CHAPTER 1

INTRODUCTION TO TVC

1.1. OBJECTIVE

To design, fabrication and testing the performance of thrust vector control system (Gimbal mechanism). Thrust vector control technology is advancing rapidly and being updating day by day. There are some types of TVC that being used in the rockets for controlling

Thrust vectoring, also **thrust vector control** or **TVC**, is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor in order to control the attitude or angular velocity of the vehicle.

The method was originally envisaged to provide upward vertical thrust as a means to give aircraft vertical (VTOL) or short (STOL) take off and landing ability.

Thrust vectoring for many liquid rockets is achieved by gimbaling the whole engine. This involves moving the entire combustion chamber and outer engine bell as on the Titan II's twin first-stage motors, or even the entire engine assembly including the related fuel and oxidizer pumps. The Saturn V and the Space Shuttle used gimbaled engines.

Figure1.1. Thrust vectoring nozzle

1.2. HISTORICAL OVERVIEW

Most currently operational vectored thrust aircraft use turbofans with rotating nozzles or vanes to deflect the exhaust stream, relative to the aircraft center line. However, the engine must be sized for vertical lift, rather than normal flight, which results in a weight penalty. Afterburning (or Plenum Chamber Burning, PCB, in the bypass stream) is difficult to incorporate and is impractical for take-off and landing thrust vectoring, because the very hot exhaust can damage runway surfaces

Tiltrotor aircraft vector thrust via rotating turboprop engine nacelles. The mechanical complexities of this design are quite troublesome, including twisting flexible internal components and driveshaft power transfer between engines. Most current tiltrotor designs feature two rotors in a side-by-side configuration. If such a craft is flown in a way where it enters a vortex ring state, one of the rotors will always enter slightly before the other, causing the aircraft to perform a drastic and unplanned roll.

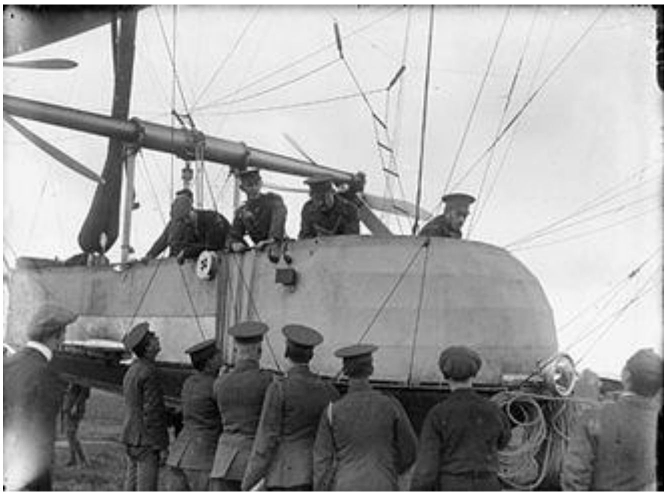


Figure.1.2. The pre-World War 1, British Army airship *Delta*, fitted with swivelling propellers

A design for a jet incorporating thrust vectoring was submitted in 1949 to the British Air Ministry by Percy Walwyn; Walwyn's drawings are preserved at the National Aerospace Library at Farnborough.

Some smaller sized atmospheric tactical missiles, such as the AIM-Sidewinder, eschew flight control surfaces and instead use mechanical vanes to deflect rocket motor exhaust to one side.

By using mechanical vanes to deflect the exhaust of the missile's rocket motor, a missile can steer itself even shortly after being launched (when the missile is moving slowly, before it has reached a high speed).

Thrust-vectoring flight control (TVFC) is obtained through deflection of the aircraft jets in some or all of the pitch, yaw and roll directions. In the extreme, deflection of the jets in yaw, pitch and roll creates desired forces and moments enabling complete directional control of the aircraft flight path without the implementation of the conventional aerodynamic flight controls (CAFC). TVFC can also be used to hold stationary flight in areas of the flight envelope where the main aerodynamic surfaces are stalled. TVFC includes control of STOVL aircraft during the hover and during the transition between hover and forward speeds below 50 knots where aerodynamic surfaces are ineffective. An example of 2D thrust vectoring is the Rolls-Royce Pegasus engine used in the Hawker Siddeley Harrier, as well as in the AV-8B Harrier II variant.

While the Lockheed Martin F-35 Lightning II uses a conventional afterburning turbofan (Pratt & Whitney F135) to facilitate supersonic operation, its F-35B variant, developed for joint usage by the US Marine Corps, Royal Air Force, Royal Navy, and Italian Navy, also incorporates a vertically mounted, low-pressure shaft-driven remote fan, which is driven through a clutch during landing from the engine It is not conceived for enhanced maneuverability in combat, only for VTOL operation, and the F-35A and F-35C do not use thrust vectoring at all.

The Sukhoi Su-30MKI, produced by India under license at Hindustan Aeronautics Limited, is in active service with the Indian Air Force. The TVC makes the aircraft highly manoeuvrable, capable of near-zero airspeed at high angles of attack without stalling, and dynamic aerobatics at low speeds. The Su-30MKI is powered by two Al-31FP after-burning turbofans.. This produces a corkscrew effect, greatly enhancing the turning capability of the aircraft.

1.3. MISSION DEFINITION AND MOTIVATION

Controlling the flight path and the attitude of a rocket-propelled vehicle enables it to reach a precise flight destination. Rocket propulsion systems always provide a “push” toward an intended destination, but they also can be made to provide torques that rotate the vehicle in conjunction with the propulsive force. By controlling the direction of thrust vectors through mechanisms described in this chapter, it is possible to influence a vehicle's pitch, yaw, and roll rotations.

Thrust vector control units integrated with the principal propulsion system are only effective while it is operating and producing an exhaust jet. For periods of free flight, when the main rocket propulsion system is off, separate propulsion units are needed for achieving control over attitude or flight path. In space, many vehicles utilize dedicated attitude-control systems with multiple independent thrust-producing units.

All chemical propulsion systems may have one of several types of thrust vector control (TVC) mechanisms. Some may apply to solid, hybrid, and liquid propellant rocket propulsion systems, but most are specific to only one of these propulsion categories. In this chapter, we describe mechanisms that consist of a single nozzle.

1.4. CHANGES

Fins are used on rockets to provide stability and control direction. It works in the same way as placing feathers at the tail of an arrow. These can be mounted at the tail portion of the rocket, which makes the design too heavy and also increases the weight of the rocket.In this, we are going to use an Arduino UNO board to upload programming by using Arduino software to control the motion of servo motors. We have used MPU 6050 (Gyroscopic sensor) to make the change in angle of the gimbal by moving it on two axes by using servos. We have installed two servos to move the gimbal mechanism. By making changes in the angle of the gyro sensor, the gimbal mechanism will move according to the moment.

1.4.1.GIMBAL MECHANISM

To maneuver the rocket in flight, several different systems can be used. Early rockets, and some air-to-air missiles, use movable aerodynamic surfaces like the elevators on an airplane. Of course, this system only works on rockets that remain in the atmosphere. rockets designed to exit the atmosphere used small vanes in the nozzle exhaust to vector the thrust. Most modern rockets, like the Space Shuttle and the Saturn V moon rockets, use a system called gimbaled thrust**.[1]**

In a gimbaled thrust system, the engine or just the exhaust nozzle of the rocket can be swelled on two axes (pitch and yaw) from side to side. As the nozzle is moved, the direction of the thrust is changed relative to the center of gravity of the rocket. The diagram illustrates three cases the rocket center line at an angle called the gimbal angle. Since the thrust no longer passes through the center of gravity, a torque is generated about the center of gravity and the nose of the rocket turns to the left. If the nozzle is gimbaled back along the center line, the rocket will move to the left.

The rocket engine gimbal is a pivot at the top of the combustion chamber that the engine thrust acts through. The engine is gimballed or tilted using hydraulic (or 12 electromagnetic) pistons often called thrust vector control (TVC) actuators, as shown here on a Merlin engine. The Quadra pod structure takes the thrust from the gimbal pad on the combustion chamber. There are two TVC actuators on most engines for X and Y control. Interestingly, on the Merlin, from that image, it looks like the 'Turbo Pump Assembly' on LHS does not gimbal with the engine since it has fixed length struts.

In inertial navigation, as applied to ships and submarines, a minimum of three gimbals are needed to allow an inertial navigation system (stable table) to remain fixed in inertial space, compensating for changes in the ship's yaw, pitch, and roll.

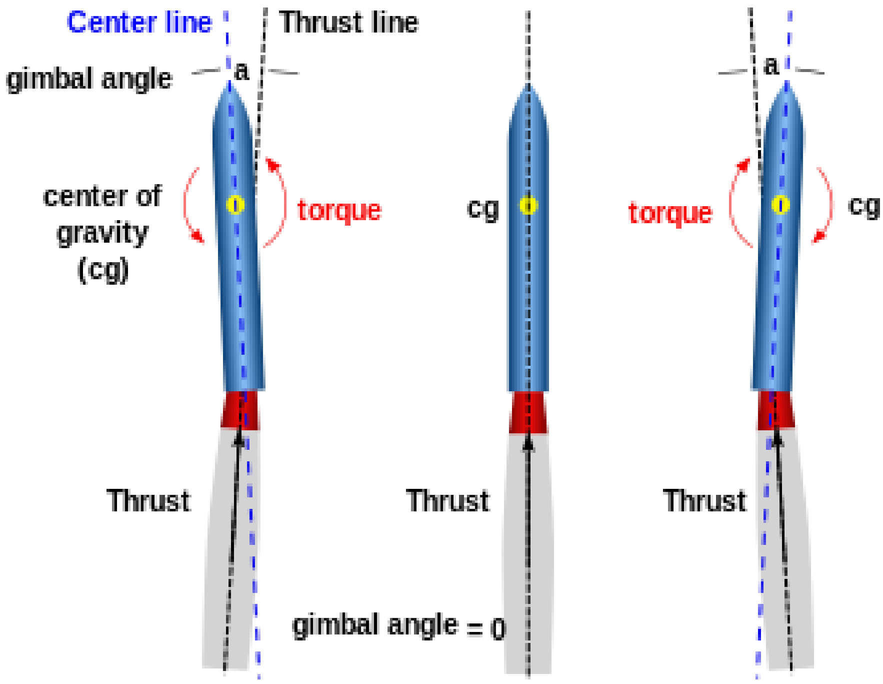


Figure.1.3. Gimbal Mechanism

To accomplish this, the gyro error signals are passed through "resolvers" mounted on the three gimbals, roll, pitch and yaw. These resolvers perform an automatic matrix transformation according to each gimbal angle, so that the required torques are delivered to the appropriate gimbal axis. The yaw torques must be resolved by roll and pitch transformations. The gimbal angle is never measured. Similar sensing platforms are used on aircraft. In inertial navigation systems, gimbal lock may occur when vehicle rotation causes two of the three gimbal rings to align with their pivot axes in a single plane.

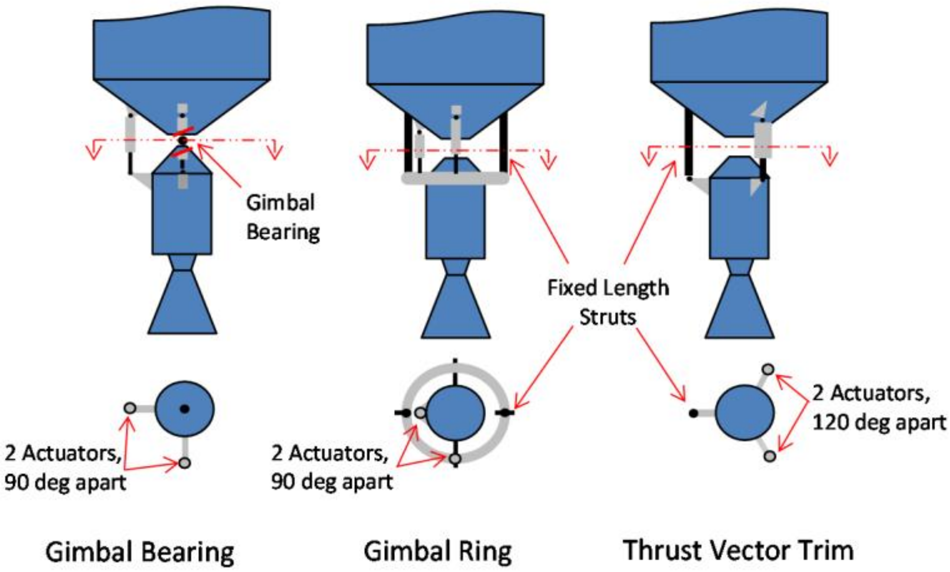


Figure.1.4. Some models of gimbal arrangements

1.4.2 IMPLEMENTING GYROSCOPE SENSOR

A common sensing approach used in accelerometers is capacitance sensing in which acceleration is related to change in the capacitance of a moving mass. This sensing technique is known for its high accuracy, stability, low power dissipation, and simple structure to build. It is not prone to noise and variation with temperature. Bandwidth for a capacitive accelerometer is only a few hundred Hertz because of their physical geometry (spring) and the air trapped inside the IC that acts as a damper.

Accelerometers have been used for a long time in automobiles for detecting car crashes and for triggering airbags at just the right moment. They have many applications in mobile devices like switching between portrait and landscape modes, tap gestures to change to the next song, tapping through clothing when the device is in a pocket, or anti-blur capturing and optical image stabilization.

