A Low Cost Prosthetic Hand using Flex Sensors and Servo Motors

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***Abstract*:- This research focuses about the simulation of the gestures of the human hand. It is an effort to replicate the movements of the human hand using a plastic 3D printed hand simulation (hand frame), using flex sensors and servo motors. The flex sensors and servo motors work in co-ordination with ARDUINO as their mediator to achieve this. The sensor sends the value to the ARDUINO the ARDUINO processes the data and sends it to the servo motors. Based on the values provided the motor moves and hence pulls the hand simulation, hence replicating the motion of the hand.**

Keywords: Flex sensors, Servo motors & ARDUINO.

1. INTRODUCTION

A robotic arm is a type of mechanical arm usually programmable, with similar functions to a human arm. The arm has links connected by joints, allowing either rotational motion or translatory displacement.

The result is a frame analogous to the functioning of a human arm. Here in our paper the robotic arm has been built on a primitive basis, however much complex and sophisticated can be built. The robot works on simple components like a steel frame for simulating fingers, sensors for detection of motion, and is driven by the ARDUINO board.

The arm includes a glove which will be worn and the sensors based on the motion of the fingers will cause the exact same motion in the steel framed arm simulation (the robotic arm).

WHY ROBOTIC ARM?

There are many situations where humans just can't just get their hands onto something. There are numerous situations when humans can't directly involve themselves. Situations like working in canyons, caves, mining, works involving minute details like manufacture of watches, automobile parts, etc. The robotic arm has its applications not just in fields where things get smaller.

It has huge applications in large industries, where a lot of manpower is needed. The robotic arm has great use when it comes to precision and monotonicity.

The research of robotic hand has grown significantly especially in the development of robotic prosthetic hand ranging from research hand to commercial hand. The available prosthetic hand in the market with great features is very expensive that make it only certain people can buy it. The purpose of this research is to develop a low cost prosthetic hand using widely used mechatronics components. The hand must be easy to manufacture, and easy to maintain with the available component in the market. The prosthetic hand also must be able to perform activities of daily living (ADLs) such as take, grasp, and hold an object.

Some researches about prosthetic hand significantly increased in the size, weight, and anthropomorphism. The prosthetic hand is used to replace the lost hand especially for transradial amputation. In order to the prosthetic hand can move using command from the remaining muscle of the amputee, the hand must read the muscle activities by using sensor. The most widely used sensor for reading the muscle activities is electromyography (EMG) sensor. Some research hands use pattern recognition method of the EMG signal to distinguish the hand movement or gesture. One of common pattern recognition method in the EMG signal recognition is neural network [1, 2]. This method is difficult to implement in the prosthetic hand control system due to the limitation of hardware memory in the microcontroller. The simple control algorithm is developed in this research using the flex sensors & servo motors to drive several grip pattern of prosthetic hand.

Some open source hand is available today to reduce the cost and to increase manufacturability. Open source prosthetic hand based on 3D print are widely used Ada Hand [3] from Open Bionics and Dextrus [4] from Open Hand Project. The state of the art prosthetic hands commercially available are Vincent Hand [5], Michelangelo [6], Bebionic [7], and iLimb [8]. They have great performance in ADLs especially for object grasping manipulation but they are still very expensive.

In this paper, the research goal is try to develop an affordable five degree of freedom (DOF) robotic prosthetic hand and two joints in each finger. For performing the activities of daily living (ADLs), the hand is designed with seven grip patterns, using widely used low cost servo motor incorporating tendon-spring mechanism. The proposed of the prosthetic hand must be able to grasping task with various objects and perform activities of daily living (ADLs). Based on the ref [9], the most used grasping pattern is power grip followed by precision grip. The prosthetic hand is designed with seven grip pattern to perform object grasping manipulation.

