Design and Development of a Low Cost Multi-DOF Bionic Arm using Control Assist Mode Functionalities

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Abstract

Bionic arm is an artificial device which replaces the lost arms of physically challenged persons to gain back some of its functions. Present bionic arms are controlled by ElectroMyoGraphy (EMG) signals. These devices are rejected by many due to the cost, weight, less Degree Of Freedom (DOF) and mainly because of the invasive procedures used to obtain better signals. This incorporates fear in amputees. Rehabilitation proves to be more challenging for the amputees who have lost their arm functionalities. The need for a simpler approach to interpret signals and control the bionic arm is necessary. This work focuses on a cost effective design and development of bionic arm control systems, which requires less rehabilitation, and is capable of providing multi DOF.

A prototype model is developed for a cost of 8000 INR which is cost effective and the fabrication cost of the modeled mechanical arm along with the control system cost upto 15,000 INR which is less expensive and affordable than that of the EMG based arm which costs around 8 lakhs. The control system developed is capable of providing more than 10 DOF. These control systems can be used independently or collectively as per the requirements of the amputees. The other advantages of the system being developed are it is simple, requires less rehabilitation time and procedures. The wiring harnesses are reduced on both the transmitter and receiver blocks by sending the signals wirelessly.

Key Words: System Engineering, Multi-DOF, Bionic Arm, Control Systems, EMG

1. INTRODUCTION

Bionic arm is an artificial device for the amputees who have lost their arm due to general diseases, high intensity electric hazards, accidents and injuries from war etc. This helps to replace the lost arm functionalities for the amputees. The most important requirement for the reliable and reasonable design of a bionic hand is to have a simple control system and user-friendly operations.

There are wide varieties of commercially available prosthetic devices available such has cable operated prostheses, electric powered prostheses etc,. Each category of these devices has benefits and weaknesses [1]. Today's advanced commercial prosthetic hands are mostly controlled by ElectroMyoGraphy (EMG) signals which are recorded by using surface or needle electrodes that perceive electrical activity associated with the patient's arm muscles [2]. These devices are inadequate due to the increase in complexities, cost, weight and low functionalities. Amputees who have lost their arm before few years would have forgotten their motor skills or arm functionality. For these amputees EMG based control systems are unreliable. There is a need for a simple approach to overcome the some of the drawbacks mentioned above. The study has been done in designing and developing speech and touch assist control circuits, which requires less rehabilitation, less expensive and which are capable of providing multi DOF.

2. MECHANICAL MODELLING OF THE BIONIC ARM

Modelling of the bionic arm is carried out in a structured approach in SolidWorks 2012 which is the 3D CAD mechanical design automation application. The drawing of the arm is carried out from the parts which are the building blocks of every model. Each part of the arm, the fingers, palm, forearm are designed by considering the dimensions in millimetre (mm) of a normal human hand.

Similarly upper and lower elbow for the bionic arm are designed. Once the modeled fingers, palm, lower and upper elbow parts of the arm are designed, they are assembled to form a bionic arm which is shown in the Fig. 1.

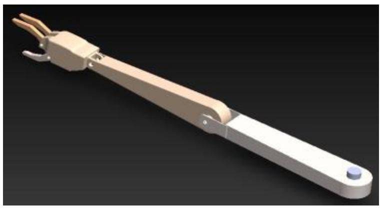


Fig. 1 Assembled Bionic Arm in CAD Software

This system is a combination of electrical and mechanical system which is user controlled. It is developed by applying the principles of systems engineering and its life cycle. The transmitter block which comprises of a microcontroller, processes the inputs given by three non-invasive control systems namely speech recognition system, keypad control and foot pressure control system. The receiver blocks consist of five DC motors which are actuated by motor drivers on the input signals that are sent from the transmitter wirelessly.