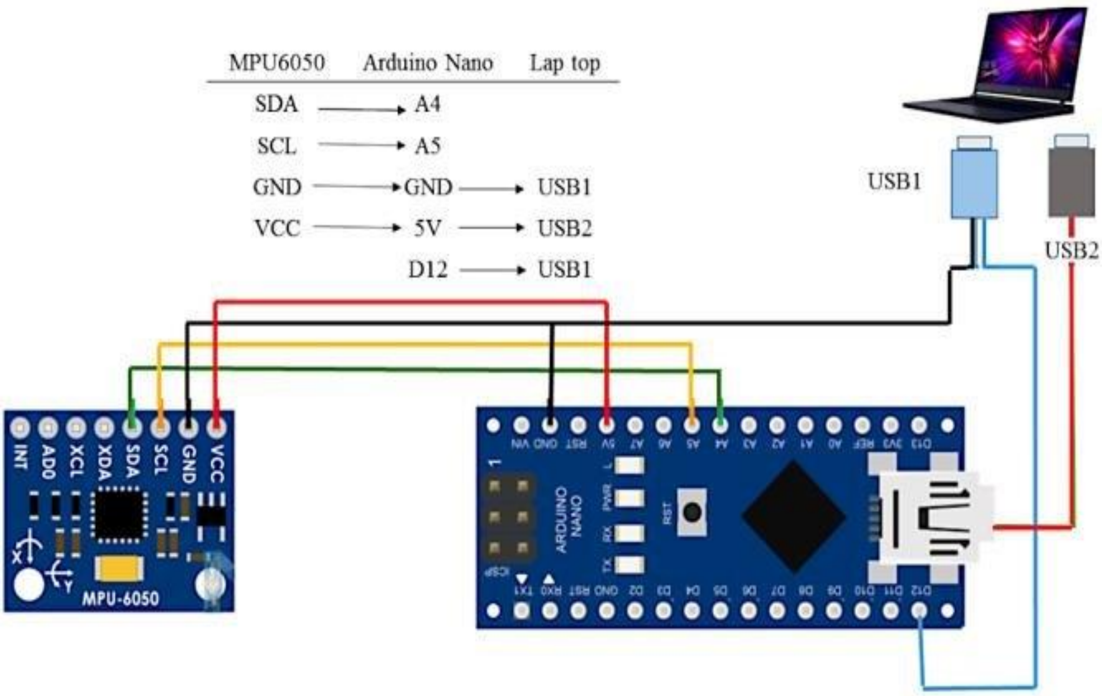


Figure.1.5. Gyroscopic connection

CHAPTER 2

LITERATURE SURVEY

Ahmet Unal, Kemal Yaman, Emri Okur and Mehmet Arif Adli

Journal of making Thrust Vector Control System originally published online in March 2018.

The rocket engines are tested statically to evaluate the performance of engine based upon thrust produced. One of the most important parameters of the rocket engine static testing evaluation is to measure the thrust produced by the engine. The thrust produced is measured using a Thrust Vector Control (TVC)test system which is a structural element equipped with load cells. In this study, a load sensor system was designed to measure the propulsion performance of a solid propellant rocket motor. The designed stand is capable of measuring axial thrust and lateral (misaligned) thrust components, and the rolling moment for rocket motors producing axial thrust up to 50 [kN].

J. H. Neilson, A. Gilchrist, and C. K. Lee

Journal of making side thrust control by secondary gas injection into rocket nozzle originally published online on 1 June 1968.

Directional control of rockets can be achieved by using secondary gas jets for providing side forces. The present investigation is concerned with the fact that a greater side force can be achieved by expanding the secondary gas into the supersonic region of the main nozzle than by expanding it directly to atmosphere.

The experiments were performed on a small axisymmetric main nozzle with a 10° semi-angle of divergence and with sonic injection through circular ports placed normal to the main nozzle axis.

The investigations centred principally on the effects of

(1) varying the secondary port size at a given axial location in the nozzle and of

(2) varying the axial location of a port of constant diameter. Side force and axial thrust augmentation characteristics were obtained for a range of primary and secondary flow inlet pressures. The results show the relative

importance of the parameters on which side force depends, the maximum side force that may be produced and the interdependence of axial thrust augmentation and side force.

Clinton B.F. Ensworth

Journal of making side thrust control for nuclear rockets originally published online in October 2013.

Future space missions may use Nuclear Thermal Rocket (NTR) stages for human and cargo missions to Mars and other destinations. The vehicles are likely to require engine thrust vector control (TVC) to maintain desired flight trajectories. This paper explores requirements and concepts for TVC systems for representative NTR missions.

Requirements for TVC systems were derived using 6 degree-of-freedom models of NTR vehicles. Various flight scenarios were evaluated to determine vehicle attitude control needs and to determine the applicability of TVC.

Various technologies are surveyed for TVC systems for the NTR applications. A key factor in technology selection is the unique radiation environment present in NTR stages. Other considerations including mission duration and thermal environments influence the selection of optimal TVC technologies Representative TVC systems are proposed and key properties such as mass and power requirements are defined. The outputs from this effort can be used to refine NTR system sizing models, providing higher fidelity definition for TVC systems for future studies.

Joseph. X and Ezra Tal

Journal of making thrust vectoring of small rocket motor using additively manufactured jet vanes originally published online in July 2021.

Small-scale thrust vector control (TVC) has the potential to enable rocket-powered micro aerial vehicles (MAV) capable of extremely fast and agile maneuvers. Jet vane TVC systems are particularly suitable for this task as they are capable of roll control and of exerting large side forces and moments at low airspeeds where aerodynamic surfaces are ineffective.

jet vanes are fabricated using selective laser sintering (SLS), and a ceramic heat shield, fabricated using stereolithography (SLA), is also designed.

We evaluate the aerodynamic and thermal performance of the proposed design through numerical simulations, including modelling of rocket exhaust composition, computational fluid dynamics (CFD), and conjugate heat-transfer. Additionally, we present a test stand that enables measurement of forces and moments under both static and dynamic jet vane inputs.

Sudhakar Kumar, Manas Das and Nirmala Venkat

Journal of making microcontroller programming using Arduino and python originally published online in June 2021.

This book explains how to interface the popular open-source microcontroller Arduino Uno with a computer, running MS Windows or Linux. It explains how one can do this through open-source software Arduino IDE. It also explains how one can use Python to access the sensors connected to Arduino Uno.

Microcontrollers are the foundation for a modern, manufacturing-based economy. One cannot fulfill the dreams of one's citizens without a thriving manufacturing sector. As it is open-source, Arduino Uno is of particular interest to hobbyists, students, small and medium scale manufacturers, and people from developing countries, in particular.

The only way we can become versatile in hardware is through hands-on training. To this end, we make use of the easily available low-cost Arduino Uno board to introduce the reader to computer interfacing.

CHAPTER 3
INTRODUCTION TO EAGLE CAD, ARDUINO PROGRAMMING

3.1. ARDUINO PROGRAMMING

When we work on Arduino we typically use Arduino IDE (Integrated development environment), which is software that's available for all major computers which provide a text editor for writing code with integrated library support and a physical programmable circuit board to run the code.

The Arduino programming language is a modified version of C/C++**.** Usually, we program in C++ with the addition of methods and functions. A program written in Arduino programming language is called sketch and saved with. ino extension. You can even use Python to write an Arduino program. All these languages are text-based programming languages. To reduce the complexity and maximize the interest of students we do have some online simulators where we don't have to buy or download anything.

3.1.1. INTRODUCTION

The Arduino Uno is a small, complete, and breadboard-friendly board based onthe ATmega328P released in 2008. It offers the same connectivity and specs of the Arduino Uno board in a smaller form factor. The Arduino Nano is equipped with 30 male I/O headers, in a DIP30-like configuration, which can be programmed using the Arduino Software integrated development environment (IDE), which is common to all Arduino boards and running both online and offline. The board can be powered through a type-B mini-USB cable or from a 9 V battery. In 2019, Arduino released the Arduino Nano Every, a pin-equivalent evolution of the Nano. It features a more powerful ATmega4809 processor and twice the RAM. Arduino Nano is a small, compatible open-source electronic development board based on an 8-bit AVR microcontroller. Two versions of this board are available;one is based on ATmega328p, and the other on Atmega168.

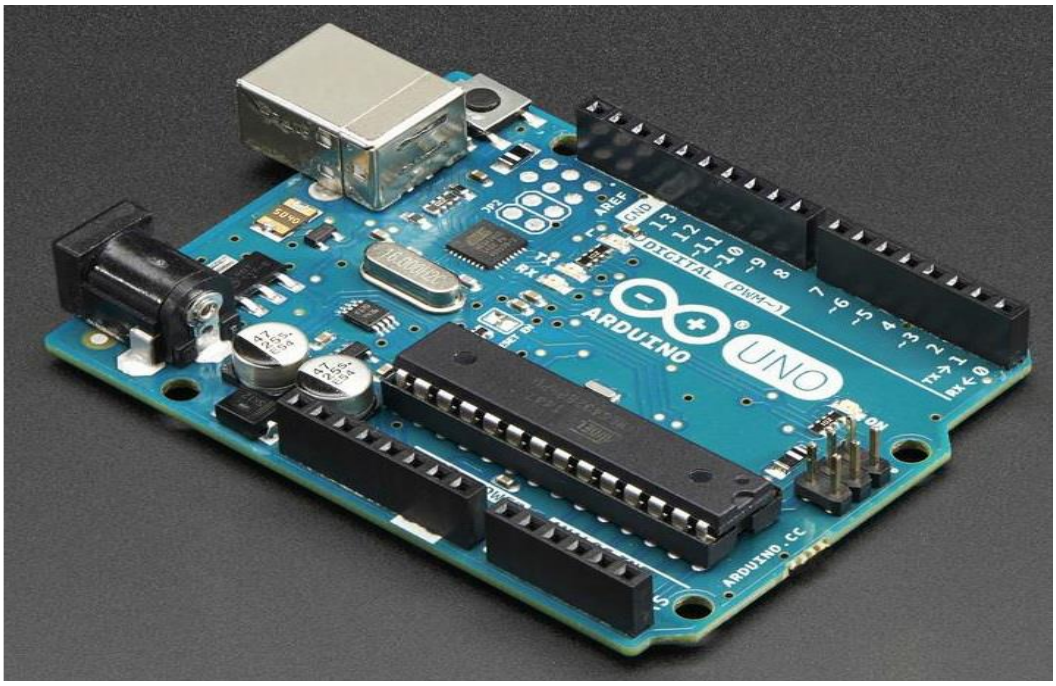


Figure.3.1. ARDUINO-UNO

Arduino Nano can perform some functions similar to other boards available in the market, however, it is smaller in size and is a right match for projects requiring less memory space and fewer GPIO pins to connect with this unit features 14 digital pins which you can use to connect with external components, while 6 analogy pins of 10-bit resolution each, 2 reset pins, and 6 power pins are integrated on the board. Like other Arduino boards, the operating voltage of this device is 5V, while input voltage ranges between 6V to 20V while the recommended input voltage rangesfrom 7V to 12V.

Power the board from an external power supply. Plus, this device is bread-board friendly in nature means you can connect this unitwith breadboards and make a range of electronic projects. The flash memory is used to store the program and the flash memory of Atmega168 is 16KB (of which 2KB is used for the Bootloader) and the flash memory of Atmega328 is 32KB. Similarly, the EEPROM is 512KB and 1KB, and SRAM is 1KB and 2KB forAtmega168 and Atmega328 respectively. The Nano board is almost similar to the UNO board with the former smaller insize with no DC power jack.

The Uno is one of the most popular Arduino boards. It consists of 14-digital I/O pins, where 6-pins can be used as PWM(pulse width modulation outputs), 6-analog inputs, a reset button, a power jack, a USB connection and more. It includes everything required to hold up the microcontroller; simply attach it to a PC with the help of a USB cable and give the supply to get started with a AC-to-DC adapter or battery.

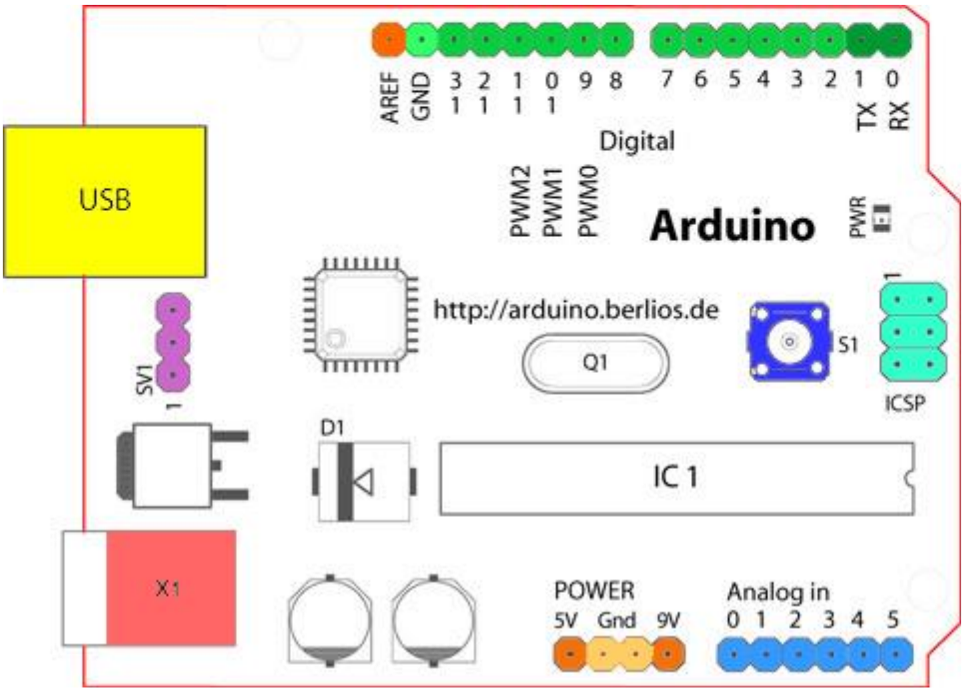


Figure.3.2. Common Components of Arduino Boards

3.2. EAGLE CAD

3.2.1. INTRODUCTION TO EAGLE

PCB DESIGN

A printed circuit board (PCB) is a laminated sandwich structure of conductive and insulating layers. PCBs have two complementary functions. The first is to affix electronic components in designated locations on the outer layers by means of soldering. The second is to provide reliable electrical connections (and also reliable open circuits) between the component's terminals in a controlled manner often referred to as PCB design.

make repair, analysis, and field modification of circuits much more difficult PCBs mechanically support electronic components using conductive pads in the shape designed to accept the component's terminals, and also electrically connect them using traces, planes and other features etched from one or more sheet layers of copper laminated onto and/or between sheet layers of a non-conductive substrate. Components are generally soldered onto the PCB to both electrically connect and mechanically fasten them to it. Printed circuit boards are used in nearly all electronic products and in some electrical products, such as passive switch boxes.