The prosthetic hand has been implemented and being used in various countries of the world. The most widespread use of the prosthetic hand is in major countries like the United States of America, China, Russia,etc, The use of the prosthetic hand is limited to developed and prosperous contries as, the prosthetic hand is usually very expensive since it is sophisticated. Technology has advanced so much that there are brain controlled hands which use brain waves. Others use voice and text inputs.

The merits of our Research:

- It helps the people who have lost one of their hands or if it is paralysed.
- Low cost. The whole work can completed under 5000 rupees, which makes the robotic hand very affordable in comparisons to its present contemporary robotic hand proposal.
- Very easily portable. Its is easy to carry the hand around.
- Light weight 3D printed modules/parts, makes it very easy for the amputees to carry it around with them.
- Has a lot of scope for modification. Its working can be made completely automatic and wireless. It can be controlled through cloud or wifi.

2. PROSTHETIC HAND DESIGN

2.1. Materials and Procedures

The hand is designed using SolidWorks Computer Aided Design (CAD) software. SolidWorks is utilized because of easy to use and operate. The solid model of prosthetic hand design can be exported into SimMechanics model for 3D animation and kinematics analysis purposes. The 3D CAD model of the prosthetic hand cover can be seen in Fig. 1. In order to the proposed of prosthetic hand has the same size and weight with the natural human hand, all of mechatronics component has are designed to fit into the hand.
After the 3D model is developed in SolidWorks, the model needs to be printed using 3D printer. The hand is made from PLA (Polylactic Acid) material. The material is selected due to lightweight property. The 3D hand model of this prosthetic hand is inspired by Ada Hand from Open Bionics. The 3D print results of palm, back cover and the fingers are shown by Fig. 2 The length of each finger is summarized in Table 1.

Fig. 2. The Developed prosthetic hand.

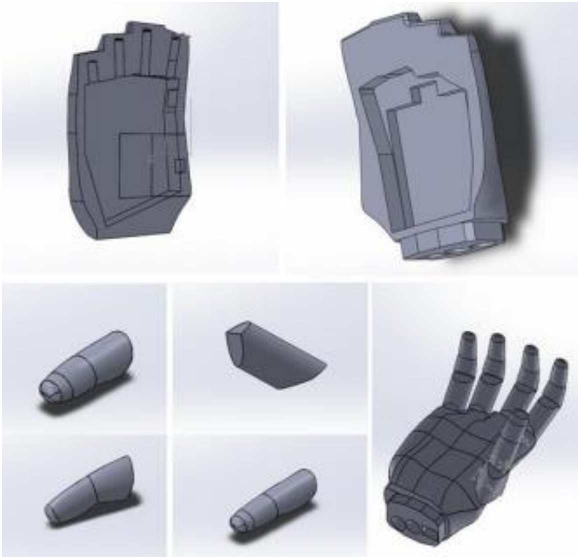

Fig.1 Finger, palm, and hand design in SolidWorks

Fingers	Distal Medial (mm)	Proximal (mm)
Thumb	61	40
Index	41	42
Middle	41	44
Ring	41	42
Little	34	34

Table 1: THE FINGER LENGTH OF PROSTHETIC HAND

The size of the prosthetic hand is 180 mm in length, 85 mm in width, and 50 mm in thick. The overall mass of the prosthetic hand is 261 grams. The size, shape, and weight of the prosthetic hand approach with the human natural hand. This is very lightweight prosthetic hand, when the user/transradial amputee used it as prosthetic hand, the user can manipulate object grasping task without feels fatigue. The general characteristics comparison of AstoHand v1.0 can be summarized in Table 2. Based on the Table II, the mass of available robotic hand varies from 261 gr to 760 gr.

3. HARDWARE AND SOFTWARE SYSTEM

Here is a brief description of working on our research work and also a way of the interaction of the various components used to create our work.

3.1 ARDUINO (UNO):

Arduino(Fig .3) is an open source, computer hardware and software company, project, and user community that designs and manufactures microcontroller kits for building digital devices and interactive objects that can sense and control objects in the physical world.

