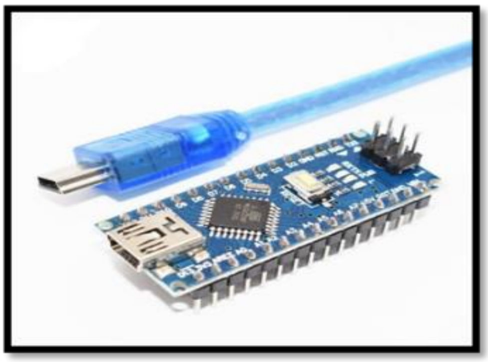

Figure 1: HC-SR04 Ultrasonic Sensor.

3.2.2. 20 KG Torque Servo

In this project, servo motors are integrated and function as linear actuators to give the prosthetic arm's fingers range of motion. The DC motors has internal components such as motor, gearbox, internal potentiometer and control circuit. The DC motors have various types of torques, a 20kg torque servo is used in the project. By adjusting the electrical pulses sent to the DC motors through a microcontroller, their rotating positions can be controlled.

Figure 2: 20KG Torque Servo.

3.2.3. EMG Sensor

This sensor uses EMG (electromyography) to sense the electrical activity of the muscles. It then converts that into a varying voltage that can be read on the analogue input pin of any microcontroller. This power can be obtained from the Arduino board. This muscle sensor uses three dry electrodes that attach to the targeted muscle group, such as biceps, forearms, and calves.

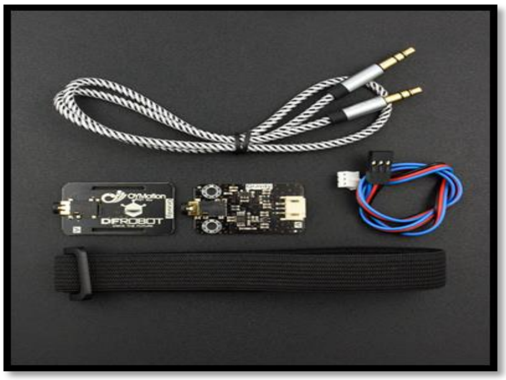

Figure 3: Analogue EMG Sensor.

3.2. Software

3.2.1. Arduino Ide

IDE stands for Arduino Development Environment, and it is used for programming Arduino modules as well as compiling the code. The IDE can be programmed with C Programming Language which can help debug, edit, and compile code. In this project we use Arduino Nano. The main code, also known as a sketch, created on the IDE platform will ultimately generate a Hex File which is then transferred and uploaded in the controller on the board.

Arduino IDE

Figure 4: Arduino IDE.

3.2.2. AutoCAD FUSION 360

Fusion 360 is a 3-dimensional Computer Aided Design program by Autodesk. The software enables the designers to go through all corners and pipeline of the design without switching multiple programs. The Software is primarily used for applications such as 3D Modelling, generative design and Renderings.

AUTODESK Fusion 360

Figure 5: AutoCAD FUSION 360.

3.2.4. **Block Diagram**

The Block diagram of components and their interactions illustrates the process at the hardware and software levels. The subject is the starting point of the flow of this project. The muscle activities will be recorded on the subject through the EMG electrode. Then, those signals will transfer to the EMG recorder module to record it. These signals will be transferred to Arduino (Microcontroller). The Arduino will analyse the signal and then send the information to the servo motor to rotate in the desired direction. The rotation in the servo causes changes in the prosthetic arm. (Fingers contracting and relaxing).

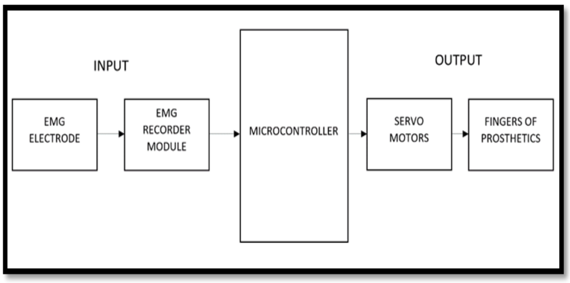

Figure 6: Block Diagram of system.

3.3. Schematic Diagram

An Arduino Nano was connected to two servos and an EMG sensor. A 6v battery is powering the two servos and an Arduino Nano; the Vcc pins will be connected to the 6v battery, which is a positive terminal. The Ground pin of the servo will be connected to the 6V battery's negative terminal. The Arduino Nano's Vin pin will be looped with the 6V battery's positive terminal. The ground pin of the Arduino Nano will be in a loop with the 6V battery's negative terminal. The signal wire from the two servos is connected to the Arduino's digital pins 3 and 5.

Meanwhile, the 3.3V output of the Arduino will power the EMG sensor. The ground wire of the EMG sensor was connected to the ground pin in the Arduino Nano. At the same time, the signal pin of the EMG sensor is connected to the analogue pin in the Arduino.

