DE-40 (DEE)

NUST COLLEGE OF

ELECTRICAL AND MECHANICAL

ENGINEERING

PAKISTAN MANUFACTURED AUTOMATED INJECTION PUMP

A PROJECT REPORT

DE-40 (DEE)

Submitted by

MAIDAH BINTE TARIQ

FIZA WAHEED

SIDRA PARVEEN

AYESHA SADDIQA

BACHELORS

IN

ELECTRICAL ENGINEERING

YEAR 2022

PROJECT SUPERVISOR

DR. MUWAHIDA LIAQUAT

YEAR 2022

NUST COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

PAKISTAN MANUFACTURED AUTOMATED INJECTION PUMP

A PROJECT REPORT

DE-40 (DEE)

Submitted by

MAIDAH BINTE TARIQ

FIZA WAHEED

SIDRA PARVEEN

AYESHA SADDIQA

BACHELORS

IN

ELECTRICAL ENGINEERING

YEAR

2022

PROJECT SUPERVISOR

DR MUWAHIDA LIAQUAT

NUST COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

CERTIFICATE OF APPROVAL

It is certified that the project "**PAKISTAN MANUFACTURED AUTOMATED INJECTION PUMP**" was done by **Maidah Binte Tariq, Fiza Waheed, Sidra Parveen and Ayesha Saddiqa** under supervision of **Dr. Muwahida Liaquat.**

This project is submitted to **Department of Electrical Engineering**, College of Electrical and Mechanical Engineering, National University of Sciences and Technology, Pakistan in partial fulfilment of requirements for the degree of Bachelor of Engineering in Electrical Engineering.

1- Maidah Binte Tariq

NUST ID:______________________________ Signature:____________________

2- Fiza Waheed

NUST ID:______________________________ Signature:____________________

3- Sidra Parveen

NUST ID:______________________________ Signature:____________________

4- Ayesha Saddiqa

NUST ID:______________________________ Signature:____________________

APPROVED BY:

Project Supervisor:__________________________Date: __________________________

Dr. Muwahida Liaquat

Head of Department:_______________________Date: _______________________

Dr. Fahad Malik

DECLARATION

We hereby declare that no portion of the work referred to this Project Thesis has been submitted in support of an application for another degree or qualification of this of any other university or other institute of learning. If any act of plagiarism, we are fully responsible for every disciplinary action taken against us depending upon the seriousness of the proven offence, even the cancellation of our degree.

1. **Maidah Binte Tariq** ____________________________

2. **Fiza Waheed** ____________________________

3. **Sidra Parveen** ____________________________

4. **Ayesha Saddiqa** ____________________________

COPYRIGHT STATEMENT

ACKNOWLEDGEMENT

First and foremost, thanks to Allah Almighty, Who gave us ability and courage to understand the things, by the grace of Whom every obstacle was dissolved in the fulfillment of this arduous task.

Apart of the efforts of the group, the success of any project depends largely on the encouragement and guidelines of many others. We wish to express our gratitude to our supervisor, **Dr. Muwahida** who was abundantly helpful and offered invaluable assistance, support and guidance.

In addition, nothing would have been possible without the help of our beloved parents. Their unrelenting support and patience were instrumental. They were always there for us in our time of need.

In the end, we can't thank enough our department, **Department of Electrical Engineering**, for nurturing us over the years and helping us excel in our field. We are appreciative of all the faculty members and staff, who have played their roles impeccably in ensuring that we are provided with the best facilities and treatment.

ABSTRACT

Robotics and their applications in numerous industries are gaining popularity around the world today. There are syringe pumps on the market that are well-suited for micro-fluidic applications, which aids research in fields like micro-environmental management. In medical and scientific research, syringe pumps can help with precise infusions, such as feeding small animals or providing small amounts to specific areas of the brain in neuroscience tests. In several advanced research sectors, syringe pumps are also useful for speeding up research and decreasing inaccuracies during fluid administration. The ability to give enhanced accuracy and precision is the most important feature of syringe pumps. Syringe pumps are also fairly simple to use. Not only does the gadget provide precise medicine dosing, but it also eliminates the need for dilution and reduces drug waste. Furthermore, this technique allows for the continuous infusion of fluids. It's also simple to change the infusion rate and solution. Our injection pump, which we created and built as part of our project, would allow us to manage the amount of fluid that flowed while remaining flexible at the input and precise at the exit.

Contents

Abstract 7
CHAPTER 1: INTRODUCTION 13
1.1 Background 13
1.2 Problem Statement 15
1.3 Objectives 15
CHAPTER 2: LITERATURE REVIEW 17
2.1 Automating Chemicals 17
2.2 Chemical Injection Pumps 17
2.2.1 Working 17
2.2.2 Types and Uses 18
1. Positive Displacement Pumps 18
2. Dynamic Pumps 19
3. Centrifugal pumps 20
4. EDDY Pump 21
5. Dosing Pump 21
2.2.3 Pumps in Food Industry 22
CHAPTER 3: METHODOLOGY 23
3.1 Objectives 23
3.2 Proposed Methodology 23
3.3 PID Controller 24
3.3.1 Algorithms used in PID controller 24
1. Interactive Algorithm: 24
2. Non-interactive Algorithm: 25
3. Parallel Algorithm: 25
3.3.2 Tuning methods for PID loop 26
3.4 3D Printing 26
3.4.1 3D Modelling 26
3.4.2 Techniques used in 3D printing 27
1. Fused Deposition Melting (FDM): 27
2. Stereolithography (SLA): 28
3. Digital Light Processing (DLP): 29
4. Selective Laser Sintering (SLS): 29
3.4.3 Why SLA is better than FDM? 29
3.5 PCB 29
3.5.1 Design 29
3.5.2 Printing the design 30
3.5.3 Substrate 30
3.5.4 Removal of excess copper 31

3.5.5 Inspection 31
3.5.6 Fusion of layers 31
3.5.7 Drilling 31
3.5.8 Plating 31
3.5.9 Outer layer protection 31
3.5.10 Tin coating 32
3.5.11 Etching 32
3.5.12 Solder Mask Application 32
3.5.13 Silk-screening 32
3.5.14 Surface Finishing 33
3.5.15 Testing 33
CHAPTER 4: SOFTWARE 34
4.1 Software 34
4.2 Circuit Diagram 35
4.2.1 Motor Control 35
4.2.1.1 Test Circuit 35
4.2.2.2 Code 35
4.2.2.2.1 Pin Declaration 36
4.2.2.2.2 Setup 36
4.2.2.2.3 Controlling Motor 37
4.2.2 Encoder Based Feedback Motor Control Circuit 37
4.2.2.1 Encoder-Based Arduino Code 39
4.2.2.1 Including Library 45
4.2.2.2 Variable Declaration 46
4.2.2.3 Pin Declaration 47
4.2.2.4 Main Motor Control 48
4.2.2.5 Current Position Correction through Arduino Timing 49
4.2.2.6 Feedback Error Correction 50
4.3 Control Systems 51
4.3.1 Calculation of Controlling Variables kp, ki, & kd 52
CHAPTER 5: HARDWARE ASSEMBLY 54
5.1 Introduction 54
5.2 Micro Metal Gearmotor HPCB 12V with Extended Motor Shaft 54
5.2.1 Gearmotor Dimensions 55
5.2.2 Versions with dimensions of carbon brushes (HPCB) 56
5.2.3 Accessories of Motor 56
1. Wheels and hubs 56
2. Mounting Brackets 57
3. Motor Controllers and Drivers 57

4. Current Sensors 58
5.2.4 Selection of the Right Gearmotor 58
5.3 Magnetic Quadrature Incremental Encoder 59
5.3.1 Cables 61
5.3.2 Installation and Pinout 62
5.3.3 Schematic Diagram 64
5.4 Arduino Nano 65
5.5 L293D Motor Driver IC 66
5.6 Voltage regulator LM7805 67
CHAPTER 6: MECHANICAL ASSEMBLY 68
6.1 Introduction 68
6.2 Design of mechanical assembly 68
6.2.1 Design Requirements 68
6.2.2 Working Principle of Injection Mechanism 69
6.3 3D Modelling and Design 70
6.3.1 Piston: 71
6.3.2 Main Assembly: 73
6.3.3 Back Plate and Casing: 74
6.3.4 Cap: 75
6.3.5 Bushings and Shaft: 76
6.3.6 Assembled 3D Model: 77
6.4 Gear Reduction and Minimum Dose Calculation 77
CHAPTER 7: VEROBOARD PROTOTYPE AND PCB 80
7.1 Veroboard Prototype 80
7.1.1 Schematic 81
7.1.2 Assembled Circuit 81
7.2 PCB 82
7.2.1 Design 82
7.2.1.1 Components used: 82
7.2.1.2 PCB 82
7.2.1.3 Etched PCB 83
7.2.2 Working 84
CHAPTER 8: DISCUSSION AND CONCLUSION 85
8.1 Problems 85
8.2 Future Recommendations 86
CONCLUSION 87

