Real-Time Robotic Hand Control Using Hand Gestures

MS INFORMATION TECHNOLOGY

Abdul Basit Riaz
MSIT-F17-005
Session: [2017 – 2019]

DEPARTMENT OF COMPUTER SCIENCE
INFORMATION TECHNOLOGY SUPERIOR UNIVERSITY
LAHORE, PAKISTAN

Real-Time Robotic Hand Control Using Hand Gestures

A project submitted in partial fulfillment of the requirements for the
Degree of Master of Science in
Information Technology

Abdul Basit Riaz

Sir Hamayun Khan

DECLARATION

This project is a presentation of my original research work. Wherever contributions of others are involved, every effort is made to indicate this clearly, with due reference to the literature, and acknowledgement of collaborative research and discussions. I also declare that this work is the result of my own investigations, except where identified by references and free from plagiarism of the work of others.

Signature: ………….

Abdul Basit Riaz

Date: ……………….

The undersigned hereby certify that they have read and recommend the thesis entitled "Real-Time Robotic Hand Control Using Hand Gestures" by Abdul Basit Riaz for the degree of Master of Science in Information Technology.

Thesis Supervisor

Thesis Committee Member

Thesis Committee Member

Head of Department

ACKNOWLEDGEMENTS

This research work has been completed obviously by me, but I am indebted to many for their guidance, support and cooperation to accomplish this task. It would be perhaps ungratefulness if I do not pay gratitude to them. First of all, I would like to thank, my supervisor .He helped me, guided me and supported me whenever required. He helped me to finalize my topic of the research when I was confused what to do. He always supported my ideas and my initiatives.

Thank You,

Abdul Basit Riaz

DEDICATION

I would like to dedicate this research work to my parents whose visionary and inspirational mentoring kindled in me an ambition to attain the higher qualification and always prays for my success in every walk of life. My Better-half, who supported and facilitated me like a true friend, besides frequently reminding me like a teacher to achieve my goal. My Daughter and Son, who could not enjoy their evenings and weekends adequately due to my higher studies and research work. And definitely my Supervisor (Sir Hamayun Khan) for always supporting, guiding me and giving me his precious time.

Table of Contents

LIST OF FIGURES

ABSTRACT

Technological advancements in recent years has set path to merger of different innovations results in helping and improving overall standards and quality of human life. This project is a little effort towards this approach as I have tried to make an artificial robotic hand which will be controlled and moved by human hand in real time. Such robotic hands are very useful in different sectors such as where it is very difficult for real humans to work in such environments robotic hands are best possible choice. These may be used for bomb disposal and other military purposes like land mines removal etc. This technology can be used for disable persons or persons with partial disabilities and other medical purposes like robotic surgeries etc.Enviroments dangerous for human health like radioactive and volcano related place for experimental and other purpose.

In proposed project an artificial hand is created with the help of 3D material. To control fingers movements five flex sensors have been used which will control each finger movement individually servo motors are used along with them. There will use some microcontroller to control the movements of servo motors like arduino etc.

The model used is that when the person gives the input to microcontroller by varying the resistance with the help of potentiometer signals are being generated which will send the signal to a specific servo motor to move due to which respective finger will move. And when these signals are stopped the motor will be stopped automatically and the finger will remain in the same position as for as more responses are given. By little hardware and software modification the proposed design would enable user to control the robotic hand using wireless technology and mobile application.

CHAPTER 1

INTRODUCTION

This chapter presents the background of the robotic hand controlled by human gestures in real time in terms of latest scientific research. Moreover, we discuss the objectives of proposed solution, design, structure and the suitable environment used for this work.

1.1 Background

Over the last decade, the world population has increased tremendously. Resulting in a whole new field of scientific innovations and improvements for the betterment of this population.
Specially, the innovations in the PC Gaming sector and medical sector has made human life easier than ever before. In medical sector, for example, the combination of medical science and engineering has made possible almost everything which was not possible before from simple and effective computerized record keeping to complex robotic surgeries. Similarly in case of hand disability from simple hand hook to modern robotic hand and used as prosthetic hand [1]. But even than in such technologically advanced era, human lives still encounter constant dangers, like traffic accidents and diseases has increased to an alarming rate as human population increased around the globe. Sadly, very few of these harms can be prevented but all other affecters of such events need enough medical facilities and care so that they may live their remaining life in best possible way with improved living standards without suffering anymore with the help of technologic advancements in biomedical engineering [2].

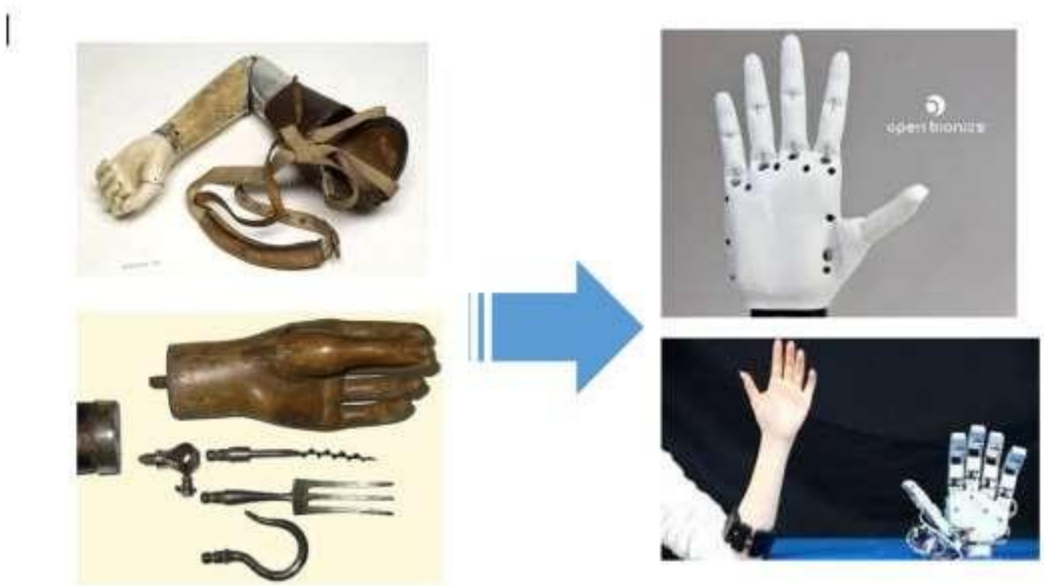


Figure-1.1: Technological advancement of prosthetic hand

In this proposed solution an artificial robotic hand is a robot controller which is programmable and will able to work almost same as real human hand. The described solution is provided by the device which has its own pattern and all the actions of device are controlled by servomotors which form a important part of robotic hand.

1.2 Problem Statement

To develop an artificial hand this may work as closer as possible with real human hand in real time. The person using this hand will be able to fully control gestures and movements of that artificial robotic hand. For this purpose special type of sensors will be used which has ability to bend along with the movement of human fingers.
Such robotic hand will be used not only in medical care sectors for patients with full and partial hand disabilities also can be used by surgeons for remote robotic surgeries ,it can also be used for different anti-terrorist and military purposes, for other scientific purposes and experiments where human involvements are not safe or suitable.

1.3 Project Approach:

The proposed project will be achieved by attaching flex sensors on some glove which can be worn on hand glove or directly on human hand, flex sensors will be worn on the finger which need to be moved on robotic hand and if used on all the fingers (five for five fingers) then motions on all the fingers on the robotic hand acoordingly.These flex sensors will further be attached with microcontroller (Arduino) in our proposed solution ,The microcontroller on the other hand will be attached with five servo motors again one for each finger and the purpose of using these motors is to control finger movements and gestures on robotic hand.

Figure-1.2: Block Diagram

1.4 Work Methodology

As per diagram given below a detailed working of the proposed project is shown in a detailed circuit diagram five flex sensors of 2.2" size will be attached to microcontroller (Arduino UNO) along with resistances of 5 Ohm each then on the other hand five servo motors will be attached with the micro controller, Any microcontroller like Arduino allows the project/circuits to designers to manage and sense the attached electronic devices. The other main device is Flex Sensors which are used for any applications and devices that requires the measurement of a repetitive bending, striking deflection, acceleration or range of motion. Servo motors used widely in the manufacturing parts of robots, industrial automation.

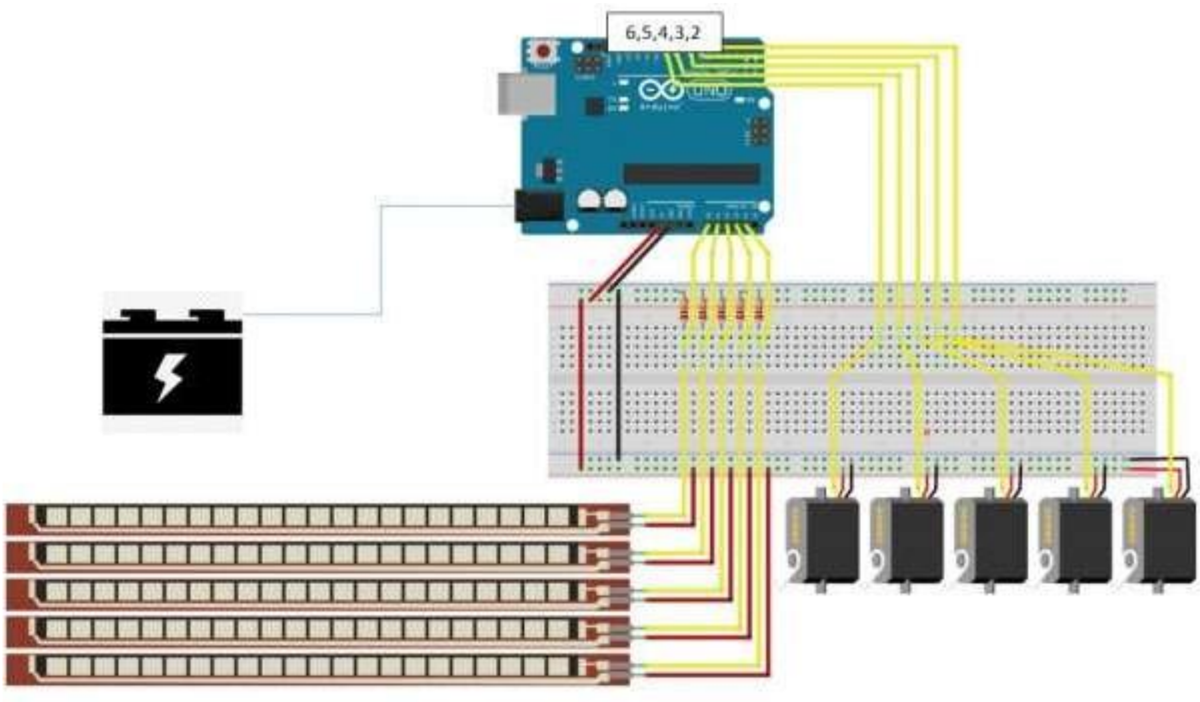


Figure-1.3: Circuit Diagram

1.5 Project Objectives & Scope of work:

The main objective of the proposed project is to design robotic hand controlled by hand gesture based on some suitable microcontroller. The goal of the project is to develop an effective real-world system that efficiently transfers and translates the hand gesture into the movement of the robotic hand made with 3-D printing material. The proposed solution in this project will help different sectors and communities of life. Including persons with hand and arm disabilities, medical community can be used by surgeons for robotic surgies,military and defense community for experimental purposes with radioactive and bomb materials etc. This proposed project may also be further enhanced in various sectors such as robotics, industrial automation and bio-medical engineering etc.

The proposed study will have the following objectives:

1) To study the 3D printing material and why it is used to make robotic hand
2) Selection of suitable microcontroller for the proposed project and functionality towards robotic hand.
3) Role of servo motors towards the proposed project.
4) To identify suitable sensors and their functionality.
5) To study the software and other hardware parts.
6) To study and explore possible modifications in software and hardware to enhance the scope of the proposed project.
7) Feasibility study towards the cost of the project.

1.6 Structure of the Dissertation

The chapter that follows Literature Review (Chapter 2), Data collection and Methodology (Chapter 3), Implementation of Proposed Solution (Chapter 4) then Results and Discussion (Chapter 5)followed by last chapter Conclusions and Recommendations (Chapter 6).then References then separate Annexures for programming code, technical diagrams and hardware specifications

CHAPTER 2

LITERATURE REVIEW

We begin with a brief introduction of human hand anatomy and structure to know how human hand and wrist moves then we will discuss about the griping ability of human hand. We will also discuss types of human hand movements furthermore we will discuss the types of human hand grips so that we may fully understand the working of real human hand.

2.1 Anatomy of the Human Hand/Wrist

2.1.1 Bones & Joints

The human hand is made up of the carpus and five fingers. The carpus or wrist consists of eight small bones known as carpus bones. These bones made wrist and connects arm with beginning of fingers. The Human hand contains of 27 bones including 05 metacarpal bones and 14 phalanges or finger bones and 08 carpus bones as shown in fig 2.1

Radiocarpal (RC) joint is used to connect hand with wrist. Every finger excluding thumb is made up of a metacarpal bone, consisting of three phalanges and four joints. These three phalanges are the prximal, middle and distal respectively.

Similarly the four joints are the distal interPhalangeal can be denoted shortly as (DIP), proximal interPhalangeal can be denoted shortly as (PIP), metacarpoPhalangeal can be denoted shortly as (MP) and The joint between finger and wrist is called carpometacarpal (CM) or intercapal (IC) joint. Human thumb only has the proximal and distal phalanges but no middle phalanx and therefore only two joints associated with them namely as metaCarpoPhalangeal joint and distal interPhalangeal.

Figure 2.1: Bone and joint in human hand/wrist. [3]

2.1.2 The Tendons:

Tendons[4], the rope like threads that attach the small muscles of your hand to the bones of the hand and fingers as shown in fig .Motion of hand and wrist is generated by these tendons. The wrist tendon starts from forearm muscles and attach into human hand bones.

Figure 2.2: Tendons of fingers and thumb. [4]

2.1.3 The Types of Tendons:

Following are the wrist and hand tendons involve in hand and wrist movement.

a) Wrist flexion tendons
b) Wrist extension tendons
c) Finger flexion and extension tendons

Tendons link the muscle fibers, which deliver power, with the help of joints and bones which moved, making possible movements like opening the hand and closing hand.

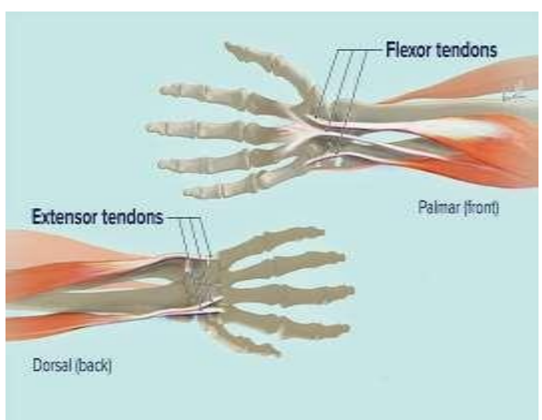


Figure 2.3: Wrist tendons link muscles to bones[5]

2.1.4 Human Hand Movement

It is important to study how human hand is moved, what are the basic types of human hand movement in order to understand the movement of robotic hand.

2.1.5 Types of human hand movement [6]:

There are different types of finger movements in human hand as given below:

Flexion:
Movement of fingers towards hand palm is called flexion of fingers and on the same way movement of thumb towards hand palm is called flexion of thumb as shown in fig.

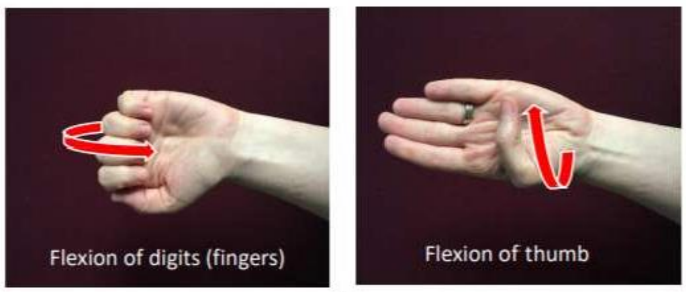


Figure 2.4: Flexion of fingers and thumb [6].

Extension:
This type of moment is apposite to flexion movement means that the movement of fingers from palm to outside and similarly movement of thumb towards outside is called extension of thumb as shown in fig 2.3.