The large numbers of PCBs can be fabricated at the same time, and the layout only has to be done once. PCBs can also be made manually in small quantities, with reduced benefits.

PCBs can be single-sided (one copper layer), double-sided (two copper layers on both sides of one substrate layer), or multi-layer (outer and inner layers of copper, alternating with layers of substrate). Multi-layer PCBs allow for much higher component density, because circuit traces on the inner layers would otherwise take up surface space between components However, multilayer PCBs and usually impractical.

A minimal PCB for a single component, used for prototyping, is called a breakout board. The purpose of a breakout board is to "break out" the leads of a component on separate terminals so that manual connections to them can be made easily. Breakout boards are especially used for surface-mount components or any components with fine lead pitch.

Advanced PCBs may contain components embedded in the substrate, such as capacitors and integrated circuits, to reduce the amount of space taken up by components on the surface of the PCB while improving electrical characteristics.

The first PCBs used through-hole technology, mounting electronic components by leads inserted through holes on one side of the board and soldered onto copper trades on the other side.

3.2.2. HISTORY

The German CAD Soft Computer GmbH was founded by Rudolf Hofer and Klaus-Peter Schmid Inger in 1988 to develop EAGLE, a 16-bit PCB design application for DOS. Originally, the software consisted of a layout editor with part libraries only. An auto-router module became available as optional component later on. With EAGLE 2.0, a schematics editor was added in 1991. The software used BGI video drivers, and XPLOT to print. In 1992, version 2.6 changed the definition of layers, but designs created under older versions (up to 2.05) could be converted into the new format using the provided UPDATE26.EXE utility.

EAGLE 3.0 was changed to be a 32-bit extended DOS application in 1994.

Support for OS/2 Presentation Manager was added with version 3.5 in April 1996. This version also introduced multi-window support with forward-/backward-annotation, user-definable copper areas, and a built-in programming language with ULPs. It was also the first to no longer require a dongle.

In 2000, EAGLE version 4.0 officially dropped support for DOS and OS/2, but now being based on Qt 3 it added native support for Windows and was among the first professional electronic CAD tools available for Linux. A 32-bit DPMI version of EAGLE 4.0 running under DOS was still available on special request in order to help support existing customers, but it was not released commercially. Much later, in 2015, a special version of EAGLE 4.09r2 was made available by CAD Soft to ease installation under Windows 7.

Starting with version 4.13, EAGLE became available for Mac OS X, with versions before 5.0.0 still requiring X11. Version 5.0.0 officially dropped support for Windows 9x and Windows NT 3.x/4.x in 2008. This version was based on Qt 4 and introduced user-definable attributes.

On 24 September 2009, Premier Farnell announced the acquisition of CAD Soft Computer GmbH.

Version 7.0.0 brought hierarchical designs, a new gridles topological pre-router called "Top Router" for the conventional rip up auto-router as well as multi-core support. Version 7.3.0 introduced native 64-bit versions for all three platforms in 2015. Version 7.6.0 dropped support for the 32-bit Mac OS X version in 2016. EAGLE 6.x.x continues to read EAGLE 7.x.x design files for as long as the hierarchical design feature isn't used.

EAGLE is a scriptable electronic design automation (EDA) application with schematic capture, printed circuit board (PCB) layout, auto-router and computer-aided manufacturing (CAM) features. EAGLE stands for Easily Applicable Graphical Layout Editor (German: Einfach Anzuwendender Grafischer Layout-Editor) and is developed by CAD Soft Computer GmbH. The company was acquired by Autodesk Inc. in 2016.

CHAPTER 4

DESIGNING OF TVC

4.1. DESIGNING OF PCB BOARD BY USING EAGLE CAD SOFTWARE

A basic PCB consists of a flat sheet of insulating material and a layer of copper foil, laminated to the substrate. Chemical etching divides the copper into separate conducting lines called tracks or circuit traces, pads for connections, vias to pass connections between layers of copper, and features such as solid conductive areas for electromagnetic shielding or other purposes. The tracks function as wires fixed in place, and are insulated from each other by air and the board substrate material. The surface of a PCB may have a coating that protects the copper from corrosion and reduces the chances of solder shorts between traces or undesired electrical contact with stray bare wires. For its function in helping to prevent solder shorts, the coating is called solder resist or solder mask.

One of the simplest boards to produce is the two-layer board. It has copper on both sides that are referred to as external layers; multi-layer boards sandwich additional internal layers of copper and insulation. After two-layer PCBs, the next step up is the four-layer. The four layer board adds significantly more routing options in the internal layers as compared to the two layer board, and often some portion of the internal layers is used as ground plane or power plane, to achieve better signal integrity, higher signalling frequencies, lower EMI, and better power supply decoupling.

"Through hole" components are mounted by their wire leads passing through the board and soldered to traces on the other side. "Surface mount" components are attached by their leads to copper trades on the same side of the board. A board may use both methods for mounting components. PCBs with only through-hole mounted components are now uncommon. Surface mounting is used for transistors, diodes, IC chips, resistors, and capacitors. Through-hole mounting may be used for some large components such as electrolytic capacitors and connectors.

In multi-layer boards, the layers of material are laminated together in an alternating sandwich: copper, substrate, copper, substrate, copper, etc.; each plane of copper is etched, and any internal vias (that will not extend to both outer surfaces of the finished multilayer board) are plated-through, before the layers are laminated together. Only the outer layers need be coated; the inner copper layers are protected by the adjacent substrate layers.

When a PCB has no components installed, it is less ambiguously called a printed wiring board (PWB) or etched wiring board. However, the term "printed wiring board" has fallen into disuse. A PCB populated with electronic components is called a printed circuit assembly (PCA), printed circuit board assembly or PCB assembly (PCBA). In informal usage, the term "printed circuit board" most commonly means "printed circuit assembly" (with components). The IPC preferred term for an assembled board is circuit card assembly (CCA), and for an assembled backplane it is backplane assembly. "Card" is another widely used informal term for a "printed circuit assembly". For example, expansion card.

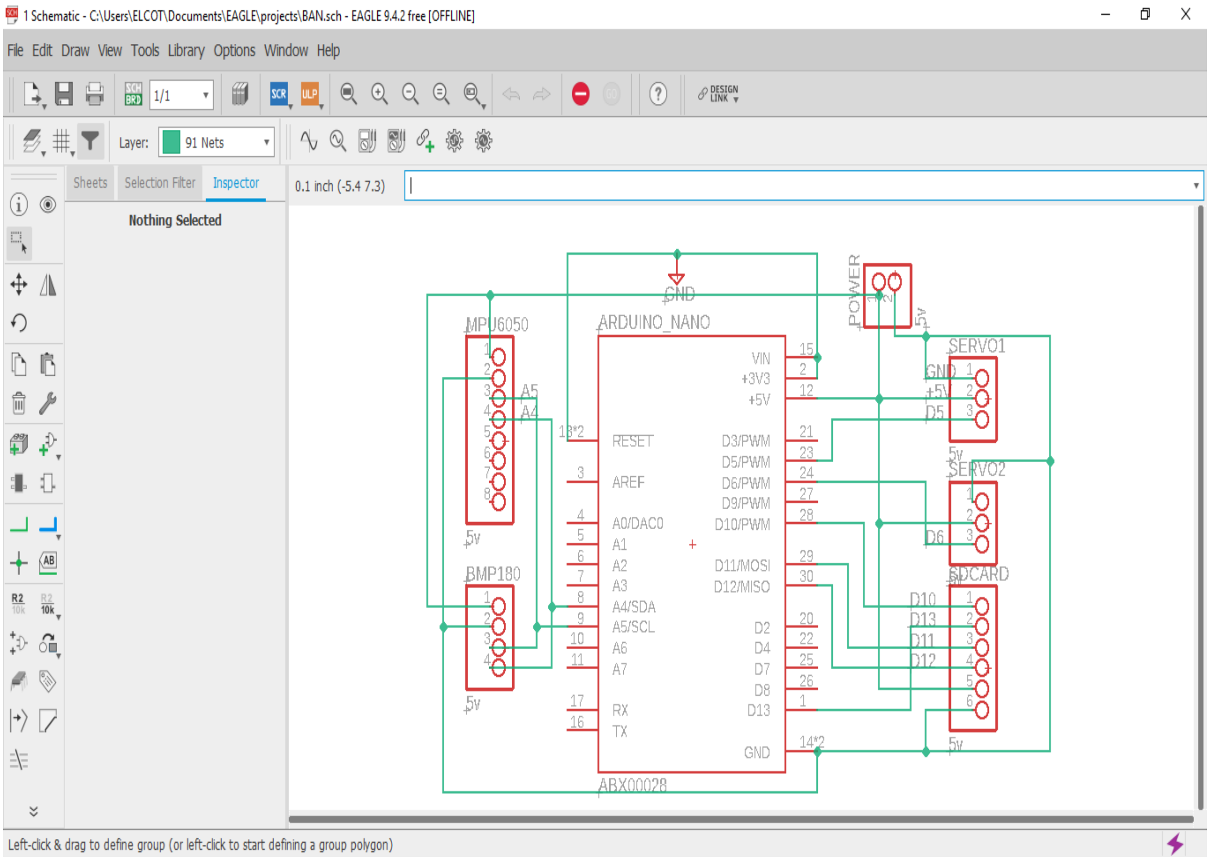


Figure.4.1. Basic design of PCB Board

Horizontal installation of through-hole parts with two axial leads (such as resistors, capacitors, and diodes) is done by bending the leads 90 degrees in the same direction, inserting the part in the board (often bending leads located on the back of the board in opposite directions to improve the part's mechanical strength), soldering the leads, and trimming off the ends. Leads may be soldered either manually or by a wave soldering machine.

Through-hole manufacture adds to board cost by requiring many holes to be drilled accurately, and it limits the available routing area for signal traces on layers immediately below the top layer on multi-layer boards. Once surface-mounting came into use, small-sized SMD components were used where possible, with through-hole mounting only of components unsuitably large for surface-mounting due to power requirements or mechanical limitations, or subject to mechanical stress which might damage the PCB.