Table of Figures

Figure 1: Illustration of Pump Machine 14
Figure 2: Basic model of the injection pump 15
Figure 3: Chemical Injection Pump 18
Figure 4: Design of Rotary Positive Displacement Pump 18
Figure 5: Basic Model of a Dynamic Pump 20
Figure 6: Pumping Systems in Food Industry 22
Figure 7: Closed Loop Feedback System 24
Figure 8: Interactive Algorithm for PID 24
Figure 9: Non-Interactive Algorithm for PID 25
Figure 10: Parallel Algorithm for PID 25
Figure 11: CAD Model 27
Figure 12: FDM Courtesy: The Technology House 28
Figure 13: Stereolithography 28
Figure 14: Gerber File 30
Figure 15: Solder Masking 32
Figure 16: Silk Screening 33
Figure 17: Proteus Design of the Test Circuit 35
Figure 18: Proteus Design of the Motor Control Circuit 37
Figure 19: Basic Block Diagram of the Working Principle 50
Figure 20: Simulink Model of DC Motor 51
Figure 21: Step Input 12V Response 52
Figure 22: Response through controlling variables 53
Figure 23: A general 12V DC Motor 54
Figure 24: Working graph of a DC Motor 55
Figure 25: Dimensions of carbon brushes (HPCB) 56
Figure 26: Wheel Adapter on a Micro Metal Gearmotor 56
Figure 27: Mounting Bracket Pair including nuts and screws 57
Figure 28: Different types of DC Motor Driver Carriers 58
Figure 29: Current Sensor Carriers 58
Figure 30: Varied Range of Metal Gearmotors 59
Figure 31: Magnetic Encoders 60
Figure 32: Magnetic Encoders aligned with a Gearmotor 60
Figure 33: Single-ended Cables with Dimensions 61
Figure 34: Twisted Female-Female Cables with Dimensions 61
Figure 35: A 6 pin Female JST Cable 62
Figure 36: Breakout Boards for JST Connectors 62
Figure 37: Magnetic Encoder alongwith the Connector Pins 63
Figure 38:Encoder Outputs using Micro Metal Gearmotor of a Magnetic Encoder 64
Figure 39: Schematic Diagram of Magnetic Encoder 64
Figure 40: An Arduino Nano including the Connector Pins 65
Figure 41: Specifications of Arduino Nano 66
Figure 42: L293D Motor Driver IC 67
Figure 43: LM7805 Voltage Regulator 67
Figure 44: Syringe available in Market 68
Figure 45: Working Principle of Injection Mechanism 69
Figure 46: Dimensions of Threaded Rod 70
Figure 47:CAD Design (LEFT)– 3D Printed parts (RIGHT) 70

Figure 48: Mechanical Drawing of the Assembly 71
Figure 49: Piston Mechanical Drawing 72
Figure 50: Blender Model of the Piston 72
Figure 51: Main Assembly Mechanical Drawing 73
Figure 52: Blender Model of Motor Casing 74
Figure 53: Back plate and Casing mechanical drawing 74
Figure 54:Cap mechanical drawing 75
Figure 55: Blender Model of Cap 75
Figure 56: Shaft 76
Figure 57: End Bushing 76
Figure 58: Support Bushing 76
Figure 59: Blender Model of Syringe Tube 77
Figure 60: Assembled 3D Model 77
Figure 61: Gear Ratios 78
Figure 62: Basic Block Diagram of the System 80
Figure 63: Veroboard Schematic 81
Figure 64: Veroboard prototype front 81
Figure 65: Veroboard prototype back 82
Figure 66: PCB Layout 82
Figure 67: Assembled PCB front 83
Figure 68: Assembled PCB back 83

CHAPTER 1: INTRODUCTION

1.1 Background

Now in the world of engineering or even in life decisions, accuracy and precision plays a vital role since a minor error can cost you billions of dollars or even cost you a life. That's why the world is moving more towards robotics and machinery revolving around controls and artificial intelligence. Even manual syringes are being rapidly replaced by programmed syringe pumps to reduce human error in everyday chemical mixings or dosages. We propose to design a modified portable injection pump that'll guarantee a precise, and controlled delivery of fluid.

For the use of modulation of small amounts of fluid, syringe pumps are used. This allows the flow of liquid to be customizable, programmable, and cost effective. These syringes are extensively used in many industries, such as medical and manufacturing industries. In the past few decades, the use of these syringes has increased and are now being implemented in the research industry as well. This growth is being developed with the inclusion of automation and miniaturization. This has resulted in the development of 'smart pumps' [1]. This has helped versatile the research industry with the additional benefits of increased accuracy, precision, and advancements in the digitalization of data storage. Hence, access to remote programming and dosage guidelines can be conveniently made.

These syringe pumps have a wide range of applications. These include transportation of chemicals, veterinary use, for feeding reactors, and liquid chromatography. Furthermore, gastight syringes are used in the performance of specific micro vaporization operations. Also, microfluidic dosage systems are extremely valuable for the epidemiological research and for diagnostic purposes. The figure below shows a labelled diagram of a syringe pump.

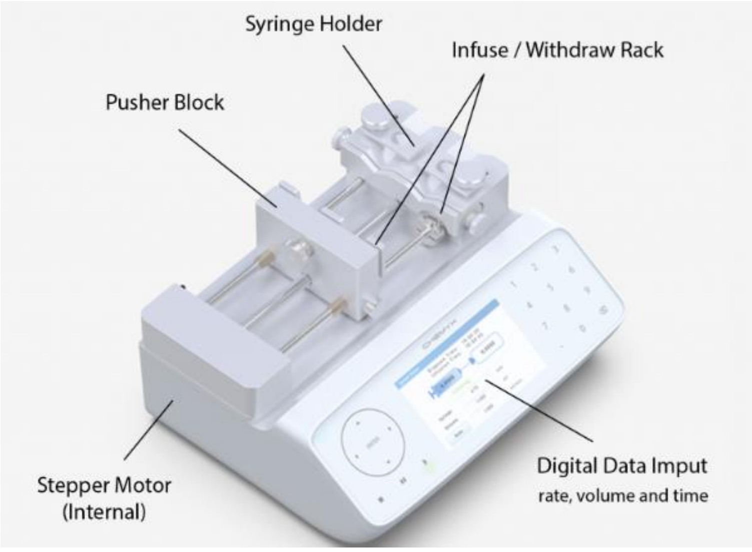


Figure 1: Illustration of Pump Machine

There are syringe pumps on the market that are well-suited for microfluidic applications, which aids research in areas like microenvironmental control. In medical and scientific research, syringe pumps can help with precise infusions, such as feeding small animals or providing small amounts to specific areas of the brain in neuroscience tests. In several advanced research sectors, syringe pumps are also useful for speeding up research and decreasing inaccuracies during fluid administration.

The ability to give enhanced accuracy and precision is the most important feature of syringe pumps. Syringe pumps are also fairly simple to use. Not only does the gadget provide precise medicine dosing, but it also eliminates the need for dilution and reduces drug waste. Furthermore, this technique allows for the continuous infusion of fluids. It's also simple to change the infusion rate and solution.

The pusher block, syringe holder, internal stepper motor, and LCD touchscreen interface are typical components of a syringe pump [2].

