INTI JOURNAL | eISSN:2600-7320
Vol.2019:13

Design and Development of a 2 Degree of Freedom 3D Printed Myoelectric Prosthetic Arm to Sustain High Load for Amputees

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Abstract

In our fast-moving world, the advancement in 3D printed myoelectric prosthetic arm has been growing rapidly in the field of rehabilitation engineering. Prosthetic wrist needs to be small and compact minimizing the space taken. There are few designs developed by other developers around the globe; however, the designs have issues such as its degree of freedom and ability to handle high load without failing. Available 3D printed prosthetic hand wrist can rotate the hand along x-axis, however movement of up and down along the y-axis has not been practically researched and developed thoroughly. The main objective of this work was to design and develop a 3D printed 2 degree of freedom wrist joint for a 3D printed myoelectric prosthetic hand which can handle load of up to 10kg. The wrist joint design was done in AutoCAD where it will be made available to public for their development of 3D printed prosthetic hand and modifications. The design connects the palm and the forearm of the 3D printed myoelectric prosthetic arm. This wrist has 2 servos where one rotates about the x-axis and another rotates about the z-axis. Furthermore, the tendons that move the fingers was carefully designed to minimize the tension when the wrist moves along the x-axis and y-axis rotation. This design was developed to be made reliable and easy to assemble. The lifting capability was tested and compared with the available 3D printed prosthetic designs. The prosthetic hand was successfully developed with the new wrist design that can handle load up to 98.1N. As the fingers could not handle load higher than 800g each, the weight was lifted at its palm section connecting to the new wrist design.

Keywords

Myoelectric, 3D Printed, Prosthetic arm, Muscle sensor, EMG

International Conference on Innovation and Technopreneurship 2019
Submission: 21 June 2019; Acceptance: 16 July 2019

Introduction

Human hands are the first principal of instrument for physical manipulation of things besides being the part of the body which contains the most sensory endings. Absence of an upper limb can severely impact one's daily living which later could influence one's working, social and mental state. Often patients suffer from amputated arm because of either upper limb injury from accidents or born with limb defects. For many decades, development of prosthetic arms has been in a poor way due to the limitations in its sensory feedback system, interfaces adopted, lack of force, degree of freedom or grasp capabilities. Most upper limb prosthetics are equipped with wrist which can rotate only, either passively by the other hand or through the myoelectric senses.

The position of hand is basically determined by the trunk and elbow when the only movement of the wrist is rotation. Several studies suggested that pattern movements located at body segments of the patient's wrist with only rotation motion (Kyberd PJ & Bertels T et. al. 2012). Base on a study on pattern motions typically in daily life of patients living (Bertels T et. al., 2009), it can be analyzed that recoup movements, on the prosthetic side shoulder were reduced by wrist flexion. On a different study, using a prosthesis simulator supports that users can handle easier and faster with their flexible wrist with prosthetics (Kyberd PJ, 2012). Few of the task can be performed faster and easier as results of flexion wrist.

World Health Organization (WHO) presented a data that there is roughly 40 million amputees around the globe in developing countries and of that, 5% only has access to prosthetic rehabilitation devices (Martin Marino et. Al., 2015). Where else in low income countries, there is only a few major cities and the transport from rural areas to the city are a challenge, costly and can take up to days. Due to that, amputees from rural areas find it difficult to constantly get to the rehabilitation centers and less likely to follow-up with check-ups (Lina Magnusson et. Al. 2013 & Richard A Gosselin, 2009).

Prosthetic hand is also a type of automaton. However, there is not much related findings on prosthetics in history until the first modern industrial robot "Unimates" back in 1960 (Siciliano & Khatib, 2016). Since the firstly developed humanoid robot Eric, researches been finding solutions to build robotic arms for humanoid robots to make them can grasp like human hand (Riskin et. Al., 2016). Over the past 30 years, there have been various developments of robotic hand styles. Most of them are actuated by motors or pneumatic motors as electricity had been used widely as high efficiency power source (Siciliano Khatib, 2016).