Arduino board designs use a variety of microprocessors and controllers. We have used the ARDUINO UNO, which has the Atmega 328P microcontroller. The board is equipped 14 digital and 6 analog input/output (I/O) pins that may be interfaced to various expansion boards and other circuits.

The boards feature serial communications interfaces, including Universal Serial Bus (USB) on some models, which are also used for loading programs for personal computers. The microcontrollers are typically programmed using a dialect of features from the programming languages C and C++. In addition to using traditional compiler tool chains, the Arduino project provides an integrated development environment (IDE) based on the Processing language project.

Fig. 3. Arduino board

Specifications: Arduino board

Modulation:	ATmega 328P
Operating/Input Voltage:	5 V / 7-12 V
CPU Speed:	16 MHz
Analog In/Out:	6/0
Flash [KB]	1
Digital IO/PWM	14/6
EEPROM [KB]:	1
Main memory: [KB]	32

3.2 Servo Motors:

Fig. 4. Servo Motors

A **servo motor (Fig.4.)** is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration. It consists of a suitable motor coupled to a sensor for position feedback. The servo we are using here is a non-continuous servo which turns for 180°and then turn back to their original position. A servomotor is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is a signal (either analogue or digital) representing the position commanded for the output shaft.
The motor is paired with some type of encoder to provide position and speed feedback. In the simplest case, only the position is measured. The measured position of the output is compared to the command position, the external input to the controller. If the output position differs from that required, an error signal is generated which then causes the motor to rotate in either direction, as needed to bring the output shaft to the appropriate position. As the positions approach, the error signal reduces to zero and the motor stops.

Hand	Developer	Mass (g)	Size (length x width x thickness, mm)	Numb. of Joint	DOF	Numb. Of Actuator	Motor Actuator Type	Joint couple method
Asto Hand v.1 (2016)	Diponegoro University	261	180 x 85 x 50	10	5	5	DC Motor	Tendon - spring
Ada Hand (2016) [3]	Open Bionics	380	215x 178 x 58	10	5	5	Lead screw	Tendon
Dextrus (2013) [4]	Open Hand Project	428	205 x 88 x 45	15	6	6	Tendon DC Motor	Tendon
Vincent Hand (2010) [5]	Vincent system	-	-	11	6	6	worm gear Motor	Linkage
Michelangelo (2012) [6]	Otto Bock	420	-	6	2	2	-	Cam design to all finger
Bebionic (2011) [7,10]	RSL Steeper	495-539	198 x 90 x 50	11	6	5	Lead Screw Motor	Lingkage
Bebionic v2 (2011) [7,10]	RSL Steeper	495-539	190-200 x 84-92 x 50	11	6	5	Lead Screw Motor	Lingkage
iLimb (2009) [8,10]	Touch bionic	450-615	180-182 x 75-80 x 35-41	11	6	5	worm gear Motor	Tendon
iLimb Pulse (2010) [8,10]	Touch bionic	460-465	180-182 x 75-80 x 35-45	11	6	5	worm gear Motor	Tendon

TABLE II. GENERAL CHARACTERISTICS OF SOME PROSTHETIC HANDS

Specifications: Servo Motor

Modulation:	Digital
Torque:	**4.8V:** 130.54 oz-in (9.40 kg-cm) **6.0V:** 152.76 oz-in (11.00 kg-cm)
Speed:	**4.8V:** 0.20 sec/ **6.0V:** 0.16 sec/60°
Weight:	1.94 oz (55.0 g)
Dimensions:	**Length:**1.60 in (40.7 mm) **Width:**0.78 in (19.7 mm) **Height:**1.69 in (42.9 mm)
Gear Type:	Metal
Rotation/Support:	180°
Pulse Cycle:	1 ms
Main memory: [KB]	32

3.3 Flex Sensors:

A flex sensor (Fig. 5) is a sensor that measures the amount of deflection or bending.