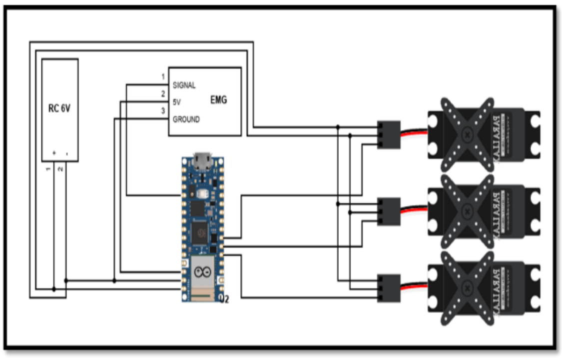

Figure 7: Schematic Diagram of system.

3.4. Design of Prototype

The project design should include five fingers, palm and forearm sockets for electronic component placements. The design objectives are to create a functional prosthetic arm with three degrees of freedom for the fingers. The fingers are separated into three parts to achieve three degrees of freedom. The forearm socket should satisfy the requirements and characteristics for the attachment with palm and compartment for electronic components.

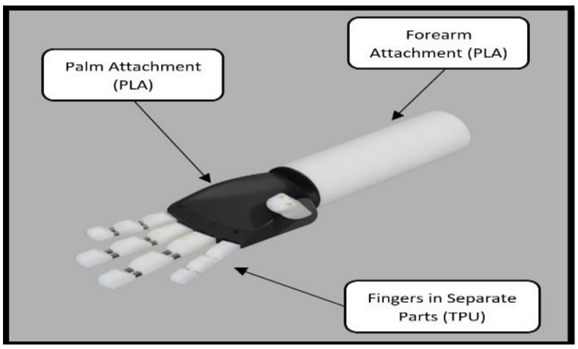

Figure 8: Design of Prototype

4. Analysis

4.1. Accuracy of EMG Sensor

The control system of the developed prosthetic arm is based on the EMG sensor shown in Figure 3. The signal obtained from the sensor is crucial in the process of controlling the finger movements based on amputee's muscle movement. The accuracy of the EMG Sensor was analysed with the data samples collected from subjects with different body mass index such as underweight, normal, overweight and obese. The data collected from these samples also proves the effectiveness of the EMG sensor on various people with different body mass index. The method carried out in obtaining data from subjects is as shown in figure 9.

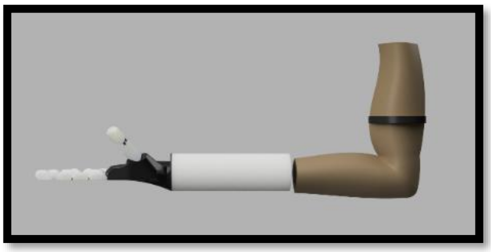

Figure 9: EMG Sensor Placement

The EMG Sensor was placed in the biceps muscle which considered as the targeted muscle group. The sensor was calibrated when tested on every subjects. BMI index of every subject was calculated prior to the testing and the accuracy of the sensor in detecting muscle movements were recorded in Table 3.1

Table 3.1: Average EMG accuracy vs BMI.

SUBJECT	BMI	THRESHOLD EMG(mV)	NUMBER OF TESTING					ACCURACY
			1	2	3	4	5	
1	UNDERWEIGHT	593.43	PASS	PASS	FAIL	PASS	PASS	80%
2	NORMAL	1590.68	PASS	PASS	PASS	PASS	PASS	100%
3	OVERWEIGHT	1000.21	PASS	PASS	PASS	PASS	PASS	100%
4	OBESE	615.09	FAIL	PASS	FAIL	PASS	PASS	80%

The average EMG voltage obtained from subjects were set as the threshold which the subject has to achieve in order to get pass on every testing as shown in Table 3.1.

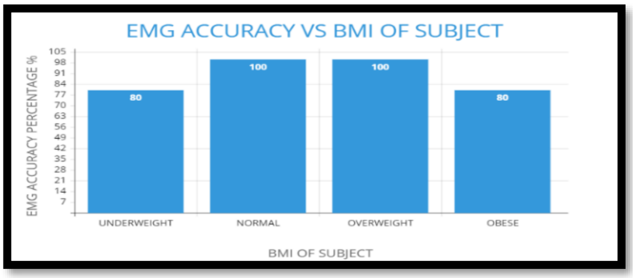

Figure 9: EMG Accuracy vs BMI of subject

Based on the chart in Figure 9, subject with normal and overweight BMI has the accuracy of 100 percentages and the subjects with underweight and Obese BMI achieved accuracy in the range of 80 percentages. The lesser body muscle ratio has led to reduce in accuracy. The results prove that the sensor is capable of integrating with users from different body composition.

5. Conclusion

The 3D printed prosthetic arm for transradial amputees have been manufactured through 3D printing. The prosthetic arm is able to translate the muscle movements of subjects into open and closed movements of prosthetic arm fingers. For the research experiment, the EMG sensor's accuracy was analysed through subjects with different body composition. The results provided positive impacts as the sensor is able to detect muscle movements of all the subjects with higher percentages. It solidifies the usability of the project on people with various body composition. To summarise, this project will provide meaningful insight into the development of prosthetics and influence the direction of future research in the path of prosthetics.

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