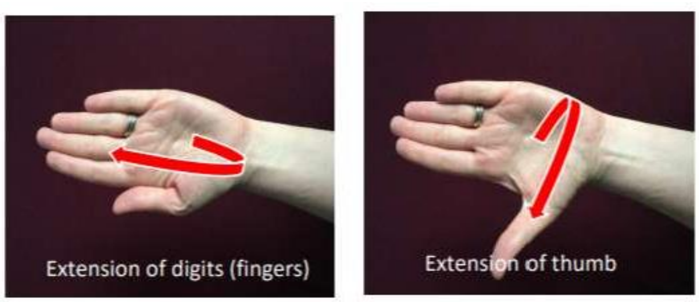


Figure 2.5: Extension of fingers and thumb [6].

Abduction:
Movements or spreading of fingers away from each other is called abduction of fingers similarly movement or spreading of thumb which makes 90 degree angle (perpendicular to the palm) is called abduction of thumb as shown in fig 2.4.

Figure 2.6: Abduction of fingers and thumb [6].

Adduction:
This type of moment is apposite to abduction movement means that moment of fingers towards each other and similarly closing the thumb towards palm removing 90 degree angle as shown in fig 2.2.

Figure 2.7: Adduction of fingers and thumb [6].

2.1.6 Human Hand Grip

As we have studied and discussed human hand movements to understand the movement of robotic hand movement similarly we need to study and discuss the concept of human hand griping and how it works as robotic hand is also provides griping and holding of objects.

2.1.7 Human Hand Grip Types

There are different types of grips that a human hand can perform [7], as shown in fig below. The human hand has a complicated and difficult formation where different necessary parts are required to accomplish an action. In order to perform a grip these components should not only have to be in a working condition but also cooperate with each other.

The pulp pinch or pinch grip: it can be performed by holding an item between the index or middle finger with the thumb, another type of grip is known as a **common grip** is a type of grip when we stitch something by hand. Another type of grip is the **lateral pinch** is when an item is held between the thumb and the side surface of the index finger, this type of grip is used when a key is used for unlocking any lock.
The **tripod pinch** is when an item is held between the thumb, index and middle finger; this type of grip is made when writing with a ball-point.

The **five-finger pinch** is when an item is held between the tips of the all fingers on the hand, without touching any finger or item to the palm.
The **diagonal volar grip** consists of holding an item with the thumb and fingers but on the same time that item is touching with the internal area of the palm; the item also has a diagonal axis in reference of the axis of the hand. If the axis of the object is transverse in reference of the axis of the hand then it is known as **transverse volar grip**.
The **spherical volar grip** is almost similar to the five-finger pinch, but in this type of grip the item has contact with the internal part of the palm.
The **extension grip** is demonstrated when holding an item between the thumb and the other Fingers, the item has no contact with the surface of the palm.

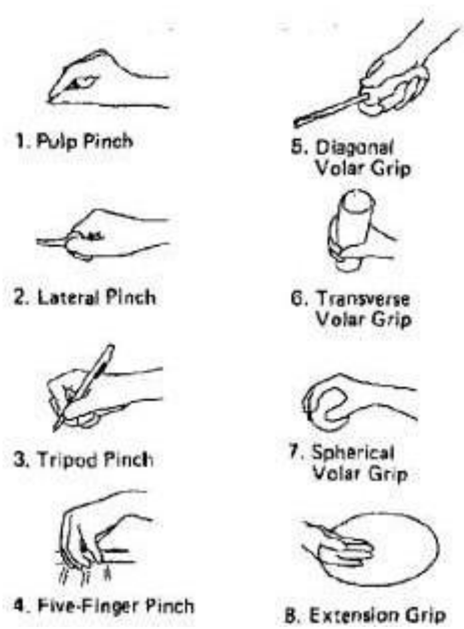


Figure 2.8: Types of human grip [7].

CHAPTER 3

METHODOLOGY

To complete the proposed solution we have collected data from different sources like experiments, human observations and technical documents/records etc. We have discussed in details about all the hardware required for this purpose and role of that hardware and possibility of using in our proposed solution along with advantages and, industry usage and their technical specification etc.

3.1 Problem statement:

To make robotic hand which acts almost like real human hand which may be used as prosthetic/bionics hand to help any disabled person who have partial or full disability from any reason or may be used in multiple experimental and scientific scenarios and environments where real human intervention is difficult or not possible like bomb disposal to tackle terrorist activities and for other military purposes and with the option of handling all these activities remotely. The proposed solution may also act as basics to towards full human like robotic with maximum human like features. On the other hand to make proposed solution as economical as possible by using already available technologies and equipment.

3.2 Work Methodology:

In the design of the robotic hand we have 3-D printed technology to make human like robotic hand this technology is very innovative now-a-days, special 3-D printed are used to make almost anything which you think in your mind.so it is the best choice to make plastic hand for this purpose we have to make different parts of the hand separately like different parts of the each fingers and palm etc. Then we have assembled these parts together to form a robotic human hand as discussed and shown in chapter 4.these printers are available from 40,000 to 4,00000 Rs.But Thanks to open source technology these 3D printer output files are available for free(.stl stereolithography files)as we have discussed in chapter 4.we have also used flex sensors which act as variable resistors .Five flex sensors are used one for each finger and we have sewed them on a glove so that we can move them easily with our fingers as discussed in detail in chapter 2.Further these flex sensors are connected to 5 servo motors one for each finger through microcontroller we have tied these servo motors with the fingers of robotic hand one servo motor for each finger separately by using fish wire as shown and discussed in detail in chapter 4 demonstrate the movements of human fingers, servo motors which will be connected to the fingers of the robotic hand through fish wires and Arduino UNO is used as microcontroller which act as controller. As for as connection of the proposed solution is concerned these all devices will be connected to some micro controller Arduino UNO in this case we will connect flex sensors to Arduino UNO in just a way that one port will be connected to the Analog in (port no A0 to A4) these ports used as ADC (digital to analog convertor)then we will give GND from Arduino on all these connections and resistance of 10 k on every point and the 2nd wire from each flex sensor will be connected to power port of the Arduino to provide 5v power to the flex sensors as shown in circuit diagram in Appendix B.

Now as a second part we will connect all servo motors to the microcontroller for this purpose after giving GRD and power to the servo motors we will attach five servo motors to the ports Nos

2,3,4,5,6 on the microcontroller which are basically digital(input/output) pins means that these pins only works in two stages 0 or 1.
To better understand work methodology of our proposed solution let's have a look on the work flow diagram:

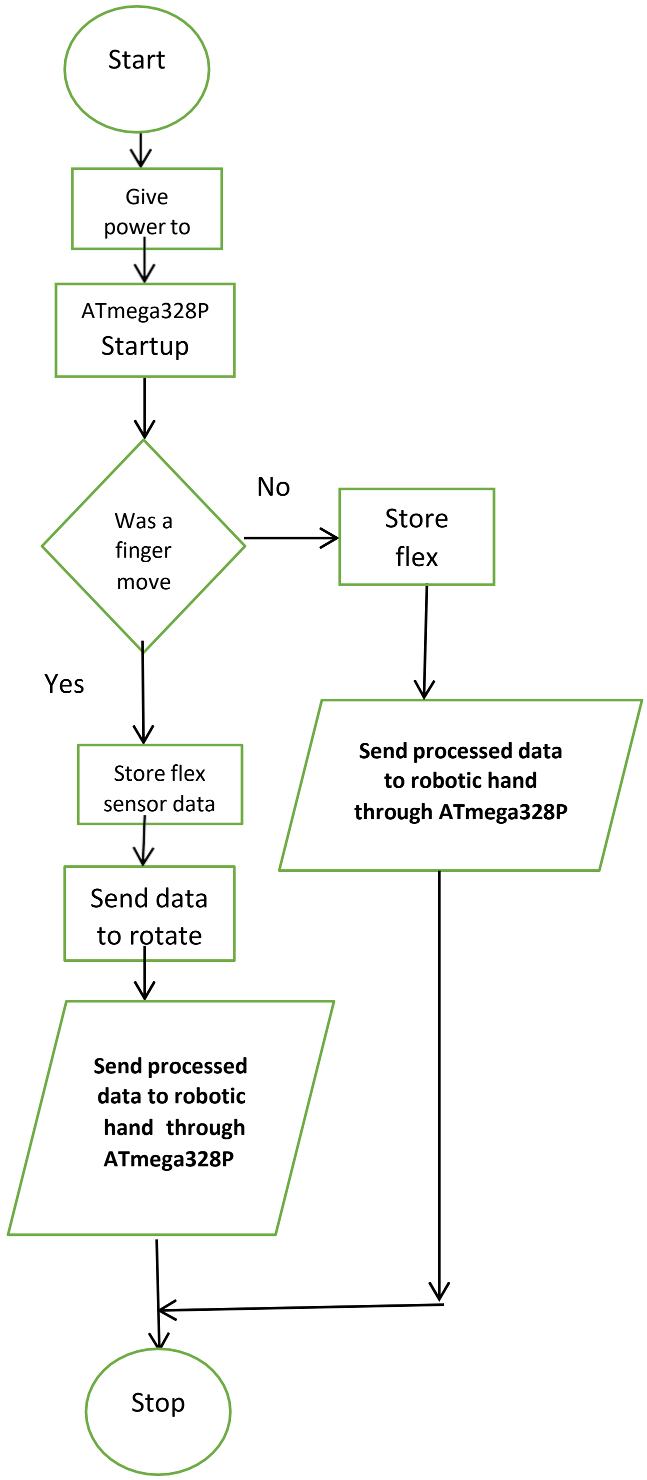


Figure 3.2: Flow chart Diagram

3.3 Proposed Solution:

To provide the solution to above mentioned problem we need to provide some solution which will be economical as well as effective and on the other hand fulfill all our needs we will try to utilize equipment and technologies which are already available in the market so that we are able to find economical solution. First of all we need to make human like artificial hand this purpose will best full filled by Like 3-D printed technology in market there are different type of 3-D printers available Polylactic Acid, commonly known as PLA material used to make required plastic parts these plastic parts can be designed in 3D modeling softwares, hard copy and soft copy of these parts are available online, soft copy of these parts are available as a free source which can be printed by using any 3D printer. flex sensors and servo motors will be used to copy the movements of real human hand and against the movement of each human finger the finger on the robotic hand will be moved respectively and to control and manage all this circuitry we also need some microcontroller in our proposed solution we have used Arduino UNO which will best choice in our case as it has multiple built-in functions and it is easy to program as well as per our requirements.

Let's discuss in detail about the major hardware components which we are going to use in our proposed solution.

3.4 Arduino Uno

3.4.1 Basic Introduction:

It is an open sourced microcontroller based electronics platform.ATmega 328P is used as microcontroller in this platform. This platform is developed by Arduino.cc First Arduino project was started in Interaction Design Institute Ivrea in 2003 by David Cuartielles and Massimo Banzi its purpose was to provide a low cost and flexible method to students and professionals for managing different devices in actual environments. Arduino programing language is used by the microcontroller in this platform, this language is originated from open source frame-work used by microcontrollers which is named as Writing.

All the Arduino programing instructions has been written in the special environment called IDE (Integrated Development Environment) which a type of software for Arduino. The Universal Serial Bus (USB) cable with one end USB-A and other end USB-B type is used to upload all programs and instructions to microcontroller in Arduino UNO and compiling of programs are done in this way as way, there is option to attach an external battery with this platform as well. Some important information about Arduino microcontroller is given in table. In this project microcontroller will receive instructions from flex sensors attached on the glove then movement of these flex sensors will control the movements of the finger of robotic hand.

Figure 3.4 : Arduino UNO[8]

3.4.2 Advantages of Arduino Technology

- It is cheap
- It is open source
- Multiplatform operability.
- It is easy to program and re-program as per requirements.
- For beginners, it is very simple to use.
- It is easily available almost in every electronic market and online as well.
- Can be used easily with multiple sensors

3.4.3 Applications of Arduino Technology

- Robotics
- Industrial and home automation and projects
- Educating purposes learning electronics using hardware and software.
- DIY electronic projects
- Multiple contributions towards new era of IoT.

3.4.4 Technical Specifications of Arduino Uno

Microcontroller	ATmega328P
Operating Voltage	5 V
Input Voltage (recommended)	7 - 12 V
Input Voltage (limited)	6-20 V
Digital I/O Pins	14 (of which 6 provide PWM output)
PWM Digital I/O Pins	6
Analog Input Pins	6
DC Current per I/O Pin	20 mA
Flash Memory	32 KB (ATmega328P) of which 0.5 KB used by boot loader
SRAM	2 KB (ATmega328P)
EEPROM	1 KB (ATmega328P)
Clock Speed	16 MHz
LED_BUILTIN	13
Length	68.6 mm
Width	53.4 mm
Weight	25 g

Technical specifications of the Arduino Uno microcontroller [8].

3.4.5 Cost of Arduino UNO:

Price of Arduino UNO which is used in this project is ranging from Rs.750 to Rs.1200, available online as well as in electronic market.

3.5 Flex Sensor

3.5.1 Basic Introduction:

It translates the amount of bend (instead of pressure or force applied) into resistance also called “deflection” which simply means redirecting something or causing it to move in a direction that’s different from the course it had been on.

The more bend, the less it resists electrical current.

So we can say that

Bending of Flex Sensor **Inversely proportional** to **Resistance** of Electric Current

It is not ideal if you want to measure *exactly *how much bend is applied or movement has occurred but it is very versatile and useful in a range of scenarios.

3.5.2 : Structure of the Flex Sensor:

The designing of this sensor can be done by using materials like plastic and carbon. The carbon surface is arranged on a plastic strip as this strip is turned aside then the sensor’s resistance will be changed.

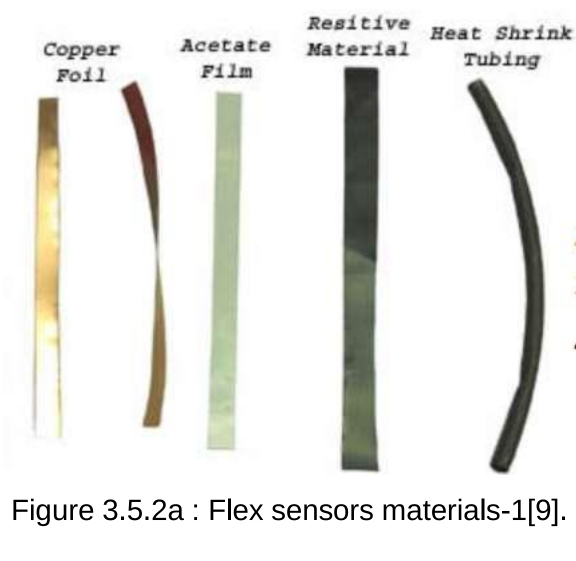


Figure 3.5.2a : Flex sensors materials-1[9].

Copper foil laminate is widely used in the electronics for circuits which are flexible or bendable. It is shown as very thin copper cladding which is stick to plastic material just same as acetate. The single guided material is used for this purpose. Copper and plastic are used in that bendable strip, each material on one side [9].

Paper, plastic or cloth can be used as resistive material, it is not necessary to only use these materials some other materials may also be used with resistive and conductive properties. The scale of the flex sensor will defined by the restiveness of that selected material. So it is better idea to use such resistive material which does not affect by humidity such material which are used to make plastic poly bags.

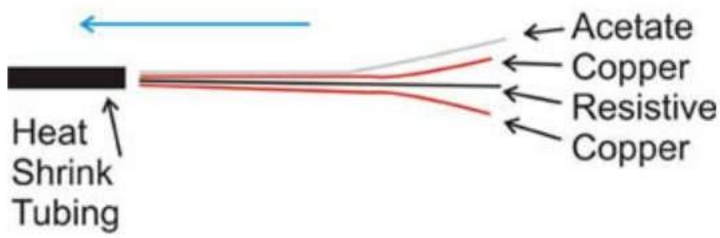


Figure 3.5.2b: Flex sensors materials-2[9]

The heat shrink tubing is basically sandwich of different resistive materials as shown in above figure. To make this sandwich we can insert the acetate strip. Which will be used to make the sensor more durable and resilient and to back after it has been bent.

Pressure and force can also effect on the results and the performance of the flex sensors. So special care is needed while using it. The size and shape of the flex sensors can be changed to adjust it in different working environments similarly resistive material can be changed to get different resistances and characteristics. These materials are easily available from electronics market.

Generally, this sensor is fixed to the exterior, and the resistance of this sensor can be changed by twisting the exterior.