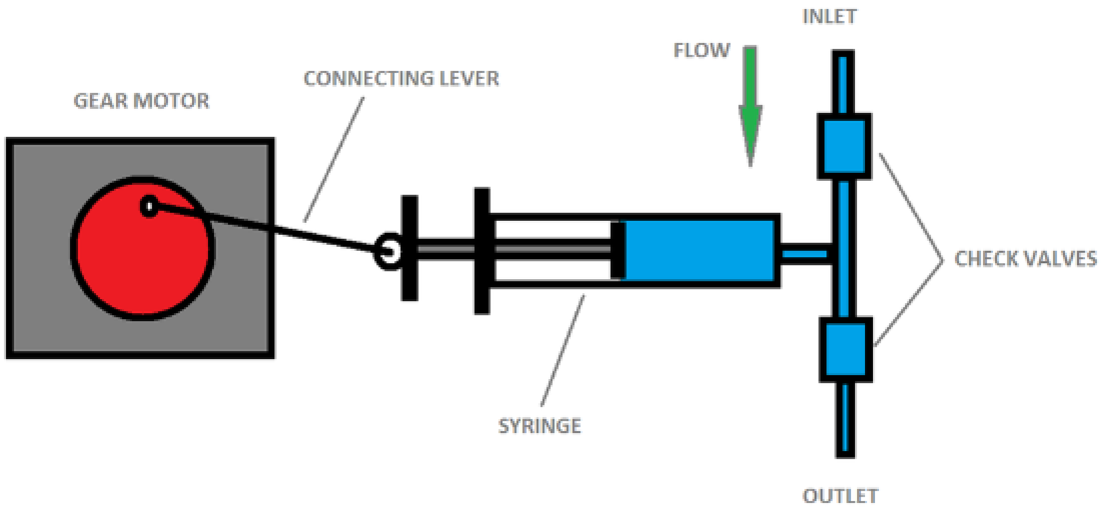


Figure 2: Basic model of the injection pump

The need to locally made this device in Pakistan lies in the fact that there are major drawbacks to use the international products. The imported products are very expensive and the hardware transportations are not that convenient thus making transport damage through imports that is another major drawback. As a result, local prototypes are required to save Pakistan's economy instead of importing it.

1.2 Problem Statement

Manual syringe pumps are not flexible as variations in manual mixing techniques can lead to false results. Human errors can cause a drastic effect. Manufacturing automatic pumps will not only help in reducing human errors but will also increase the accuracy and precision of the fluid being measured. Moreover, importing the products causes transportation damages. Also, it becomes highly expensive considering the external taxes being involved which could result in a downfall in Pakistan's unstable economy. Additionally, manual operations lack the now-highly-demanded specification of customer defined inputs to a defined accuracy [3].

1.3 Objectives

Aiming to standardize, simplify, and automate the chemical laboratory procedures in order to avoid the risk of potential errors. In achieving the prior mentioned statement our main objectives are:

- Design a local and affordable chemical mixing injection pump.
- Develop circuitry to effectively drive and control the device.

- Develop a model and implement control system of the device.
- Develop a mechanical assembly to fit the syringe and convert rotational motion into linear motion.
- Develop a stand-alone device to transfer fluids.

CHAPTER 2: LITERATURE REVIEW

2.1 Automating Chemicals

Innumerable methods rely on industrial chemicals. Chemicals are essential in the development of products, substances, and resources that fuel the global economy, stock our shelves, and feed our families. In the end, so much of the manufacturing job that drives output would be impossible without chemicals. When it comes to safeguarding the integrity of important assets, industrial speciality chemicals are very useful. We require chemicals to protect infrastructure and machinery from corrosion, kill harmful microorganisms, and neutralise hazardous by-products that might otherwise harm them.

With the current state of chemical management operations, however, giving the proper amount of chemical at the right time to the right area 24/7 is nearly impossible. Industrial manufacturing processes are quite dynamic, and they change frequently in order to maximise and speed up the production. [4] Unfortunately, chemical treatment procedures rarely keep up, putting industrial equipment at danger of failure on a regular basis. Operational managers require real-time, automated chemical programmes as well as full visibility into their performance in order to be effective.

2.2 Chemical Injection Pumps

Chemical pumps are utilised in a variety of industries, including the petrochemical, food processing, and chemical industries, as well as refinery off-site applications and high-temperature heating systems. They transport liquids that are hot, frosty, hostile, explosive, flammable, hazardous, polluted, and extremely valuable.

2.2.1 Working

A dosing pump pulls a predetermined volume of liquid into its chamber and injects it into a tank or pipe containing the fluid to be dosed. It's driven by an electric motor or an air actuator, and it features a controller that controls the flow rate and turns the pump on and off.

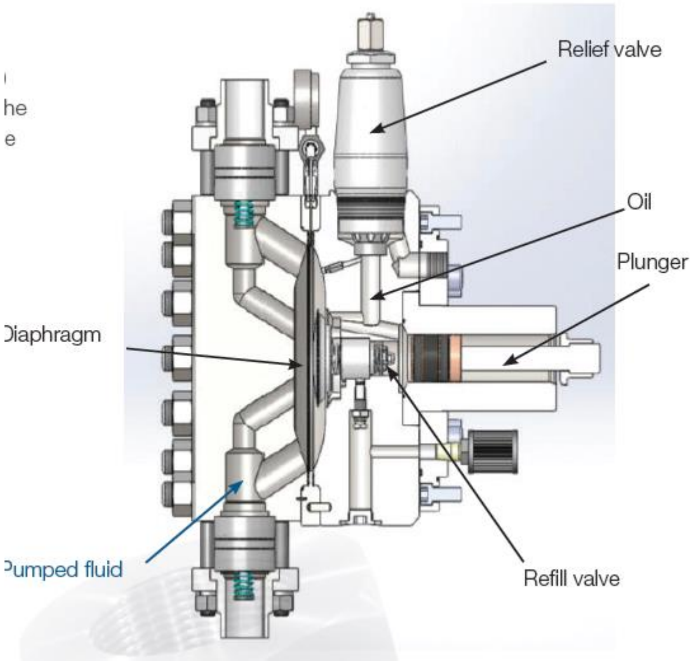


Figure 3: Chemical Injection Pump

2.2.2 Types and Uses

Pumps are primarily divided into two types; positive displacement pumps and dynamic pumps.

1. **Positive Displacement Pumps**

   Positive displacement pumps are designed to deliver a specific amount of fluid at a specific moment. On the suction side, internal chambers fill up, allowing for a higher-pressure discharge at the outlet. Depending on how fluid is ejected, positive displacement pumps can be reciprocating or rotational.

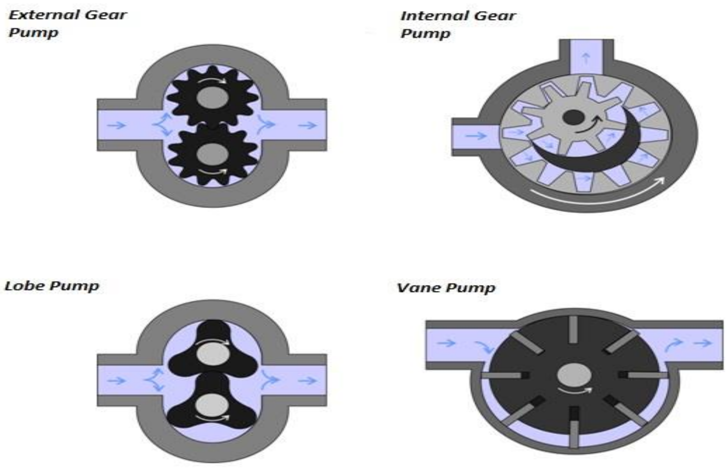


Figure 4: Design of Rotary Positive Displacement Pump

Sub-type	Description	Examples
Reciprocating Pump	Expansion and contraction inside the cavity, such as a piston, flow is established. During expansion, water flows into the cavity and during contraction it is forced out, with check valves controlling the flow direction.	Bladder Diaphragm Peristaltic Piston / plunger
Rotary Pump	The rotor of this pump catches water in cavities and releases it at the outlet. The spaces between gear teeth or screw threads, for example, might be used as cavities. The rotor shape is premeditated to collect "pockets" of water and displace them in the proposed direction. Some designs utilise more than one shaft, but the idea is the same.	Gear Screw Progressing cavity Rotary lobe Rotary vane

2. Dynamic Pumps

The dynamic pump is a form of velocity pump that uses increased flow velocity to impart kinetic energy to the fluid. When the velocity of the flow is lowered prior to or as it exits the pump into the discharge pipe, this increase in energy is transformed to a gain in potential energy (pressure) [5].

