DEVELOPMENT, CONTROL AND STRUCTURAL ANALYSIS OF BIONIC ELBOW JOINT

Faiza Rasheed[1], Saleem Abid Tabassum[2], Ijaz Ahmad Chaudhry[3], Urwah Arif[4], Hafiz Muhammad Osaid
Department of Industrial Engineering, UMT Lahore, UET, Faisalabad, Pakistan
[1]faiza.rasheed@umt.edu.pk, [2] salim.tabassum@umt.edu.pk, [3]ijaz.ahmad@umt.edu.pk, [4]urwah.arif@uet.edu.pk

ABSTRACT: *During the last decade or so, Pakistan is unlucky to face the increasing number of amputees owing to a series of earthquakes, road accidents and terrorism. But the paucity of progress and advancement in the field of prosthetics is failing the provision of artificial limbs for doomed amputees. This field demands extensive work, consideration and dedication for amelioration of damned Pakistani populace. This research aims to provide amputees the potential for their routine life errands; to ameliorate their pecuniary and personal autonomy through the establishment of bionic elbow joint. Presently, many developed countries are functioning well in the realm of prosthetics, and are offering mobile and user friendly feigned limbs to amputees but a catholic research work is obligatory in Pakistan to create cost-effective and handy artificial limbs. This delve rally round to study the subject of biomedical engineering and its relevant techniques in detail with the help of Matlab, DAQNavi, ANSYS. It explores mathematical techniques and artificial intelligence for the study of electromyographic signals; likewise Artificial Neural Networks (ANN), dynamic recurrent neural networks (DRNN), and fuzzy logic system.*

Keywords—Prosthetics, Bionic elbow, Artificial elbow joint.

I. INTRODUCTION

1.1 Problem Statement:

Upper and lower limbs play the major role for performing daily routine life activities. Currently in Pakistan research work is being carried on bionic hand. But just a hand cannot fulfill the requirements of an amputee who has lost his complete upper limb. A hand can just pick and drop the objects but cannot move them from one place to another that renders a dilemma for those amputees. Therefore befitting economical design of the bionic arm with elbow needs to be developed to suit Pakistan's economic and technological conditions.

The elbow joint is a hinge joint that makes only extension and flexion movements. This research work will focus on making possible these movements of a bionic arm. The aim of this research is to design a bionic elbow joint to facilitate amputees for routine work.

The pedestal idea for this research is based on the usage of electromyographic (EMG) signal to establish elbow movement. Nowadays artificial limbs are renowned but they are passive models since they are deficit of mobility. To fulfill this aim, bionic elbow joint is modeled rendering artificial limbs mobile and help mitigating enormous troubles of destitute people. Here the bionic elbow joint is designed to provide flexion and extension movement of natural elbow joint; by using EMG signal. The later stage stages include signal acquirement, processing and then limb actuation through a microcontroller.

II. LITERATURE REVIEW

2.1 Non-backdrivable series elastic actuator for prosthetic elbow:

Usually commercially available prosthetic elbows have only motion control through stiff actuators. Now, in order to provide less stiffness to resemble human physiology, an actuator (motor) has been created to provide impedance control also. This impedance control property provides nice response to environmental variations and perturbations. This less stiff motor is non-backdrivable and is capable to be used in prosthetics as it is power preserving. In this paper authors recommend to use series elastic actuators (SEA) to generate torque without energy drain. The non-backdrivable series elastic actuators provide advantages of high fidelity, reliable force output, design robustness, stable torque control and less damage in case of inadvertent contact. [1]

2.2 Functional design of a transmission for elbow prosthesis:

This paper directs to a new approach in prosthetic elbows design. Electromyographic elbows can easily replace the passive ones if they possess the properties of comfort, durability, lighter in weight, less power consumption, easy and natural movement control. A well planned good mechanical design can acquire these properties. A design of series of linkages allows good mechanical efficiency and low angular velocity of elbow. For efficient transmission, links will have low momentum of inertia. [2]