3.5.3 Working of Flex sensors: [10]

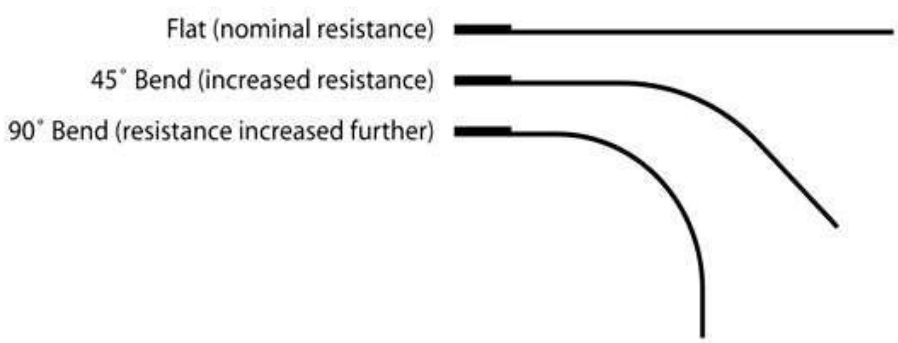


Figure 3.5.3: Bend angles of flex sensors [10]

Flex sensor is a basically a variable resistor whose terminal resistance increases when the sensor is bent. So this sensor resistance increases depends on surface linearity. So it is usually used to sense the changes in linearity.

Flex sensor is a completely linear it will be having its nominal resistance. When it is bent 45º angle the this resistance increases to twice as before. And when the bent is 90º the resistance could go as high as four times the nominal resistance. So the resistance across the terminals rises linearly with bent angle. So in a sense the Flex sensor converts flex angle to resistance. For convenience we convert this resistance into voltage.

3.5.4 Types of Flex Sensors:

These sensors are classified into two types based on its size namely 2.2-inch flex sensor & 4.5-inch flex sensor. The size, as well as the resistance of these sensors, is dissimilar except the working principle [11].

Therefore the suitable size can be preferred based on the necessity. Here this article discusses an overview of 2.2-inch flex-sensor. This type of sensor is used in various applications like computer interface, rehabilitation, servo motor control, security system, music interface, intensity control, and wherever the consumer needs to modify the resistance throughout bending.

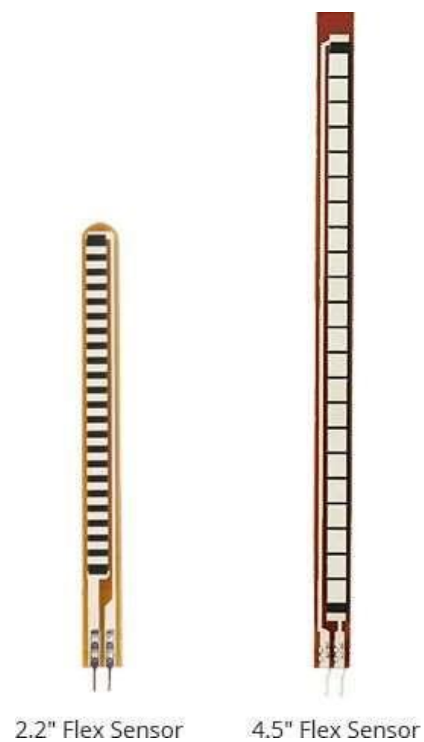


Figure 3.5.4 : Types of flex sensors[11]

Depending on the type of resistive material used on the surface of the Flex Sensor, they are classified as[10]:

1. Conductive ink-based flex sensor

2. Fiber optic flex sensor

3. Capacitive flex sensor

4. Velostat flex sensor

3.5.5 Directions to Use

Flex sensors are designed to flex in only one direction – away from ink (as shown in the figure). Bending the sensor in another direction may damage it.

Figure 3.5.5: Directions to use flex sensors [11]

Also take care not to bend the sensor close to the base, because the bottom of the sensor (where the pins are crimped on) is very fragile and can break when bent over [11].

3.5.6 Specification and Features of Flex Sensors [11]:

The specifications and features of this sensor include the following.

- Operating voltage of this sensor ranges from 0V to 5V
- It can function on low-voltages.
- Power rating is 1 Watt for peak & 0.5Watt for continuous.
- Operating temperature ranges from -45ºC to +80ºC
- Flat resistance is 25K Ω

- The tolerance of resistance will be ±30%
- The range of bend resistance will range from45K -125K Ohms

3.5.7 Application of Flex Sensors [11]:

- Automotive controls
- Fitness Products
- Robotics
- Gaming (Virtual Motion)
- Virtual Reality gaming consoles
- Medical Devices
- Musical Instruments
- Animatronics
- Angle Displacement Measurement
- Industrial Controls

3.5.8 Cost of Flex Sensor:

Price of flex sensor 2.2 inches which is used in this project is ranging from Rs.2500 to Rs.3000 each

3.6 Servo Motor

3.6.1 Basic Introduction

Servo is derived from word servomechanism, so we can say that a servo motor is in fact a servomechanism motor. It is a specific type of automated control system which handles and manages the motion or position of an item or component.

3.6.2 Hardware Structure:

As shown in below figures a servo motor consists of different parts.[12]

1-A DC Motor: It is nothing more than a DC motor which is able to change directions or it can change force in any direction clock wise or counter clock wise. It is a normal motor which receives electrical power as an input and convert it into mechanical power.

2-Control Circuit: There is a potentiometer in servo motor which is which is directly attached with the outer gears of servo motor, potentiometer is worked as variable resistor. The pot's position specifies servo motor's shaft position. A tiny circuit board is used inside servo motor which get instructions from the potentiometer and manages the servo.

Figure 3.6.2-a: Inside structure of a typical servo motor-part-1[12].

3-Reduction Gears: The basic purpose of using gear is to slow down the fast speed of DC motor so that servo motor can be used in more efficient way. Gears made it possible to equal several revolutions of the motor equal one revolution of the servo's shaft. There are horns outside the body of servo motor. These horns are able to connect rods and other components to the servo. Horns are available in different shapes and sizes.

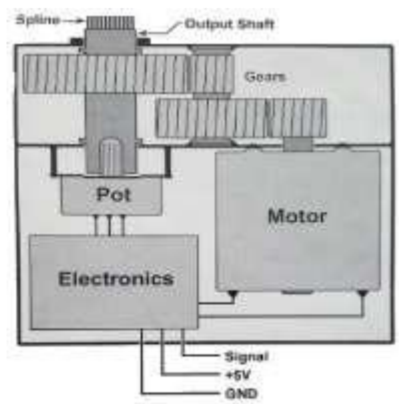


Figure 3.6.2-b:Inside structure of a typical servo motor-part-2[12]

3.6.3 MG995 Servomotor:

These type of servomotors are used in variety of applications where accuracy is required. This type of servomotor is a very common one.
Servo motors (or called servos in short) are complete and independent electric devices which have ability to rotate or push components or parts of a machine with great accuracy and precision.

The main thing about servos is its features which make it selectable and easy to work with. The main component of a servo is a tiny direct current or DC motor, almost similar to which is used in an low-cost toy. Such type of motors usually works on battery electricity and rotates at high RPM (rotations per minute) but shows very low torque. Due to good arrangement of gears slows down high speed of motor and increasing torque (big force, little distance) on the other side. The actual work done is the same making it more useful. The purpose of using plastic in low-cost servomotors is to make them lighter, portable to use them in any environment.[13]

But on the other hand metal gears can be used to increase the power, durability and usability. These TowerPro MG995 Metal Gear Servo Motors are the speedy servo motors with the good torque which is 10 kg/cm.
Getting an original TowerPro Servo Motor is an expensive option. Finding original Tower pro servos is a difficult task, because most of the shops inside market and online selling non-gunine or fake Tower pro servo motors[14].
Due to reliability and good performance these servos are usually first choices.The TowerPro MG995 High-Speed Digital Servo Motor is able to rotate at 90° in each direction making it possible 180° rotation by servo motor. It it made up of good internal circuit which gives good torque, holding power, and faster and good response to outside inputs.

To keep it safe from dust and moisturize these servos are packed in durable and solid plastic body, making it best choice for all remote controlled toys and vehicles etc.

Figure 3.6.3: MG-995 Servo motor[13]

3.6.4 Applications (usage in industry):

Figure 3.6.4: Applications of servo motors [15]

Servos are used in several places: from toys to home electronics to electric boat and planes. If we have a remote controlled toys like helicopter, airplane, or car so it means that we are using at least a one or two servos. In a car or helicopter, servos move levers backwards and forwards to control steering or adjust wing surfaces. The shaft is rotated when connected to the fuel engine throttle, servos role is basically to manage the speed of a car or other vehicle. Servos have a vital role in the devices which we use in our daily life. Electronic devices such as cameras and DVD players use servos to open out or close back the disc trays

3.6.5 Advantages of Servo motors:

1. It provides high output power as compared to size and weight of the motor.
2. Encoder determines accuracy and resolution.
3. 1t provides high efficiency. Up to 90% with light loads.
4. It has ability to speedily accelerate loads.
5. Noise free at even high speeds.
6. Vibration free operation.

3.6.6 Features of Servo motors:

1. Think connection cables.
2. High-quality motor inside.
3. High resolution.
4. It provides positioning with high accuracy.
5. It provides response with fast control.
6. It provides constant torque as long as servo works.
7. It provides excellent griping or holding power.

3.6.7 Specification of Servo motors[13]:

- Weight(gm) : 55
- Operating Voltage : 4.8 – 7.2 V
- Operating Speed @4.8V : 0.20sec/60°
- Operating Speed @6.6V : 0.16sec/60°
- Stall Torque @4.8V : 10 kg-cm
- Stall Torque @6.6V : 12 kg-cm
- Operating Temperature (°C) : -30 to 60
- Dead Band Width : 1 µs
- Gear Type : Metal
- Rotational Degree : 180
- Servo Plug : JR
- Cable Length : 30 mm
- Length (mm) : 40.5
- Width (mm) : 20
- Height (mm) : 44

3.6.8 Cost of Servo Motor:

Price of MG995 Servo motor which is used in this project is ranging from Rs.650 to Rs.900 each

Chapter 4

IMPLEMENTATION OF PROPOSED SOLUTION

In this chapter we will discuss how our proposed solution will be implemented. As discussed in earlier chapter we have collected hardware related to our proposed solution so we will discuss how to assemble these hardware together along with 3-D printed parts to make a final shape of the prosthetic hand.

The robotic hand is basically 3D-printed hand similar to prosthetic hand with the help of Gael Langevin's open-source library [16] and different parts of the hand is made up using 3D-printers. Other parts like forearm is also made similarly because it has a built in section for the servo motors, in order to make robotic hand artistic and perfect. The glove is also used to connect with flex sensors to fingers to robotic hand.

4.1 The making of Robotic Hand & Forearm

The robotic hand is basically 3D-printed hand similar to prosthetic hand with the help of Gael Langevin's open-source library [16] and different parts of the hand is made up using 3D-printers. Other parts like forearm is also made similarly because it has a built in section for the servo motors, in order to make robotic hand artistic and perfect. The glove is also used to connect with flex sensors to fingers to robotic hand.

4.2 The Robotic Hand

The robotic hand and forearm is made up with 3D-printer using open source library as described earlier. The hand is made up of five fingers, a palm and a wrist, as shown in figure 3.1. The hand and forearm were connected and attached with the help of adhesive glue, seven M3 nuts, seven M3 screws and 3 mm polylactic acid (PLA) filament.

4.3 The Fingers

In order to understand the making of finger of 3-D printed hand we can divide whole operation in following easy to understand steps.

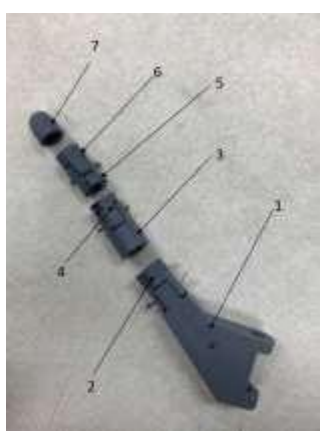


Figure 4.3A:3-D printed finger

Step 1.1 After getting 3-D printed parts of the finger we will start the process of assembling it.
Step 1.2 To avoid mixing of and confusing, ensure to keep every single finger-part separate from the next. In order to effectively assemble each finger, mark all six parts from biggest to smallest with numbers 1 to 6 as shown in figure below.

Step 1.3 Now, using some glue or any other good quality adhesive, glue part 2 and 3 together making sure that they are facing the same direction. Each part has a rectangle mark due to which parts can be combined in the right direction with the glue. Just like the other parts as we have done before part 4 and 4 will be joined with the help of glue as shown in figure below.

Step 1.4 Wait glue to be dried after that connect these parts either PLA filament 3 mm or with 3mm screws which ever easily available.3mm screws can be arranged from any local hardware. After complete joining all parts makes sure that each joint is moving fluently without any obstacle or blockage.

Figure 4.3B. : Finalizing 3-D printed finger

4.4 The Hand

Step 2.1 after finishing assembling of fingers we will attach fingers with thumb. It will be done by connectecting thumb with by wrist of the hand as shown in fig.special 3-D printed bold will be used for this purpose called entretoise.

Step 2.2 After wards index and middle fingers will be attached with 3mm filament as used for the other joints earlier. After attaching the index and middle fingers, the ring and small finger will be attached just like the thumb as shown in fig.

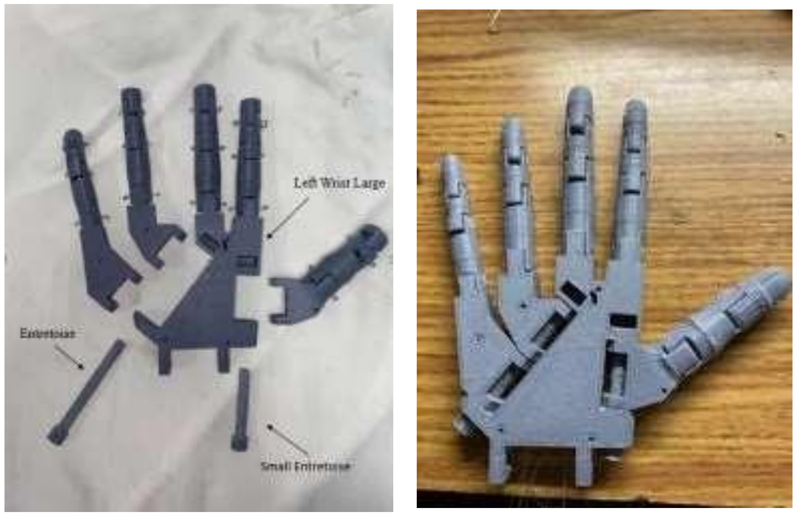


Figure 4.4. : Attaching 3-D printed hand parts

4.5 Threading the Fish wire

The role of the fish wire will be just like tendons in the human hand, wrist and arm.Five 85 cm long fishing wire were used to attach from the five servo motors through the wrist of the hand, the palm of the hand and finally through the fingers of the hand. Let's see step by step how it is done.

Step 3.1 upon finishing the assembling of fingers the next step will be threading the fish wire through the wrist holes at the bottom of the wrist will be used for this purpose we will begin with the top hole and through the palm we will reach the top of the finger.

Make sure that enough cable has been left for re-thread back purpose from the top of the finger using second hole at the top of the finger.

Step 3.2 Fasten the wire in the mid of the knot and then bind insulation tape to the knot to avoid the cable from wrapping up through the hand.

Figure 4.5. :Fish wire for threading

Step 3.3 After finishing it, wrap the thread back using the nearby hole at the upper side of the finger keeping in mind that there will be finger cap on the top upper side of the finger and proceed to thread through the back side of the hand ending the wire on the third hole of the wrist in this way middle hole will remain open.

4.6 The Forearm

Step 4.1 While setting up the forearm, two 3-D printed parts will be glued together which will form outer cover of the forearm as shown in figure below.

Step 4.2 After glue is dried, and then fix the servo bed which is actually place to hold five servo motors in the forearm.

It is highly recommended to wait until all glue parts be dried before attaching any further parts.

Step 4.3 The assembling of the forearm will be completed after attaching the forearm to the wrist as shown in figure below.

Figure 4.6: Attaching parts to form forearm

4.7 Fixing Servo Motors

Step 5.1 After fixing the servo bed in the bottom part of forearm now we are reading to install the servo motors for this purpose we need five servo motors and twenty screws four screws for each servo motor to fix these on servo bed. Usually these screws will be provided along with servo motors.

One thing is to note is that try using metal gears with servo motors as their performance is much better.

Step 5.2 we will install three motors in one direction and the other two in the different direction to confirming that motions of the servo will be completely as per figures and attaching the fish wire accordingly.