Dynamic pumps can be further segmented based on the method used to accomplish velocity gain. Pumps of this type have a variety of characteristics:

- Continual power
- Increase in kinetic energy due to the conversion of more energy (increase in velocity)
- Increased velocity (kinetic energy) is converted to a rise in pressure head.

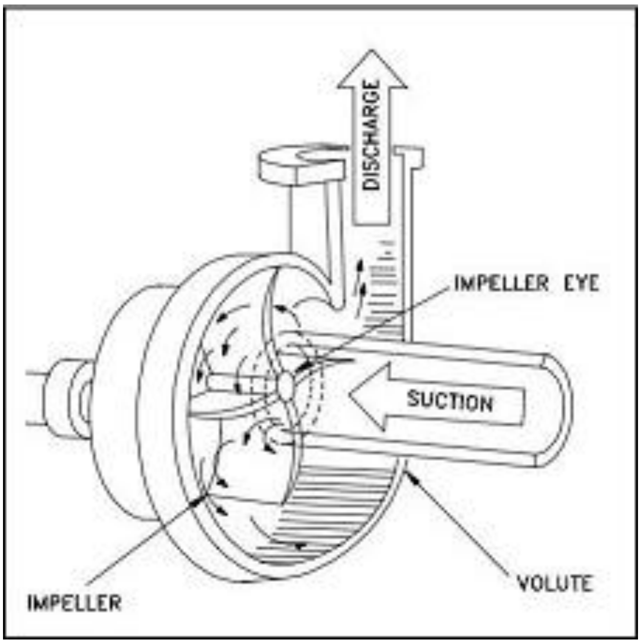


Figure 5: Basic Model of a Dynamic Pump

3. Centrifugal pumps

In the chemical sector, the most common type of pump are centrifugal pumps. Because of the simplicity and efficiency of their design and operation, they are the most popular type of chemical pump. They are also less costly than other types of pumps.

When a centrifugal pump rotates, the fluid is accelerated outer by the impeller's curved blades. Impellers are usually powered by an electric motor or a combustion engine, and their movement creates suction at the pump intake, which pulls water inside.

Centrifugal pumps are divided into three sorts based on the type of water flow they create. The impeller shape and the pump's structure both influence the flow pattern [6].

Sub-type	**Description**	**Performance**
Axial Flow Pump	It provides water flow along the impeller shaft direction, and is also known as a propeller pump.	Low pressure High flow rate
Radial Flow Pump	This pump creates flow perpendicular to the shaft (at a 90° angle).	High pressure Low flow rate

Mixed Flow Pump	This pump produces a conical flow pattern around the shaft by combining radial and axial flow.	Medium flow rate Medium pressure

4. EDDY Pump

Pumping very viscous material is a snap with the EDDY Pump. The geometric rotor of the EDDY Pump functions as a mixer on thixotropic materials and offers a shear thinning effect, allowing the pump to transfer high viscosity liquids significantly faster than other pumps.

5. Dosing Pump

A dosing pump is a positive displacement pump that is used to deliver extremely precise flow rates of a chemical or other substance into a fluid stream. This industrial pump works by drawing a certain amount of fluid into a chamber and then injecting that volume rate into the dosed container.

Comparison between Centrifugal and Positive Displacement Pumps

Both types of pumps move fluids in a specific direction, however continually rushing a fluid is not the same as displacing it in defined volumes. As a result, both pump types have significant performance variances.

Pump type	**Centrifugal pump**	**Positive displacement pump**
Effect of system pressure	Flow is lowered when the system puts more pressure against the pump.	Regardless of system pressure, flow remains constant. In response, the pump simply increases pressure.
Effect of fluid viscosity	The higher the viscosity of the fluid, the lower the flow rate and the lower the efficiency.	The flow rate of a fluid increases as the viscosity of the fluid increases.

2.2.3 Pumps in Food Industry

In processing and industrial applications, food pumps are used to transfer, mix, and dosage fluid and semi-fluid substances throughout the food and beverage industry. Pumps for food processing are made of food-grade materials with smooth surfaces to prevent food contamination and bacteria build-up.

Centrifugal pumps and positive displacement (PD) pumps, such as progressive cavity (CP) pumps and rotating lobe (RL) pumps, are commonly employed in food and beverage applications. The most popular type of kinetic-energy pump is the centrifugal pump.

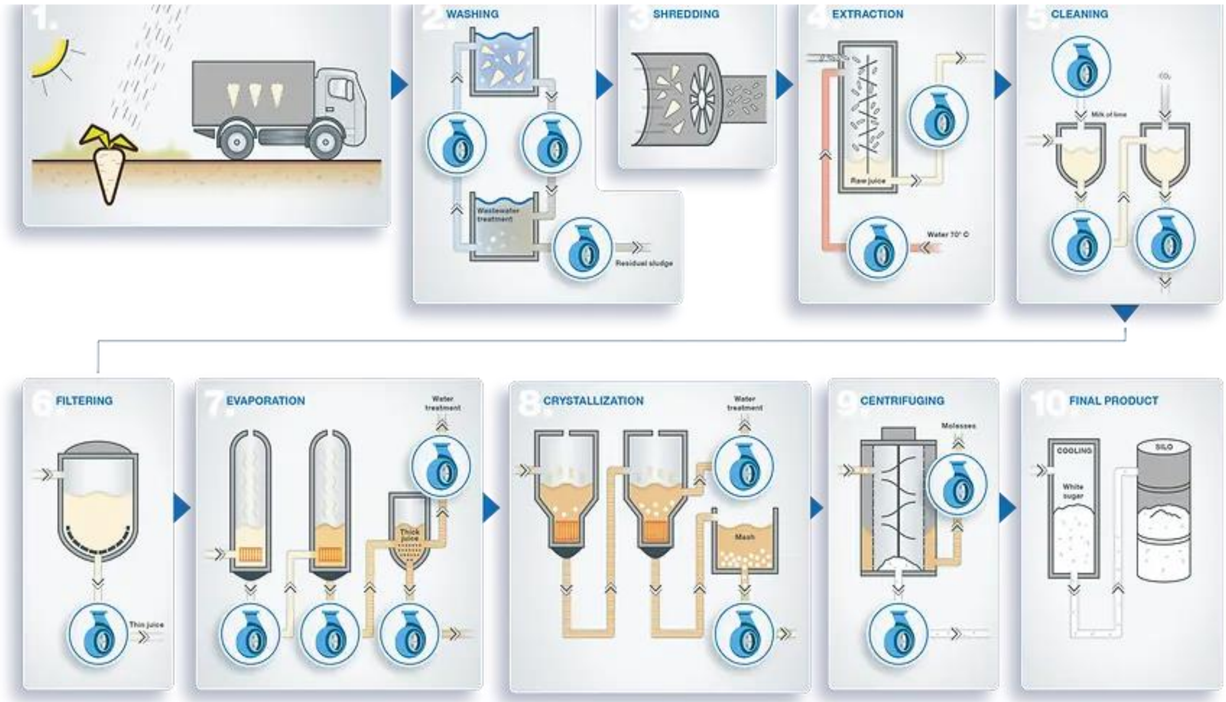


Figure 6: Pumping Systems in Food Industry

CHAPTER 3: METHODOLOGY

3.1 Objectives

Our project aims to design a low-cost automated injection pump that can be used locally with the main application revolving around laboratory chemical mixings for certain reactions. User-defined input encoded through the control system developed would help resolve the issues regarding variations in hand mixing processes while using manual syringe pumps, which otherwise can lead to erroneous results. The automatic pump will not only reduce human errors, but will also improve the accuracy and precision of the fluid being measured. Furthermore, developing local prototype would diminish the transportation losses if importing the pre-designed goods, and also the expensiveness when external tariffs are included in, which would otherwise jeopardize Pakistan's fragile economy. Furthermore, manual procedures lack the now-common requirement of specifying customer-defined inputs to a given precision thus motivating us to design an automated self-contained fluid transmission device.