3. DESIGN FLOW OF INTELLIGENT BIONIC ARM CONTROL SYSTEM

The functional block diagram of the proposed intelligent bionic are is shown in Fig. 2. It consists of a transmitter block which contain of various components for controlling the movements of the hand. Both transmitter and the receiver consists of PIC18F458 microcontrollers, which are responsible for controlling the input and output signals of the system. The user inputs to the three control systems i.e. the voice assist, keypad and foot pressure control systems on the transmitter are processed by the microcontroller and the respective signals to the receiver are sent wirelessly using a RF 433 MHz module. On the receiver block, the signals are decoded, processed and sent to L293D motor driver circuits to control the different actions of the arm.

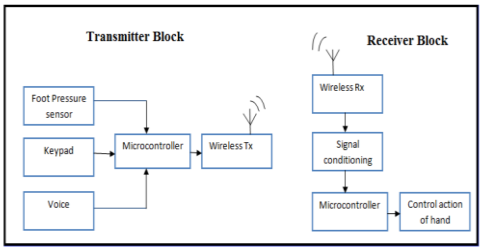


Fig. 2 Functional Block Diagram of Intelligent Bionic Arm

4. CONTROL-ASSIST MODE BIONIC ARM CONTROL

4.1 Speech Recognition System:

Amputee who lost their upper extremities decades ago would have forgotten their motor skills or arm functionalities. For these amputees, the voice operated bionic arm can be developed which allows them to control the arm for different DOF and interact with the environment just by verbal communication. The speech recognition circuit (SRC) shown in Fig. 3 is capable of controlling the prosthetic hand using voice commands. The ability to communicate with a prosthetic hand through speech is the ultimate goal for bionic arm control. The user needs minimal experimentation and/or training with the prosthetic hand before using it for any practical purpose. The HM2007 SRC is a speaker-dependent system, where it only recognizes the individual voice that is trained for the circuit [2]. The microphone built on the SRC is able to clearly detect voices from a distance of 1 foot. The SRC circuit has a response time of less than 300 ms and it requires a 5 V DC power supply.

The main component of the SRC is the HM2007 speech recognition chip. The HM2007 is a single chip CMOS voice recognition LSI with the on-chip analog front end, voice analysis, regulation process and system control functions [4]. This system consists of an 8k SRAM which is responsible for storing the trained word patterns that can be used at any time. The speech recognition system carried out entering input from 4x3 keypad, the voice input are recorded from user through MIC which are converted to electrical signals for processing. When the voice of the users matches with the trained recorded speech pattern, the 8 bit signals are sent from the latch to the microcontroller for rotating the respective motors to obtain different movements of the arm. SRC is capable of storing 20 words pattern which has a length of 0.98 sec, thus with this system multiple movements of the arm can be achieved.

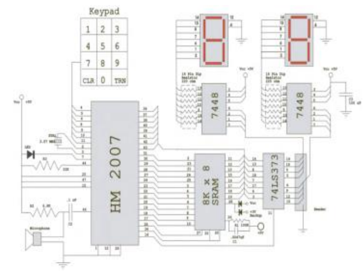


Fig. 3 Speech Recognition System [3]

4.2 Keypad Assit Control:

A keypad control system is cost effective and can help amputees to obtain multiple movements of the arm as it consists of 12 switches which is shown in Fig. 4, each switch can count for a different movement of the arm. Keypad outputs can directly be interfaced to the microcontroller or keypad decoder IC.

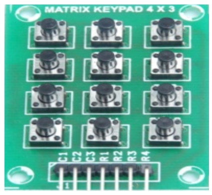


Fig. 4 Keyboard used to Control Bionic Arm

4.3 Force Sensor:

Force sensors shown in Fig. 5 act as force sensing resister in an electrical circuit. When a force is not applied to the sensor, its resistance is very high and when a force is applied to the sensor, its resistance decreases with respect to applied force [5]. This sensor can be used to measure force up to 10 kg. Force sensors are placed on specified locations where there can be more amount of pressure applied by the feet.

Fig. 5 Force Sensor used to Control Bionic Arm

5. DESIGN AND IMPLEMENTATION OF THE TRANSMITTER BLOCK

The three simple control systems namely, the keypad control mode, foot pressure and the speech assist control blocks are implemented in transmitter side on the hardware and tested for their results which is shown in Fig. 6. The implemented control system is operated individually or collectively as per the requirements of the amputee.