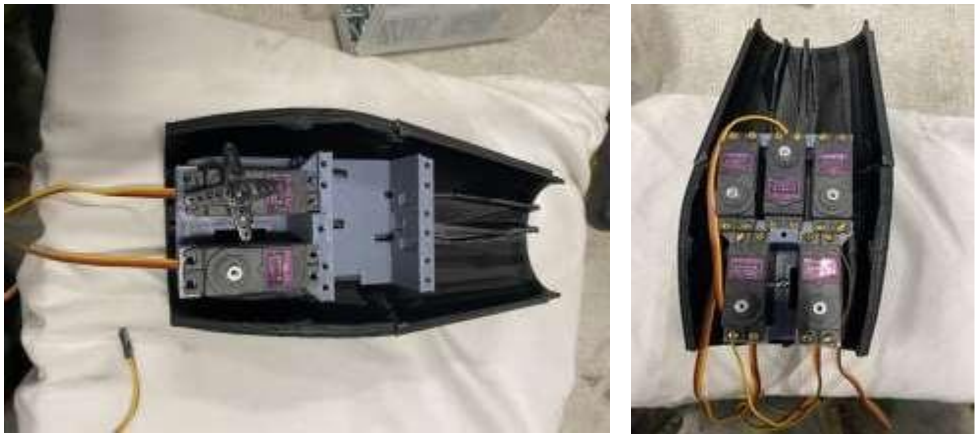


Figure 4.7: Fixing servo motors in servo bed

4.8 Attaching Hand and Wrist together

First of all we need to know that there are two rows of fish wires which are connected to hand fingers, we can divide these rows as top row and bottom row.

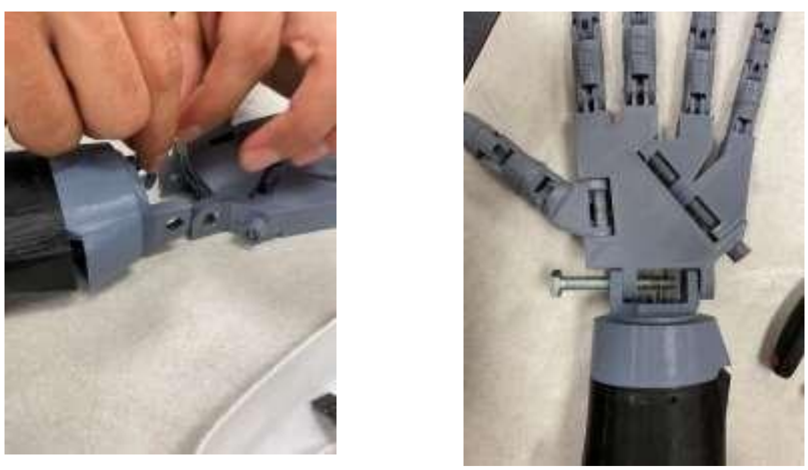


Figure 4.8 Attaching Hand and Wrist together

Step 6.1 Hand and wrist will be attached using a bolt as shown in fig below, we fix that bolt in such a way that the upper row of fish wires will pass from the upper side of the bolt and bottom row of the fish wires will pass through the bottom side of the bolt.

Step 6.2 after completing this process lock the bolt using 3cm bold nut but with taking special care of fish wires so that they may not be twist on each other making it easier to perform the next step which is to connect these fish wires with the five servo motors already fixed in servo bed as shown in figure.

4.9 Attaching Fish wires to the Servo motors

Step 7.1 Make sure that servo motors are properly fixed in servo bed with the help of screws and glue now attach servo pulley with servo motor using glue the pulley is 3-D printed and will be available along with servo motors so make sure when you buy servo motors get pulley and other small parts as well.

Step 7.2 once pulley has been fixed on servo motor's shaft using glue. Now before attaching fish wires to the servos make sure that servo motors are set to ninety degrees using arduino software program by attaching the arduino board to the computer or laptop.

Figure 4.9 Attaching Fish wires to the Servo motors

Step 7.3 When pulleys of the servo motor are fixed at the same level. Now set all pulleys of all five servo motors to zero degree.

Avoid moving pulley of any servo motor by hand manually otherwise you need to set it again, all at the same level

Step 7.4 after adjusting the pulleys of the servo motors now attach each servo motor with each finger separately. Bind each finger with individual pulley of servo motor tightly without any loose. Use holes of the pulley of this purpose.

Step 7.5 after each finger tightly connected with pulley make sure you have attached it with square knot at each pulley's end of the every servo.

To avoid any future loosing, slipping and un-binding of the knot glue can be used on the knot at each pulley's end. All above process need to repeated for each individual finger.

4.10-Preparing glove for attaching flex sensors

Now it's time to attach five flex sensors (each sensor for every individual finger) so that against every flex sensor movement 3D printed hand's finger will be moved.

Step 8.1 First, make very small holes in the plastic of the sensors. But making sure not to touch resistive material on the flex sensors. Another effective of doing that we will make small pockets on the glove one for every finger to put flex sensors in it. Now insert your hand into the glove tightly.

Step 8.2 With the help of ballpoint or marker draw lines on each finger of the glove according to the size and position of the flex sensors. One thing to note here is that we are using flex sensors of size 2.2 inches so we will do this all work accordingly. The purposes of these lines are they will guide us to sew sensors/pockets on each finger of the glove

Figure 4.10 Attaching flex sensors on glove

Step 8.3 Now attach or fix the small circuit or PCB attaching this glove to the rest of project. Female jumper wire will be used for this purpose. This circuit will be directly attached to all the five sensors through tiny cables. Make the glove part de-attachable to the rest of the robotic hand so that these small wires could not be damaged.

4.11-Connections and power options:

We will attach flex sensors and servo motors with an arduino as per circuit diagram while attaching flex sensors with arduino first connection wire from flex sensors will be connected with 5v pin of arduino and shown as red in circuit diagram (in Appendix-B) the second wire of flex sensors will be attached in pins A0 to A4 of arduino these connections are shown with black lines in circuit diagram we will also connect 5 resistances (10k each) as shown in circuit diagram The main GND (ground)

wire, which is attached to all the separate GND wires from the flex sensors, will be connected with Arduino's GND.
Similarly we will connect battery to the power pin of the arduino and connect servo motors to the arduino as every servo motor has three wires the brown wire is GND and will be connected to the GND pin of the arduino, the middle wire of the servo motor red colored will be connected to the 5v power on the arduino and lastly orange colored wire which is a signal wire will be connected to the pins 2,3,4,5,6 on the other side of the arduino where there are digital pins.`
To operate we can give minimum 5V/4A using power adapter or from any battery source. In this case we have attached dry battery having 6V/4.5A.

Figure 4.11: Battery and Power options for robotic hand.

Final Proposed solution (Robotic hand, Glove with flex sensors)

Chapter 5

RESULTS & DISCUSSION

In this chapter we will discuss different methods to test the 3D-printed prosthetic hand, we have tested our proposed solution in different scenarios we have done test to check its griping ability as well as its ability to copy human hand movements as discussed below:

5.1 Investigation of Research Questions

The research questions which are explored are the coping capability of the robotic hand through the real human hand glove having flex sensors on it; also we have investigated and checked the grip ability of the robotic hand. This research was performed through visual observation.

5.1.2 Ability to copy human hand movements

In order to test the copying ability and re-action of the robotic hand with real human hand movement using flex sensor glove the test to investigate was divided into two parts. The first part involved of contracting each finger separately (on the robotic hand) with the real hand using flex sensor glove. The second part of the investigation has been done by contracting or moving multiple fingers (more than one) As shown in figure below to examine if there was any major delay between the glove and the robotic hand.

5.1.3 Grip Ability

The grip ability of the robotic hand was evaluated by holding items into the open fingers/palm of the robotic hand and then try to close the hand. This was done in different steps;
Firstly items/objects of different hardness, sizes and weights have been tested with the help of human hand/flex sensor glove. Furthermore we have tried to test different types of human hand grips as discussed earlier (fig 2.8) using robotic hand. Details of the tests and results can be seen below

5.2 Tests to Check Performance of Purposed Solution

5.2.1 Test-Ability to copy human hand movement

Every finger is able to contract separately, but somehow some fingers performed little better than others. For example the movement of the index and little finger of the robotic hand is not much satisfactory as compared to remaining all other fingers.
We more test this ability by putting the robotic hand in further tests as shown in above figures including different hand signs.

Table I- Sample human hand actions obtained in robotic hand controlled by the glove worn real human hand to check delay or any errors.

Action No & Name	Real hand movement using Glove	Corresponding Robotic hand movement	Error % and delay
1.Thumb movement			Almost 1 second delay with no significant error
2.Index finger movement			1 second delay with almost 20 % error as flex sensor is not be able to bend to the required angle while bending separate finger
3.Middle finger movement			Almost 1 second delay with no significant error

4.Ring finger movement			Almost 1 second delay with no significant error
5.Little finger movement			1 second delay with almost 20 % error as flex sensor is not be able to bend to the required angle while bending separate finger.
6.Full hand movement (bending)			Almost 1 second delay with no significant error
7.Full hand movement (stretching)			Almost 1 second delay with no significant error

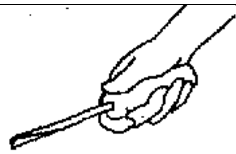
Result: The result was quite satisfactory with very little to no major delays in the robotic hand movement.

5.2.2 Grip Test

In order to know about griping capacity of the robotic hand we have conducted grip test as well which has resulted that it only grips very limited range of objects specially griping works quick perfectly in soft to semi-soft objects. The griping will not work on the objects with slippery surfaces. As for as weight lifting capacity is concerned its grip will work roughly 160 grams almost. Now we will discuss the shapes which provides better capacity to robotic hand as discussed earlier and shown in figure 2.8.

Table 2- Analyzing human hand grips to which extent they are possible with robotic hand (trying all kind of grips as discussed in figure 2.8)

Type of human hand grip	**Demonstration with robotic hand**	**Possibility of demonstration and accuracy**
 1. Pulp Pinch		This type of hand grip is not possible as fingers of robotic hand are not able bend to such angle/extent
 2. Lateral Pinch		This type of hand grip is not possible as fingers of robotic hand are not able bend to such angle/extent
 3. Tripod Pinch		This type of hand grip is not possible as fingers of robotic hand are not able bend to such angle/extent

 4. Five-Finger Pinct		This type of human hand grip is possible as in picture when can see its demonstrator but following factors to consider 1-Material and surface of cloth 2-length and size of cloth
 5. Diagonal Volar Grip		This type of hand grip is not possible as fingers of robotic hand are not able bend to such extent
 6. Transverse Volar Grip		This type of human hand grip is possible as in picture when can see its demonstrator but following factors to consider 1-Material and surface of body 2-weight and thickness of body
 7. Spherical Volar Grip		This type of human hand grip is possible as in picture when can see its demonstrator but following factors to consider 1-Material and surface of body 2-weight and thickness of body

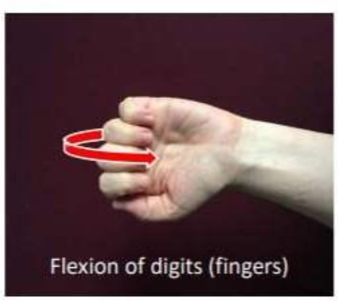
 B. Extension Grip		This type of human hand grip is possible as in picture when can see its demonstrator but following factors to consider 1-Material and surface of body 2-weight and thickness of body

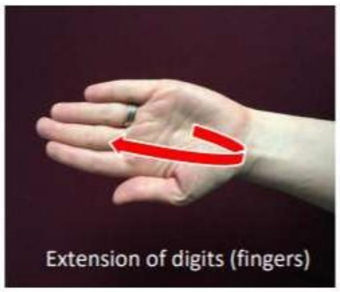
Results: The robotic hand provides good griping capacity towards oblong cylindrical shaped items so these are easier to grip and after that it also provides griping ability to rectangular and spherical items to some extent and with the weight lifting capacity of 160 grams roughly as mentioned above.

5.2.3 Demonstration of human hand movements

As discussed in section 2.1.5 earlier we have studies all possible types of human hand movements we have discussed basic functionality of these types of movements. Now in this section we will try to implement these basic human hand movement types with robotic hand, we will see if our proposed solution(robotic hand) is not be able to perform any of the movement type what are the reasons behind it.

Table 3- Analyzing types of human hand movement to which extent they are possible with robotic hand (trying all kind of grips as discussed in section 2.1.5)

Type of human hand movement	Real hand demonstration	Demonstration with robotic hand	Possibility of demonstration and accuracy
1.Flexion of figures			It is possible to demonstrate this type of hand movement however there is difference between bending angle of real hand and robotic hand due to hardware constraints.

2.Flexion of thumb			It is possible to demonstrate this type of hand movement however there is difference between bending angle of real hand and robotic hand due to hardware constraints.
3.Extension of fingers			It is possible to demonstrate this type of hand movement as shown
4.Extension of thumb			It is possible to demonstrate this type of hand movement as shown
5.Abduction of fingers			This type of hand movement is not possible due hardware constrains of the robotic hand.
6.Abduction of thumb			This type of hand movement is not possible due hardware constrains of the robotic hand.

7.Adduction of figures			This type of hand movement is not possible due hardware constrains of the robotic hand.
8.Adduction of thumb			This type of hand movement is not possible due hardware constrains of the robotic hand.

Results: The robotic hand provides good demonstration of most of the movement types except serial No 5 to 8 due to hardware constrains of robotic hand because we have designed our robotic hand in such a way to perform only up(open) and down(close)movements of the fingers.

Chapter 6

CONCLUSIONS AND RECOMENDATIONS

In this chapter we will conclude our discussion by presenting limitations recommendations and future scope of our proposed solution.

The output product we got as a result of this project is a robotic hand with having all possible functions of the real human hand like imitation ability as well as griping ability as discussed earlier.

On the glove we have made very small pocket on each figure to insert flex sensors in it but still flex sensors need to be adjusted many times so that they can fit perfectly as flex sensors slipped out of those packets again and again. And better fitting of the flex sensors with human hand fingers is required so that servo motors be moved in full angle range without facing any resistance or obstacle.

Another important aspect is the size and material of the glove on which flex sensors are attached. As flex sensors are strip type and glove is fixed length and its material is not stretchable so due to all these aspects fitting of the flex sensors are not proper as it should be.

So avoid such issues we can use glove of some flexible material and secondly glove finger size should be as close as to the length of flex sensors (means not much large not much short) to obtain maximum results when considering imitation ability of the robotic hand.

Now considering all above limitations we can still say that the imitation ability of the robotic hand is quite good there is no much delay as well.

Now at this point if we start considering that robotic hand is unable to perform all the motion types which a human hand can perform as shown in figure 2.6 and 2.7, the answer to this issue lie in the mechanical construction of the robotic hand which limits its imitation ability for example motion types like adduction or abduction couldn't be performed. .

The up and down movement of the wrist can be added in this project just like fingers which will give this project more real look similar to real human arm for this purpose additional servos and flex sensors can be used. Afterwards we will be able to test the imitation of the wrist motion along with the fingers of the robotic separately and combined at the same time and will check any significant delay in their motions.

Another improvement which can be made is developing mobile app to control the movement of the robotic hand and fingers along with wireless control it will be required and useful in environments where it is not good for humans to work there due to high areas like process of bomb disposal very high temperature environments or working near volcanoes etc.

The connections of flex sensors along with controller (small circuit) on the glove is very fragile and very thin wires used for this purpose so there must be some insulation or glue to strengthen connections and wires otherwise there is chance to lose or break the connections or wires.

Future Work:

As well as future scope is concerned we can add wireless zigbee module to extend the range between flex sensors based glove and robotic hand which can give up to 291 meters of range [18]as compared to nRF24L01 which only gives maximum of 200 feet[19].

Secondly we can add GPRS/GPS hardware to control it from anywhere from the internet.

Furthermore video camera can be added to robotic hand for live video streaming to improve the feature of wireless control.

Robotic hand can be attached to metal detector or bomb detectors (any device, machine or person).Temperature sensor may also be added to monitor the environmental temperature on real time which will be definitely used useful for any activity.
As discussed earlier griping ability of the robotic hand can work perfectly fine but with some limitation of object's weight, size, shape and type of body surface/hardness.

Regarding all these factors we have already discussed about the results as well in this chapter but one important factor which also can be considered as limitation is surface, structure and shape of palm and finger of the robotic hand. As the surface of the palm is flat and hard which results as a weak griping capability the robotic hand. The robotic hand could grip objects of varying sizes and shapes. The gripping ability can be improved to enhance the overall performance and output of the product we can achieve this task by altering the structure and construction of 3-D printed robotic hand it will definitely improve the griping functionality but on the other hand it will need extra time and cost.

