Prosthetic Arm and Hand Design

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***Abstract*—The research work presents the design of prosthetic arm and hand. It's a bioengineering approach in order to develop a robotic arm and hand for the disabled persons, resembling human upper limb. Usually, prosthetic arm is less efficient and it requires multiple data channels for multiple degrees of freedom. We have developed a prosthetic arm and hand using single data channel to control four different movements i.e., hand opening/closing, supination/pronation of wrist, flexion of arm and extension of arm. Prosthetic is being used by disabled persons who have been paralyzed during warfare or any other critical injury due to neuro muscular diseases. Signal acquisition is made through muscle sensor and after the purification and pre-filtering of the achieved signal, Arduino microcontroller has been used to control the motion of the upper limb. Arm and gripper is made of acrylic material while support and base is made from aluminum and iron respectively. The various motions were differentiated on the basis of classification of their respective amplitude values. EMG sensor is interfaced with upper limb of human body to receive signal from human muscle and motion of each joint is actuated by its respective motor accordingly.**

***Index Terms*—Decomposition of EMG myoware sensor signal, prosthesis, upper limb prosthesis, upper limb amputation, upper-extremity amputee.**

I. Introduction

A prosthetic arm which could actuate natural movements can be built by simulating some embedded electronic systems and afterwards creating a proper interrelationship between sensors, controllers, controlling softwares and finally actuators to drive the system altogether. These are the things which prove to be a daring task for the manufacturers while making a prosthetic arm.

The prosthesis as a design model makes no pretense of trying to replace the lost limb physiologically but is there as an aid to help provide some of the functions that were lost. Much effort in the field of upper-extremity prosthesis research is directed toward the creation of prostheses as true limb replacements; however, in current practice we are mostly limited to prostheses as a design model.

Various other designs have been developed using different techniques [4]. Present model of the prosthetic arm can be used for training and testing for fabricating a real and wearable prosthetic arm. It can also be used in biomedical labs to let students understand the concepts of Electromyography (EMG) sensors in a better way. A person should have enough knowledge of EMG signals before taking the first step in this work [1].

Implanted Myoelectric sensors (IMES) were also studied. It was a multi-channel/ multifunction prosthetic hand/arm controller system capable of receiving and processing signals from up to sixteen IMES [7].

Mark Novak in his work described the details about the signal conditioning circuit for the EMG sensor [10]. The actuator of the exoskeleton taking the place of the biceps was a DC motor acting on the elbow joint of the exoskeleton. The design of this exoskeleton took its controlling signal from electrical signals in the biceps muscle. This electrical signal, called the Electro myo-gram (EMG), was basically a measure of the electrical activity in the biceps. The amplitude of this EMG signal was directly related to the amount of force delivered by the biceps. From this amplitude we can make a close determination of the force delivered by the biceps and translate this force into the torque which can then be sent to the exoskeleton actuator – the DC motor. Here there was a deficiency between the torque measurements and actual movements of the actuators after the model was assembled.

Many more prominent works in the field includes Robotic Hand by Ichiro Kawabuchi [9]. This can be considered as one of the most sophisticated robotic hands ever built. It comprised of individual mechanisms for each of its degree of freedom (DOF) that included global fingertip mechanism, abduction adduction mechanism independent terminal joint mechanism etc.

The problems, which we have to face while designing a prosthetic arm and hand, are more complex than solving some corresponding problems for a robotic arms. In fact, robotics and prostheses has much less in common than one might expect. Although some size, weight, and power constraints must be placed on robots and manipulators, robotic actuators can often be as large and as heavy as required to achieve a specific result. Energy to move the actuators can be easily obtained from the power sources. We can consider prosthesis as a subset of vast field of manipulator arm and robotics.

II. Design and Torque Calculation of Mechanical Structure

Base of the model is made of iron to make it hold the entire model easily. Its support and the remaining body (i.e., arm and hand gripper) have been prepared from aluminum and acrylic respectively. Acrylic parts have been prepared through laser cutting. Model consists of a high torque stepper geared motor for the elbow joint and two servo motors for the supination, pronation and hand opening, closing. The lengths of arm and hand are set with respect to actual arm and hand.

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A. Frame Material Selection

Acrylic is favored for arm and hand due to its less weight and is adhered with black polish to increase its strength [2]. The whole frame of the design is made up of acrylic and the reason for using acrylic is that it is cost effective and the acrylic frame fulfills all our requirements for the support function and also possesses a significant amount of strength to bear external loads.

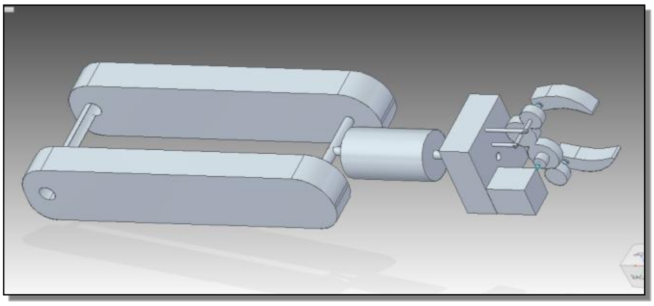

Fig. 1. Proposed CAD model.