3.2 Proposed Methodology

The main goal our project achieves is the automation of the manual syringes. We are controlling the amount of liquid flown at the output using a mini-DC geared motor and a 3D mechanical assembly. All of the operations are controlled by a microcontroller. After creating the PID control system, the Arduino-based microcontroller is programmed to achieve the requisite values of kp, ki, and kd. A magnetic disc and a hall effect sensor are used in the feedback loop to assure precision and accuracy, as well as to reduce deviations from the setpoint. The required RPM and PPR DC geared motor's speed and direction of rotation are adjusted to establish the liquid flow per pulse. Additionally, the low RPM of the motor enables our design to achieve the desired mixing of chemicals in mL, since very slow speed would correspond to small and accurate volumes of fluid being transferred. [7]

The electrical circuitry is followed by the 3D modelling designed in a way to convert the rotational motion of the motor to linear motion of the shaft which is to be led by the fluid containing chamber. The input is hardcoded into the Arduino code, which could also be inputted through an external keypad. The fluid chamber is replaceable with the desired chemical to transfer. Our project uses SLA material for the 3D model to achieve compact design to save space and reduce the cost.

Thus, now instead of using hand-power to control syringes, through the use of automation and control, the user’s comfort is enhanced as a result of electrical stability and mechanical strength.

3.3 PID Controller

A **proportional-integral-derivative** controller is a closed loop feedback controller broadly used in control systems. Controller calculates the error between setpoint and process variable and try to minimize this error by changing control variables.

The PID controller has three constant parameters controlled separately. That's why PID is also called **three-term control**. These three terms or constants are **proportional (P)** which depends on current error, **integral (I)** depends on sum of errors in past and derivative **(D)** which predicts the future errors

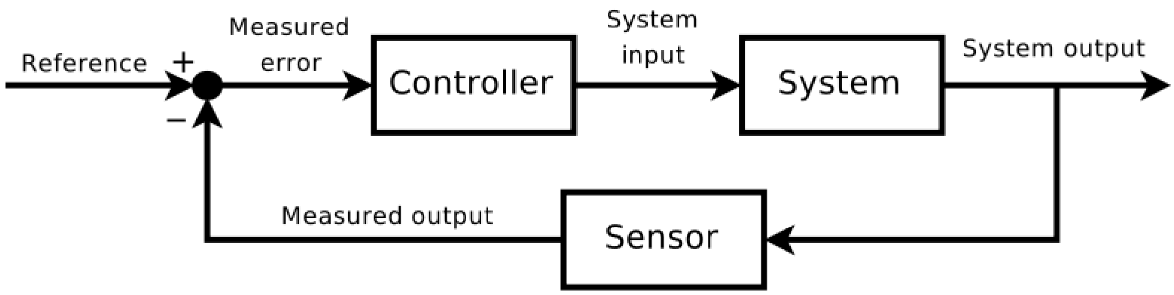


Figure 7: Closed Loop Feedback System

3.3.1 Algorithms used in PID controller

1. **Interactive Algorithm:**

$$u(t) = K_c \left[e(t) + \frac{1}{Ti} \int_0^t e(\tau) d\tau \right] \times \left[1 + T_d \frac{d}{dt} e(t) \right]$$

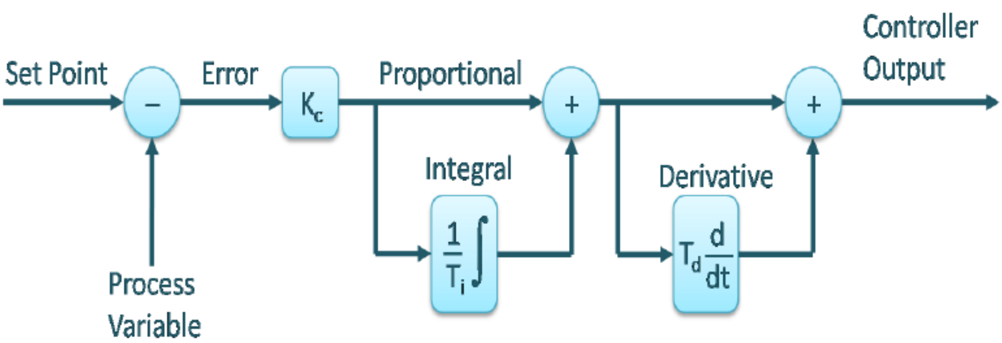


Figure 8: Interactive Algorithm for PID

2. **Non-interactive Algorithm:**

$$u(t) = K_c\left[e(t) + \frac{1}{Ti}\int_0^t e(\tau)d\tau + T_d\frac{d}{dt}e(t)\right]$$

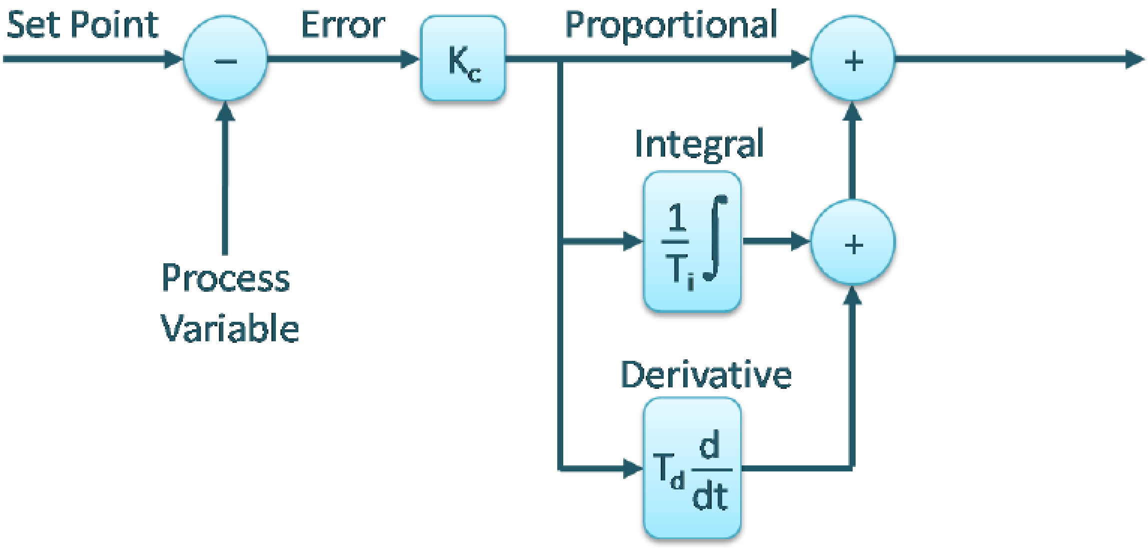


Figure 9: Non-Interactive Algorithm for PID

3. **Parallel Algorithm:**

$$u(t) = K_p e(t) + K_i\int_0^t e(\tau)d\tau + K_d\frac{d}{dt}e(t)$$

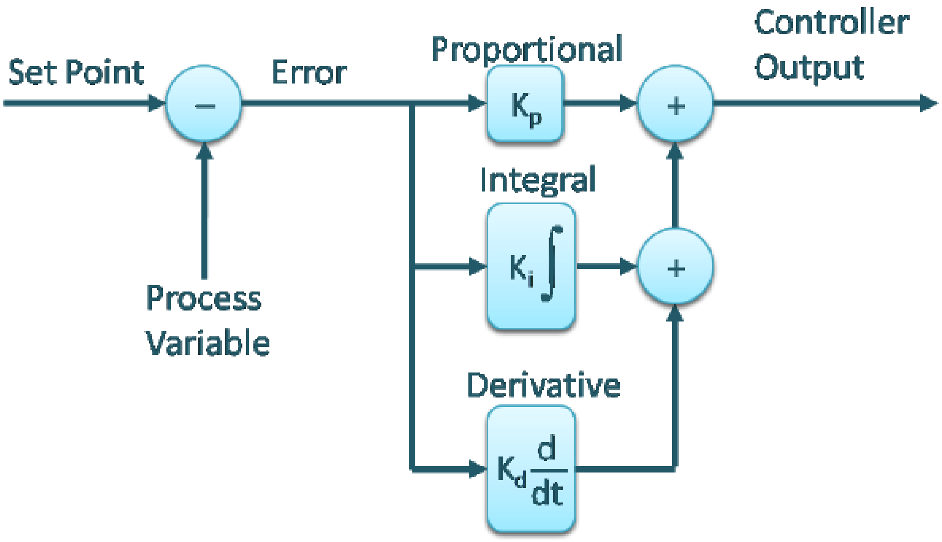


Figure 10: Parallel Algorithm for PID

Where,

K_p = Proportional gain, Ki = Integral gain, K_d = Derivative gain

error = Setpoint – output

Table 2: Effect of increasing controller parameter independently

Parameter	Rise Time	Overshoot	Settling Time	Steady-State Error	Stability
K_p	Decrease	Increase	Small change	Decrease	Degrade
K_i	Decrease	Increase	Increase	Eliminate	Degrade
K_d	Minor change	Decrease	Decrease	No Effect	Improve for small values