One possible solution to this issue can be acquired by removing the rigidness of the robotic hand which offer resistance to the proper griping and this can be done by adding non-slippery material to the palm and fingers like some silicone rubber etc. as shown in figure below

Figure 6.1: Robotic Hand with improved grip

This approach will restrict items from slipping out of the hand, because of the improved friction and better surface contact area. Material like silicone rubber will also give support to the robotic hand while holding items of rigid surfaces, it was not possible in the earlier version of robotic hand. One possible solution to resolve this issue to make robotic hand as accurate as possible and that also looks like and work like human hand. To obtain this objective we will make a silicone material model almost same as rubber that will looks like human hand. Especially we will apply this silicon material to fingers and palm by doing this slippery surface will be removed result in maximizing the friction which will also increase and improve the griping capability of the existing robotic hand so this solution will be the best possible as for as performance is concerned. One other benefit of the solution will be it is also enhance overall looks of the robotic hand. We can also change color of PLA material and silicone which we will use on it.so that it looks more professional and good looking.

Other improvements which can enhance the appearance and functionality of this project are given as under:
Flex sensors based glove can have wireless connection [17] to connect with the rest of the project (3-D printed hand and servos) wirelessly it will increase portability and ease of use. It can be done by attaching a wireless module for example nRF24L01 which is wireless transceiver module.

Figure 6.2: nRF24L01- wireless transceiver module

The robotic hand has both imitation ability and griping ability by using flex sensor based glove, furthermore it can grip objects with weight roughly almost up to 160 grams.
However the robotic hand’s performance towards both features is quite satisfactory but definitely it has opened the doors for improvement in both research areas.

References:

[1] N. Mohanta, R. Mishra, A. K. Sharma, and M. Raj, "Design and Control Dynamics of Multi-Fingered Prosthetic Hand," Nov. 2019, pp. 405–409, doi: 10.1109/ISCON47742.2019.9036265.

[2] P. Sihombing, R. B. Muhammad, H. Herriyance, and E. Elviwani, "Robotic Arm Controlling Based on Fingers and Hand Gesture," Jun. 2020, pp. 40–45, doi: 10.1109/MECnIT48290.2020.9166592.

[3] "Phalanges: Definition, Location, Anatomy, Functions, Diagram," *TheSkeletalSystem.net*. https://www.theskeletalsystem.net/phalanges (accessed Apr. 18, 2021).

[4] "Why Does My Hand Hurt?," *WebMD*. https://www.webmd.com/pain-management/carpal-tunnel/ss/slideshow-hand-pain-reasons (accessed Apr. 18, 2021).

[5] B. F. MD, "Soft Tissues of the Wrist," *Sports-health*. https://www.sports-health.com/sports-injuries/hand-and-wrist-injuries/soft-tissues-wrist (accessed Apr. 18, 2021).

[6] "73-4443.pdf." Accessed: Apr. 18, 2021. [Online]. Available: https://static.rapidonline.com/pdf/73-4443.pdf.

[7] C. Sollerman and A. Ejeskär, "Sollerman hand function test. A standardised method and its use in tetraplegic patients," *Scand J Plast Reconstr Surg Hand Surg*, vol. 29, no. 2, pp. 167–176, Jun. 1995, doi: 10.3109/02844319509034334.

[8] "Arduino Uno Rev3 | Arduino Official Store." https://store.arduino.cc/usa/arduino-uno-rev3 (accessed Apr. 18, 2021).

[9] "Flex Sensor Construction Article Page 2." https://www.imagesco.com/articles/flex/sensor-pg2.html (accessed Apr. 18, 2021).

[10] "Flex Sensor & Arduino Interfacing - Measure Bend/Resistance," *How To Electronics*, Jun. 11, 2020. https://how2electronics.com/interfacing-flex-sensor-with-arduino/ (accessed Apr. 18, 2021).

[11] "In-Depth: Interfacing Flex Sensor with Arduino," *Last Minute Engineers*, Apr. 06, 2020. https://lastminuteengineers.com/flex-sensor-arduino-tutorial/ (accessed Apr. 18, 2021).

[12] "An Introduction to the Servo Motor: How Servos motors work.," *Circuit Crush*, May 10, 2019. https://www.circuitcrush.com/servo-motor-introduction/ (accessed Apr. 18, 2021).

[13] "Servo Motor Guide | What are Servo Motors?" https://www.anaheimautomation.com/manuals/forms/servo-motor-guide--old.php (accessed Apr. 18, 2021).

[14] E. A. Khalid, W. Abbood, and O. Abdullah, "Real-Time Control of Robotic Hand by Human Hand at Low Cost," *Journal of Mechanical Engineering Research and Developments*, vol. 43, pp. 455–467, Jun. 2020.

[15] "Servo Motors - Working Principle, Controlling and Applications," *ElProCus - Electronic Projects for Engineering Students*, Oct. 24, 2013. https://www.elprocus.com/servo-motor/ (accessed Apr. 18, 2021).

[16] "InMoov – open-source 3D printed life-size robot." http://inmoov.fr/ (accessed Apr. 27, 2021).

[17] F. Salman, Y. Cui, Z. Imran, F. Liu, L. Wang, and W. Wu, "A Wireless-controlled 3D printed Robotic Hand Motion System with Flex Force Sensors," *Sensors and Actuators A: Physical*, vol. 309, p. 112004, Jul. 2020, doi: 10.1016/j.sna.2020.112004.

[18] "A Bluetooth & ZigBee Comparison For IoT Applications." https://www.link-labs.com/blog/bluetooth-zigbee-comparison (accessed Apr. 29, 2021).

[19] "nRF24L01 Pinout, Features, Circuit & Datasheet," *Components101*. https://components101.com/wireless/nrf24l01-pinout-features-datasheet (accessed Apr. 29, 2021).

Appendix-A

Source Code

```
#include<Servo.h>

Servo servo_1;
Servo servo_2;
Servo servo_3;
Servo servo_4;
Servo servo_5;

int F_S1 = A0;
int F_S2 = A1;
int F_S3 = A2;
int F_S4 = A3;
int F_S5  = A4;

int f1, f2, f3, f4, f5;

void        setup(){
Serial.begin(9600);

servo_1.attach(2);
servo_2.attach(3);
servo_3.attach(4);
servo_4.attach(5);
servo_5.attach(6);
```

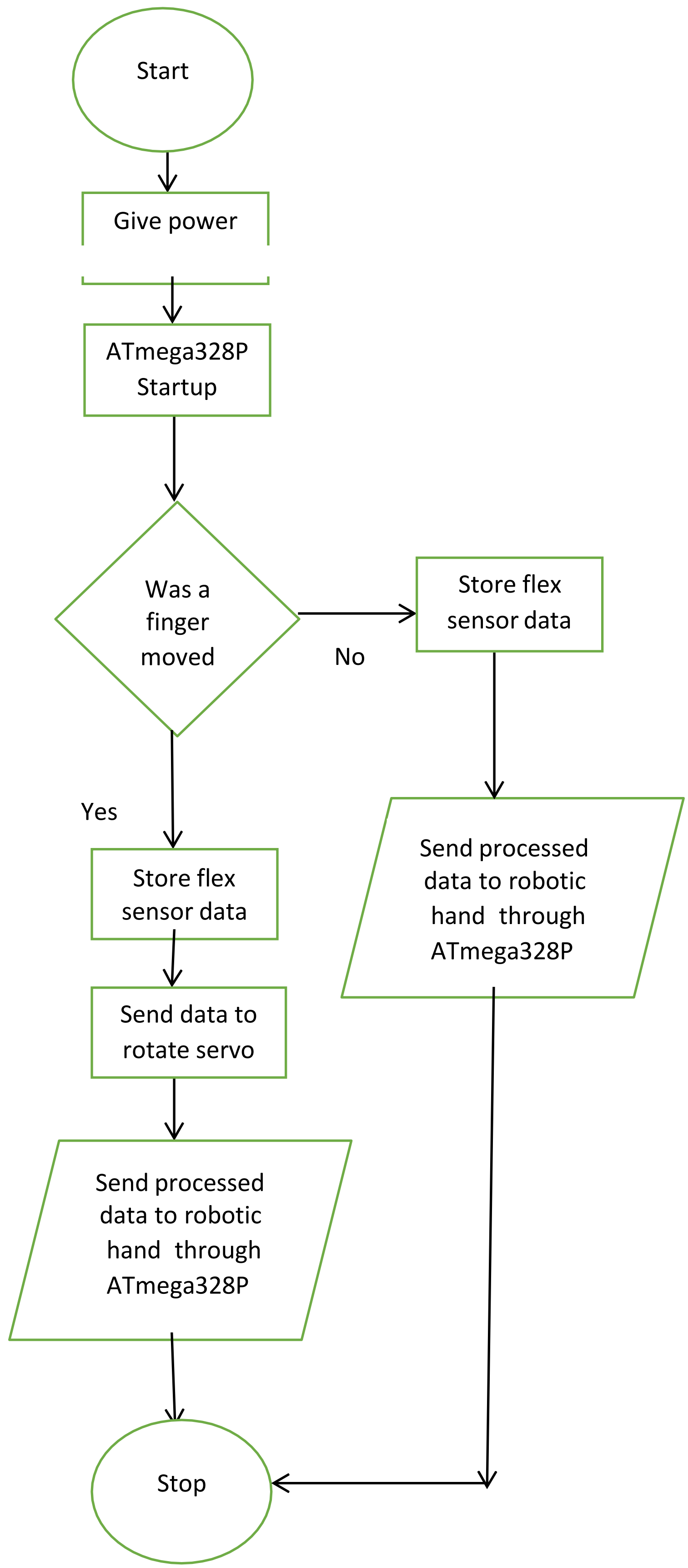
```
pinMode(F_S1, INPUT);
pinMode(F_S2, INPUT);
pinMode(F_S3, INPUT);
pinMode(F_S4, INPUT);
pinMode(F_S5, INPUT);

delay(1000);
}
void loop(){
f1  =  analogRead(F_S1);
f2  =  analogRead(F_S2);
f3  =  analogRead(F_S3);
f4  =  analogRead(F_S4);
f5  = analogRead(F_S5);

Serial.print("F1=");
Serial.print(f1);
Serial.print(" F2=");
Serial.print(f2);
Serial.print(" F3=");
Serial.print(f3);
Serial.print(" F4=");
Serial.print(f4);
Serial.print(" F5=");
Serial.println(f5);

f1 = map(f1, 390, 350, 20, 120);
f2 = map(f2, 410, 250, 0, 100);
```

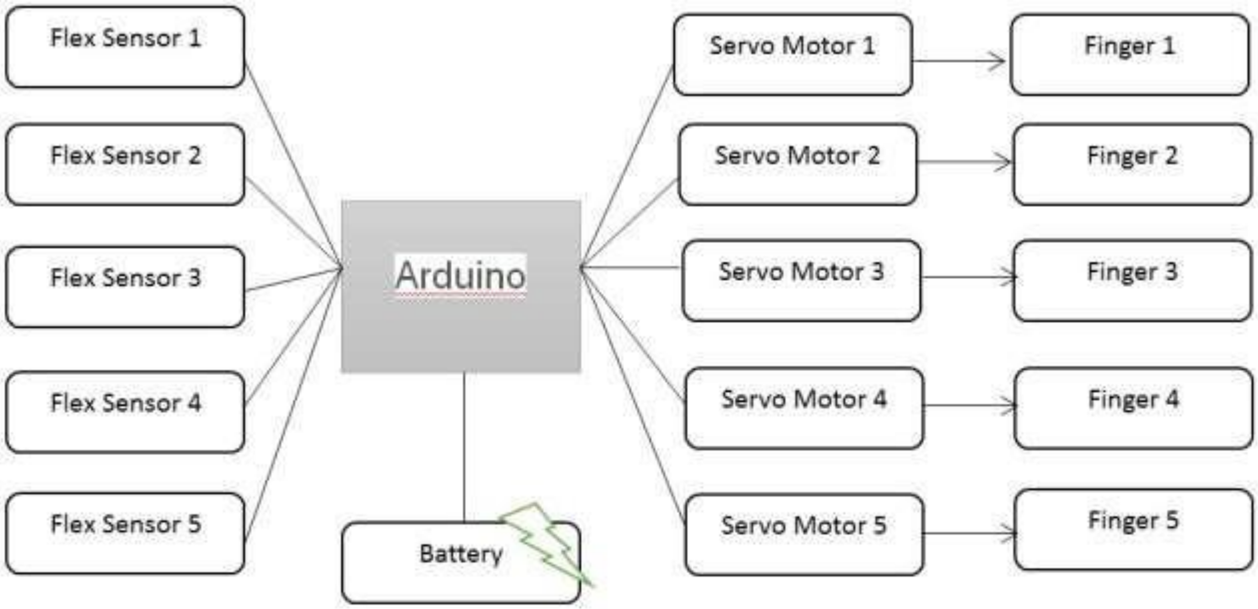
```
f3 = map(f3, 440, 270, 60, 150);
f4 = map(f4, 390, 230, 150, 30);
f5 = map(f5, 390, 250, 30, 180);

servo_1.write(f1);
servo_2.write(f2);
servo_3.write(f3);
servo_4.write(f4);
servo_5.write(f5);

delay(200);
}
```