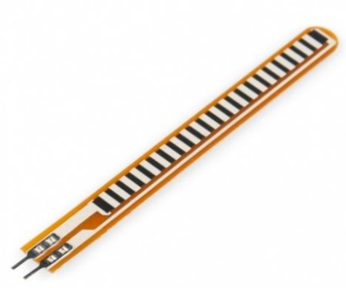

Fig. 5. Flex Sensor

Specifications: Flex Sensor

Life Cycle:	>1 million minutes
Height:	0.43mm (0.017")
Temperature Range:	35°C to +80°C
Flat Resistance:	10K Ohms
Resistance Tolerance:	±30%
Bend Resistance Range:	60K to 110K Ohms
Rating :	0.50 Watts continuous. 1 Watt Peak

Usually the sensor is stuck to the surface, and resistance of sensor element is varied by bending the surface. Bending is similar to varying voltage and hence it is often called flexible potentiometer.

3.4 Robotic Arm:

Fig. 6. Robotic Arm

This part of the paper is the real show-stopper. This is the Robotic hand's frame. It can be made from a lot of things like wood, plastic, metal, etc. It is the part that drives the main motive of the project. A 3D printed frame is the most suitable for this paper since it is easy to make, light weight and cheap. Almost any design specification can be met using 3D printing techniques.

- Other than these main components we need jumper wires for connections.
- We need a bread board for converging all the connections into one place.
- A 7.4v 2200 mAh Lithium-Poylmer battery to power the servo motors and 9v Nickel- Cadmium battery for powering the ARDUINO.
- Fishing nylon wires for the movements of the hand frame.

4. DESIGN AND IMPLEMENTATION

4.1 Circuit diagram

Here is how the **servo motors** are connected.

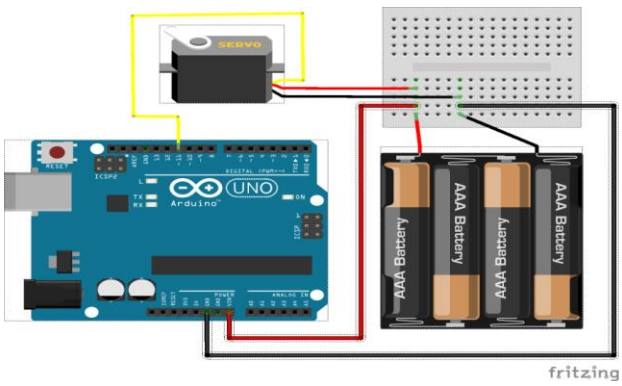

Fig. 7. Circuit diagram

The servo motor is a linear actuator. There are two types of servo motors, one which rotates 360° and is continuous and, another one which has a 180° rotation and is non continuous. The problem with continuous motor is that it does not move in the backward direction, it is always clockwise or anticlockwise. This is a drawback as the fingers move both front and back. Hence we chose the 180°, non-continuous motor.

4.2 Connections

The servo motor has three connections. One is ground, one is power and the other one is for the digital output pin. Since these motors are capable of lifting heavy weights up to 9kg, these require power from external batteries. The wattage is 5v and the current required is 1A. Fig 8 shows how the **f**lex sensors are connected.

The flex sensors are of three types:

- Conductive ink based flex sensor
- Fibre optic flex sensor
- Capacitive flex sensor

We have used a conductive ink based ink sensor in this paper. Each box in the flex sensor is filled with conductive ink. Each time there is a bend there is a change in the relative positions of the particles in the filler liquid. Hence there is a change in the resistance, and a change in the voltage. The flex sensor needs an analog input, power and ground connections.

