AFFORDABLE BIONIC ARM USING ELECTROMYOGRAPHY

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Abstract : A 3D printable design for an affordable myoelectric prosthetic arm is presented. The prosthetic arm is electronically actuated with servos and controlled by a user flexing his/her muscles. The presented bionic arm has the potential to be utilized by an amputee or a person born without a limb. This sort of technology does exist although it's expensive and customarily not available to people in developing countries. Ascension and advancement of the 3D printing industry allows individuals to become small scale manufacturers. Recent advancements show 3D printed prosthetic arms being attached to victims of war throughout geographic region. These devices are purely mechanical and significantly less complex than other myoelectric devices. Nevertheless, in this paper it shows that 3D printed devices have the potential to positively impact people's lives. 3D printing has its own limitations but growth and development within the field will only result in improvements over time. This project topic covers a vast range of engineering disciplines. The basis of the system is an innovative mechanical design for a 3D printed prosthetic arm. Modern-day electronic actuators like servo motors and circuitry animate the device and permit for classy control schemes. It's hoped that this work is going to be of importance to a various audience.

I. INTRODUCTION

Without an argument we should admit that the one of the most valuable part of any human being is their hands and legs. The main challenge is the task of replacing a missing human limb, especially a hand, which makes one truly appreciate the complexity of the human body. For centuries, innovators are trying to find a solution to lost human hand devices. From ancient civilizations some prosthetic devices have been discovered around the world which shows the ongoing progress of prosthetic technology. Until recent times, the prosthetic limbs designing has progressed. Early innovations such as the wooden legs can be thought of as simple prosthetic structures. History shows that for a long time prostheses have remained passive devices that offer little in the terms of control and movements. Times have passed, usage of improvised materials and designs started incorporating hinges and pulley systems. This led to world of simple and mechanical body powered devices such as metal hooks which can open and close as the user bends their elbow. And recently, there are different ways to enormous advancements in prosthetic devices. Focusing on both physical aspects of a device, control and biofeedback systems[9]. Slowly time lead us to Cyborgs, an advanced human beings integration between machine and body. In future prosthetic devices will be faster, stronger and maybe even healthier than our biological limbs. Throughout the course of this work more details of myoelectric Bionic Arm will be explored .It's being aimed to design a device that mimics the function of the human arm as best as possible and can be controlled by muscular contractions[5].

Myoelectric Controlled Prosthesis

Myoelectric Bionic Arm measures electromyography (EMG) signals that are generated from the contraction of muscles near an amputee's residual limb. These signals are measured using electrodes that are placed on the surface of the skin or embedded directly into muscles -implanted myoelectric sensors[8]. These signals are amplified and sent to an arduino which analyses this information and controls the internal actuators. Myoelectric devices allows for far greater amounts of control than mechanical devices.

II. LITERATURE REVIEW

A. Modern Prosthetic Arm

Prosthetic arms like Bebionic 3[14] and iLimb[15] are myoelectric controlled robotic arms that are commercially available to the public. There are a number of prosthetic arms existing in research labs around the world which are usually developed as prototypes to test advanced designs and concepts. The research of prosthetics are complex in perspective of mechanical design, control and monitoring systems.

B. The Human Hand

The human hand contains at least 27 bones, 30 and more individual muscles and over 100 ligaments, nerves and arteries[12]. The prostheses aim to apply the functions of the human body and return functionality to individual. Before any further discussion, let us understand the meaning of a Degree Of Freedom (DOF) for a reader with a no engineering background[4]. Think about an imaginary point in space. From this point; it can move along 3 different axes i.e; it can move forward/backward, up/down and left and right. At the same point it can also rotate around 3 different axes. For example, human neck has 3 degrees of rotational freedom – missing extremities. No current prosthetics can match the flexibility and functionality of the human hand[7]. The neck can look left/right, up/down and tilt our head sideways. That means a single point can have a total of 6 degrees of freedom(3 translational, 3 rotational). The human finger has 4 degrees of freedom in total. Three of them are the rotations of each joint which combine to control flexion and extension of the finger. The knuckle also allows for adduction. Fingers and all joints in the human body are actuated (moved) by contraction of muscles and tendons.

C. Connection to the Body

Exerting pressure on a damaged soft tissue areas can lead to a significant compromise of the remaining appendage. Problems of an amputee experience may include swelling, pain and can cause interrupt of blood circulation. The sockets must be designed in such a way that, it is safe and comfortable for the user, should be kept hygienic and distributes the weight of the prosthesis in an optimal manner. The common way of fitting a prosthetic is by creating a custom socket that fits around the amputees stump. The socket can either be self-suspending or suction fitted. In order to increase comfort and load distribution, a padding can be provided like inflatable air pockets or by reducing the density and stiffness can be used at a sensitive region. Several prosthetic arms use some form of thermo softening plastic to create a custom socket. A form is created around amputee's stump by heating a plastic sheet. A prosthetic sock can be used to create a snug fit between the user and the device.