Appendix-B

PROJECT DIAGRAMS

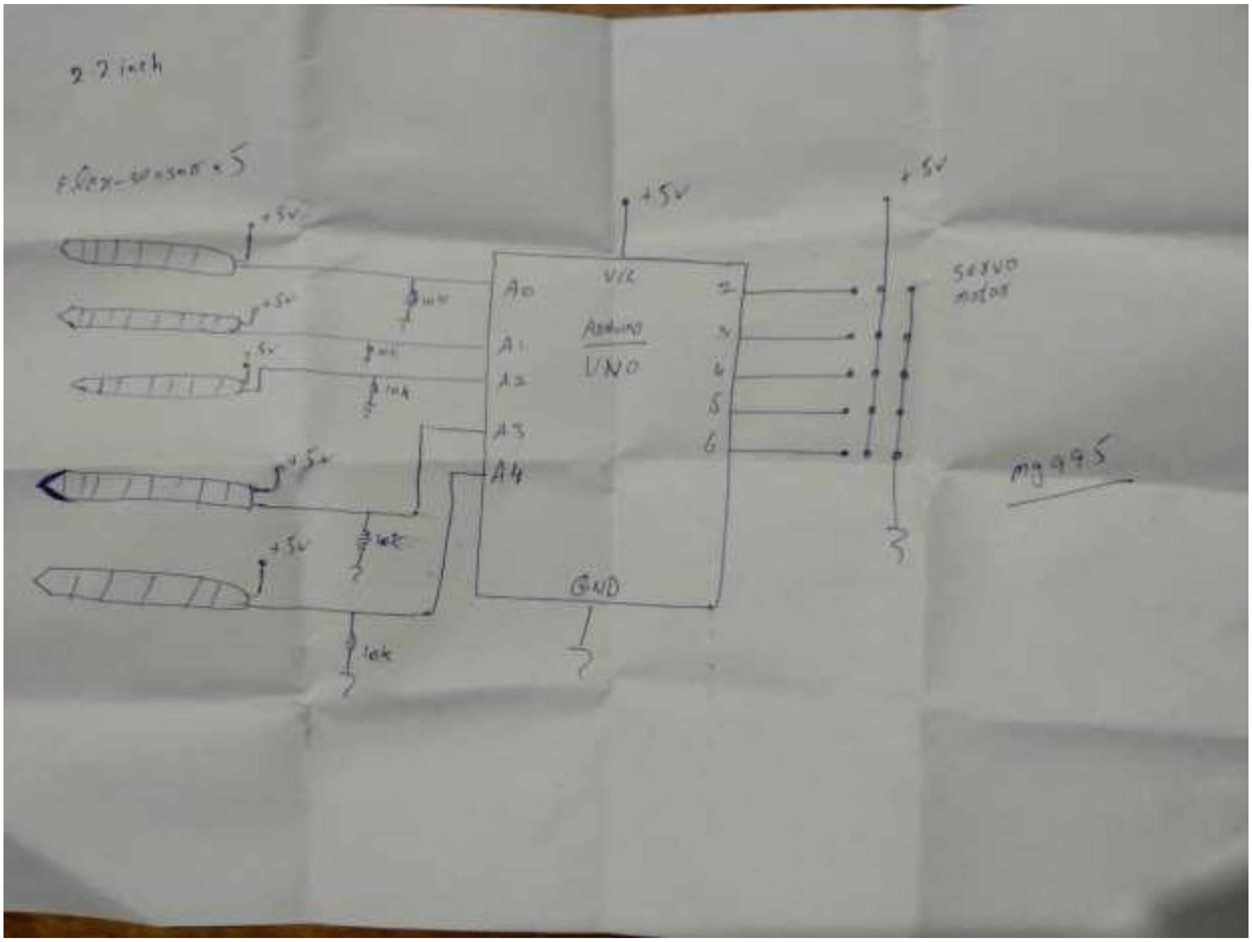
Flow Chart Diagram



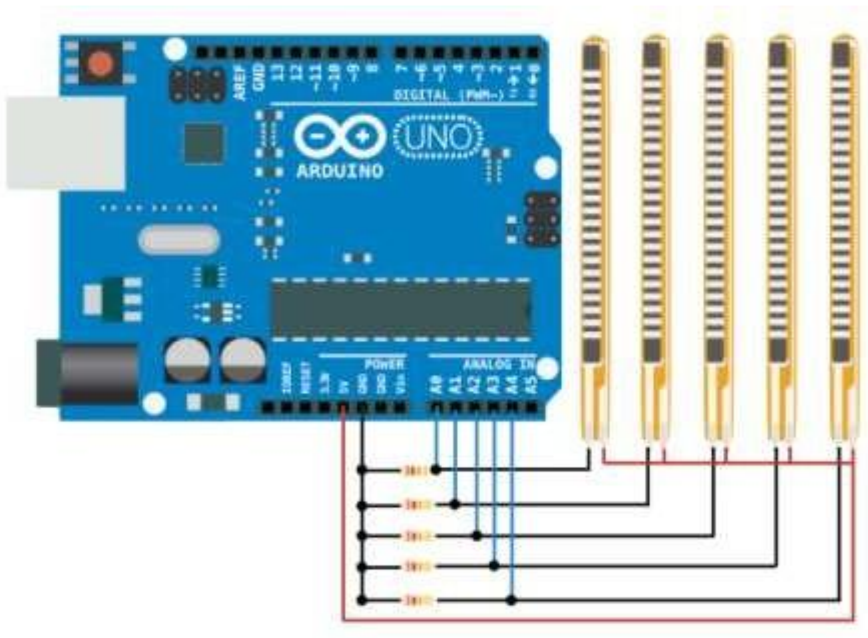


Block Diagram

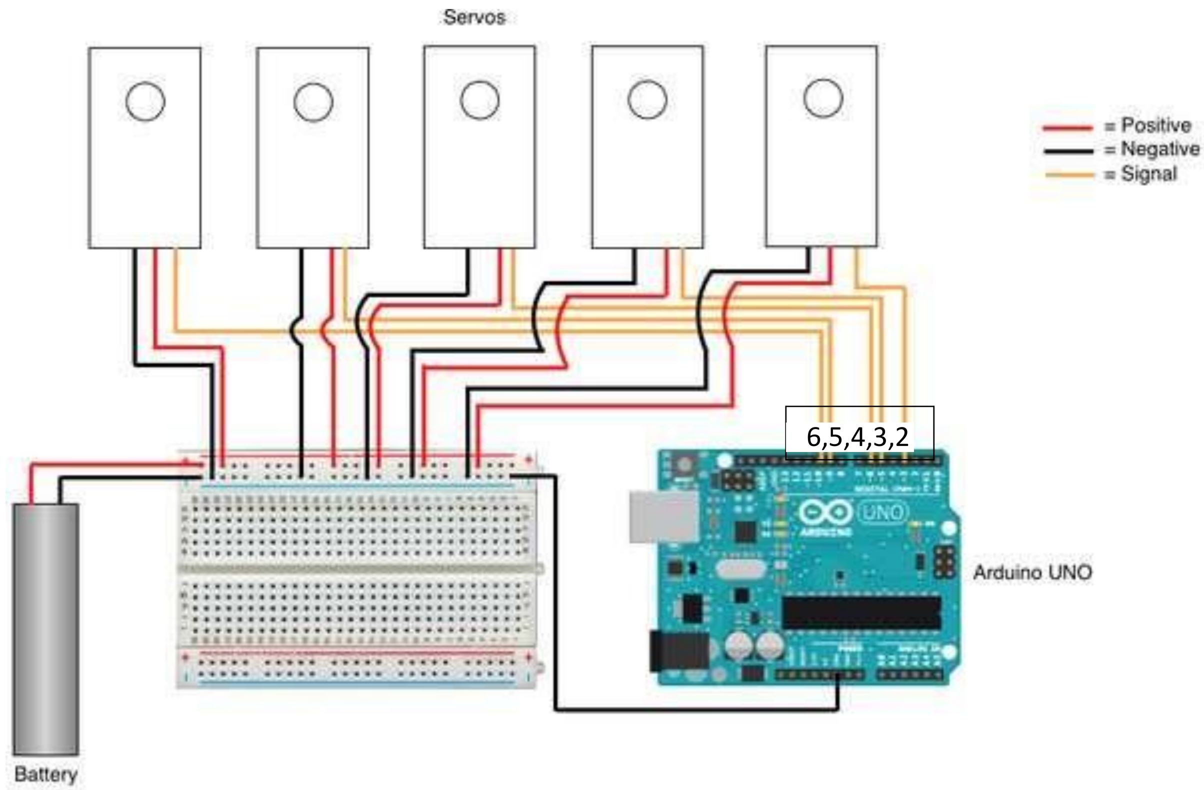
Circuit Diagram



Hand drawn circuit diagram of the project



Computerized circuit diagram (part-i)-Interfacing flex sensors with Ardiuno



Computerized circuit diagram (part-ii)-Interfacing servos with Ardiuno

Appendix-C
DATA SHEETS

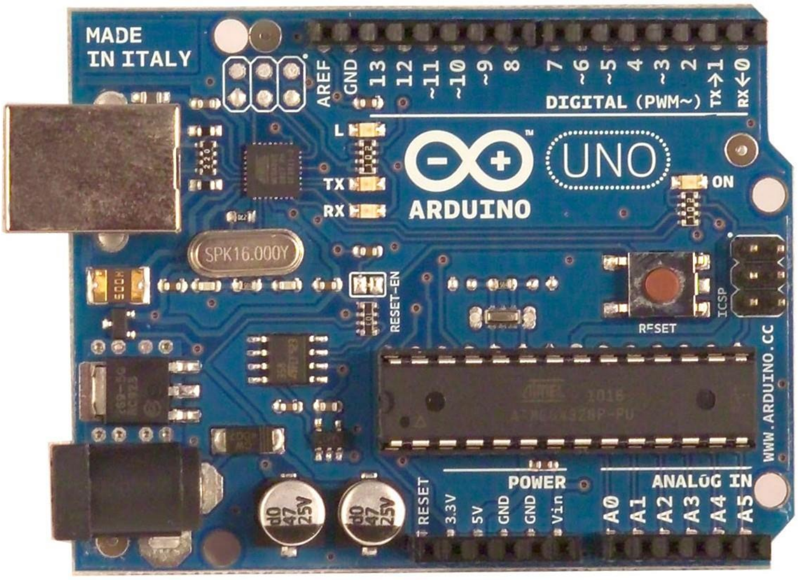
1. **Arduino Datasheet**

2. **Flex Sensor Datasheet**

3. **Servo Motor Datasheet**

4. **PLA(3-D Printed Material) Datasheet**

Arduino UNO



Product Overview

The Arduino Uno is a microcontroller board based on the ATmega328 (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analog inputs, a 16 MHz crystal oscillator, a USB connection, a power jack, an ICSP header, and a reset button. It contains everything needed to support the microcontroller; simply connect it to a computer with a USB cable or power it with a AC-to-DC adapter or battery to get started. The Uno differs from all preceding boards in that it does not use the FTDI USB-to-serial driver chip. Instead, it features the Atmega8U2 programmed as a USB-to-serial converter.

"Uno" means one in Italian and is named to mark the upcoming release of Arduino 1.0. The Uno and version 1.0 will be the reference versions of Arduno, moving forward. The Uno is the latest in a series of USB Arduino boards, and the reference model for the Arduino platform; for a comparison with previous versions, see the index of Arduino boards.

Index

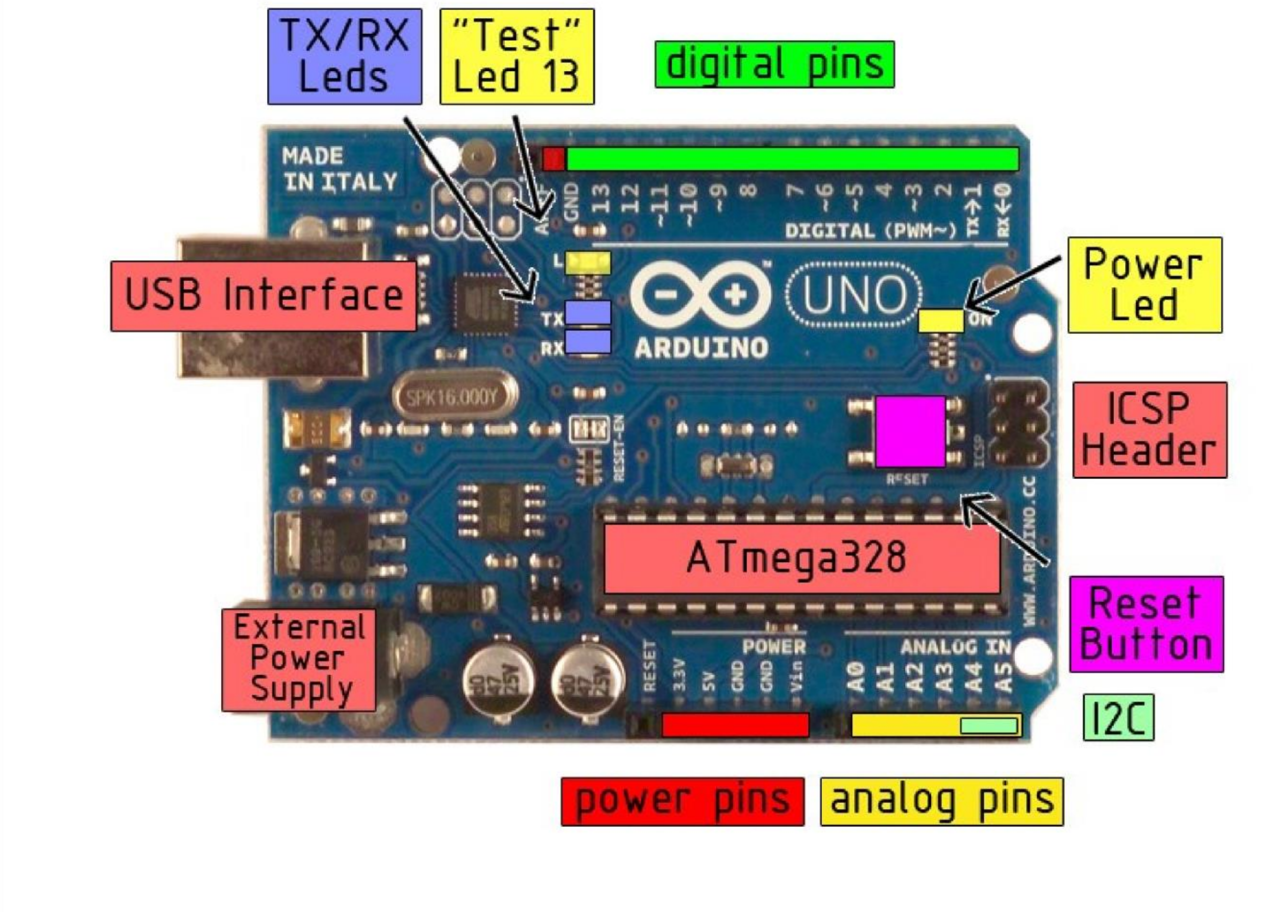
Technical Specification

EAGLE files: arduino-duemilanove-uno-design.zip Schematic: arduino-uno-schematic.pdf

Summary

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage (recommended)	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by bootloader
SRAM	2 KB
EEPROM	1 KB
Clock Speed	16 MHz

the board



Power

The Arduino Uno can be powered via the USB connection or with an external power supply. The power source is selected automatically.

External (non-USB) power can come either from an AC-to-DC adapter (wall-wart) or battery. The adapter can be connected by plugging a 2.1mm center-positive plug into the board's power jack. Leads from a battery can be inserted in the Gnd and Vin pin headers of the POWER connector.

The board can operate on an external supply of 6 to 20 volts. If supplied with less than 7V, however, the 5V pin may supply less than five volts and the board may be unstable. If using more than 12V, the voltage regulator may overheat and damage the board. The recommended range is 7 to 12 volts.

The power pins are as follows:

- **VIN.** The input voltage to the Arduino board when it's using an external power source (as opposed to 5 volts from the USB connection or other regulated power source). You can supply voltage through this pin, or, if supplying voltage via the power jack, access it through this pin.
- **5V.** The regulated power supply used to power the microcontroller and other components on the board. This can come either from VIN via an on-board regulator, or be supplied by USB or another regulated 5V supply.
- **3V3.** A 3.3 volt supply generated by the on-board regulator. Maximum current draw is 50 mA.
- **GND.** Ground pins.

Memory

The Atmega328 has 32 KB of flash memory for storing code (of which 0,5 KB is used for the bootloader); It has also 2 KB of SRAM and 1 KB of EEPROM (which can be read and written with the EEPROM library).

Input and Output

Each of the 14 digital pins on the Uno can be used as an input or output, using pinMode(), digitalWrite(), and digitalRead() functions. They operate at 5 volts. Each pin can provide or receive a maximum of 40 mA and has an internal pull-up resistor (disconnected by default) of 20-50 kOhms. In addition, some pins have specialized functions:

- **Serial: 0 (RX) and 1 (TX).** Used to receive (RX) and transmit (TX) TTL serial data. TThese pins are connected to the corresponding pins of the ATmega8U2 USB-to-TTL Serial chip .
- **External Interrupts: 2 and 3.** These pins can be configured to trigger an interrupt on a low value, a rising or falling edge, or a change in value. See the attachInterrupt() function for details.
- **PWM: 3, 5, 6, 9, 10, and 11.** Provide 8-bit PWM output with the analogWrite() function.
- **SPI: 10 (SS), 11 (MOSI), 12 (MISO), 13 (SCK).** These pins support SPI communication, which, although provided by the underlying hardware, is not currently included in the Arduino language.

- **LED: 13.** There is a built-in LED connected to digital pin 13. When the pin is HIGH value, the LED is on, when the pin is LOW, it's off.

The Uno has 6 analog inputs, each of which provide 10 bits of resolution (i.e. 1024 different values). By default they measure from ground to 5 volts, though is it possible to change the upper end of their range using the AREF pin and the analogReference() function. Additionally, some pins have specialized functionality:

- **I²C: 4 (SDA) and 5 (SCL).** Support I²C (TWI) communication using the Wire library.

There are a couple of other pins on the board:

- **AREF.** Reference voltage for the analog inputs. Used with analogReference().
- **Reset.** Bring this line LOW to reset the microcontroller. Typically used to add a reset button to shields which block the one on the board.

See also the mapping between Arduino pins and Atmega328 ports.

Communication

The Arduino Uno has a number of facilities for communicating with a computer, another Arduino, or other microcontrollers. The ATmega328 provides UART TTL (5V) serial communication, which is available on digital pins 0 (RX) and 1 (TX). An ATmega8U2 on the board channels this serial communication over USB and appears as a virtual com port to software on the computer. The '8U2 firmware uses the standard USB COM drivers, and no external driver is needed. However, on Windows, an *.inf file is required..

The Arduino software includes a serial monitor which allows simple textual data to be sent to and from the Arduino board. The RX and TX LEDs on the board will flash when data is being transmitted via the USB-to-serial chip and USB connection to the computer (but not for serial communication on pins 0 and 1).

A SoftwareSerial library allows for serial communication on any of the Uno's digital pins.

The ATmega328 also support I2C (TWI) and SPI communication. The Arduino software includes a Wire library to simplify use of the I2C bus; see the documentation for details. To use the SPI communication, please see the ATmega328 datasheet.

Programming

The Arduino Uno can be programmed with the Arduino software (download). Select "Arduino Uno w/ ATmega328" from the **Tools > Board** menu (according to the microcontroller on your board). For details, see the reference and tutorials.

The ATmega328 on the Arduino Uno comes preburned with a bootloader that allows you to upload new code to it without the use of an external hardware programmer. It communicates using the original STK500 protocol (reference, C header files).

You can also bypass the bootloader and program the microcontroller through the ICSP (In-Circuit Serial Programming) header; see these instructions for details.