3.3.2 Tuning methods for PID loop

- Ziegler-Nichols open loop method
- Ziegler-Nichols closed loop tuning method
- Cohen-Coon method
- SIMULINK
- PID tuning Toolbox in MATLAB

3.4 3D Printing

The term “3D printing” encompasses different types of processes in which a material combines or hardens controlled through computer to produce three dimensional objects and the material is added together usually layer by layer. 3D printing being used in the manufacturing process which further helps in various engineering medical and industrial fields. [8]

3.4.1 3D Modelling

3D-models for printing can be designed using a computer-aided design (CAD) package.3D-printed models created using CAD, lead to lesser errors which can be taken care of before printing, which allows you to check object’s design before printing.

The process of manual modelling in the preparation of numeric data for three-dimensional computer graphics is like plastic art, such as sculpture. CAD files can be stored in a stereolithography (STL) file format, which stores information based on surface triangulation of CAD models. Before printing a model, errors must be checked.

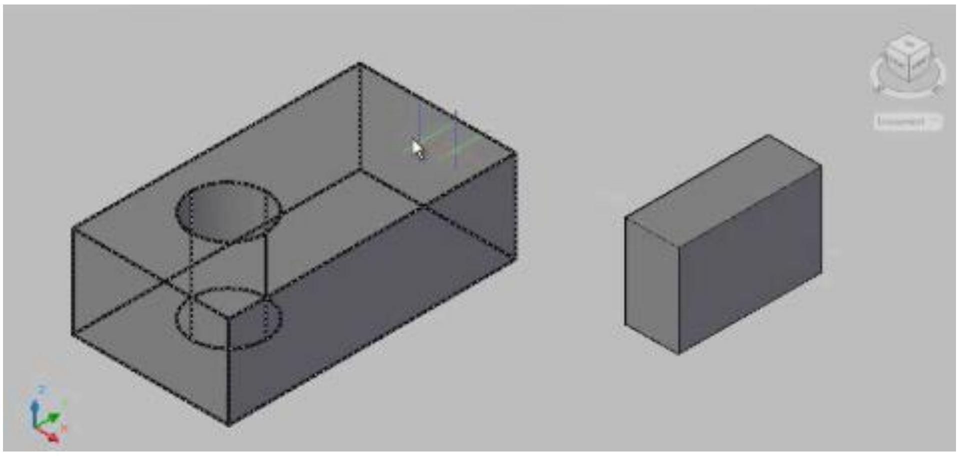


Figure 11: CAD Model

3.4.2 Techniques used in 3D printing

There are several types of 3D printing techniques which are used to developed 3D structures and objects. Some of them are discussed below

- Fused Deposition Modelling (FDM)
- Stereolithography (SLA)
- Digital Light Processing (DLP)
- Selective Laser Sintering (SLS)

1. Fused Deposition Melting (FDM):

FDM is affordable technique for 3D modelling. The great thing about this technology is all components developed via FDM technology can be used for high performance purpose due to Engineering graded thermoplastic, which is quite beneficial for manufacturers. 3D printers based on FDM technology construct object layer after layer. Specialized program used to divide CAD models into layers and devise the program to assemble each layer. Printer heats the thermoplastic extrudes this material through nozzle on a printing bed. The software running the printer divide 3D model into three-dimensional axis coordinates and control nozzle position. Each layer of plastic material binds together and hardens to form an object. We can print ready to use components. Thermoplastic which are used in this technique are ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid) plastic.

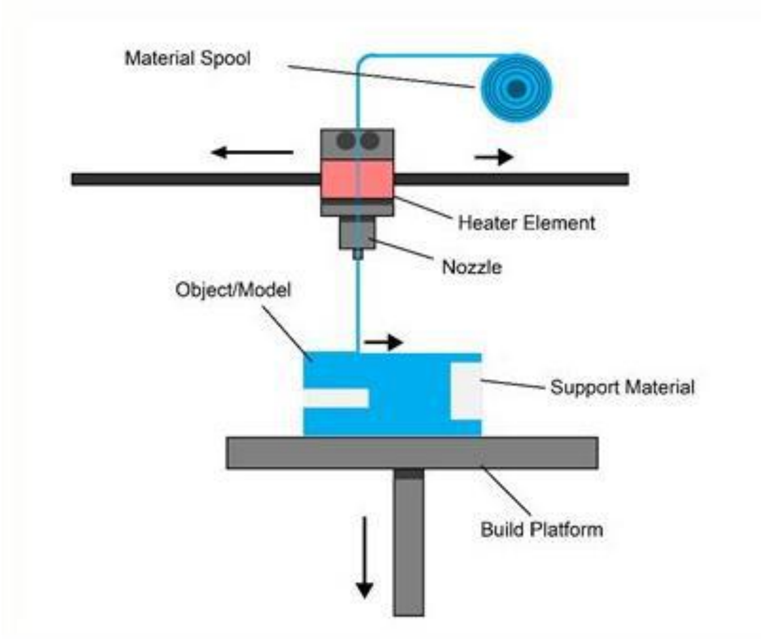


Figure 12: FDM Courtesy: The Technology House

2. Stereolithography (SLA):

SLA 3D printers use excess of plastic which hardens after sometimes to form a solid object. After the plastic hardens, laser form another layer until printing is finished. Printed parts must go through solvent. and then passed through ultraviolet oven to complete the process. SLA printed objects are smooth, but quality depends upon the printer used. [9]

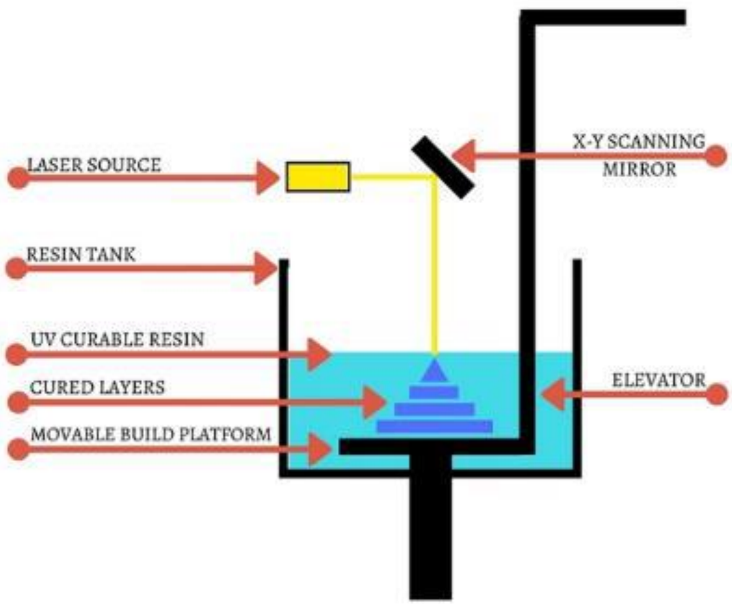


Figure 13: Stereolithography

3. **Digital Light Processing (DLP):**

DLP is more like stereolithography, it uses micromirrors laid on a semiconductor chip. It uses another source for lighting unlike SLA. Plastic resin is used as a material. Transparent container holds this material. This resin hardens when exposed to photon or brighter light. The printing speed of DLP is quicker than previous techniques. A layer can be produced within few seconds and move onto next layer.

4. **Selective Laser Sintering (SLS):**

SLS is a process, with the help of laser to develop strong 3D model. The material used for SLS technique is powdered rather than liquid resin unlike previous technologies. The material used can be nylon, glass, ceramic and metals like aluminium, steel and silver. Due to wide range of material this is used for customized products**.**

3.4.3 Why SLA is better than FDM?

SLA produces high resolution objects. The reason is that optical sensors are used. Less force is applied to printing model. The surface finishing is smoother than FDM. When compared to SLA printing speed is faster than FDM.