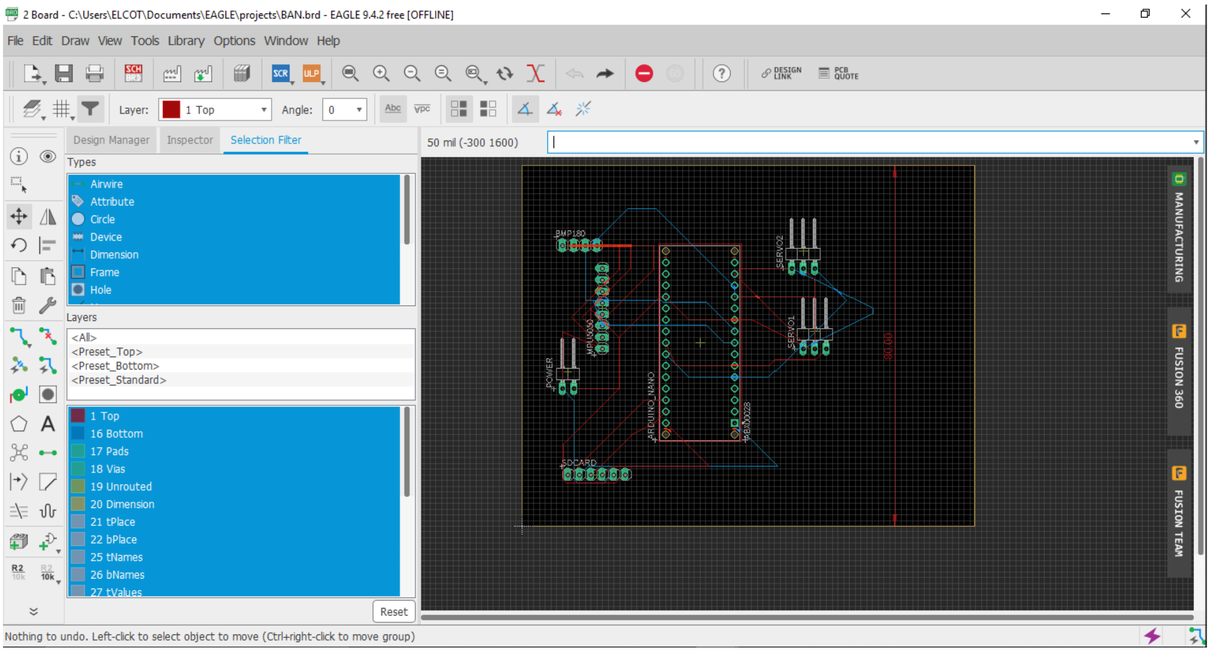


Figure.4.2. Final layout of PCB Board

4.2. PROGRAMMING OF SENOSORS AMD ARDUNO UNO BY ARDUINO SOFTWARE

GYROSCOPIC SENSOR

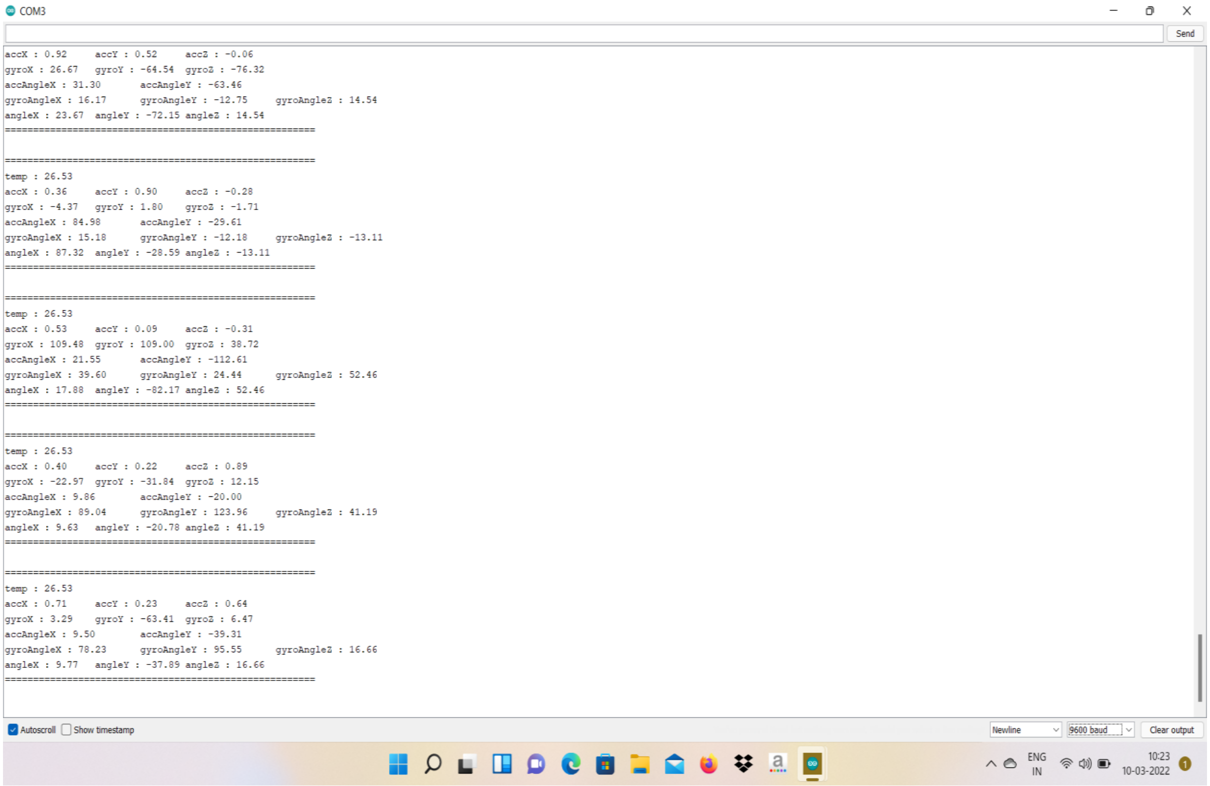
A gyroscope (from Ancient Greek , "circle" and, "to look") is a device used for measuring or maintaining orientation and velocity. It is disc in which the axis of rotation (spin axis) is free to assume any orientation by it.

Fig.4.3. Gyroscopic Sensor

PROGRAMMING

```
#include <MPU6050_tockn.h>

#include <Wire.h>

 MPU6050 mpu6050(Wire);

 long timer = 0;

 void setup() {

 Serial.begin(9600);

  Wire.begin();

  mpu6050.begin();

  mpu6050.calcGyroOffsets(true);

Void loop () {

  mpu6050.update ();

  if(millis() - timer > 1000){

    Serial.println
("=================================================
=============");

    Serial.print("temp : ");Serial.println(mpu6050.getTemp());

    Serial.print("accX : ");Serial.print(mpu6050.getAccX());

    Serial.print("\taccY : ");Serial.print(mpu6050.getAccY());

    Serial.print("\taccZ : ");Serial.println(mpu6050.getAccZ());

    Serial.print("gyroX : ");Serial.print(mpu6050.getGyroX());

    Serial.print("\tgyroY : ");Serial.print(mpu6050.getGyroY());
```

OUTPUT



BAROMETRIC SENSOR

A barometric pressure sensor is a sensor that detects atmospheric pressure. Various types of pressure sensors exist utilizing different materials and methods as shown below based on the pressure values to be measured. Among these, sensors that detect atmospheric pressure are called barometric pressure sensors.

The phenomenon in which the resistivity (electrical conductivity) changes based on the pressure applied to this resistance is called the piezoelectric effect, and ROHM's barometric pressure sensor is an IC (ASIC*) that combines a Piezo resistive pressure-receiving element (diaphragm structure that integrates a Piezo resistor utilizing MEMS* technology) with a temperature compensation function, control circuit, and other components in a single package, making it easy to obtain atmospheric pressure information with high accuracy.

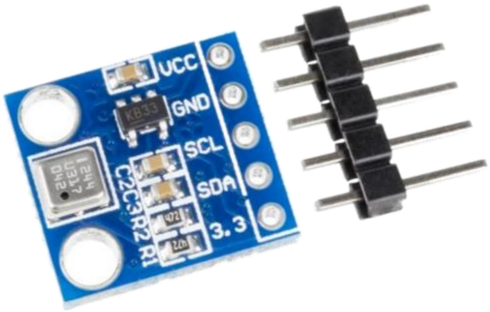


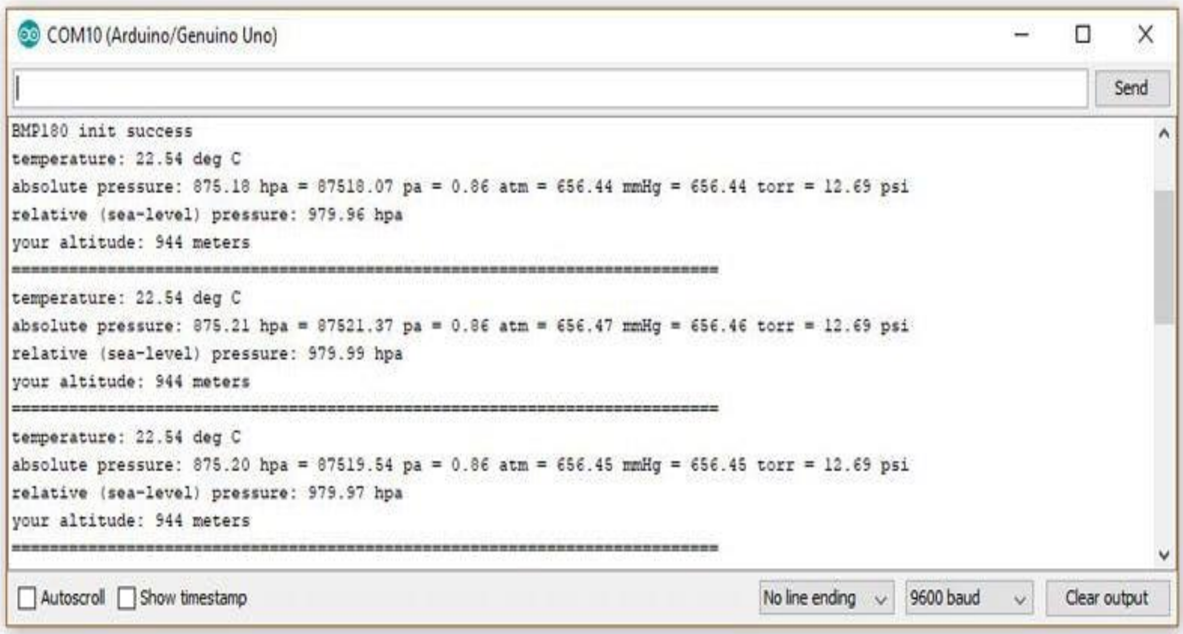
Figure.4.4. Barometric sensor

PROGRAMMING

```
#include <SFE_BMP180.h>
#include <Wire.h?
SFE_BMP180 pressure;
#define ALTITUDE 943.7 // Altitude of Electropeak Co. in meters
void setup() {
Serial.begin(9600);
if (pressure.begin())
Serial.println("BMP180 init success");
else
{
Serial.println("BMP180 init fail\n\n");
Serial.println("Check connection");
while (1);
}
}
void loop() {
char status;
double T, P, p0, a;
```

```
Serial.print(" pa = ");
Serial.print(P * 0.000986923, 2);
Serial.print(" atm = ");
Serial.print(P * 0.750063755, 2);
Serial.print(" mmHg = ");
Serial.print(P * 0.750061683, 2);
Serial.print(" torr = ");
Serial.print(P * 0.014503774, 2);
Serial.println(" psi");
p0 = pressure.sealevel(P, ALTITUDE); // we're at 943.7 meters
Serial.print("relative (sea-level) pressure: ");
Serial.print(p0, 2);
Serial.println(" hpa ");;
a = pressure.altitude(P, p0);
Serial.print("your altitude: ");
Serial.print(a, 0);
Serial.println(" meters ");
}
else Serial.println("error retrieving pressure measurement\n");
}
else Serial.println("error starting pressure measurement\n");
}
else Serial.println("error retrieving temperature measurement\n");
}
else Serial.println("error starting temperature measurement\n");
Serial.println("========================================
=====================================");
delay(5000);
}
```

OUTPUT



4.3. DESIGNING IN CURA SOFTWARE

4.3.1. GIMBAL MECHANISM FRAME

Cura is an open source slicing application for 3D printers. It was created by David Braam who was later employed by Ultimaker, a 3D printer manufacturing company, to maintain the software. Cura is available under LGPLv3 license. Cura was initially released under the open source Affero General Public License version 3, but on 28 September 2017 the license was changed to LGPLv3. This change allowed for more integration with third-party CAD applications. Development is hosted on GitHub. Ultimaker Cura is used by over one million users worldwide and handles 1.4 million print jobs per week. It is the preferred 3D printing software for Ultimaker 3D printers, but it can be used with other printers as well.

Ultimaker Cura works by slicing the user's model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object.

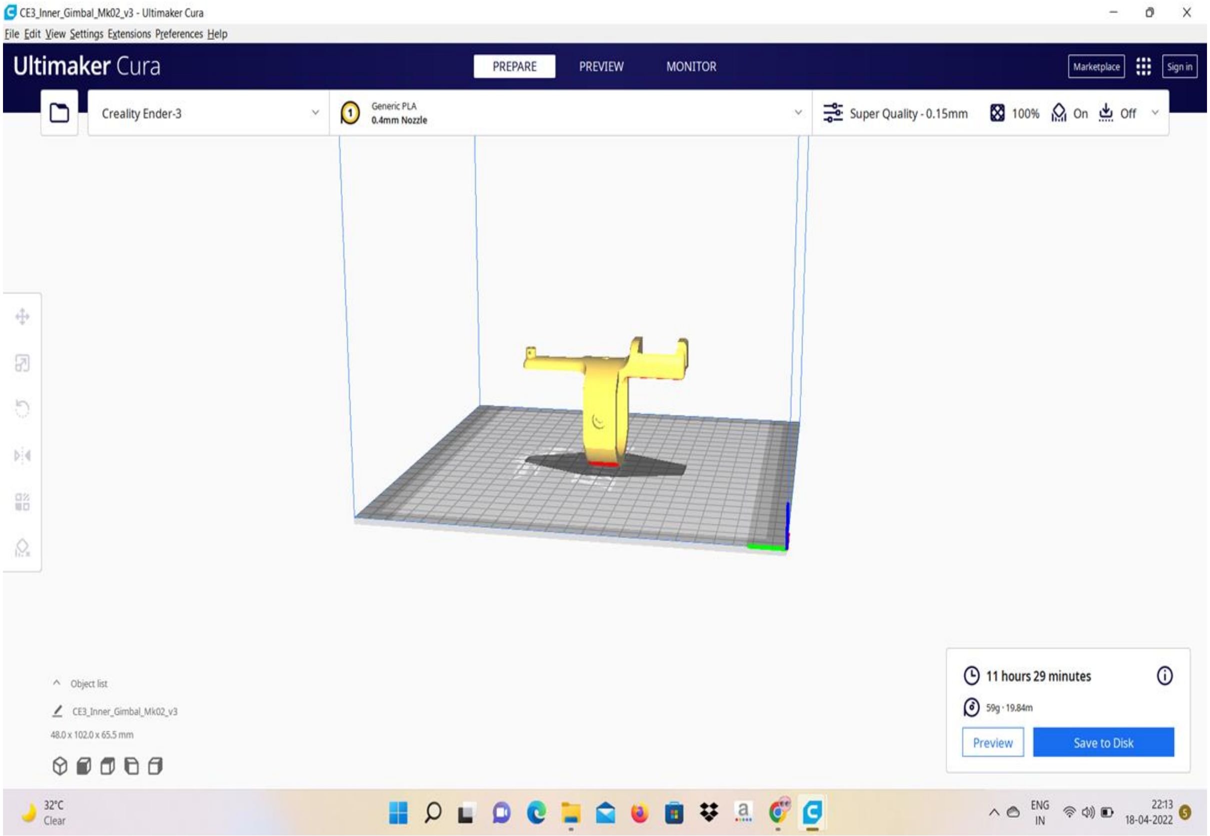


Figure.4.5. Gimbal frame in CURA Software

4.3.2. SERVO MOTOR MOUNT

Their first software ran under a modified version of Replicator-G. They changed this later to Cura because more and more users started using this software in favor of Replicator-G, which was originally produced with Makerbot in mind. When the lead developer for Cura started working for Ultimaker, Ultimaker Cura became the lead software product for Ultimaker. Cura rapidly became a favorite of 3D printing enthusiasts.