D. User Control

Electromyography senses myoelectric signals, That are electrical pulses within the body produced by contracting muscles. The surface electrodes on the user's skin can detect these small signals and in the case of prosthetics be used to control the device. The problem with surface EMG techniques is that there are a lot of cross talk between muscle signals. Because muscles groups, especially in the arm, are physically closer to each other, therefore difficult to determine exactly which muscle is generating the measured signal via the surface electrodes. One of ways for resolving this problem is through Target Muscle Re-innervation (TMR)[11]. And this one is actually a surgical process. Residual nerves from the amputated limb are transferred to re-innervate new muscle targets that have otherwise lost their function. These re-innervated muscles then serve as amplifiers of the amputated nerve motor signals, allowing for more intuitive control of advanced prosthetic arms[13].

III. DESIGN AND MANUFACTURING

To create a useful myoelectric prosthesis there should be a well-designed mechanical system which mimics the functionality of the human arm as best as possible[1]. Apart from other things mechanical design involves how joints are actuated and the types of forces present in the system. The bionic arm design (Figure 3.1) presented in this section can be entirely manufactured with a 3D printer and basic tools[10].

As discussed in the literature reviews; artificial tendons are a viable way of actuating bionic hands[3]. The tendons can be anything like a string with high strength which does not stretch when tensioned. These lines connected to the fingers and are tensioned by motors in the forearm. When tendons are pulled; the fingers opens and closes. The servo motors must be completely placed inside the device in order to make it portable and attachable to an amputee. Ideally it would be like; these motors are placed closer to the fingers as possible, however due to their relatively large size it's hard to house the motors used inside the palm section. Instead the motors housed within the forearm. The notion to use standard servo motors to drive the tendons was made very early. The servo motors are DC electric motors which can be controlled to rotate to specific angular positions.

Figure 3.1: 3D Printed Design

Solid works is a computer design software package made for modelling solid mechanical components and assemblies. Solid works is a popular tool in the engineering industry and has been used extensively in designing and analysing mechanical components. Each finger consist of three individually printed components connected together with polypropylene pins[2]. Tendons are connected to finger as shown in Figure 3.2 and a tendon locking point is created. Rotational forces are applied to the joints when the tendon is pulled and the finger curls up.

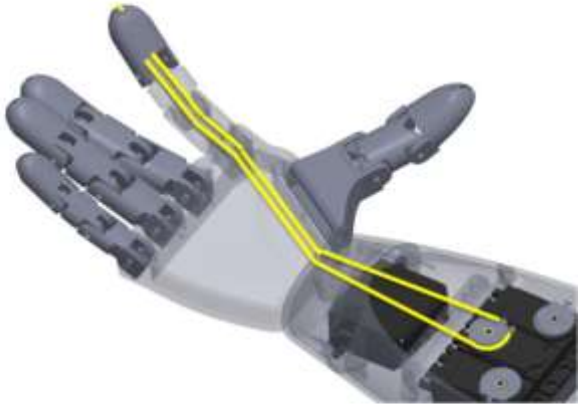


Figure 3.2 : Index finger controlled using tendons

The tendon locking point is much needed so that when the tendon is tensioned it pulls the finger and causes all joints to rotate. To open the finger from a closed position tension is applied to one end of the tendon. High quality fishing line has been used as it has minimal stretch when tensioned. Tendons in human hand also works in a similar way. However, there are many more biological tendons attached to the bones allowing for more precise control of the fingers. As the servo motor rotates in one direction it pulls the tendon and closes the finger. To open it the motor is rotated in the other direction. The Figure 3.2 shows the artificial tendon drives the index finger based on servos direction. The thumb, index and middle fingers are connected to individual servos. Because the interior space of the arm is limited the ring and pinky fingers have both been tied to one servo, meaning they open and closes together.

Figure 3.3: EMG Sensor board

Fig 3.4 : Actuator - Servo motor

Signal flow - a user flexing generates an analogue signal which is amplified, rectified and smoothed by the EMG sensor board(Figure 3.3). The arduino uses this analogue signal to generate a pulse width modulated signal. The servo motors which tension the tendons causing the fingers to curl up.

As discussed earlier, the actuators used in this system are standard servo motors(Figure 3.4). These motors can be controlled to rotate to angular positions up to ± 90 degrees from rest. Since the artificial tendons moves in order to open and close each finger, the angular rotation of each servo somewhat affects how precisely the fingers can be controlled. Servo motors that are relatively inexpensive have been used in this system to maintain a low cost.