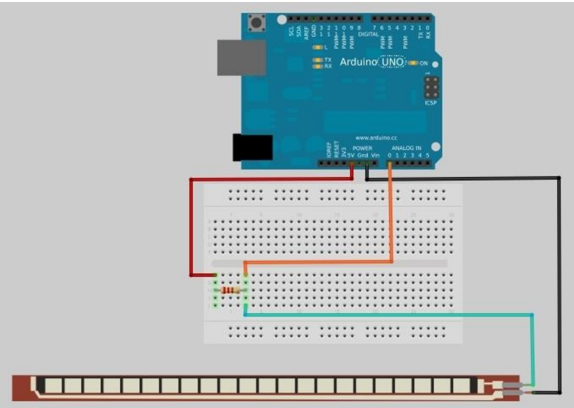

Fig. 8. Flex Sensor connection

Fig 9 shows the connection of **servo motors** as well as **flex sensors**.

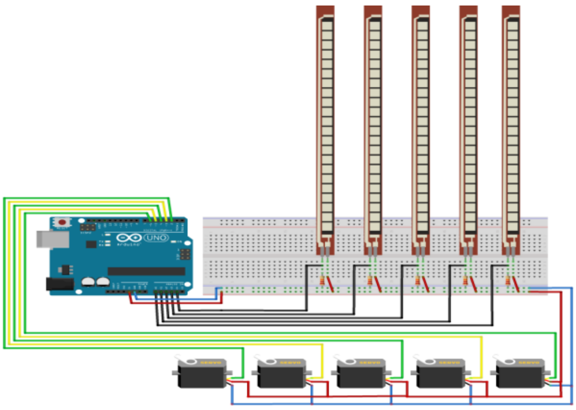

Fig. 9 Servo Motor & Flex Sensor connection

All five servo motors have been given the connections to PWM Pins (Pulse Width Modulation). These pins act as potentiometers and hence provide varying voltage. This is done because servo motors need variable voltage for their working. All 5 flex sensors have been connected to the five analog pins. The servo motors must be connected to a lithium-polymer battery so that it works properly.

4.3 Working

The Fig 10 shows the flow of data through various hardware components used in the paper. It starts from the Flex sensors , passes through the ARDUINO, goes to the servo motors and finally terminates in the hand frame simulation.

- The first step is to make sure all the connections are proper and ensure that there are no loose connections.
- We also verify whether all the servo motors are getting enough power from the battery.
- When the user wears the gloves, that have flex sensors attached to it and moves the hand, there is a change in the voltage due to the change in the resistance caused to the particles in the flex sensor.

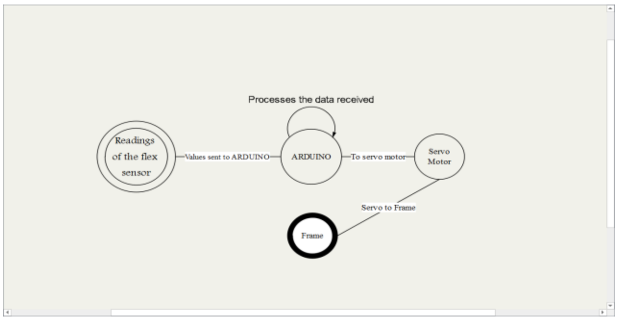

Fig. 10 Data Flow diagram

- These voltage values are read as analog values from analog pins and given as input to the Arduino.
- These analog values must be converted to angles, which the servo motor will take as input. A function called 'map' is used for this.
- Once the values are in angles, they are given as the input to the servo motors. The value indicates the amount (angle) by which the servo motor must rotate.
- The flex values are converted in such a way that the amount of bend of the flex sensor in the glove is same as the amount by which the servo turns.
- This is done by lots of trial and errors and by extensive calibration.
- Doing this will ensure that the hand frame bends just like the hand of the user.
- The servo motors and the hand frame is connected using fishing nylon wire.
- When the servo motor rotates it pulls the string and hence the hand frame.
- Since the motor is a 180° non-continuous motor, the rotation can happen in both clockwise and anti-clockwise direction, and the hold and release simulation of the fingers of the hand can be achieved.
- When folded the motor turns in the clockwise direction and vice versa when released.