The ATmega8U2 firmware source code is available . The ATmega8U2 is loaded with a DFU bootloader, which can be activated by connecting the solder jumper on the back of the board (near the map of Italy) and then resetting the 8U2. You can then use Atmel's FLIP software (Windows) or the DFU programmer (Mac OS X and Linux) to load a new firmware. Or you can use the ISP header with an external programmer (overwriting the DFU bootloader).

Automatic (Software) Reset

Rather than requiring a physical press of the reset button before an upload, the Arduino Uno is designed in a way that allows it to be reset by software running on a connected computer. One of the hardware flow control lines (DTR) of the ATmega8U2 is connected to the reset line of the ATmega328 via a 100 nanofarad capacitor. When this line is asserted (taken low), the reset line drops long enough to reset the chip. The Arduino software uses this capability to allow you to upload code by simply pressing the upload button in the Arduino environment. This means that the bootloader can have a shorter timeout, as the lowering of DTR can be well-coordinated with the start of the upload.

This setup has other implications. When the Uno is connected to either a computer running Mac OS X or Linux, it resets each time a connection is made to it from software (via USB). For the following half-second or so, the bootloader is running on the Uno. While it is programmed to ignore malformed data (i.e. anything besides an upload of new code), it will intercept the first few bytes of data sent to the board after a connection is opened. If a sketch running on the board receives one-time configuration or other data when it first starts, make sure that the software with which it communicates waits a second after opening the connection and before sending this data.

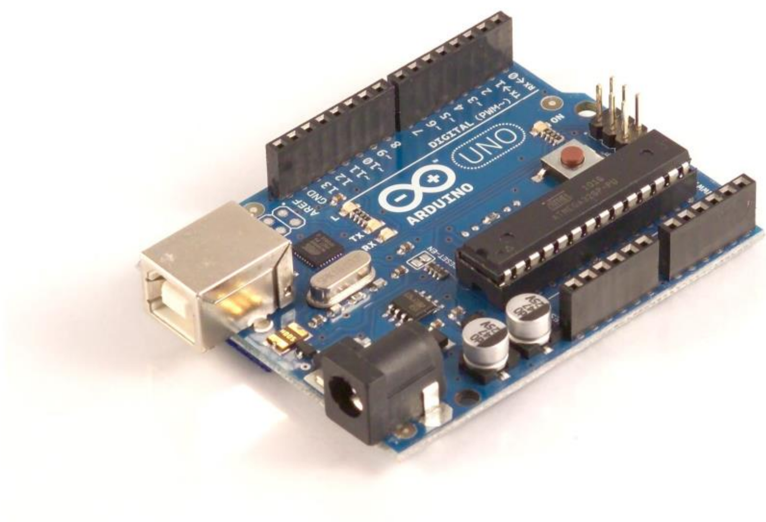
The Uno contains a trace that can be cut to disable the auto-reset. The pads on either side of the trace can be soldered together to re-enable it. It's labeled "RESET-EN". You may also be able to disable the auto-reset by connecting a 110 ohm resistor from 5V to the reset line; see this forum thread for details.

USB Overcurrent Protection

The Arduino Uno has a resettable polyfuse that protects your computer's USB ports from shorts and overcurrent. Although most computers provide their own internal protection, the fuse provides an extra layer of protection. If more than 500 mA is applied to the USB port, the fuse will automatically break the connection until the short or overload is removed.

Physical Characteristics

The maximum length and width of the Uno PCB are 2.7 and 2.1 inches respectively, with the USB connector and power jack extending beyond the former dimension. Three screw holes allow the board to be attached to a surface or case. Note that the distance between digital pins 7 and 8 is 160 mil (0.16"), not an even multiple of the 100 mil spacing of the other pins.



How to use Arduino

Arduino can sense the environment by receiving input from a variety of sensors and can affect its surroundings by controlling lights, motors, and other actuators. The microcontroller on the board is programmed using the Arduino programming language (based on Wiring) and the Arduino development environment (based on Processing). Arduino projects can be stand-alone or they can communicate with software on running on a computer (e.g. Flash, Processing, MaxMSP).

Arduino is a cross-platoform program. You'll have to follow different instructions for your personal OS. Check on the Arduino site for the latest instructions. *http://arduino.cc/en/Guide/HomePage*

Linux Install **Windows Install** **Mac Install**

Once you have downloaded/unzipped the arduino IDE, you can Plug the Arduino to your PC via USB cable.

Blink led

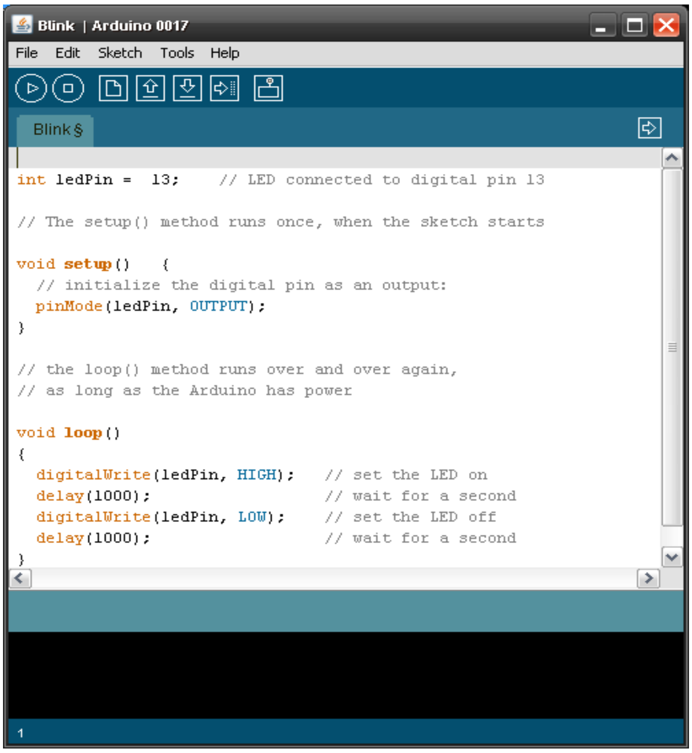
Now you're actually ready to "burn" your first program on the arduino board. To select "blink led", the physical translation of the well known programming "hello world", select

**File>Sketchbook>
Arduino-0017>Examples>
Digital>Blink**

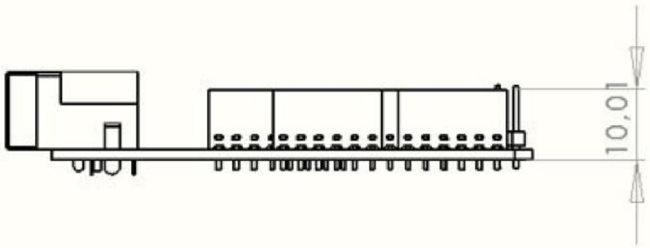
Once you have your skecth you'll see something very close to the screenshot on the right.

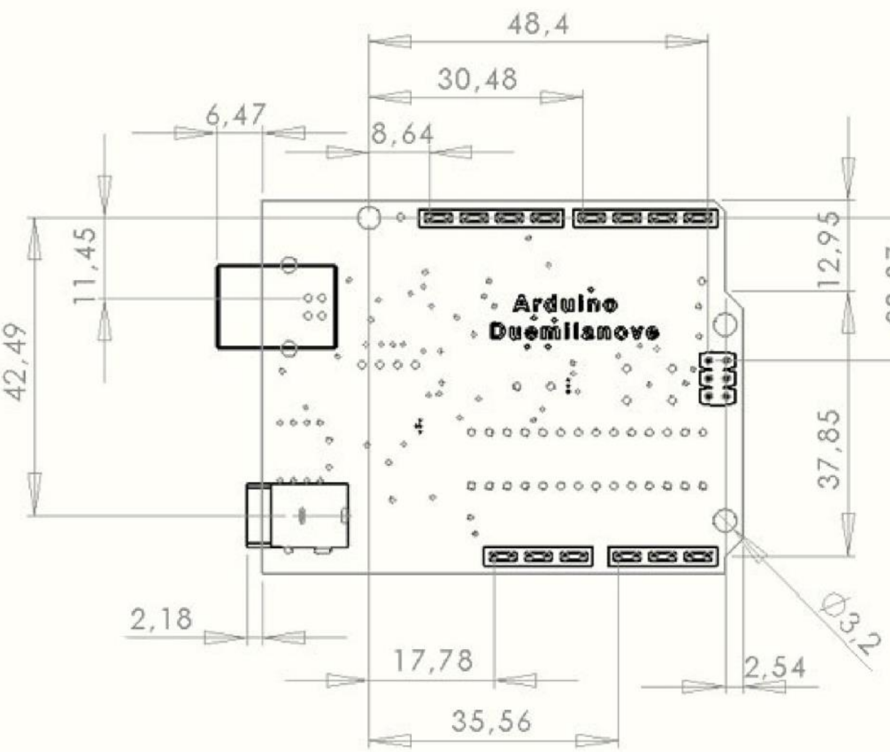
In **Tools>Board** select

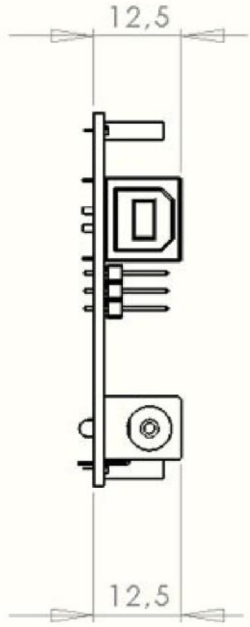
Now you have to go to
Tools>SerialPort
and select the right serial port, the one arduino is attached to.

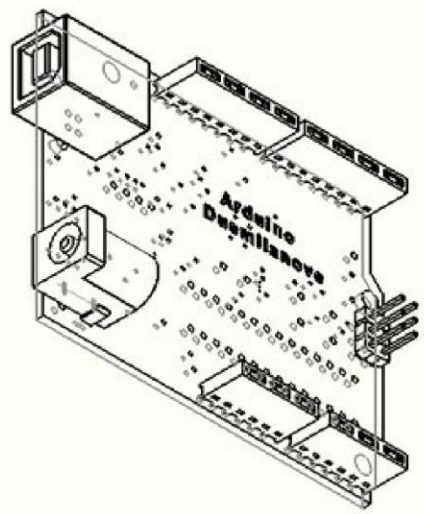


Dimensioned Drawing









Terms & Conditions

1. Warranties

1.1 The producer warrants that its products will conform to the Specifications. This warranty lasts for one (1) years from the date of the sale. The producer shall not be liable for any defects that are caused by neglect, misuse or mistreatment by the Customer, including improper installation or testing, or for any products that have been altered or modified in any way by a Customer. Moreover, The producer shall not be liable for any defects that result from Customer's design, specifications or instructions for such products. Testing and other quality control techniques are used to the extent the producer deems necessary.

1.2 If any products fail to conform to the warranty set forth above, the producer's sole liability shall be to replace such products. The producer's liability shall be limited to products that are determined by the producer not to conform to such warranty. If the producer elects to replace such products, the producer shall have a reasonable time to replacements. Replaced products shall be warranted for a new full warranty period.

1.3 EXCEPT AS SET FORTH ABOVE, PRODUCTS ARE PROVIDED "AS IS" AND "WITH ALL FAULTS." THE PRODUCER DISCLAIMS ALL OTHER WARRANTIES, EXPRESS OR IMPLIED, REGARDING PRODUCTS, INCLUDING BUT NOT LIMITED TO, ANY IMPLIED WARRANTIES OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE

1.4 Customer agrees that prior to using any systems that include the producer products, Customer will test such systems and the functionality of the products as used in such systems. The producer may provide technical, applications or design advice, quality characterization, reliability data or other services. Customer acknowledges and agrees that providing these services shall not expand or otherwise alter the producer's warranties, as set forth above, and no additional obligations or liabilities shall arise from the producer providing such services.

1.5 The Arduino™ products are not authorized for use in safety-critical applications where a failure of the product would reasonably be expected to cause severe personal injury or death. Safety-Critical Applications include, without limitation, life support devices and systems, equipment or systems for the operation of nuclear facilities and weapons systems. Arduino™ products are neither designed nor intended for use in military or aerospace applications or environments and for automotive applications or environment. Customer acknowledges and agrees that any such use of Arduino ™ products which is solely at the Customer's risk, and that Customer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

1.6 Customer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products and any use of Arduino™ products in Customer's applications, notwithstanding any applications-related information or support that may be provided by the producer.

2. Indemnification

The Customer acknowledges and agrees to defend, indemnify and hold harmless the producer from and against any and all third-party losses, damages, liabilities and expenses it incurs to the extent directly caused by: (i) an actual breach by a Customer of the representation and warranties made under this terms and conditions or (ii) the gross negligence or willful misconduct by the Customer.

3. Consequential Damages Waiver

In no event the producer shall be liable to the Customer or any third parties for any special, collateral, indirect, punitive, incidental, consequential or exemplary damages in connection with or arising out of the products provided hereunder, regardless of whether the producer has been advised of the possibility of such damages. This section will survive the termination of the warranty period.

4. Changes to specifications

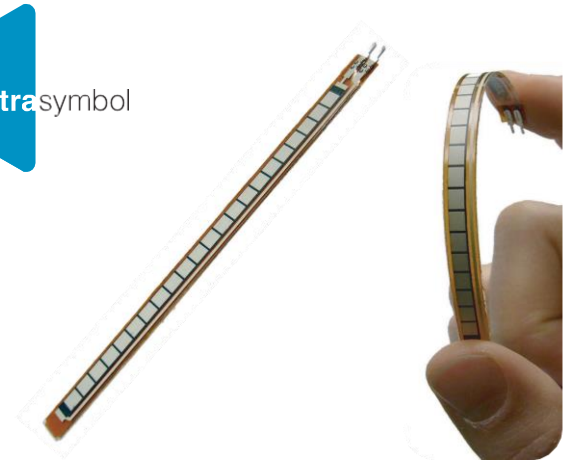
The producer may make changes to specifications and product descriptions at any time, without notice. The Customer must not rely on the absence or characteristics of any features or instructions marked "reserved" or "undefined." The producer reserves these for future definition and shall have no responsibility whatsoever for conflicts or incompatibilities arising from future changes to them. The product information on the Web Site or Materials is subject to change without notice. Do not finalize a design with this information.

Enviromental Policies

The producer of Arduino™ has joined the Impatto Zero® policy of LifeGate.it. For each Arduino board produced is created / looked after half squared Km of Costa Rica's forest's.