Figure 3.5 : Arduino used

The use of higher quality servos would surely increase finger strength and precision but would cost significantly more. Arduino (Figure 3.5) has been used as the central computer for this system. Arduino has a microcontroller and this act as the central processing system of the hardware. We code arduino using C language. There is a software platform Arduino IDE which helps to code the arduino.

EMG sensor boards are used to sense and measure muscle activity. Using a wall power supply is enough for testing and debugging but a prosthetic arm needs to be powered by a source an amputee can easily carry around. Servo motors consumes a major amount of current during operation. Disposable batteries are not a good solution, since the servos would drain too much power meaning they would have to be replaced quite frequently. Lithium Polymer (LiPo) batteries has high energy density and are rechargeable. To create a Pulse Width Modulation(PWM) we could use a software timer to accurately control the timing and duration of a pulse. Another option would be to use the inbuilt PWM generator feature of the arduino. The problem with both these options is that there are no enough software timers to control each servo. Six servos are to be controlled and only there are only four timers available. Here two 16-bit software timers have been used to control six servos. Six PWM signals need to be generated on all output pins. Every 3.3ms the beginning of a new pulse is created on a new output line. After six cycles 20ms will be passed and a new pulse begins on the first signal line. For circuit completion we use a Printed Circuit Board(PCB). All the components are connected to it. And these PCB's can be printed according to our design.

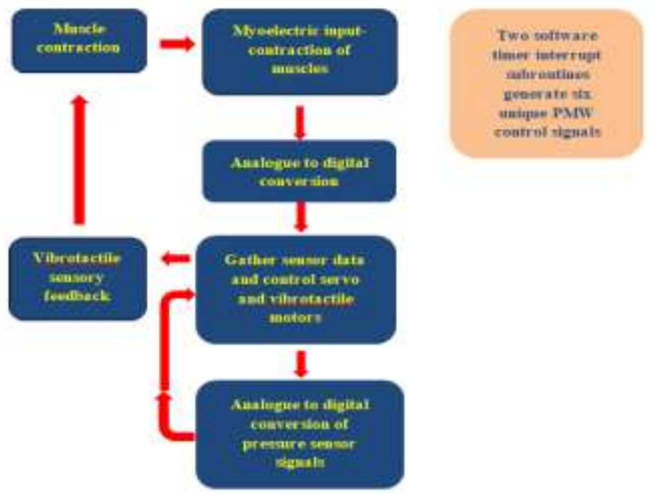


Figure 3.6: Control Flow Diagram

Control flow is shown in Figure 3.6. It's possible to control the opening and closing of fingers to perform different grips as well as allowing for wrist and elbow rotation states. This design allows the user to close the fingers more by flexing harder. The magnitudes of the EMG signals were used to increase the pulse widths of the PWM servo signals linearly. Ideally we'd prefer to include pressure sensors on each finger to supply some feedback. These sensors provide information to the arduino about what quantity force is being applied at each fingertip. It provides some sensory feedback to the user, thereby letting them know whenever they're grasping an object and the way much force they're applying

IV. TESTING AND RESULTS

The final system is a bionic arm offering six degrees of freedom and the ability to be controlled through myoelectric signals. The total design consists of a thirty six individual 3D printed components. It is highly recommended that the user should watch the short videos in the provided CD along with our product. These videos shows some preprogrammed commands to control the action of the device. All components were 3D printed using the material PLA plastic. Actuation: The fingers move in a relatively smooth and natural manner. The finger movement is dependent on several factors like friction between moving plastic components, servo controllers and also on tendon's are tension. From testing using small household objects indicates the fingers can provide at least 300g of force each. The servo motors could be rotated more to increase the tension on the tendons further. This would effectively increase the closing force of each finger. The servo used at the elbow is not capable to move the entire forearm. The servo used in the elbow has a torque of 10kg-cm. A high quality servo could provide a torque of 25kg-cm, which is coupled with the gear system this would be more than enough to safely rotate the arm about the elbow.

A. Mechanical Calculations

Required Elbow Torque**:** The final weight of the arm will be around one kilogram. To simplify calculations let's assume that a point load of 1kg acts on the arm 13.5cm from the elbow pivot. This is the torque required at the elbow point to lift the arm. The servo motors can provide only a maximum torque of 10kg-cm. An increase in torque by 135% should theoretically be enough to lift the arm. However, it is never good for servos to be running at their maximum torque, especially for a longer time. Ideally we want the servos to run at half of it's maximum torque only. The key to increase the torque is to have a larger gear (Larger the gear larger the reaction time) connected to the forearm. The forearm gear was designed to be as large as possible and still fit into the elbow space. The small gear was made as small as possible while still providing gear teeth strong enough to transfer high torques (Refer Figure 4.1 to see a basic gear system).