5. RESULTS AND DISCUSSION

The Fig.11 shows the connections of Arduino

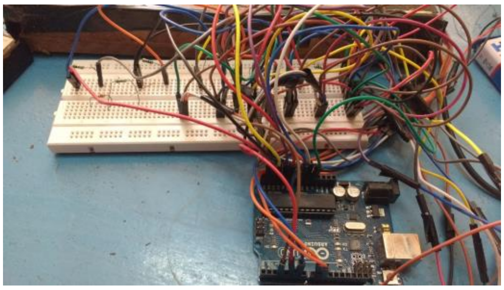

Fig. 11 connections of Arduino

The Fig.12 shows the connection of **servo motors**

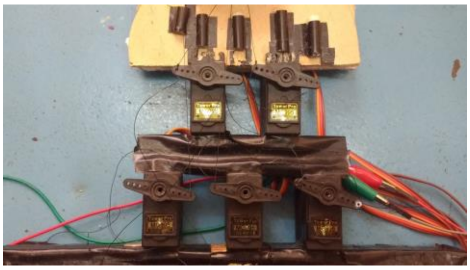

Fig. 12 connections of servo motors

The Fig.13 shows the connections of **flex sensors**

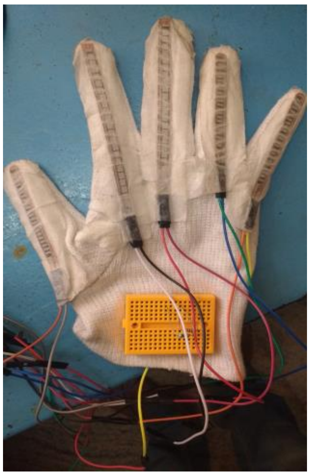

Fig. 13 Connections of flex sensors

The Fig.14 shows the connection of hand **frame**

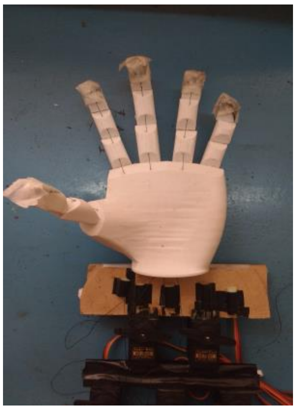

Fig. 14 connections of hand frame

The Fig.15 shows the connections of the entire components

After assembling all the components, and powering the Arduino and the servo motors, the hand frame simulates the user's hand almost perfectly. It replicates the motion of the user's hand, and hence moves exactly like a human hand.

CONCLUSIONS

The proposed of the prosthetic hand is light weight. The servo motors as actuator give the hand lightweight structure and low cost prosthetic hand. This hand can be used as prosthetic hand for transradial prosthesis because of its size and weight which approach the human hand. The prosthetic hand also has seven grip patterns that enable it to do activities of daily living. It works just like a human hand simulation, but with a lesser precision of course. The prosthetic hand just doesn't have applications in helping the physically disabled people, but also has wide applications in manufacture industries, field of aeronautics and space, in mining industries and many more.

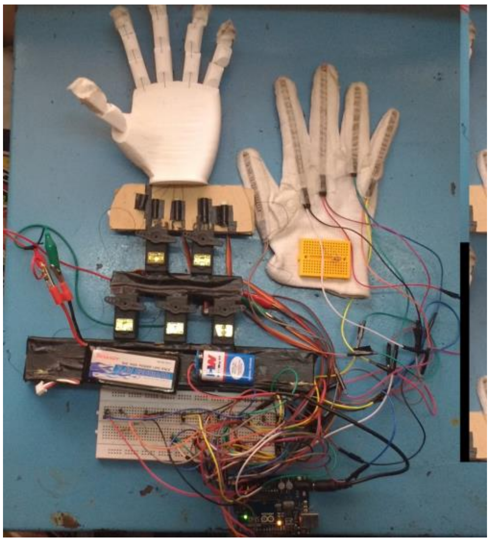

Fig. 15 Connections of the entire components

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