For the production of our injection pump, we used SLA as it was more reliable.

3.5 PCB

The small green boards which help electronic device work. The PCB connects all the components inside. PCB usually made using copper. The copper is placed to a substrate and grooved its specific ways as PCB is to be designed. There are many steps for PCB manufacturing. All the steps and details are given below.

3.5.1 Design

PCBs must be according to developer's abilities and design constraints, a printed circuit board layout via printed circuit board design software. The PCB industry has created Gerber as output file. At this stage, all aspects of PCB design are being tested. [10]

The software executes project control algorithms to make design error free. Designers check the elements related to the breadth of the track, the distance between the edges of the board, the distance between the tracks and the holes and the size of the holes.

The design process is usually done using software, which checks all the aspect of circuit, its continuity and simulations. Using trace calculator, copper lines are kept away so there is lesser chance of short circuit. The same technique is used to distinguish copper way between different layers.

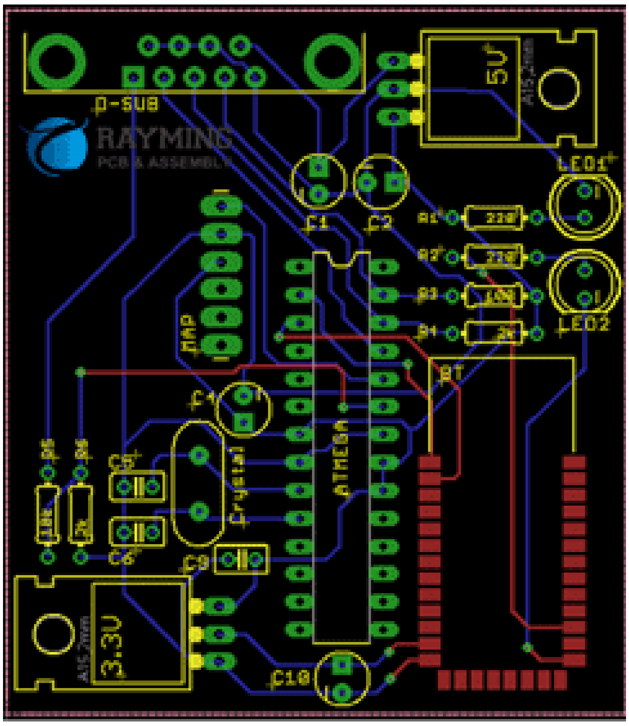


Figure 14: Gerber File

3.5.2 Printing the design

Printing on a printed circuit board begins after the developers display the circuit board files. A special printer is used, called a plotter, which makes films from printed circuit boards for printing PCBs. Technician by using these films for blueprint of printed circuit boards. Special printer, plotted printer, print the PCB design. Films are produced through this printer which shows the details of different layers. Different colours are used for different layers. For perfect assembling of films, the holes for recording must be drilled. The accuracy of the hole is achieved by adjusting the table.

3.5.3 Substrate

The main form of the printed circuit board consists of a multilayer board, the base material of which is an epoxy resin and fiberglass. The base ensures a durability. Copper is bonded on both sides. In the design of printed circuit boards, cleanliness matters. The copper side of the laminate is cleaned and enters the deactivated environment.

The substrate which is insulating material on which components are mounted together takes its form after going into oven. Copper is already placed to dual sides of sheet. The required copper paths are kept safe while excess copper is removed through etching. A photo-sensitive material is used to place all over the board. This material hardens when expose to ultraviolet. This hardness covers the structure. This material is aligned with original PCB design. [11]

After the placement of photo-sensitive material, board is exposed to ultraviolet light. Light shows the path of copper. The board is washed with the help of alkaline solution to get rid of photo resist.

3.5.4 Removal of excess copper

Now that the solvent has released the unwanted copper from board, cured shows resistance that protects copper needs flushing.

3.5.5 Inspection

Layers are inspected for alignment. Optical punch is used to sense the alignment. Once the alignment is done, another machine is used to detect any other defect in this board. Because after that no fault can be corrected.

3.5.6 Fusion of layers

Metal clamps holds the layers for lamination process to begin. Epoxy is used to laminate between the layers. Pins are punched across the layers to maintain alignment which can be removed according to application.

3.5.7 Drilling

Holes drilled in the stack of the board. All components that should appear later, such as the copper connection through the holes and the lead elements, depend on the accuracy of the exact holes. The holes are drilled to the width of the hair - the diameter reaches 100 microns. For holes, computer guided drills are used to open into substrate and inner layers. After drilling, any copper near hole is removed. Buffer material board under the drilling target to provide a clean hole. The exit material prevents any unnecessary breaks in the outlets of the planter. Upon completion of drilling, additional copper, which aligns the edges of the working panel, is removed using the profiling tool.

3.5.8 Plating

Before platting board is cleaned through series of chemicals. These chemicals coat the channel through copper which seeps through the drilled holes.

3.5.9 Outer layer protection

Just like the previous step, photo-sensitive material is placed then exposed to ultraviolet light which hardens the required pathways to protect outer layer. Then excess of this material is removed.

3.5.10 Tin coating

Thin copper is layer is coated to required pathways using plating. After copper, tin is used to coat the board which protects the required copper from etching and environmental hazards.

3.5.11 Etching

For removal of excess copper, final etching is done. Tin provides protection the required copper paths.

3.5.12 Solder Mask Application

The green colour which is usually prominent in a PCB is solder mask. Excess solder mask is removed through ultraviolet while required is heated on the PCB.

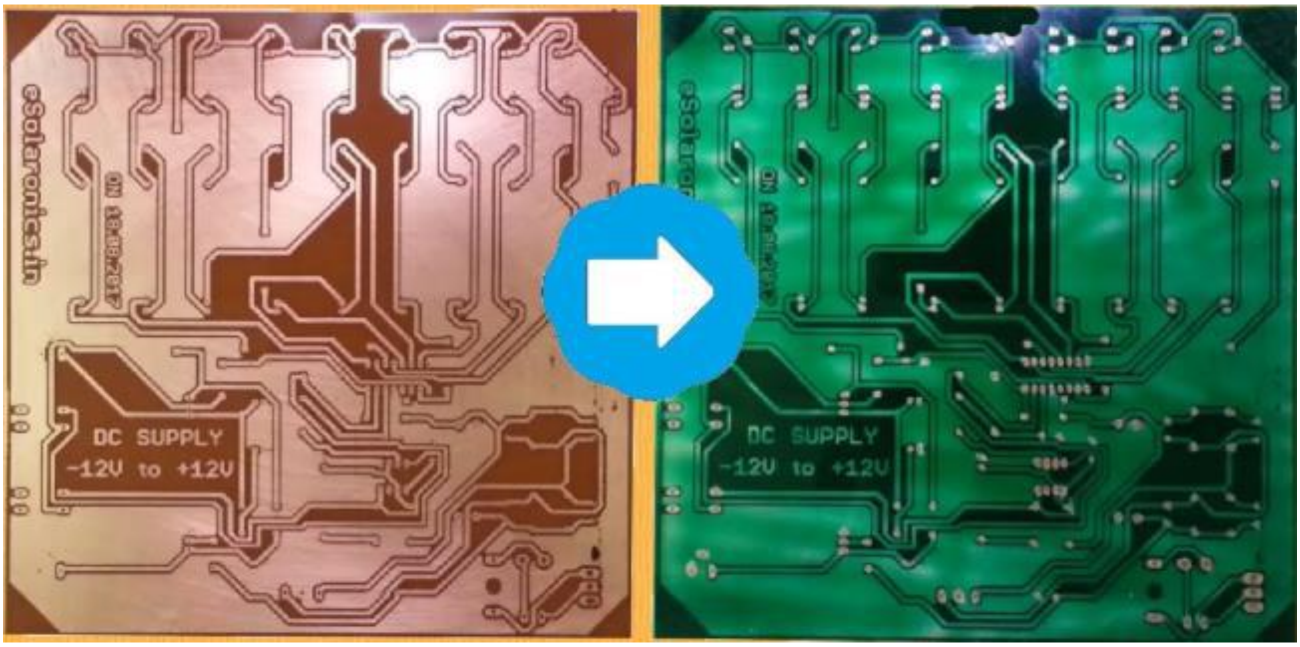


Figure 15: Solder Masking

3.5.13 Silk-screening

This process prints the circuit information on PCB. It usually prints the name of component or number of a component according to provided design. This printing can be read through naked eye. [12]