The Ultimaker 3 is the successor to the successful Ultimaker 2+ family. It features dual extrusion, compatibility with various other Ultimaker materials including PVA, PC, ABS, Nylon and Breakaway. It was released in October 2016. The LCD control screen is recoloured from blue to white and the navigation of the menus has been updated. In addition to this, when an Ultimaker material is placed on the spool holder, the Ultimaker 3 will automatically detect the material and its colour through NFC, along with an estimate of its remaining length. In 2019, The Mediahq recognized the Ultimaker 3 as the Best 3D Printer of 2019 for Enthusiasts.

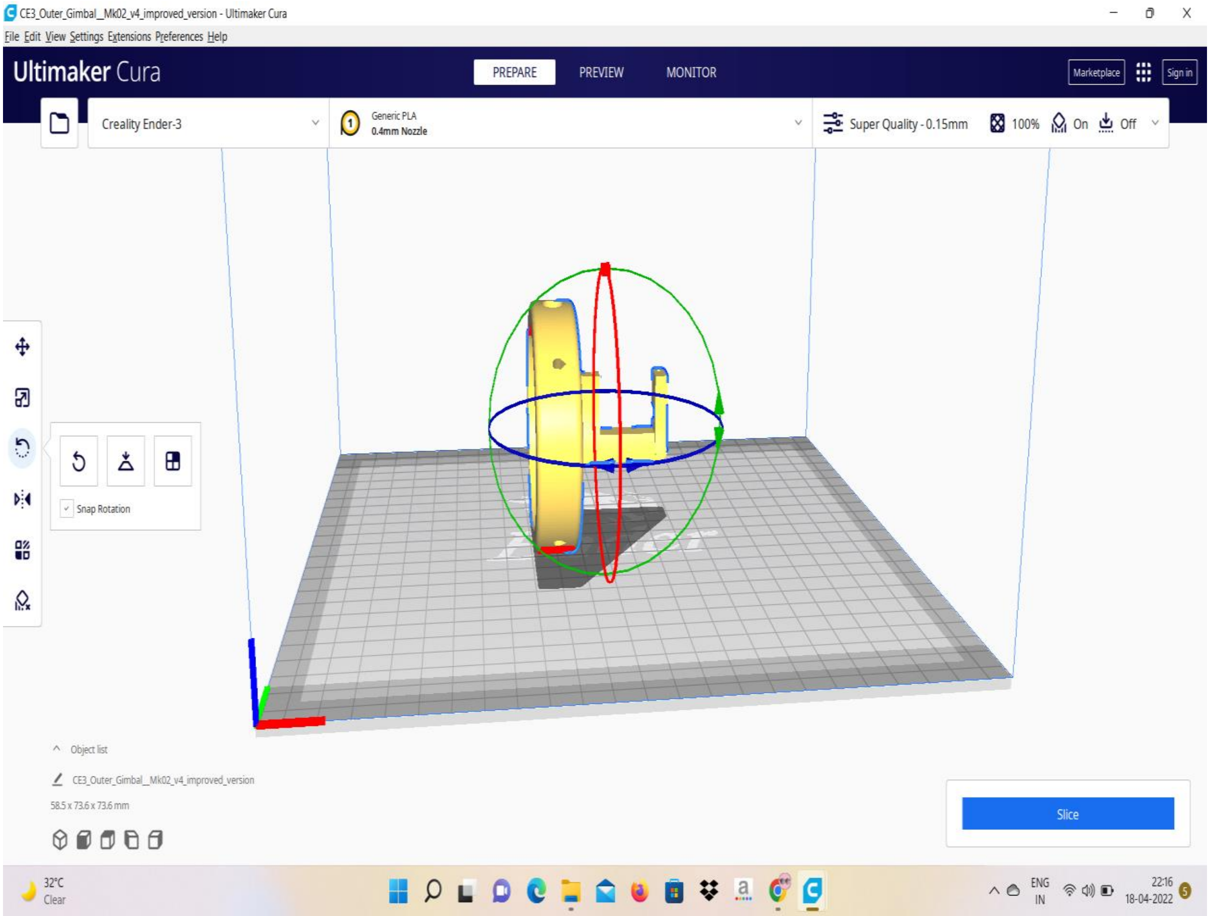


Figure.4.6. Design of motor mount in CURA Software

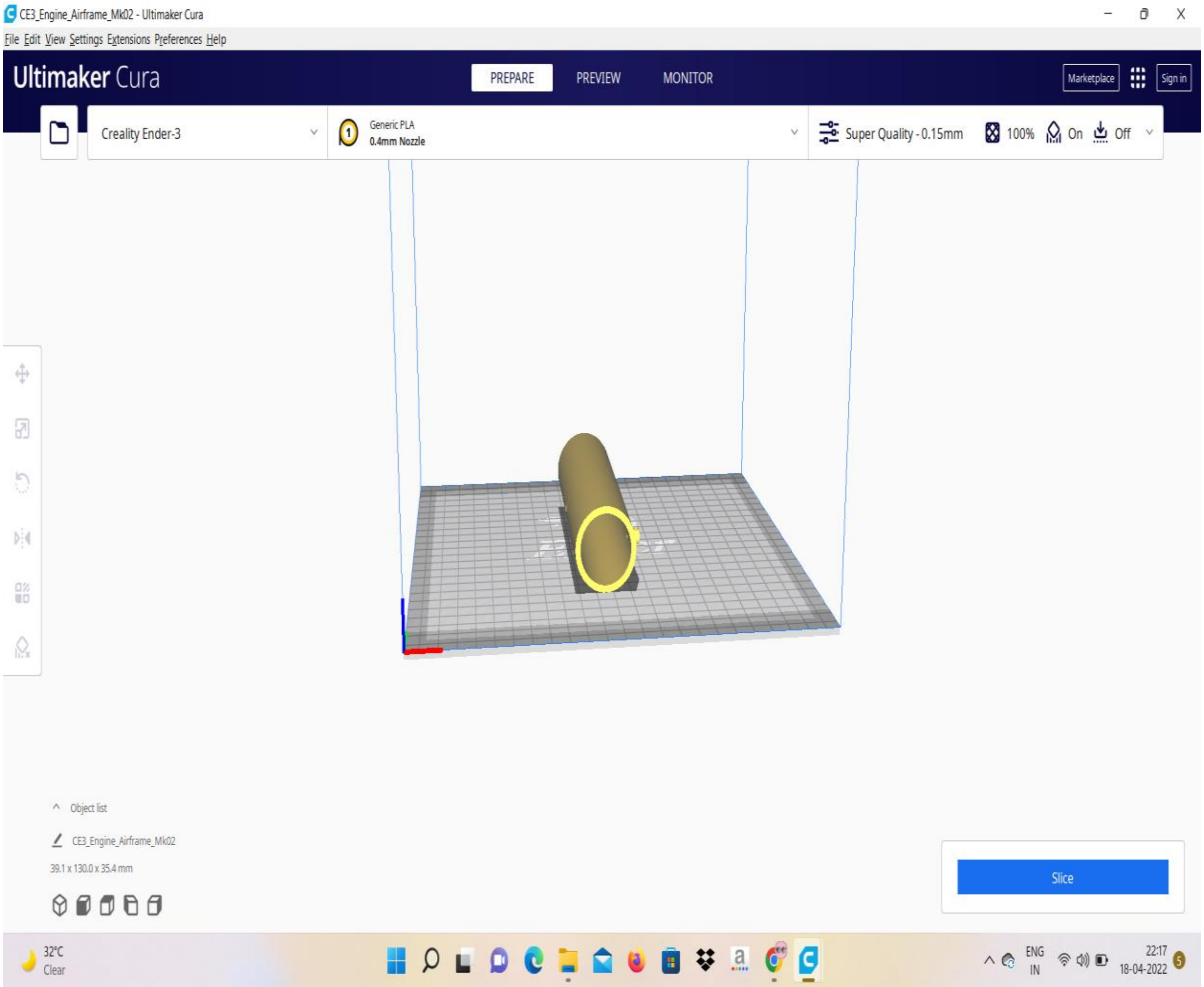


Figure.4.7. Design of frame of gimbal body

Ultimaker Cura works by slicing the user’s model file into layers and generating a printer-specific g-code. Once finished, the g-code can be sent to the printer for the manufacture of the physical object.

CHAPTER 5

ADDITIONAL FEATURES AND INNER PARTS OF GIMBAL MECHANISM

5.1. SERVO MOTOR

5.1.1. UNDERSTANDING SERVO MOTOR

A servomotor (or servo motor) is a rotary actuator or linear actuator that allows for precise control of angular or linear position, velocity and acceleration.[1] It consists of a suitable motor coupled to a sensor for position feedback. It also requires a relatively sophisticated controller, often a dedicated module designed specifically for use with servomotors.

A servomotor is a closed-loop servomechanism that uses position feedback to control its motion and final position. The input to its control is a signal (either analogue or digital) representing the position commanded for the output shaft.

The very simplest servomotors use position-only sensing via a potentiometer and bang-bang control of their motor. This type of servomotor is not widely used in industrial motion control, but it forms the basis of the simple and cheap servos used for radio-controlled models.

Servomotors are not a specific class of motor, although the term *servomotor* is often used to refer to a motor suitable for use in a closed-loop control system.

Servomotors are used in applications such as robotics, CNC machinery, and automated manufacturing.

Figure.5.1. Servo motor

The type of motor is not critical to a servomotor and different types may be used. At the simplest, brushed permanent magnet DC motors are used, owing to their simplicity and low cost. Small industrial servomotors are typically electronically commutated brushless motors. For large industrial servomotors, AC induction motors are typically used, often with variable frequency drives to allow control of their speed.

5.1.2. WHY A SERVO MOTOR?

Servomotors are generally used as a high-performance alternative to the stepper motor. Stepper motors have some inherent ability to control position, as they have built-in output steps. This often allows them to be used as an open-loop position control, without any feedback encoder, as their drive signal specifies the number of steps of movement to rotate, but for this the controller needs to 'know' the position of the stepper motor on power up. Therefore, on first power up, the controller will have to activate the stepper motor and turn it to a known position, e.g. until it activates an end limit switch. This can be observed when switching on an inkjet printer; the controller will move the ink jet carrier to the extreme left and right to establish the end positions. A servomotor will immediately turn to whatever angle the controller instructs it to, regardless of the initial position at power up.

5.1.3. SPECIFICATIONS

In control engineering a servomechanism, usually shortened to servo, is an automatic device that uses error-sensing negative feedback to correct the action of a mechanism. On displacement-controlled applications, it usually includes a built-in encoder or other position feedback mechanism to ensure the output is achieving the desired effect.

The term correctly applies only to systems where the feedback or error-correction signals help control mechanical position, speed, attitude or any other measurable variables. For example, an automotive power window control is not a servomechanism, as there is no automatic feedback that controls position—the operator does this by observation. By contrast a car's cruise control uses closed-loop feedback, which classifies it as a servomechanism..

Positioning servomechanisms were first used in military fire-control and marine navigation equipment. Today servomechanisms are used in automatic machine tools, satellite-tracking antennas, remote control airplanes, automatic navigation systems on boats and planes, and antiaircraft-gun control systems. Other examples are fly-by-wire systems in aircraft which use servos to actuate the aircraft's control surfaces, and radio-controlled models which use RC servos for the same purpose.

Many autofocus cameras also use a servomechanism to accurately move the lens. A hard disk drive has a magnetic servo system with sub-micrometer positioning accuracy. In industrial machines, servos are used to perform complex motion, in many applications.

5.2. ARDUINO UNO BOARD

5.2.1 INTRODUCTION

The Arduino Uno is an open-source microcontroller board based on the Microchip ATmega328P microcontroller and developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 6 analog I/O pins, and is programmable with the Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by the USB cable or by an external 9-volt battery, though it accepts voltages between 7 and 20 volts.

.

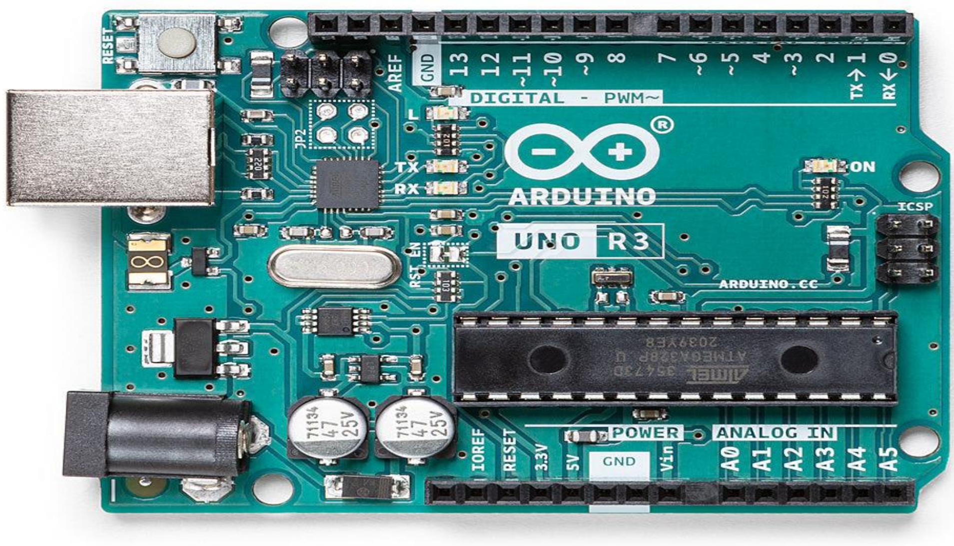


Figure.5.2 Arduino UNO board

Arduino Uno is a microcontroller board based on the ATmega328P (datasheet). It has 14 digital input/output pins (of which 6 can be used as PWM outputs), 6 analogue inputs, a 16 MHz ceramic resonator (CSTCE16M0V53-R0), 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. You can tinker with your Uno without worrying too much about doing something wrong, worst-case scenario you can replace the chip for a few dollars and start over again.