2.3 ProDigits™ prosthesis for partial hand absence:

Externally powered prosthetic hands have been available for amputees since long. But amputees with partial hand loss have not been facilitated with Electromyographic prosthetic hands. This paper provides information about ProDigits™ partial hand prosthesis that has been developed by Touch bionics for such amputees. This device has free individual movements of fingers. This device is built into a socket designed to accommodate remaining hand portion. The purpose of this device is to provide amputees with normal grasping activities of life with either congenital or acquired, one or more finger loss. [3]

2.4 Design of bionic hand using noninvasive interface:

This paper discusses a project which aim is to restore motor functionality and limited sensory information to an amputee. Control signals are acquired through magnetic Hall Effect sensors and are safely transmitted to hard ware through electronic circuitry which then sends output pulses to properly drive the mechanical system. Furthermore a microcontroller is used to control the output movements of prosthetic hand and also enables the feedback from pressure sensors fitted on bionic hand. [4]

2.5 Physiology of elbow joint:

Elbow joint is primarily a hinge joint with two basic functions. First comprises what is called as supination and pronation. In this action palm twists up and down while the elbow remains quiet. Second is the flexion and extension which comprises the forearm bending and straightening function. This movement occurs at the joint where humerus and the ulna bones meet together, with the flexion movement amplitude of about 135^0. And the angle between long axis of the arm and the long axis of the forearm; during extension; is about 170^0. This angle is named as carrying angle. [5]

2.6 Electromyography:

Electromyography is an electrical technique for medical applications, to appraise and record the electrical activity created by skeletal muscles fibers. These are actually small currents which are muscle fibers reaction to nervous stimulation. There are two measurement methods for EMG signal namely non-invasive method of externally placed electrode; and invasive method of inserting the needle in the muscle. But generally, the action potentials are sensed via non-invasive method; where electrodes are placed over the target muscle skin surface. The common use of non-invasive method is indebted to the merits of surface electrodes being user friendly, no medical administration required and least distress for its appliances. After being detected by the electrodes, the EMG signal is further processed for the removal of noise signal attached with it inherently, and amplification. Finally it is sent to a computer system where it can be accumulated and examined. [6][7]

2.7 Characteristics of EMG Signal:

EMG signal is primarily linked with skeletal muscles and is rather unsteady and haphazard in nature and its working range varies from micro volts to millivolts. The working potentials of measured EMG signal are usually found between 50μV and up to 20-30mV. This amplitude depends on factors like muscle under inspection, the body prerequisites and varies from person to person as well. Also the frequency band of compatible energy is 0-500Hz. The chief aspects influencing recognition and recording of EMG signal are electrodes features, their contact with skin and muscle tissues, amplifier design and ADC for succeeding storage and utilization. Here two main features depict the quality of measured EMG signal. Firstly; signal to noise percentage and secondly; the signal distortion. These two features have prominent influence on signal reliability. [8]

2.8 Electrode and Amplifier Design:

To achieve EMG signal, the most critical point of the whole electronic equipment is the electrode design to be selected. All the succeeding stages of electromyography will be massively affected by this electrode detected signal. This is the very reason for the significance of selection of an apposite electrode that would make possible the provision of maximum fidelity of signal.

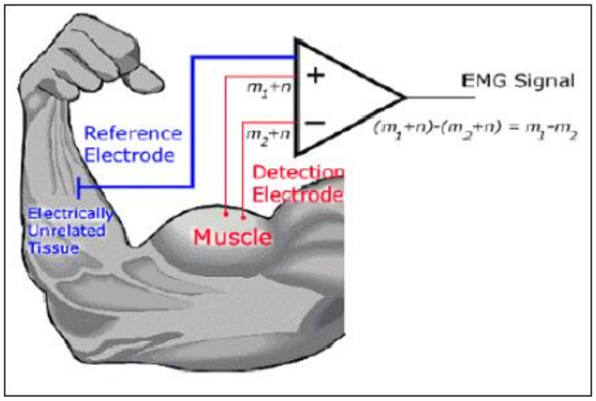

Figure 1 Differential amplifier arrangement; 'm' denotes EMG signal and 'n' denotes noise signal. [8]

Since the EMG signal is of very low amplitude, hence requires amplification. Therefore, EMG electrodes with proper differential amplification, input impedance, filtering and stability are chosen. [8]

2.9 Electrodes placement:

Motor point is a fundamental cell body; a point from where the electrical signal originates, hence called as innervations zone. An EMG electrode should not be placed on motor point on the body, in lieu be placed between two motor points. Electrodes provide best results when placed parallel to the end long axis of the intended muscle and at the middle location of the muscle; since this placement renders the contact possible with maximal muscle fibers. Also it is inappropriate to place the electrode at the outside edge of muscle and on or near the tendon as it deteriorates the EMG signal strength.