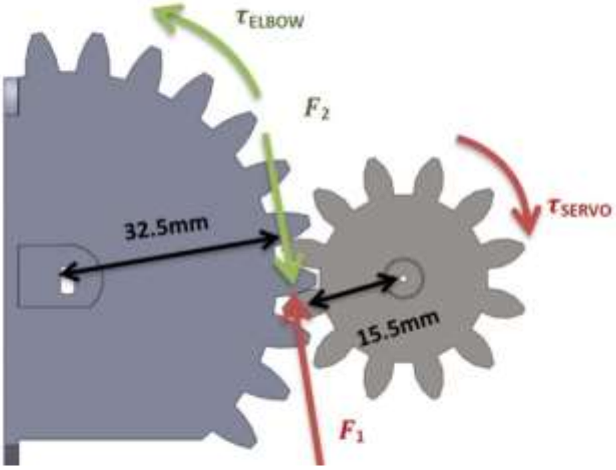
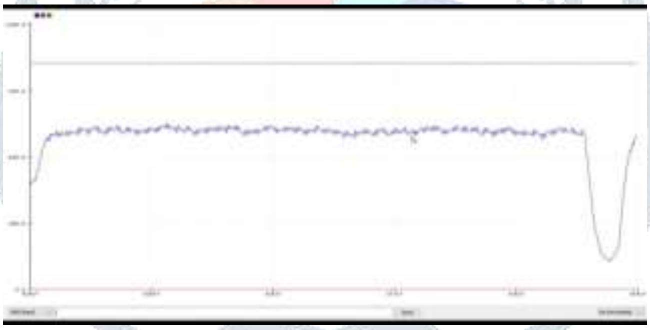


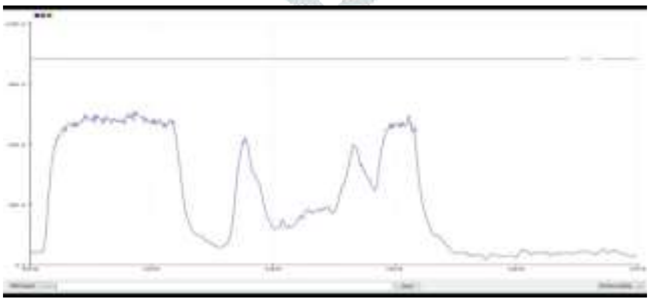
Figure 4.1: Gear systems and calculations

B. Control and Training

It’s possible to instruct the hand to close, rotate to a certain position, rotate back and then reopen. And the accuracy of the product won’t be 100%.And hoping that in future a 90% accurate arms would become possible. Initially the EMG signals (Figure 4.2) were sampled for every 100ms converting the magnitude of the signal to a decimal value[6]. Here arm is developed in such a way that, the servos will be sensitive to the EMG values so that only corresponding rotation will be there. The movements like elbow raise, wrist twisting, finger closing etc. are done by examining the individual’s available muscles. And based on that we can code and allocate the servos and do the corresponding movements. However, even if we code it efficiently, it will take time for the person to become familiar with the prosthetic arm. That is due to his older memory on hand movements that was developed and stored in his brain, from his childhood or earlier. So to become trained it will take time for him. And for this, there will be manual video which shows how to contract his/her muscle for corresponding movements. And these muscle movements for corresponding person may vary from person to person(it’s based on remaining muscles,nerves etc.). This training will take time to become expert; And that is based on the persons caliber. It may vary from person to person and ranges to maximum less than 1yr



Emg signals while muscles are free



Emg signals while contraction of the muscle

Figure 4.2: Interpreted EMG signals

Equations and simple calculations:

τ_{SERVO} =10

$F_{1=}\frac{\tau_{SERVO}}{15.5}$

$F_{1=6.67Kg}$

$F_1 = F_2$(2nd law of Motion)

$\tau_{ELBOW} = F_2 d_2$

$\tau_{ELBOW} = 21.6\ Kg\ cm$

Table 1: The cost of already existing Prosthetic arms may vary based on the number of extra sensors used and considering their durability

Description	Min Cost in rupees	Max Cost in rupees
Arm	89999	250000

Table 2: Overall cost for building our 3D printed Prosthetic Arm

Description	Cost
Printing material	1*3000
EMG Sensor board	2*3000
Servo motor	6*600
PCB	1*40
Arduino UNO	1*600
LiPo Batteries	1*1500
Total	≈ Rs. 15000

V. CONCLUSION AND FUTURE WORK

The aim was to develop a good-economic bionic arm that is affordable to even a common man. And it’s successfully completed the 3D printing and as discussed the accuracy didn’t met 100%. Approximate 70% accurate in movements was achieved, but the speed is less. Thus an overall 65% accurate bionic arm is developed. And the product is printed with PLA and it’s strength will be to an extent. So the product should be handled with care. The product is heat resistant as the material used is PLA. This may be considered as an improvement to be researched in future

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