"Uno" means one in Italian and was chosen to mark the release of Arduino Software (IDE) 1.0. The Uno board and version 1.0 of Arduino Software (IDE) were the reference versions of Arduino, now evolved to newer releases. The Uno board is the first in a series of USB Arduino boards, and the reference model for the Arduino platform; for an extensive list of current, past or outdated boards see the Arduino index of boards.

5.2.2. CONNECTION BETWEEN ARDUINO AND SERVO MOTOR

There are many beginners suffering from the basics of Arduino. So, I decided to start a series of articles discussing about basics of Arduino programming. Many of students and hobbyists have a very good interest in electronics. And they drop their interest because of programming. But the true fact is Arduino programming very simple. We need to understand every line of code and its use.

Servo motors are extremely useful in so many different applications; it'd be good to learn how to control them! Solenoid and DC motor control have been shown already; for the most part, they are both pretty straightforward (only power and ground connections) methods of motor control. We'll be controlling our servo using PWM on an Arduino.

A servo motor is a little different, using 3 connections (Power, Ground, and Signal) to move the motor to a certain rotary position. This position is dictated by what is sent on the signal wire. Once the motor reaches the position specified by the signal, it will hold its position and resist any forces that try to move it from that position. This resistance is known as the Torque Rating of the servo and will be found on the datasheet.

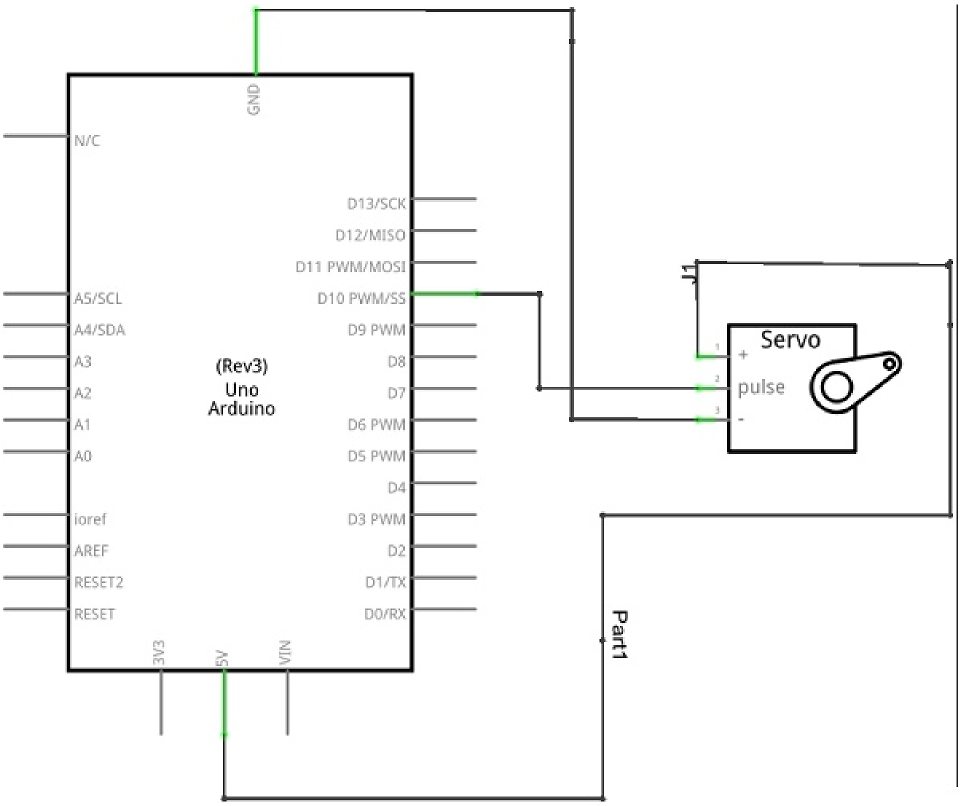


Figure.5.3. Connection between servo motor and Arduino UNO

5.3 SENSORS

5.3.1 GYROSCOPIC SENSOR

MPU6050s are configurable accelerometers and gyroscopes. So, you are capable to measure acceleration, rotation speed and temperature. The gravity is added to the acceleration. From these data the current angle of MPU6050 is calculated in degrees. You can set sensor ranges too. Bigger ranges imply less quality in measurements while smaller ranges make the quality better. You can store a high variety of measured data to instantly react or later analyse them.

Figure.5.4. Gyroscopic Sensor

Besides sensing the angular velocity, Gyroscope sensors can also measure the motion of the object. For more robust and accurate motion sensing, in consumer electronics Gyroscope sensors are combined with Accelerometer sensors.

This sensor consists of an internal vibrating element made up of crystal material in the shape of a double – T- structure. This structure comprises a stationary part in the centre with 'Sensing Arm' attached to it and 'Drive Arm' on both sides.This double-T-structure is symmetrical. When an alternating vibration electrical field is applied to the drive arms, continuous lateral vibrations are produced. As Drive arms are symmetrical, when one arm moves to left the other moves to the right, thus cancelling out the leaking vibrations. This keeps the stationary part at the centre and sensing arm remains static.

When the external rotational force is applied to the sensor vertical vibrations are caused on Drive arms. This leads to the vibration of the Drive arms in the upward and downward directions due to which a rotational force acts on the stationary part in the centre.

5.3.2 BMP 180 SENSOR

The BMP180 is the function compatible successor of the BMP085, a new generation of high precision digital pressure sensors for consumer applications. The ultra-low power, low voltage electronics of the BMP180 is optimized for use in mobile phones, PDAs, GPS navigation devices and outdoor equipment. With a low altitude noise of merely 0.25m at fast conversion time, the BMP180 offers superior performance. The I2C interface allows for easy system integration with a microcontroller. The BMP180 is based on piezo-resistive technology for EMC robustness, high accuracy and linearity as well as long term stability. Robert Bosch is the world market leader for pressure sensors in automotive applications. Based on the experience of over 400 million pressure sensors in the field, the BMP180 continues a new generation of micro-machined pressure sensors.

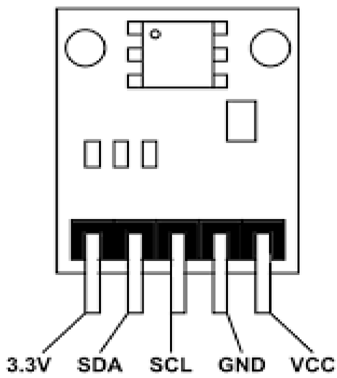


Figure.5.5.BMP 180 Sensor

BMP180 is one of sensor of BMP XXX series. They are all designed to measure Barometric Pressure or Atmospheric pressure. BMP180 is a high precision sensor designed for consumer applications. Barometric Pressure is nothing but weight of air applied on everything.

CHAPTER 6

FABRICATION AND CHOOSING OF MATERIALS

6.1. Fabrication

6.1.1. Materials used for fabrication

1. PLA (Polylactic Acid)

2. 3D printer

6.1.2. PLA material

Polylactic acid or polylactide (PLA) is a thermoplastic polyester with backbone formula (C3H4O2) n or [–C (CH3) HC (=O) O–] n, formally obtained by condensation of lactic acid C (CH3) (OH) HCOOH with loss of water (hence its name). It can also be prepared by ring-opening polymerization of lactide [–C (CH3) HC (=O) O–] 2, the cyclic dimer of the basic repeating unit. PLA has become a popular material due to it being economically produced from renewable resources. In 2010, PLA had the second highest consumption volume of any bioplastic of the world, although it is still not a commodity polymer. Its widespread application has been hindered by numerous physical and processing shortcomings. PLA is the most widely used plastic filament material -in 3D printing. The name "polylactic acid" does not comply with IUPAC standard nomenclature, and is potentially ambiguous or confusing, because PLA is not a polyacid (polyelectrolyte), but rather a polyester.

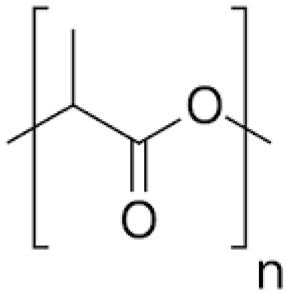


Figure.6.1. PLA chemical formula

MATERIL PROPERTIES OF PLA	NATURE WORKS OF PLA	BIOMER L9000
Melt flow rate (g/10 min)	4.3-2.4	3-6
Density (g/cm^3)	1.25	1.25
Yellowness index	20-60	-
Tensile strength at yield (MPA)	53	70
Elongation at yield (%)	10-100	2.4
Flexural modulus (MPA)	350-450	3600
Melting point ºC	120-1704	

Table.6.1. PLA PROPERTIES

6.2. Production

The monomer is typically made from fermented plant starch such as from corn, cassava, sugarcane or sugar beet pulp. Several industrial routes afford usable (i.e. high molecular weight) PLA. Two main monomers are used: lactic acid, and the cyclic di-ester, lactide. The most common route to PLA is the ring-opening polymerization of lactide with various metal catalysts (typically tin octoate) in solution or as a suspension. The metal-catalyzed reaction tends to cause racemization of the PLA, reducing its stereoregularity compared to the starting material (usually corn starch). Another route to PLA is the direct condensation of lactic acid monomers. This process needs to be carried out at less than 200 °C; above that temperature, the entropically favoured lactide monomer is generated. This reaction generates one equivalent of water for every condensation (esterification) step. The condensation reaction is reversible and subject to equilibrium, so removal of water is required to generate high molecular weight species. Water removal by application of a vacuum or by azeotropic distillation is required to drive the reaction toward polycondensation. Molecular weights of 130 kDa can be obtained this way. Even higher molecular weights can be attained by carefully crystallizing the crude polymer from the melt. Carboxylic acid and alcohol end groups are thus concentrated in the amorphous region of the solid polymer, and so they can react. Molecular weights of 128–152 kDa are obtainable thus shown in given below figure 6.2

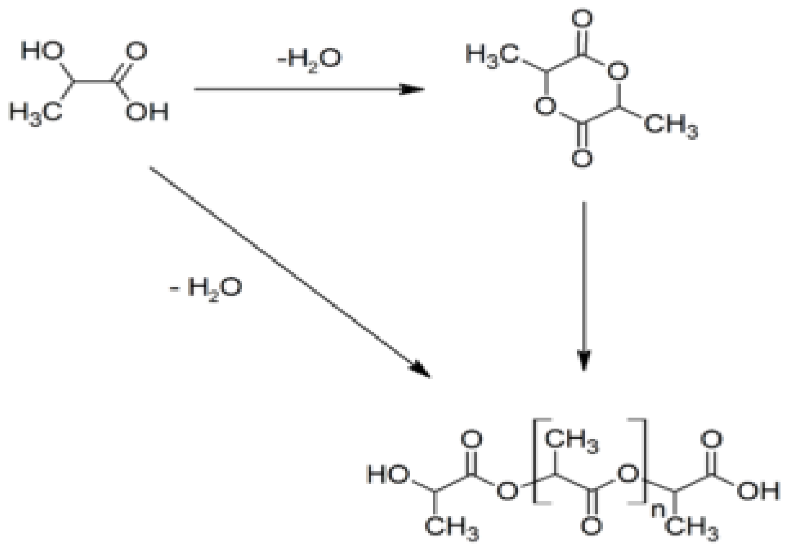


Figure.6.2. Production of PLA

Polymerization of a racemic mixture of L- and D-lactides usually leads to the synthesis of poly-DL-lactide (PDLLA), which is amorphous. Use of stereospecific catalysts can lead to heterotactic PLA which has been found to show crystallinity. The degree of crystallinity, and hence many important properties, is largely controlled by the ratio of D to L enantiomers used, and to a lesser extent on the type of catalyst used. Apart from lactic acid and lactide, lactic acid O-carboxyanhydride ("lac-OCA"), a five-membered cyclic compound has been used academically as well. This compound is more reactive than lactide, because its polymerization is driven by the loss of one equivalent of carbon dioxide per equivalent of lactic acid. Water is not a co-product. The direct biosynthesis of PLA similar to the poly (hydroxyalkanoate) s has been reported as well. Another method devised is by contacting lactic acid with a zeolite. This condensation reaction is a one-step process, and runs about 100 °C lower in temperature.

6.3. Properties

6.3.1. Chemical properties

Due to the chiral nature of lactic acid, several distinct forms of polylactide exist: poly-L-lactide (PLLA) is the product resulting from polymerization of L, L-lactide (also known as L-lactide). PLA is soluble in solvents, hot benzene, tetrahydrofuran, and dioxane.

6.3.2. Physical properties

r PLA polymers range from amorphous glassy polymer to semi-crystalline and highly crystalline polymer with a glass transition 60–65 °C, a melting temperature 130-180 °C, and a tensile modulus 2.7–16 GA.[12][13][14] Heat resistant PLA can withstand temperatures of 110 °C.[15] The basic mechanical properties of PLA are between those of polystyrene and PET.[12] The melting temperature of PLLA can be increased by 40–50 °C and its heat deflection temperature can be increased from approximately 60 °C to up to 190 °C by physically blending the polymer with PDLA (poly-D-lactide). PDLA and PLLA form a highly regular stereo complex with increased crystallinity. The temperature stability is maximized when a 1:1 blend is used, but even at lower concentrations of 3–10% of PDLA, there is still a substantial improvement. In the latter case, PDLA acts as a nucleating agent, thereby increasing the crystallization rate [citation needed.With high surface energy, PLA has easy printability which makes it widely used in 3-D printing. The tensile strength for 3-D printed PLA was previously determined. There is also poly (L-lactide-co-D, L-lactide) (PLDLLA) – used as PLDLLA/TCP scaffolds for bone engineering 6.3.3. Solvent welding PLA can be solvent welded using dichloromethane. 6.3.4. Organic Solvents for PLA is soluble in a range of organic solvents. Ethyl acetate, due to its ease of access and low risk of use, is of most interest. If the filament is soaked in a small amount of ethyl acetate, it will dissolve and can be used to clean 3D printing extruder heads or remove PLA supports.