Furthermore; to measure EMG signal, a reference or ground electrode is inevitable for the provision of a common reference. Also the reference electrode necessitates being sited remote from the sensing electrode and on an electrically unbiased tissue as well, e.g. a bony eminence. [8]

III. RESEARCH METHODOLOGY

3.1 Electrodes selection:

Electromyography testing purposes are being accomplished by using commonly available ECG electrodes since they serve as detecting electrodes. Detecting electrodes are sited at bicep muscle to sense elbow joint EMG signal, and the reference electrode at the tricep muscle. Since the bicep muscle is primarily accountable for transporting elbow flexion signal. Flexion is caused by the bicep muscle contractions and extension by tricep muscle contractions.

Figure 2 Appropriate locations of electrodes [9]

3.2 Differential Amplifier:

Common noise present at both electrodes sites demands differential amplification; to be removed. For this objective, an apt differential amplifier (AD620AN) is selected owing to its aspects of elevated input impedance, common mode rejection ratio (CMRR), signal to noise ratio, frequency band and genuine gain used. It is an economic, less power requiring, small sized, high accuracy instrumentation amplifier. AD620AN supplementary features render it especially compatible and fitting for therapeutic applications. [10]

Here the gain is designed to 100, with the assistance of external resistors of 499Ω.

Equation for the gain is:

$$\text{Gain} = \frac{49.4\text{K}\Omega}{R} + 1$$

$$= \frac{(49.4 \times 1000)}{499} + 1$$

$$= 99 + 1$$

$$= 100$$

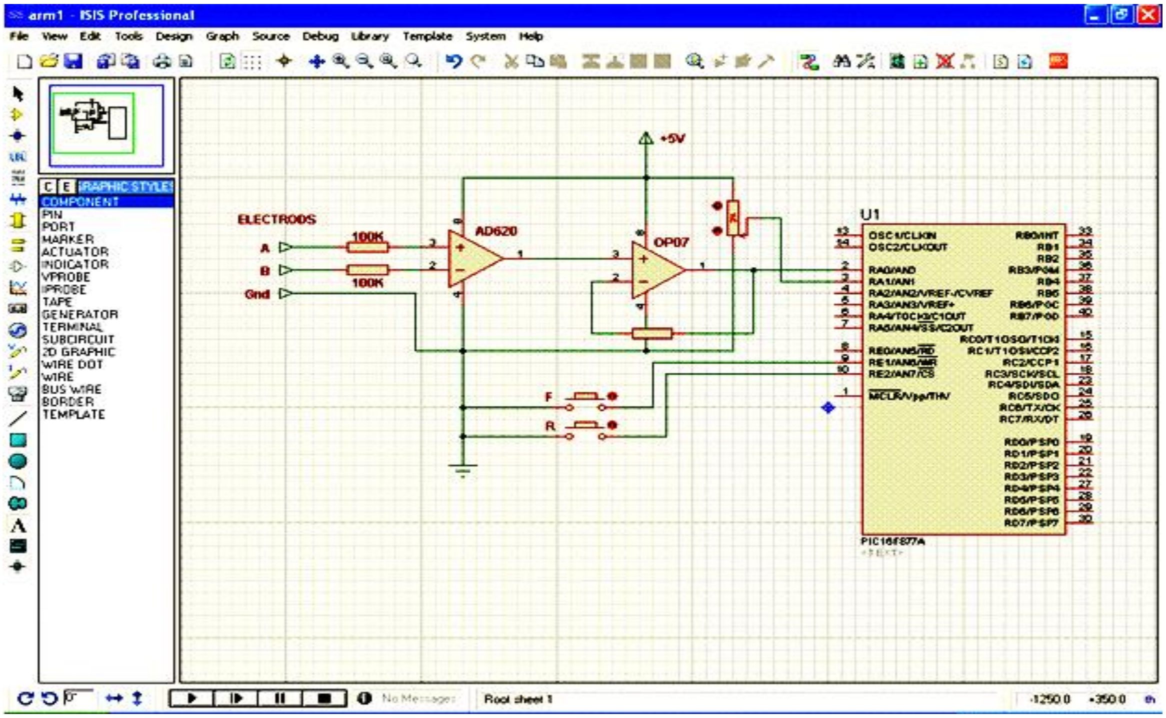

Figure 3 Electrical circuitry design on Proteus

3.3 Amplification and Filtration:

Before further processing, the rising noise coupled with EMG signal requires to be eliminated at this juncture. Else wise it would cause the deterioration of signal potency. OP07 is a soaring accuracy operational amplifier with ultralow offset voltage and a high open loop gain. This is a first order high pass filter with cut off frequency 20Hz. In this research, OP07 is deployed to get rid of noise disruption and for doing rectification, so as to avoid the amplification of this distracting signal as well.

$$F_C = \frac{1}{2\pi RC}$$

$$= \frac{1}{2 \times 3.14 \times 1.7 \times 10^3 \times 4.7 \times 10^{-6}}$$

$$= 20\text{Hz}$$

Table 1 Signal strength across different components

Circuitry Component	Signal amplitude in arm extended position	Signal amplitude in arm’s flexed position
Electrode 1	0.1mV	0.2mV
Electrode 2	0.05mV	0.1mV
AD620AN	0.05V	0.2V
OP07	1.09V	1.5V

3.4 Microcontroller:

Subsequent to passing through all phases of signal processing; including differential amplification, filtration, amplification etc; now the signal necessitates to be utilized to trigger the artificial limb hardware via microcontroller. The microcontroller deployed here is PIC16F877A, (where PIC symbolizes for Peripheral Interface Controller).

Microcontroller is programmed to receive two EMG signals from bicep and tricep muscles, compare their respective amplitudes with a preset average signal and show the required flexion or extension function of elbow joint.

3.5 Flow chart for elbow joint actuation:

Initially an average signal is set, and coming EMG signal is compared with it every time it is generated. When the newly generated signal is higher than this average signal; forward function is called. The forward function renders elbow flexion movement through clockwise rotation of motor.

On the contrary, when coming signal is less than average signal, a back function is called. This back function rotates motor in counter clockwise direction to impart flexion movement.

IV. RESULTS AND DISCUSSIONS

4.1 Signal Interfacing with Computer:

The USB-4704 is a powerful, multifaceted data acquisition (DAS) module by Advantech with usb port with many portable capabilities, and is equipped with analog I/O, digital I/O and counter functions in a single unit, making it suitable for lab experiments, testing, data logging, and training. It is a 14bit usb multifunction module used for EMG signal analysis on computer system. [11]

The module is interfaced with computer system through the installation of software called DAQNavi which offers both analog and digital signal view according to requirement.

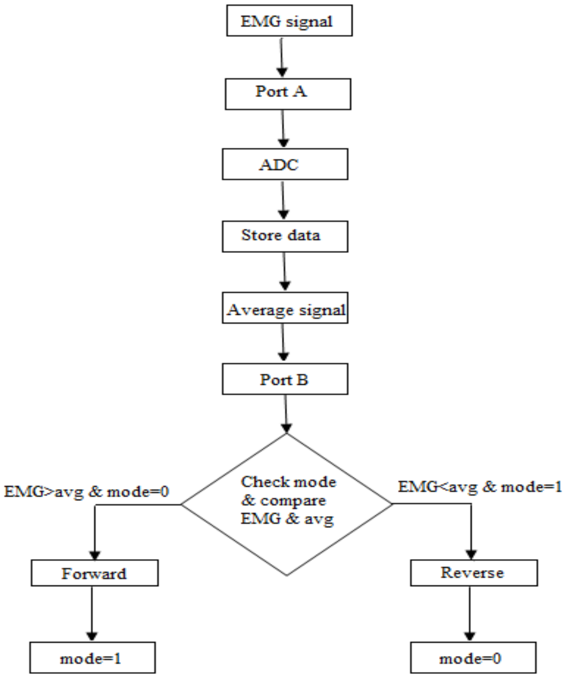

Figure 4 Flow chart for elbow joint actuation

Figure 5 Advantech-USB-4704; data-acquisition-module [11]