Keypad control was implemented on the Microcontroller board which consists of a 4x3 matrix keypad shown in Fig. 7. These buttons or the keys on the keypad are assigned for the 10 arm movements along with the ON and OFF of the LED.

Foot pressure sensors shown in Fig. 8 are placed on the toe and the heel for maximum amount of pressure extraction. Since the output of force sensors is resistive, the voltage conversion is done using a simple voltage divider circuit. The foot control works such that when pressure applied near the toe reaches to 9.8 N which is equal to 4.3 V the shoulder is moved down. And when the heel pressure reaches to 12.25 N equal to 4.6 V another DOF of the shoulder is obtained.

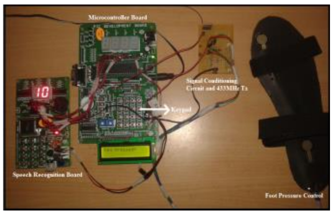
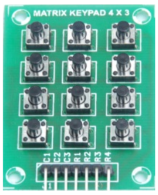


Fig. 6: Voice Control, Keyboard and Force Sensor Interfaced to Microcontroller



Keys	Arm Movements
*	Clockwise
#	Anticlockwise
0	Led On/Off
4	Shoulder Up
1	Shoulder Down
5	Elbow Up
2	Elbow Down
6	Palm Up
3	Palm Down
7	Grasp
8	Release

Fig. 7 Actions Assigned for Keypad Control System

Force Sensor	Arm Movements
F1-Heel Sensor	Shoulder Up
F2-Toe Sensor	Shoulders Down

Fig. 8 Actions Assigned for Foot Pressure Control System

Fig. 9 shows the HM2007 speech recognition kit which gives an 8 bit data output that is connected to the PIC18F458 microcontroller on the development board. The speech recognition kit receives the input from the user and compares with the previously trained words. This is then encoded to binary form and compared with the microcontroller coding. If this matches then the microcontroller sends commands to the receiver to obtain the respective arm movements.

Memory Location	Arm movements
01	Anticlockwise
02	Clockwise
03	Shoulder Up
04	Shoulder Down
05	Elbow Up
06	Elbow Down
07	Palm Up
08	Palm Down
09	Led On
10	Stop
11	Stop
12	Led Off

Fig. 9 Actions Assigned for Speech Recognition Circuit

An LCD is connected to the development board, and the PIC18F458 is programmed such a way that it displays the message, indicating the commands of the keys pressed, the ADC values of the force applied and the voice commands of the SRC.

6. DESIGN AND IMPLEMENTATION OF THE RECEIVER BLOCK

6.1 OWI Robotic Arm Edge Assembly:

Fig. 10 shows the OWI Robotic Arm Edge is selected for the implementation and testing of the control systems since the features of the robotic hand satisfies the needs for our application as it has a gripper to open and close, palm motion of 120^0, an extensive elbow range of 300^0, shoulder rotation of 270^0, elbow motion of 180^0, vertical reach of 15 inches, horizontal reach of 12.6 inches, and lifting capacity of 100 g.

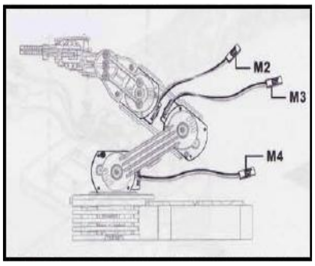


Fig. 10 Assembled OWI Robotic Arm Edge

6.2 Motor Driver Circuitry:

Three L293D motor driver circuitry which is shown in Fig. 11 is implemented for the five DC motors to actuate clockwise and anticlockwise. These drivers act as current amplifiers since they take a low-current control signal and provide a higher-current signal. This higher current signal is used to drive the motors of the bionic arm.