6.4. Applications

PLA is used as a feedstock material in desktop fused filament fabrication 3D printers (e.g. RepRap).[30][31] PLA-printed solids can be encased in plaster-like moulding materials, then burned out in a furnace, so that the resulting void can be filled with molten metal. This is known as "lost PLA casting", a type of investment casting. PLA can degrade into innocuous lactic acid, so it is used as medical implants in the form of anchors, screws, plates, pins, rods, and as a mesh. Depending on the exact type used, it breaks down inside the body within 6 months to 2 years. This gradual degradation is desirable for a support structure, because it gradually transfers the load to the body (e.g. the bone) as that area heals. The strength characteristics of PLA and PLLA implants are well documented. PLA can also be used as a decomposable packaging material, either cast, injection-molded, or spun. Thanks to its bio-compatibility and biodegradability, PLA has also found ample interest as a polymeric scaffold for drug delivery purposes. Racemic and regular PLLA has a low glass transition temperature, which is undesirable. A stereo complex of PDLA and PLLA has a higher glass transition temperatures, lending it more mechanical strength. It has a wide range of applications, such as woven shirts (iron ability), microwavable trays, hot-fill applications and even engineering plastics (in this case, the stereo complex is blended with a rubber-like polymer such as ABS). Such blends also have good form stability and visual transparency, making them useful for low-end packaging applications. Pure poly-L-lactic acid (PLLA), on the other hand, is the main ingredient in Sculptra, a long-lasting facial volume enhancer, primarily used for treating lipoatrophy of cheeks. Progress in biotechnology has resulted in the development of commercial production of the D enantiomer form, something that was not possible until recently.

6.5. Degradation

PLA is degraded abiotically by three mechanisms: Hydrolysis: The ester groups of the main chain are cleaved, thus reducing molecular weight. Thermal degradation: A complex phenomenon leading to the appearance of different compounds such as lighter molecules and linear and cyclic oligomers with different Mw, and lactide. Photodegradation: UV radiation induces degradation. This is a factor mainly where PLA is exposed to sunlight in its applications in plasticulture, packaging containers and films. After 30 days of submersion in DMEM+FBS, a PLLA scaffold lost about 20% of its weight. PLA samples of various molecular weights were degraded into methyl lactate (a green solvent) by using a metal complex catalyst. PLA also be degraded by some bacteria, such as Amycolatopsis and Saccharothrix. A purified protease from Amycolatopsis sp., PLA depolymerase, can also degrade PLA. Enzymes such as pronase and most effectively proteinase K from Tritirachium album degrade PLA.

6.6. End of life

Four possible end of life scenarios are the most common: Recycling: which can be either chemical or mechanical. Currently, the SPI resin identification code 7 ("others") is applicable for PLA. In Belgium, Galactic started the first pilot unit to chemically recycle PLA (Loopla)[citation needed]. Unlike mechanical recycling, waste material can hold various contaminants. Polylactic acid can be recycled to monomer by thermal depolymerization or hydrolysis. When purified, the monomer can be used for the manufacturing of virgin PLA with no loss of original properties [citation needed] (cradle-to-cradle recycling).[dubious – discuss] Composting: PLA is biodegradable under industrial composting conditions, starting with chemical hydrolysis process, followed by the microbial digestion, to ultimately degrade the PLA. Incineration: PLA can be incinerated, leaving no residue and producing 19.5 MJ/kg (8,368 btu/lb) of energy. Landfill: the least preferable option is landfilling because PLA degrades very slowly in ambient temperatures.

6.7. 3D PRINTED FRAME

A 3D printed GIMBAL MECHANISM frame is attained and various finite element analysis performed on the frame are distinctly mentioned and plotted in the figures. Further, we have also taken 3d printed motor mount to install servo motors. Also, we have implemented the Arduino board to control and also gyro sensor and barometric sensor. This shows the main advantage of the gimbal mechanism.

Figure.6.3. 3D Printed Frame of Gimbal mechanism

CHAPTER 7

ASSEMBLING METHODOLOGY AND TESTING OF GIMBAL MECHANISM

7.1. ASSEMBLING PARTS OF GIMBAL MECHANISM

7.1.1. ASSEMBLING OF FRAME

We have printed the parts individually of three parts separately and we have assembled the parts by screwing the steel screw, we can use whichever materials we like to construct the gimbal mechanism, just make sure to pick materials which can hold structure and shape, such as plastic, or metal. For Gimbal we have to make sure that, we use material which can hold the load and withstand the mechanism. We used PLC material, which is a plastic material and printed and assembled.

7.1.2. ASSEMBLING OF MOTORS

If we are building a gimbal mechanism, how the role of the frame and screws, the same role will be there for the servo motors, that we are going to use. Make sure that we have correctly printed the motor mounts for the assembling of two servo motors. We have fixed the motors to the motor mount safely to make the movements accurate of the mechanism by using the connecting rods to the frame.

7.1.3. ASSEMBLING OF ARDUINO UNO

In our project, the Arduino will be acted as a Flight controller, it interprets input from the source of our laptop, where we are going to upload the programming to the Arduino UNO Board, in that so many electronics will be there to control the movement of the gimbal mechanism for the axis that we want.

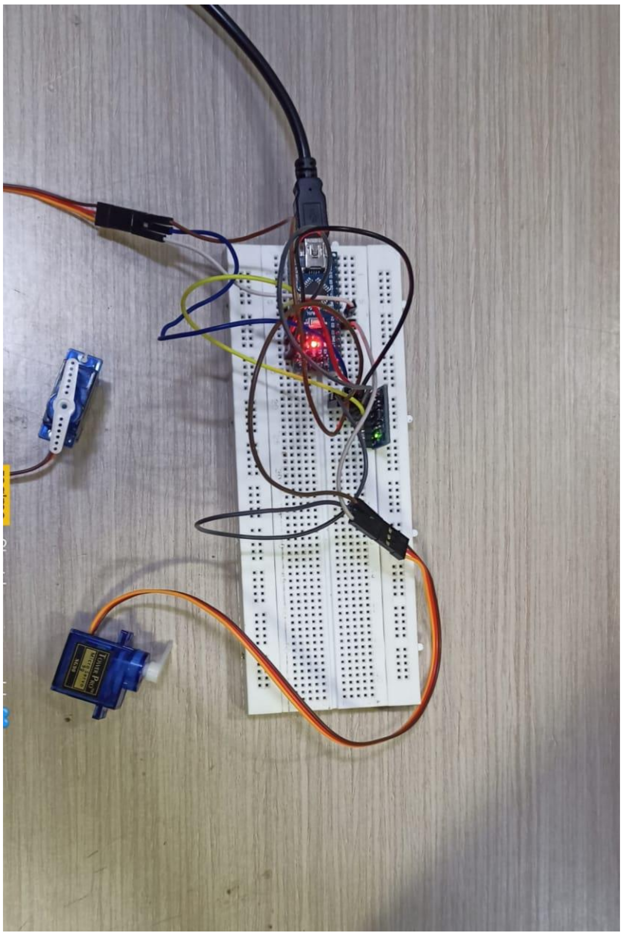


Figure.7.1. Assembling of Gyroscopic sensor

7.1.4. ASSEMBLING OF GYRO SENSOR

A gyroscope is an instrument, consisting of a wheel mounted into two or three gimbals providing pivoted supports, for allowing the wheel to rotate about a single axis. A set of three gimbals, one mounted on the other with orthogonal pivot axes, may be used to allow a wheel mounted on the innermost gimbal to have an orientation remaining independent of the orientation, in space, of its support.

In the case of a gyroscope with two gimbals, the outer gimbal, which is the gyroscope frame, is mounted so as to pivot about an axis in its own plane determined by the support. This outer gimbal possesses one degree of rotational freedom and its axis possesses none. The second gimbal, inner gimbal, is mounted in the gyroscope frame (outer gimbal) so as to pivot about an axis in its own plane that is always perpendicular to the pivotal axis of the gyroscope frame (outer gimbal). This inner gimbal has two degrees of rotational freedom.

Here we have taken Gyroscopic sensor, which is MPU6050 works as the main instrument for our project and it can be used as the movement for the gimbal mechanism, by moving the sensor it make changes in the direction accordingly.

The axle of the spinning wheel defines the spin axis. The rotor is constrained to spin about an axis, which is always perpendicular to the axis of the inner gimbal. So the rotor possesses three degrees of rotational freedom and its axis possesses two. The wheel responds to a force applied to the input axis by a reaction force to the output axis.

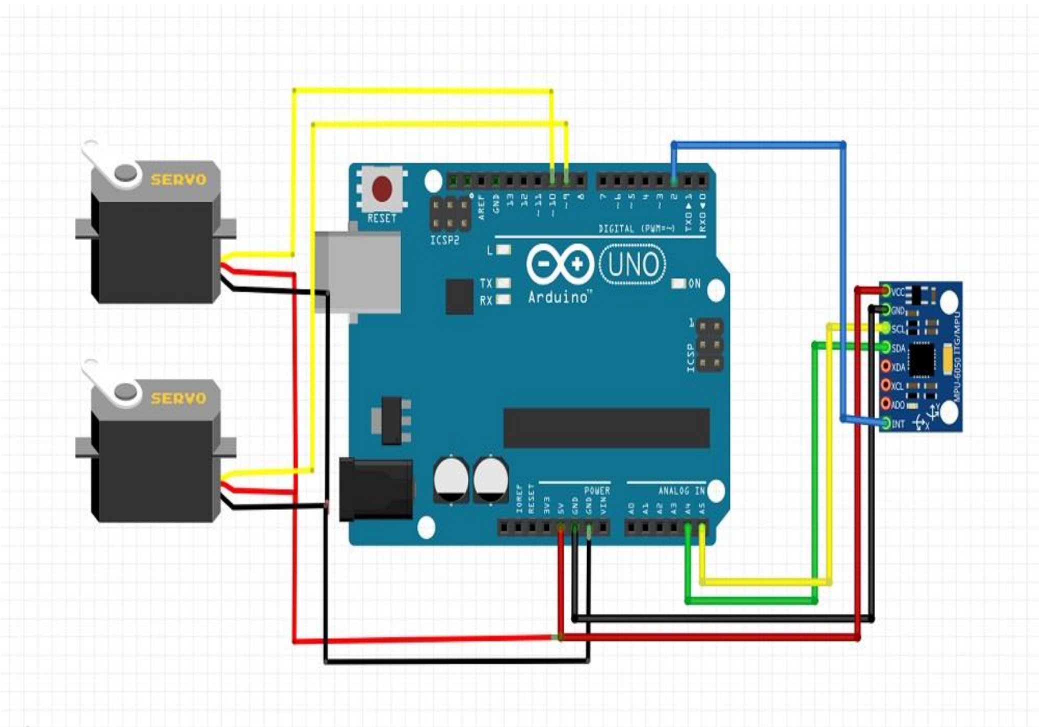


Figure.7.2. Electronic circuit connections of our gimbal mechanism

7.2 TESTING AND VALIDATION

After assembling, testing can be done by giving all the connections of the electronic parts like servo motors, Arduino UNO, Gyroscopic sensor, Barometric sensor, Bread board by using jumper wires. The programming can be compiled and uploaded to UNO board by using cable from Laptop.