In recent years, western countries have been encountering amputation loss cases and most are because of inadequate knowledge of medical field. Increasing number of Americans suffered from various of upper limb loss where back in 2005 it was around 541,000, however by 2050 the number of cases is expected to double (Ziegler-Graham et al., 2008). Roughly 5200 and 3500 upper limb amputations in Italy and in UK are reported yearly respectively. Amputees must adapt their daily living life and minimize the consequences, thus artificial hands are used to help them with daily activities such as writing, opening pad locks, dressing and grabbing different objects. (Thurston, A. JW. Ganong, 2001). Several 3D printed prosthetics can be printed from open source designs (Slade et al., 2015 & ten Kate et al., 2017). However, from their reports, the functions such as its degree of freedom of its wrist are limited.

Ideal features of artificial limbs such as light weight, compact, efficient and able to maintain lifting capability are equally important to be balanced in an artificial limb. Myoelectric signals (MES) can be sensed by myolectrodes and amplified to determine muscle’s naturally generated electricity (Cameron Currie, 2013). After passing through designed processing controller units, these signals can be assigned to control a particular degree of freedom in the prosthesis as shown in FIGURE 2. Over the past decade, technology of 3D printing has enabled 3D printed prosthetics a cheaper alternative. As the filaments of the 3D printers are developed over the years, different type of filament materials is available now at cheaper cost which indirectly drives down the cost of producing 3D prosthetic arms. In market, range of various ability and function in durability, hand grips, control system, user inputs, reliability, cost and comfort and each of it has its individual pros and cons to its user.

Generally, a 3D printed prosthetic arm will need to use three electrodes which reads the EMG signals. Depending on the prosthetic device, but normally 5 DC motors will be attached to control the fingers individually and a single servo motor to control the wrist movement. Touch sensors are attached at the fingertips to get feedback loop when the prosthetic grip on an object. Conducting research and study the mechanism involved to develop a prosthetic hand is the main task needed to be done first. The device usually necessary to be light weighted and the size need to be ideal in respect to the patients arm for it to be used optimally. Another purpose is to ensure the development of the prosthetic hand is kept at low cost and can be produced in a month period of time to enable patients to receive their hand ideally when all the technology and implementation has been tested to fit the patient.

The objective of this project was to design and develop a two degree of freedom wrist of a 3D printed prosthetic arm controlled with electromyography (EMG) sensors which can sustain load of 10 KG for amputees. The wrist design was made to join the palm section and the forearm where it connects. The palm and fingers design were obtained from a prosthetic arm which was developed by Mahdi Elsayed Hussein back in 2014. The design was available through open source platform online which can be downloaded, and 3D printed. Convenience of using the bionic arm, comfort and adaptability of it are also equally important for an amputee to continue use their bionic arm in their daily living.

Methodology

Initially a prosthetic arm design will be obtained from an open source design platform as there are thousands of designs already available on the internet up to date designed by developers. There have not been many research and designs on the wrist joint section. The design of palm being used in my prosthetic arm testing was designed by Mahdi Elsayed Hussein as shown in Figure 1.0 below back in 2014 while he was developing a prosthetic arm. The original design has one degree of freedom where it can rotate along the x-axis only. The idea was to increase its degree of freedom to two degree of freedom where it can rotate along the x-axis and y-axis.

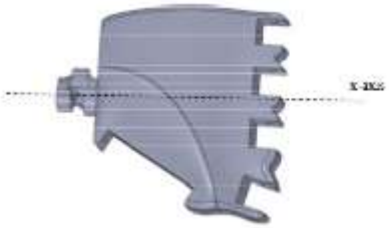

Figure 1. Palm Section Design (Mahdi Elsayed Hussein, 2014)

The designing process of the wrist begin by estimating the width of the joint section where it connects to the palm. A width of 68mm ideally is the part where it should connect to the palm. The wrist should be short and compact, so the total length is more like a normal human hand length and size. As can be seen from Figure below, the connection part to the wrist servo is the only body which connects the fingers and palm to the forearm as designed by Mahdi.