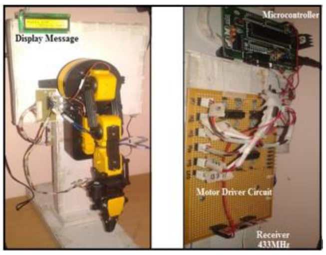


Fig. 11 Motor Drivers and the OWI Robotic Arm

7. RESULTS AND DISCUSSIONS:

System design simulations are carried out in Proteus 7 software. Fig. 12 shows the Proteus simulation which is designed and tested for the transmitter block which consists of the three control modes such as speech recognizer, keypad and force sensor.

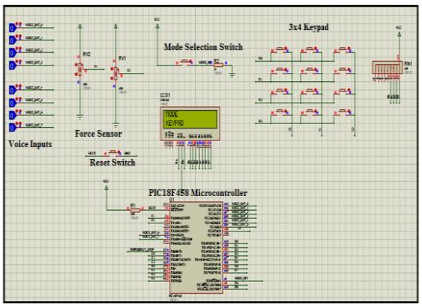


Fig. 12 Transmitter Simulation in Proteus Software

Fig. 13 shows the simulation which is designed and tested for the receiver block that consists of the motor driver circuits which runs clockwise and anticlockwise for obtaining different DOFs.

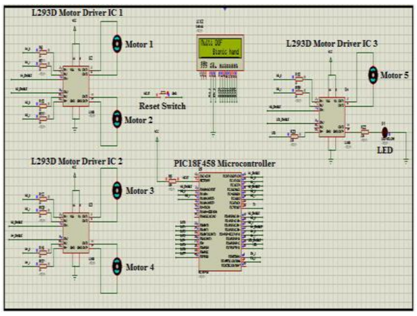


Fig. 13 Receiver Simulation in Proteus Software

The movements of the arm for different DOFs are simulated and tested for its functionality in SolidWork 2012 software. The in the Fig. 14 shows the two DOFs for fingers, 2 DOFs for palm, 2 DOFs for elbow and 2 DOFs for shoulder that are obtained after performing the motion study.

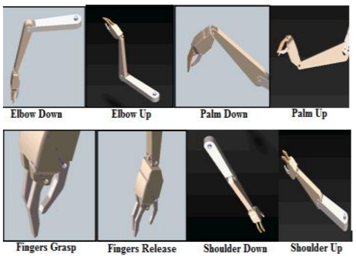


Fig. 14 Simulated DOFs for Bionic Arm in SolidWork

Fig. 15 shows the implementation of the bionic arm for different degrees of freedom which allows the amputees to maximize their interactions to the world and obtain daily activities. 10 DOFs are obtained with the help of a simple keypad and the speech recognition modes. The foot pressure control system allows for a 2 DOFs as there are two force sensors that are placed on the foot sole. Increasing the number of force sensors on the foot on the pressure areas increases the DOFs of the arm.

Fig. 15 DOFs Implemented for OWI Robotic Arm Edge

8. CONCLUSION

The need for a low cost and multi-DOF bionic arm is developed using simple control modes, which requires less rehabilitation, non-invasive and can be affordable when compared to EMG based arm. A prototype model is developed for a cost of 8000 INR which is cost effective and the fabrication of the mechanical modelled arm as per the SolidWork design along with the control system may cost upto 15,000 INR which is less expensive and affordable than that of the EMG based arm which costs around 8 lakhs.

EMG operated arms are limited to movements due to the less number of electrodes used in the development. Each electrode can count for a single movement of the arm. Placing number of surface electrodes or using invasive procedures are not effective. EMG based signals obtained are week, unreliable, changes with time and the signals are patient dependent which varies from one person to other. But the control systems such as keypad, foot pressure and voice assist systems which are designed and developed are capable of providing more than 10 degrees of freedom. And these control systems can be used independently or collectively used as per the requirements of the any amputees.

9. FUTURE WORK

A feedback control system can be introduced for the developed bionic arm, to obtain a good output response to control the movements of the arm more precisely. The external noise affects the speech recognizing therefore filtering process can be developed to avoid the inconsistency in the operation of the arm. The complexity of the electronic circuitry can be reduced by fabricating on the printed circuit board. The system that is developed consists of two fingers which can be improved by introducing five fingers for a better grasping and gripping of the objects.

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