FLEX SENSOR FS

Special Edition Length



Features

- Angle Displacement Measurement
- Bends and Flexes physically with motion device
- Possible Uses
  - Robotics
  - Gaming (Virtual Motion)
  - Medical Devices
  - Computer Peripherals
  - Musical Instruments
  - Physical Therapy
- Simple Construction
- Low Profile

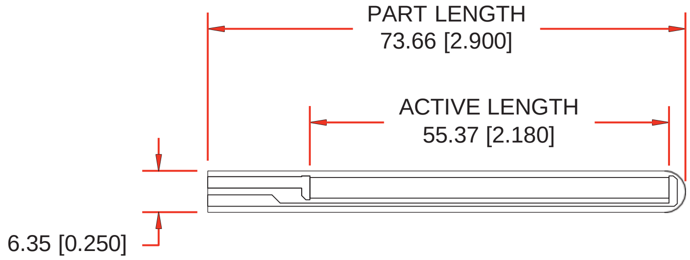
Mechanical Specifications

-Life Cycle: >1 million
-Height: ≤0.43mm (0.017")
-Temperature Range: -35°C to +80°C

Electrical Specifications

-Flat Resistance: 25K Ohms
-Resistance Tolerance: ±30%
-Bend Resistance Range: 45K to 125K Ohms (depending on bend radius)
-Power Rating : 0.50 Watts continuous. 1 Watt Peak

Dimensional Diagram - Stock Flex Sensor

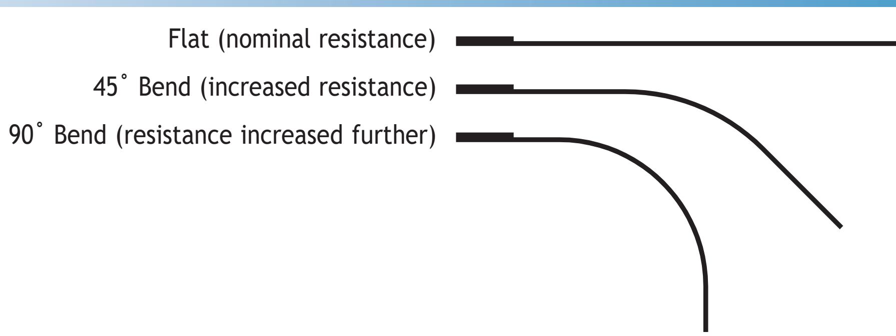


How to Order - Stock Flex Sensor

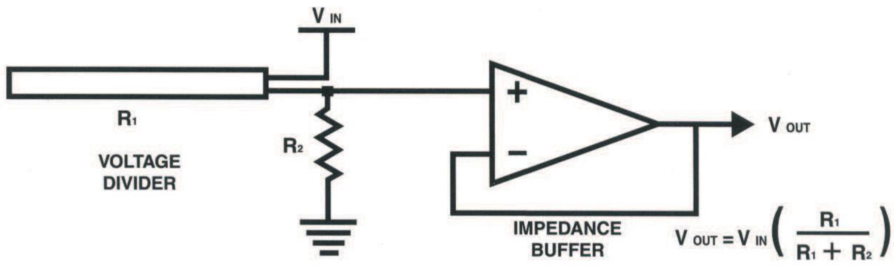
FS — L — 0055 — 253 — ST

Series	Model	Active Length	Resistance	Connectors
FS = Flex Sensor	L = Linear	0055 = 55.37mm	253 = 25K Ohms	ST = Solder Tab

How It Works



BASIC FLEX SENSOR CIRCUIT:

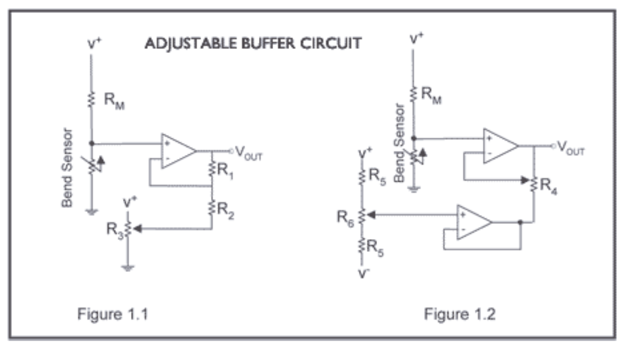


Following are notes from the ITP Flex Sensor Workshop

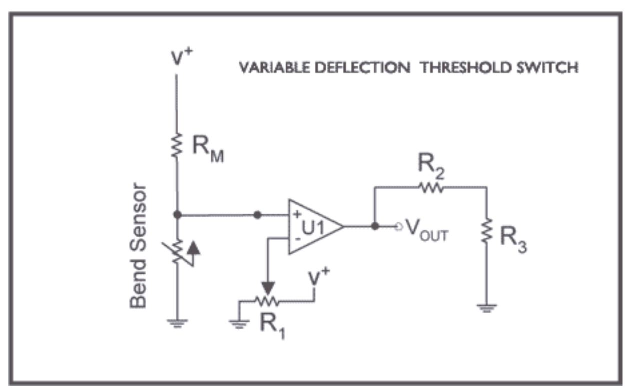
"The impedance buffer in the [Basic Flex Sensor Circuit] (above) is a single sided operational amplifier, used with these sensors because the low bias current of the op amp reduces errer due to source impedance of the flex sensor as voltage divider. Suggested op amps are the LM358 or LM324."

"You can also test your flex sensor using the simplest circut, and skip the op amp."

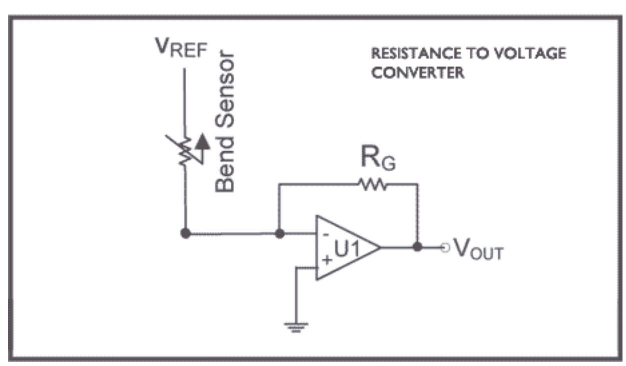
"Adjustable Buffer - a potentiometer can be added to the circuit to adjust the sensitivity range."



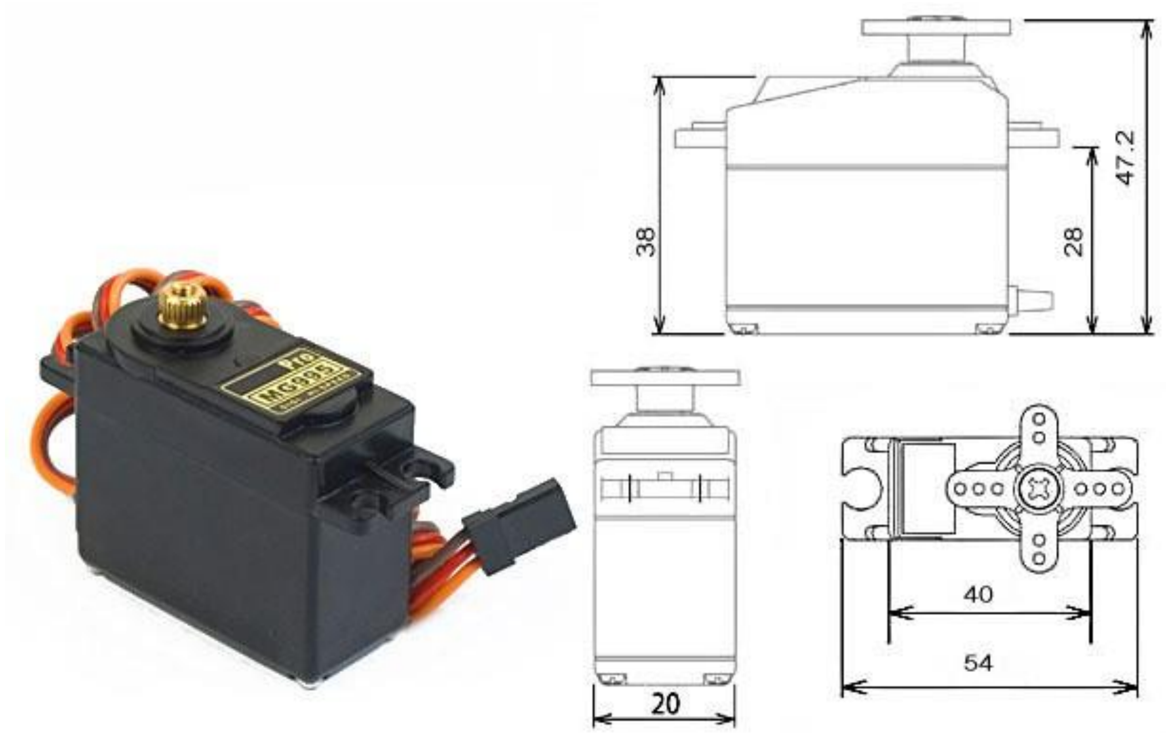
"Variable Deflection Threshold Switch - an op amp is used and outputs either high or low depending on the voltage of the inverting input. In this way you can use the flex sensor as a switch without going through a microcontroller."



"Resistance to Voltage Converter - use the sensor as the input of a resistance to voltage converter using a dual sided supply op-amp. A negative reference voltage will give a positive output. Should be used in situations when you want output at a low degree of bending."



MG995 High Speed Metal Gear Dual Ball Bearing Servo

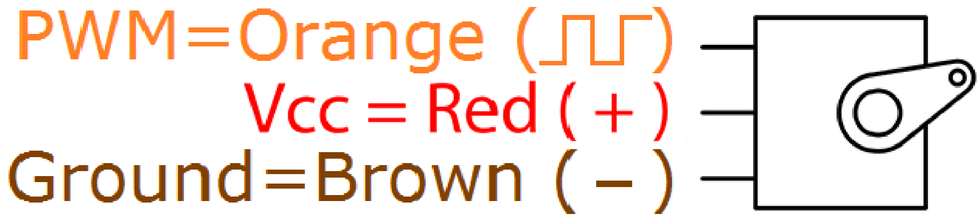


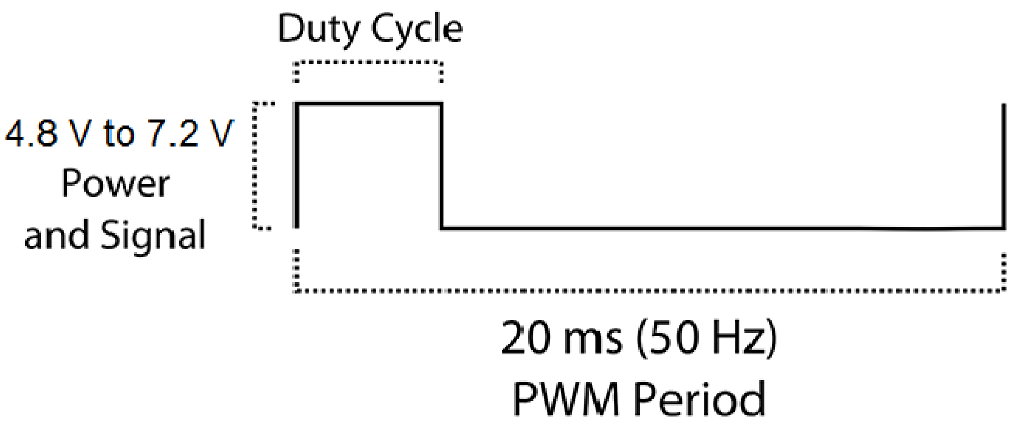
The unit comes complete with 30cm wire and 3 pin 'S' type female header connector that fits most receivers, including Futaba, JR, GWS, Cirrus, Blue Bird, Blue Arrow, Corona, Berg, Spektrum and Hitec.

This high-speed standard servo can rotate approximately 120 degrees (60 in each direction). You can use any servo code, hardware or library to control these servos, so it's great for beginners who want to make stuff move without building a motor controller with feedback & gear box, especially since it will fit in small places. The MG995 Metal Gear Servo also comes with a selection of arms and hardware to get you set up nice and fast!

Specifications

- Weight: 55 g
- Dimension: 40.7 x 19.7 x 42.9 mm approx.
- Stall torque: 8.5 kgf·cm (4.8 V), 10 kgf·cm (6 V)
- Operating speed: 0.2 s/60º (4.8 V), 0.16 s/60º (6 V)
- Operating voltage: 4.8 V a 7.2 V
- Dead band width: 5 µs
- Stable and shock proof double ball bearing design
- Temperature range: 0 ºC – 55 ºC


PWM=Orange
Vcc = Red (+)
Ground=Brown (–)


Duty Cycle
4.8 V to 7.2 V
Power
and Signal
20 ms (50 Hz)
PWM Period

Technical data sheet PLA

BCN3D

Description

PLA (Polylactic Acid) is a biodegradable, sustainable and food safe polymer made from organic sources.

It is the most common used filament in FFF 3D printers for its ease of use and awide range of applications, especially those not mechanically or thermally demanding. Definitely a good starting point to learn about the 3D Printing manufacturing process.

Properties

- Detailed and glossy surface quality
- Good tensile strength
- Rigid, fragile behaviour
- Good UV resistance
- Withstand operating temperatures up to 50 °C.
- Odor-free, ideal for educational and office environments
- Compatible with PVA supports
- Low humidity resistance

Recomendations

Plastics absorb moisture from the air. For long periods of time without printing, it is recommended to keep the PLA spools in a box or airtight container with desiccant to keep them dry.

PLA emits low levels of gasses and particles when printed. We recommend printing it in a well-ventilated area to ensure a healthy environment.

Filament specifications

Diameter	Ø 2.85 mm
Max roundness deviation	≥ 95%
Net filament weight	750 g
Specific gravity (ISO 1183)	1,24 g/cm3

Mechanical properties

	Typical value	Test method
MFR 210°C/2,16 kg	9,56 gr/10 min	ISO 1133
Tensile strength at yield	70 Mpa	ISO 527
Strain at yield	5 %	ISO 527
Strain at break	20 %	ISO 527
Tensile Modulus	3120 MPa	ISO 527
Impact strength-Charpy method 23°C	3.4 kJ/m2	ISO 179
Moisture absorption	1968 ppm	ISO 62

Thermal properties

	Typical value	Test method
Melting temp.	115±35°C	ISO 11357
Vicat softening temp.	60 °C	ISO 306
Glass transition temp.	57 °C	ISO 11357

Printing settings

Extruder temperature	190 °C - 220 °C
Bed temperature	65 °C
Speed	10-70 mm/s
Retraction speed	40 mm/s
Retraction distance	4 mm
Cooling fan	Yes
Minimum layer height	0.05 mm

More information about PLA: https://www.bcn3dtechnologies.com/en/3d-printer/filaments/#pla

Technical data sheet PLA

Ultimaker

Chemical name	Polylactic acid
Description	Ultimaker PLA filament provides a no-hassle 3D printing experience thanks to its reliability and good surface quality. Our PLA is made from organic and renewable sources. It's safe, easy to print with and it serves a wide range of applications for both novice and advanced users.
Key features	Good tensile strength and surface quality, easy to work with at high print speeds, user-friendly for both home and office environments, PLA allows the creation of high-resolution parts. There is a wide range of color options available.
Applications	Household tools, toys, educational projects, show objects, prototyping, architectural models, as well as lost casting methods to create metal parts.
Non-suitable for	Food contact and in-vivo applications. Long term outdoor usage or applications where the printed part is exposed to temperatures higher than 50 ˚C.

Filament specifications	Value	Method
Diameter	2.85±0.10 mm	-
Max roundness deviation	0.10 mm	-
Net filament weight	350 g / 750 g	-
Filament length	~44 m / ~95 m	-

Color information	Color	Color code
	PLA Green	RAL 6018
	PLA Black	RAL 9005
	PLA Silver Metallic	RAL 9006
	PLA White	RAL 9010
	PLATransparent	n/a
	PLA Orange	RAL 2008
	PLA Blue	RAL 5002
	PLA Magenta	RAL 4010
	PLA Red	RAL 3020
	PLAYellow	RAL 1003
	PLA Pearl White	RAL 1013

Mechanical properties (*)	Injection molding		3D printing	
	Typical value	**Test method**	**Typical value**	**Test method**
Tensile modulus	-	-	2346.5 MPa	ISO 527 (1 mm/min)
Tensile stress at yield	-	-	49.5 MPa	ISO 527 (50 mm/min)
Tensile stress at break	-	-	45.6 MPa	ISO 527 (50 mm/min)
Elongation at yield	-	-	3.3 %	ISO 527 (50 mm/min)
Elongation at break	-	-	5.2 %	ISO 527 (50 mm/min)
Flexural strength	-	-	103.0 MPa	ISO 178
Flexural modulus	-	-	3150.0 MPa	ISO 178
Izod impact strength, notched (at 23˚C)	-	-	5.1 kJ/m^2	ISO 180
Charpy impact strength (at 23˚C)	-	-	-	-
Hardness	-	-	83 (Shore D)	Durometer

Thermal properties	Typical value	Test method
Melt mass-flow rate (MFR)	6.09 g/10min	ISO 1133 (210 ˚C, 2.16 kg)
Heat deflection (HDT) at 0.455 MPa	-	-
Heat deflection (HDT) at 1.82 MPa	-	-
Glass transition	~60 ˚C	ISO 11357
Coefficient of thermal expansion	-	-
Melting temperature	145-160 ˚C	ISO 11357
Thermal shrinkage	-	-

Other properties	Typical value	Test method
Specific gravity	1.24	ASTM D1505
Flame classification	-	-

(*) See notes.

Notes

Properties reported here are average of a typical batch. The 3D printed test specimens were printed in the XY plane, using the normal quality profile in Cura 2.1, an Ultimaker 2+, a 0.4mm nozzle, 90% infill, 210 ˚C nozzle temperature and 60 ˚C build plate temperature. The values are the average of 5 white and 5 black specimens for the tensile, flexural, and impact tests. The Shore hardness D was measured in a 7-mm-thick square printed in the XY plane, using the normal quality profile in Cura 2.5, an Ultimaker 3, a 0.4 mm print core and 100% infill. Ultimaker is constantly working on extending the TDS data.

Disclaimer

Any technical information or assistance provided herein is given and accepted at your risk, and neither Ultimaker or its affiliates make any warranty relating to it or because of it. Neither Ultimaker nor its affiliates shall be responsible for the use of this information, or of any product, method or apparatus mentioned, and you must make your own determination of its suitability and completeness for your own use, for the protection of the environment, and for the health and safety of your employees and purchasers of your products. No warranty is made of the merchantability or fitness of any product; and nothing herein waives any of Ultimaker's conditions of sale. Specifications are subject to change without notice.

Version — Version 3.011
Date — 16/05/2017

Ultimaker