After thorough research has been done, a few calculations were done to determine the suitable size of the design. A load of 98.1 N was used where it is about 10kg of loading applied to the palm of the hand. The force divided by two because the forces act on two side of the wrist joint design. In addition, ANSYS simulation was done with static loading on the wrist design to simulate the bending moment occur during lifting of the load.

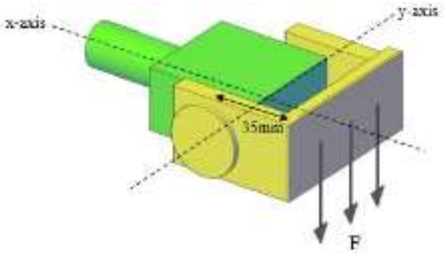

Figure 2. Force acting downward and palm facing upward

Results and Discussion

Power from both servos provide two degree of freedom movement at the wrist joint. The bearing help sustain half the load acting on the servo which connects wrist 1 to wrist 2, thus enabled it to lift the weight of 98.1 Newton. The ANSYS simulation produced detailed results with its colour region base on the given scale of each picture indicating the stresses acting on the body of wrist 1 and wrist 2.

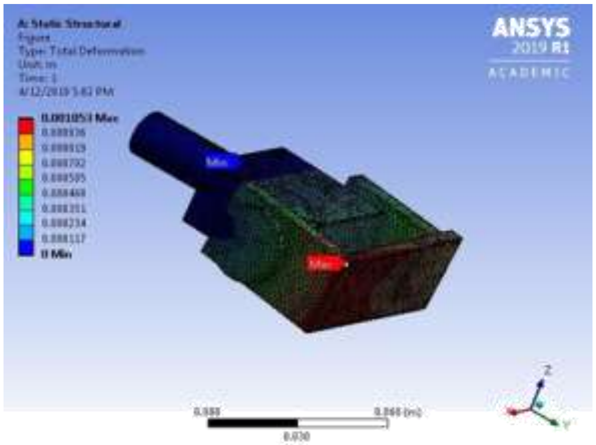

Figure 3. Total deformation for force acting

The wrist can be rotated about its x-axis and about its y-axis providing 2 degree of freedom for the motion of wrist. Most 3D printed prosthetic devices can only rotate about the x-axis, this this new design help provide an additional degree of freedom for user to perform more gestures that can be programmed to it. Other than that, the printing time obtained for all the parts total time of printing was 30 hours 22 minutes which was roughly 30 hours’ time. Thus, producing this prosthetic arm could take up to 2 days for full assembly process. The materials for each component are also listed for future references. The Arduino Uno was used because it provides sufficient signal ports to control all 7 servo and its more stable for this prototyping work compared to other Arduinos. In addition, the development total cost came up to RM 622.55 at an average locally in Malaysia. However better performance servo to handle higher torque for the fingers grip can be replaced with higher price. The design provides the basic need of a low-cost prosthetic device for someone looking for a budget rehabilitation device compared to others in the market.

Conclusions

The present study designed and developed a prosthetic arm to sustain high load for amputees. The necessary calculations were done for determining the physical limitations needed to fabricate and test the prosthetic arm 3D printed from an open source design available from the internet. Its capability to handle high load and ensure it can be made available to the public at a lower cost compared to the one available in the current market was also tested, whereby designing the wrist joint was a challenge in meeting its requirements. The dimensions were designed according to the palm and assembled with the body of the prosthetics. The Ansys simulation were done and the safety factor obtained were more than 2 which means that it is safe and idea to be used. The design can sustain loading of 98.1 N. Overall costing was roughly RM 650.00 to develop the prosthetic hand locally in Malaysia.

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