Each part was separaetely designed and then assembed completely on SolidEdge program. "Fig. 1" shows the CAD model of the design.

We can calculate the torques for each joint motor based on the dimension of that particular part as shown in "Fig. 2".

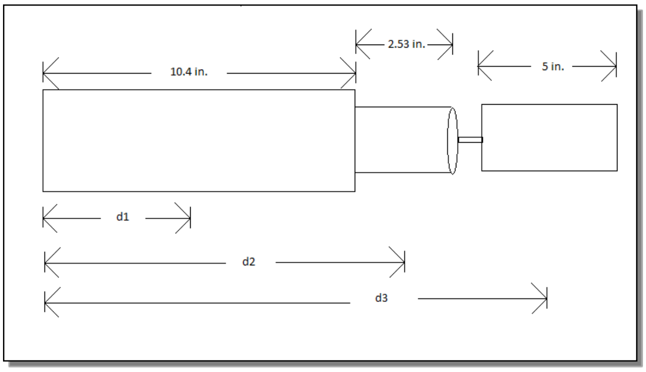

Fig. 2. Dimension of each part.

$$Sum\ of\ Torques = -\tau(elbow) - \tau(wrist) - \tau(gripper)$$

$$Sum\ of\ Torques = -(13.2)(1*98) - (30)(0.3*9.8) - (40)(0.45*9.8)$$

$$Torque = 400.2\ Ncm$$

Or, counter torque will be 4 Nm. So we can say that the main elbow motor which bears the weight of whole model should have atleast 4.5Nm torque or 45 kgf cm.

Torque calculations for wrist and gripper motors can be stated as

$$Torque = Force * Displacement$$

$$Torque = (0.5*9.8)*(5*0.0254)$$

$$Torque = 0.635\ Nm$$

For 480 rpm Servo motor, i.e., 50.4 rad per sec

$$Power = Torque * Angular\ speed$$

$$Power = 0.635 * 50.4$$

$$Power = 30.004W$$

$$Current = Power/Voltage$$

$$Current = 30.004/12$$

$$Current = 2.667A$$

III. Methodology

A. Mechanical Design

The mechanical design would be made of acrylic so that it goes not only light weight but also have much strength. The mechanical design consists of the following parts:

1) Mechanical links
2) Joints
3) Electrical Actuators (Servos and Stepper geared motor)

B. Electrical

For actuation, the electrical motors would be used. A 12V battery is required to deliver power to the high torque stepper motor while the rest of the motors can be easily operated directly from the controller's 5V voltage. So the main electrical items would be:

1) 12V DC battery.
2) Stepper geared motor.
3) Two Servo motors
4) EMG Amplification Circuit

C. Control

Then main thing in designing a prosthetics model is its control. The biological electrodes would be connected to the body of the operator. A microcontroller would get signal from the sensing unit and would actuate the motors accordingly. So following components would be used:

1) Microcontroller
2) Biological Electrodes

The research work consists of three phases. In very first phase, the signal acquisition is made through the muscle sensor placed at the bicep of the amputee so that various motions can be achieved by expansion and contraction of muscles [8]. A reference terminal is also placed over the bony part apart from the bicep. The myoware sensor facilitates us with two type of analogue outputs either we can choose a purified signal output or we can attach our signal pin to raw output pin to acquire a raw and unfiltered signal from the sensor. If we want to draw the output as a raw signal then we first need to apply various signal conditioning analysis like low pass, high pass filters to extract only those particular signals from the output that lies within our interested range of frequency. In the second phase we apply different signal filtering analysis like low and high pass filters.

D. Low Pass Filter

A low-pass filter is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. The exact frequency response of the filter depends on the filter design and values of the components being used.

E. High Pass Filter

A high-pass filter is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The amount of attenuation for each frequency depends on the filter design.

F. Band Stop Filter

In signal processing, a band-stop filter or band-rejection filter is a filter that passes most frequencies unaltered, but attenuates those in a specific range to very low levels. It is the opposite of a band-pass filter.

G. Notch Filter

A notch filter is a band-stop filter with a narrow stopband. Actual parameters for these filters depends on type of signal required at the output. This entirely is based on the frequency of the out signal. As the signal is not having enough strength to visualize it therefore, it is passed through amplifier circuit [3].

Low pass, high pass and band stop pass filters are demonstrated in the “Fig. 3”, “Fig. 4” and “Fig. 5” respectively.

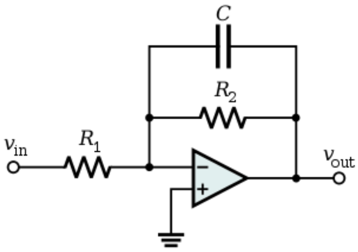

Fig. 3. LOW pass filter.

After applying the signal processing techniques, the output signal is now purified enough to get our amplitude values printed on Arduino monitor serially.

The signal processing can be done via software techniques using wavelet and short term Fourier analysis [5] and [6].

Complete flow of steps to be followed is being demonstrated in the “Fig. 5”.