PROGRAMMING FOR WORKING

```
#include "Wire.h"
#include "I2Cdev.h"
#include "MPU6050.h"
#include "Servo.h"
MPU6050 mpu;
int16_t ax, ay, az;
int16_t gx, gy, gz;
Servo servo1;
Servo servo2;
int val1;
int val2;
int prevVal1;
int prevVal2;
void setup()
{
Wire.begin();
Serial.begin(38400);
Serial.println("Initialize MPU");
mpu.initialize();
```

```
Serial.println(mpu.testConnection() ? "Connected" : "Connection failed");
servo1.attach(2);
servo2.attach(5);
}
void loop()
{
mpu.getMotion6(&ax, &ay, &az, &gx, &gy, &gz);
val1 = map(ax, -171, 17000, 180,0);
if (val1 != prevVal1)
{
servo1.write(val1);
prevVal1 = val1;
}
val2 = map(ay, -171, 17000, 0, 180);
if (val2 != prevVal2)
{
servo2.write(val2);
prevVal2 = val2;
}

}
```
[5]

RESULT OF PRODUCT

PARAMETERS

Voltage: 5V

Deflection: 180^{o}

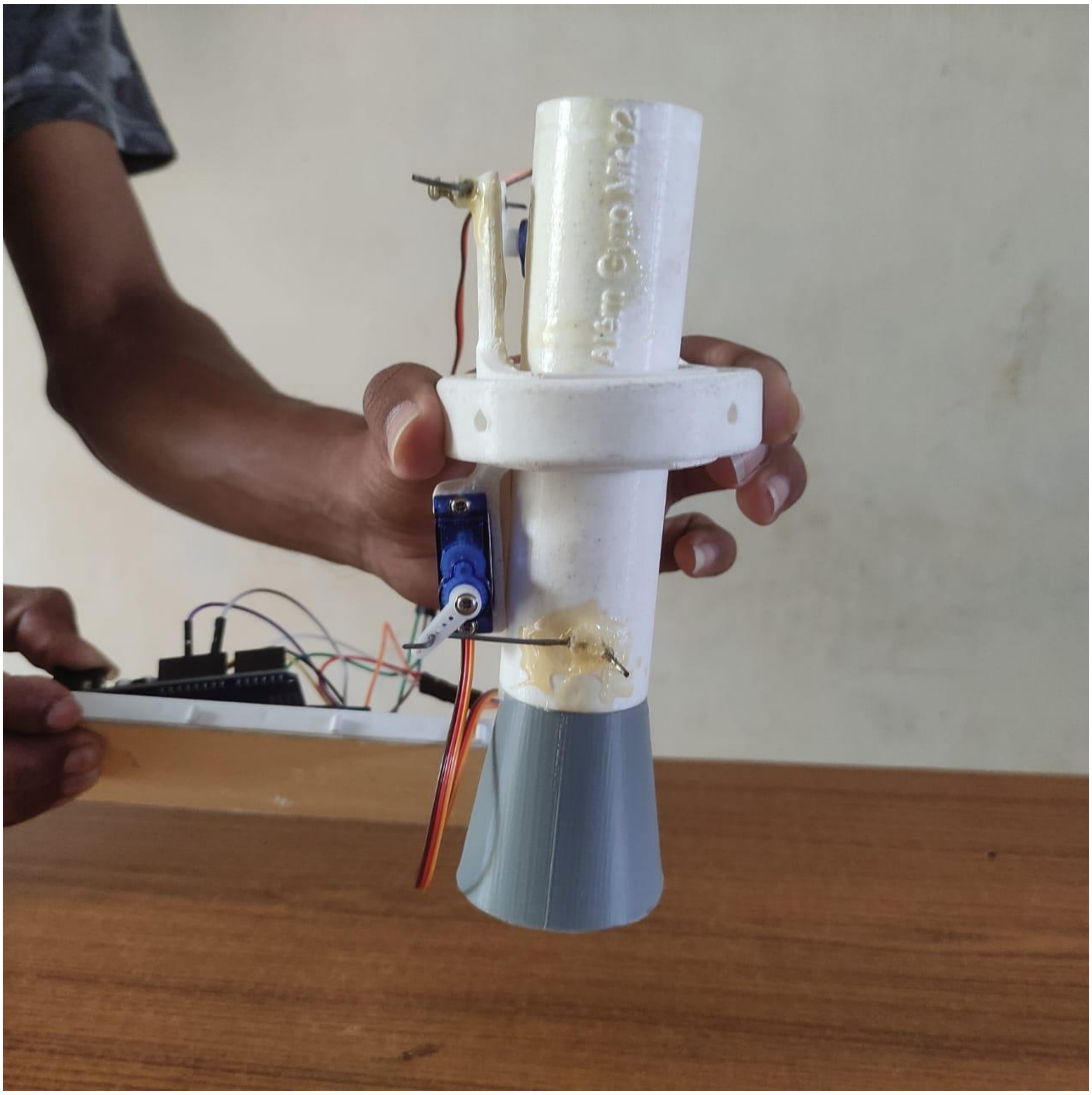


Figure.7.3 Deflection along one direction

After making all the connections, the rocket nozzle can be controlled by changing the direction of the gyroscopic sensor tilting it in one direction, make changes in deflection of nozzle according to that as shown in Fig.7.3, the same thing applies to the other condition, if we move the gyroscopic sensor in another direction, it will move in opposite direction as shown in Fig.7.4.

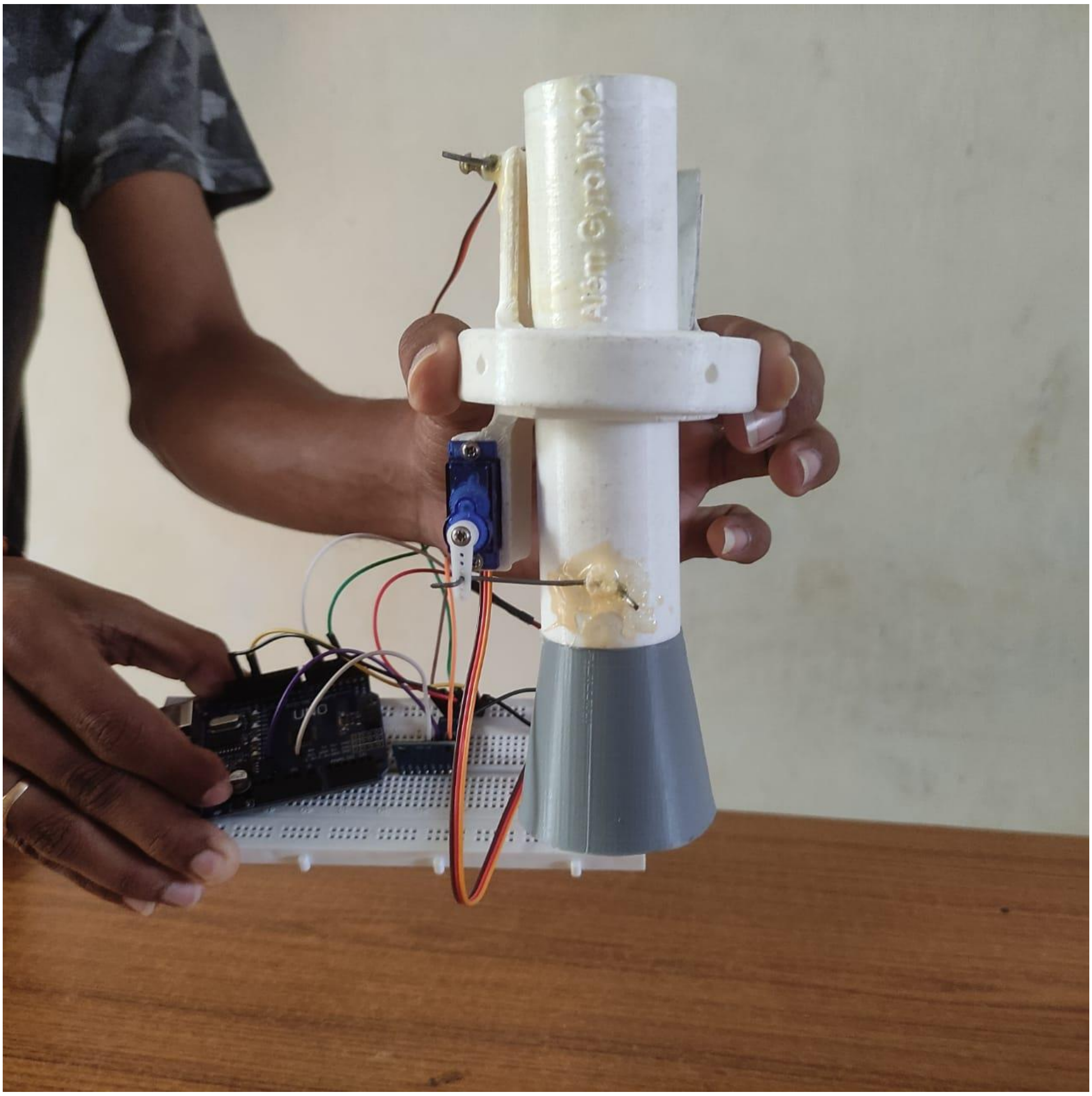


Figure.7.4. Deflection along another direction

CHAPTER 8

CONCLUSION & RESULT

The aim of the presented work was the design and fabrication of a thrust vector control system (gimbal mechanism) model thrust vectoring, also known as thrust vector control (TVC), is the ability of an aircraft, rocket, or other vehicle to manipulate the direction of the thrust from its engine(s) or motor(s) to control the attitude or angular velocity of the vehicle. In recent years the Gimbal Mechanism in Thrust Vector Control is the most useful mechanism that has been implementing by many successful companies in space launch vehicles, including the Space Shuttle, the Saturn V lunar rockets, and the Falcon 9.

Our developed thrust vector control system (Gimbal Mechanism) for a model rocket instead of using a fin stabilized system. Guided model rocket can be made using thrust vector control system. Thrust vectoring concept is implemented in model rocket using gimbal mechanism. In this further development can be done by increasing the performance of mechanism using additional other TVC system like Thrust Vector Control by injecting propellant at the Rocket nozzle.**[2]**

This project is particularly concentrated to make controlling and stability of rocket easily and can be implemented in future rockets, which makes less load to rockets.

Future enhancement can be done by adding SD card and other storage devices, which stores programming instead of uploading at every time to microcontroller. Moreover, the designed control system should be updated with the extra electronic devices. A mass variation model should also be considered when long flight times are taken into account.

Our project Design and Fabrication of Thrust Vector Control (Gimbal mechanism) was successfully assembled and tested for working. The result was, it can be used for controlling the vector of rocket vector within 180 degrees by rotation of nozzle.

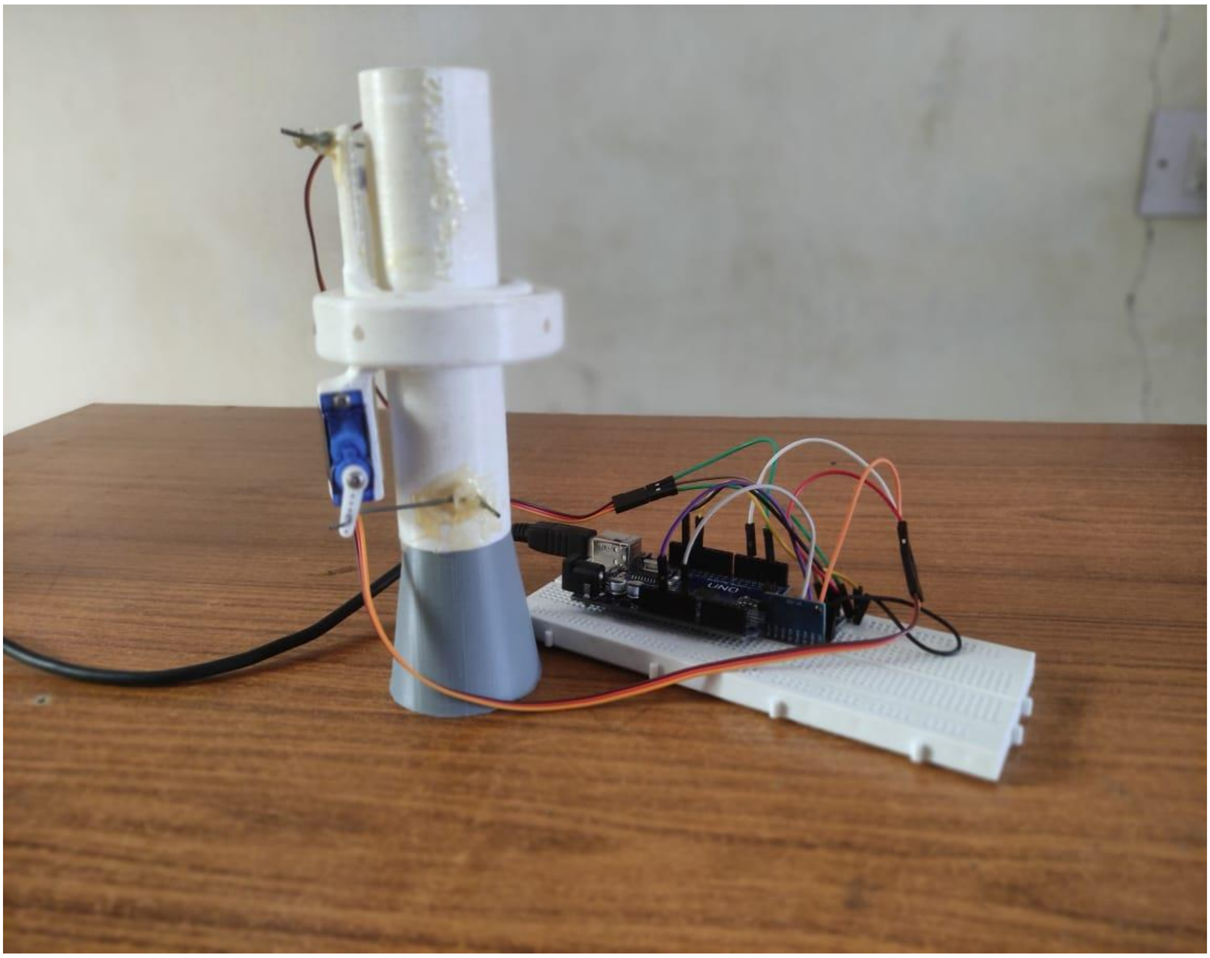


Figure.8.1. Final product

REFERENCES

1. Design and Implementation of thrust vector control system by Ahmet Unal, Kemal Yaman, Emri Okur and Mehmet Arif Adli. Journal of making Thrust Vector Control System originally published online in March 2018.

2. Side Thrust Control by Secondary Gas Injection into Rocket Nozzles by J. H. Neilson, A. Gilchrist, and C. K. Lee.Journal of making side thrust control by secondary gas injection into rocket nozzle originally published online on 1 June 1968.

3. Thrust vector control for nuclear rockets by Clinton B.F. Ensworth. Journal of making side thrust control for nuclear rockets originally published online in October 2013.

4. Thrust Vectoring of Small -scale Rocket motor using additively manufactured jet vanes by Joseph. X and Ezra Tal. Journal of making thrust vectoring of small rocket motor using additively manufactured jet vanes originally published online in July 2021.

5. Microcontroller Programming Using Arduino and Python by Sudhakar Kumar, Manas Das and Nirmala Venkat. Journal of making microcontroller programming using Arduino and python originally published online in June 2021.