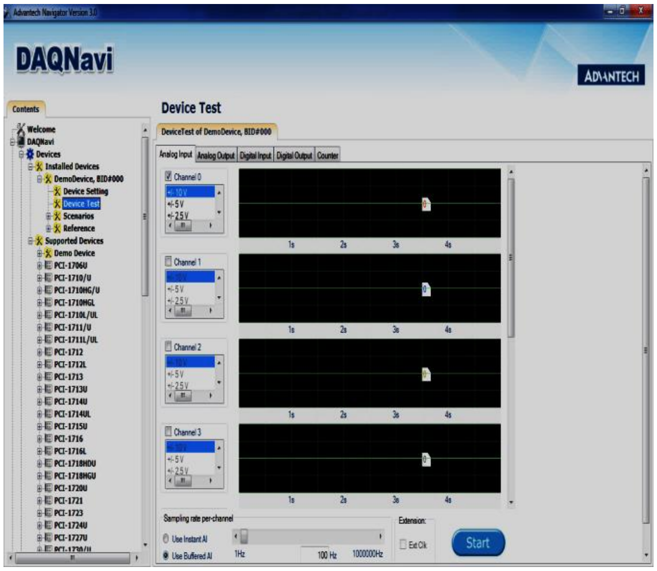

Figure 6 DAQNavi software

The EMG signal across different components; when the arm is depicting its positions of extension and flexion, is viewed as below.

- Electrode 1:

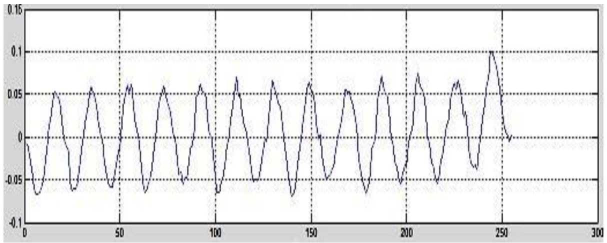

Figure 7 Signal reaching electrode 1in Arm's Extended Position

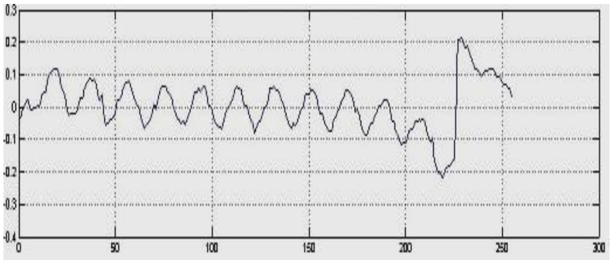

Figure 8 Signal reaching electrode 1 in Arm's flexed position

- Electrode 2:

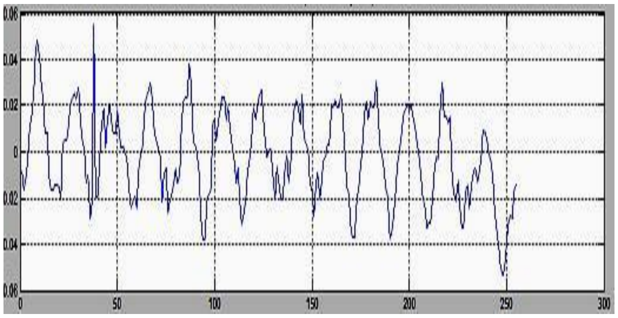

Figure 9 Signal reaching electrode 2 in arm extended position

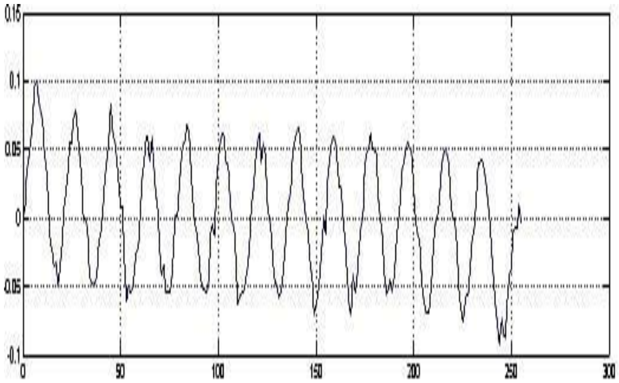

Figure 10 Signal reaching electrode 2 in arm flexed position

- Signal reaching microcontroller:

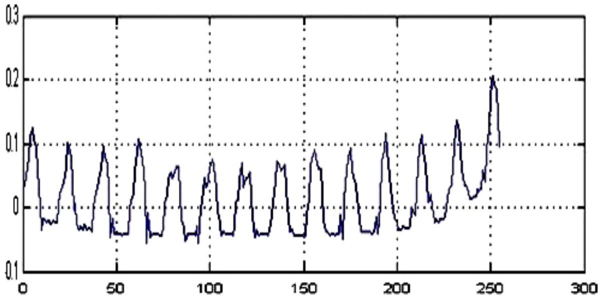

Figure 11 Signal reaching microcontroller; in arm's flexed position

4.2 Artificial limb model:

A worm gear DC motor of 12volt is used in the elbow joint prototype. The size of DC motor is usually kept comparatively large to support large loads, unlike servo motor which is unable to support large loads functions owing to its smaller size. Worm drives presents an efficient attribute of braking, i.e. when no power is applied to the worm drive, the load cannot turn. When load creeping is adverse this characteristic is particularly advantageous. They usually posses raised torque and alleviated speeds. Furthermore the motor is timed in unbiased way and will travel in both directions with same speed; by simply exchanging the power polarity to motor contacts.

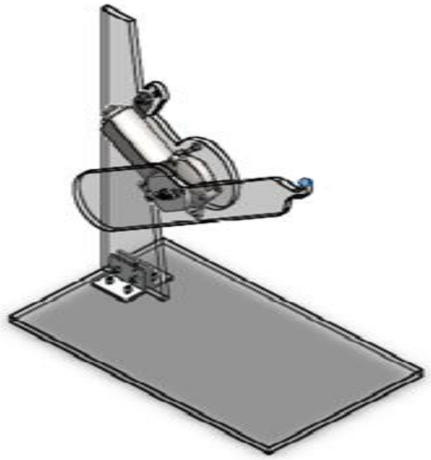

Figure 12 Bionic elbow joint Solidworks model

V. CONCLUSIONS AND RECOMMENDATIONS

For the movement of elbow joint simple worm gear motor has been installed in the hardware. Joint is flexed and as soon as the EMG signal departs it will go back to its initial position. But the EMG signal is incredibly interactive, depending extremely on person's physiological conditions like either feeling lethargic, tranquil, active, stressed etc. In every circumstance the electromyographic signals fluctuates heavily. Even high or low blood pressure influences it profoundly.

A great deal of delve is obliged to be accomplished in the domain of electromyography. Even a design of mere bionic arm deficits many vital attributes of natural human arm. Wrist rotary motion for supination and pronation is obligatory for normal errands. Independent movement of fingers and even individual bionic finger design demands extensive research. By intellectual and smart designing, weight bearing capacity of bionic arm and grasp recognition should be upgraded. The entire arm till shoulder joint necessitates to be established, since progressive number of people is helpless to face the affliction of amputation in daily accidents and adversities. There is space for improvement of flexion degree of bionic elbow joint to closely emulate natural elbow joint in regular life chores. Besides, a profound research work is requisite to distinguish EMG signals for diverse movements and actions. Even in just the arm structure, muscles hold and transmit signals for distinct and independent movements of fingers, for making fist, for supination and pronation, for elbow flexion extension. Making economic, pragmatic, viable and readily available artificial limbs for general underprivileged populace is the vital concern. Since the desolation of limb loss does not create only scantiness of corporal capability and façade appearance, also renders mental impairment.

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