The last phase is to differentiate the three motion on the basis of the output magnitudes. Individual is asked to perform the three motion and then the corresponding values from the screen are read.

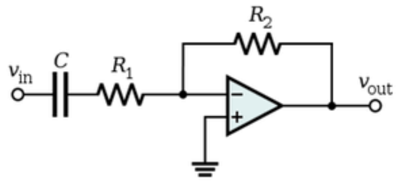

Fig. 4. HIGH pass filter.

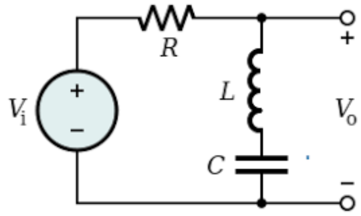

Fig. 5. Band stop filter.

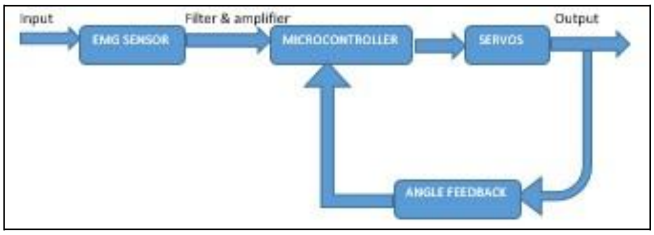

Fig. 5. Flow diagram from input to actuation.

In the Table I, the magnitude values obtained after performing the three motions are shown.

These values get altered from person to person moreover if the particular individual is tired or have recently did some exercise the values may vary and therefore set again to get proper results.

The last phase is to send these values to our controller and it is programmed to actuate the particular motor on the basis of their respective values.

TABLE I: MAGNITUDE VALUES

Type of motion	Reading #1		Reading #2		Reading #3		Average range
	Min.	Max.	Min.	Max.	Min.	Max.	Min-Max
Hand opening/ closing	200	330	250	350	230	380	0-399
Wrist supination/pronation	410	480	415	495	412	486	400-499
Extension of arm	490	665	510	680	507	670	500-700
Flexion of arm	812	910	750	960	920	980	Greater than 700

II. PROGRAMMING ALGORITHM

The microcontroller follows the following algorithm from receiving the signal from the EMG sensor to actuating the particular motion:

1) Activation of analogue to digital converter (ADC) of controller;
2) Wait for the EMG sensor to give a value;
3) If the EMG sensors gives a value greater than or equal to the thresholds that have already been set then the corresponding motion is performed by one of the respective motors;
4) If the EMG sensor gives a value less than the particular threshold required for the motor, then the corresponding motor does not show any response.

IV. CONCLUSIONS AND RESULTS

This upper limb prosthetic arm and hand model has three degrees of freedom that are in operated in parallel to the amputee’s motions with whom the sensor is attached and follows the directions as indicated by the amputee and provides support. If, in an unfortunate accident or in warfare, a person gets his hand paralyzed or if he loses his complete forearm still he can manage to do his ordinary daily tasks. Present model of the prosthetic arm can be used for training and testing for fabricating a real and wearable prosthetic arm and also be used in biomedical labs for demonstrating the concepts of EMG sensor to students in a better way. This model has three joints, all of them are being controlled using single EMG sensor. Initial signal processing and pre amplification is being done within the Myoware sensor and the motions were distinguished on the basis of their respective voltage level amplitude value. The control system of our Prosthetic arm model has been developed using Arduino UNO which actuates the two servos and one stepper motor. The prosthetic model is cheap and having a good strength. So making it easy to purchase and use.

V. Applications

It is being used by disabled persons who have been paralyzed during warfare or any other injuries. Present model of the prosthetic arm can be used for training and testing for fabricating a real and wearable prosthetic arm. The model can also be used in biomedical labs to let students understand the concepts of EMG sensors in a better way. The Revolutionizing Prosthetics program is ongoing and aims to continue increasing functionality of the DARPA arm systems so service members with arm loss may one day have the option of choosing to return to duty. It can provide support to partially paralyzed persons for performing their works effectively and efficiently.

VI. Future Research Work Prospects

All of the three degrees of freedom are being obtained by acquiring the stimulating muscle potential's signal via single EMG muscle sensor. But the overall result of classification and efficiency of the project can't be attained 100%. So we can furtherly improve the performance of the system by making use of at least two EMG sensors, one for biceps (to control elbow movement) and other one at forearm muscle (to control wrist and gripper movement) for controlling these three degrees of freedom. Moreover, a fully sophisticated hand can also be made by using more biosensors and strengthening our algorithm. In the near future, there can be a fully functioning brain controlled upper limb prostheses i.e., walking upstairs, rotating an ankle, navigating sloped terrains—just by thinking about doing them. The technique being used is called targeted muscle reinnervation, which transfers nerves from an amputated limbs to healthy muscles [11].

Acknowledgment

We certify that project work titled "*Prosthetic Arm and Hand Design*" is our own work. The work has not been presented elsewhere for assessment. Where material has been used from other sources it has been properly acknowledged / referred.

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