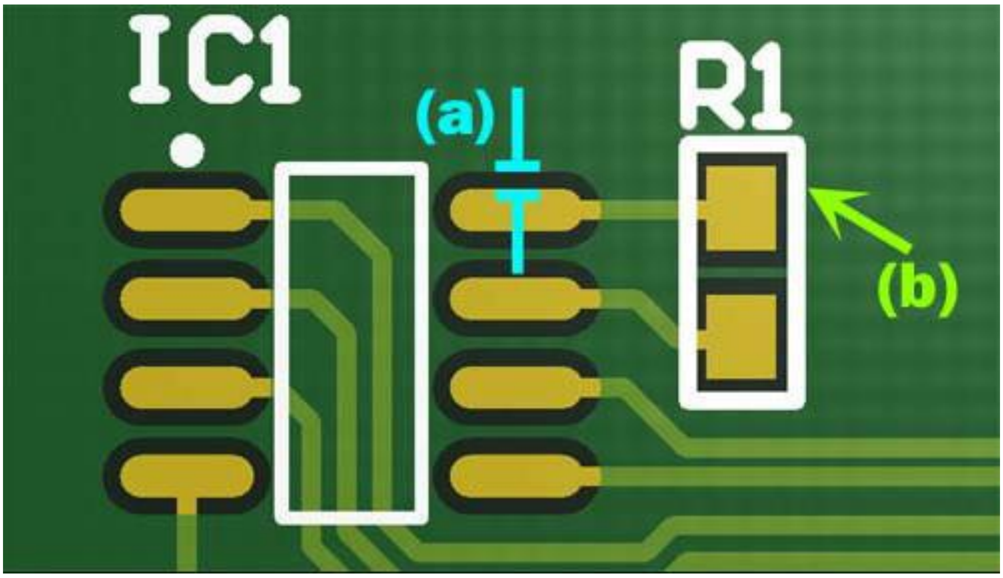


Figure 16: Silk Screening

3.5.14 Surface Finishing

Depending upon the requirements, another layer of solder mask is placed on the board which increases the quality of board.

3.5.15 Testing

Technician runs electrical tests on the board. This process confirms the PCB functioning according to blueprints provided.

CHAPTER 4: SOFTWARE

4.1 Software

Before proceeding on towards hardware, we designed our circuitry on software first to test out our prototype. The different systems we had to design were the encoder-based motor control circuit, the Arduino coding for the operation of the microcontroller, and finally the control system. The software we used are:

- PROTEUS
- SIMULINK
- ARDUINO IDE

Proteus was used for the simulation work. We made the circuit on proteus and used the components which we were intended to use in our hardware work. Proteus is actually a tool used for the electronic design automation. Proteus is a software developed by Lab Center Electronics for the simulation electronic devices and Circuits. Proteus can be used for the designing of the circuit and also for the creation of PCB layout structure. Thus, we used it for our project. Firstly, there was no library for Arduino in the Proteus. We added the library of the Arduino in the proteus file.

Following is the way of adding a library in proteus:

- First, download the library you want to install in proteus.
- Unzip the file and copy the library file.
- If you are using Proteus 8 professional, then go to C:\ProgramData\Labcenter Electronics\Proteus 8 Professional\LIBRARY.
- Paste the file in Library folder and then restart the software.

This is how each library is added in to the proteus.

Moreover, due to the absence of Encoder library in Arduino IDE, we added the library through the path Sketch/Include Libraries/Manage Libraries, and then installing the desired Encoder Library.

SIMULINK was used to design the PID control systems.

4.2 Circuit Diagram

4.2.1 Motor Control

4.2.1.1 Test Circuit

Initially, we designed the motor control circuit without the encoder feedback system to compare results.

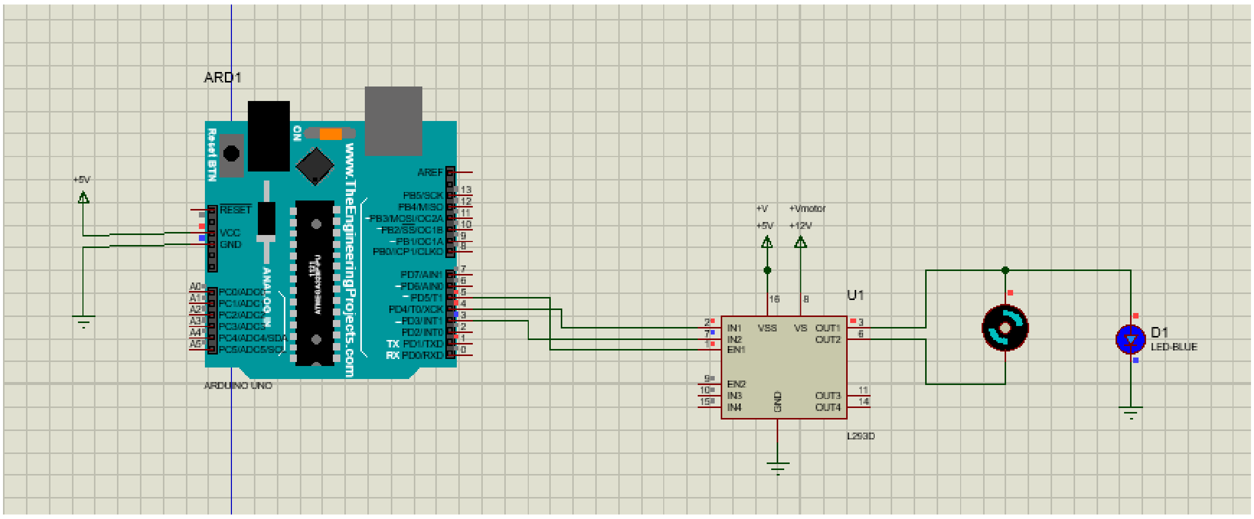


Figure 17: Proteus Design of the Test Circuit

Arduino UNO or NANO could be used as a microcontroller because we intended to communicate with one device at a time. We have used Motor Driver L293D to control and drive our motor, with pins 2 and 7 (IN1 & IN2) being responsible in controlling the direction of motor, i.e., if one input is HIGH and the other is LOW (1 or 0) the motor either rotates clockwise or counter clockwise, and if both the inputs are either HIGH or LOW then the motor stops. The pin 1 (EN1) is responsible for controlling the speed of the motor with input varying from 0-5V.

4.2.2.2 Code

```
int speedPin = 5;

int dir1 = 4;

int dir2 = 3;

int mSpeed = 255;



void setup() {
```

pinMode(speedPin,OUTPUT);

pinMode(dir1,OUTPUT);

pinMode(dir2,OUTPUT);

Serial.begin(96000);

}

void loop() {

digitalWrite(dir1,HIGH);

digitalWrite(dir2,LOW);

analogWrite(speedPin, mSpeed);

}

4.2.2.2.1 Pin Declaration

```
int speedPin = 5;
int dir1 = 4;
int dir2 = 3;
int mSpeed = 255;
```

As mentioned before the speed and direction pins of the motor driver which are led by the Arduino, they were first declared. ‘mSpeed’ corresponds to different input voltage values (in binary form) to the speed pin.

4.2.2.2.2 Setup

```
void setup() {
pinMode(speedPin,OUTPUT);
pinMode(dir1,OUTPUT);
pinMode(dir2,OUTPUT);
Serial.begin(96000);

}
```

The speed and direction pins of Arduino are setup as outputs since they would be inputted to the motor driver. Begin serial communication between PC and Arduino with the set delay.

4.2.2.2.3 Controlling Motor

```
void loop() {
digitalWrite(dir1,HIGH);
digitalWrite(dir2,LOW);
analogWrite(speedPin, mSpeed);
}
```

The motor was controlled by setting different direction configurations and speed values.

4.2.2 Encoder Based Feedback Motor Control Circuit

The final design of the circuitry incorporated the magnetic disc and a hall effect sensor (encoder) to give feedback to the control system and to manage the speed and direction of motor automatically.

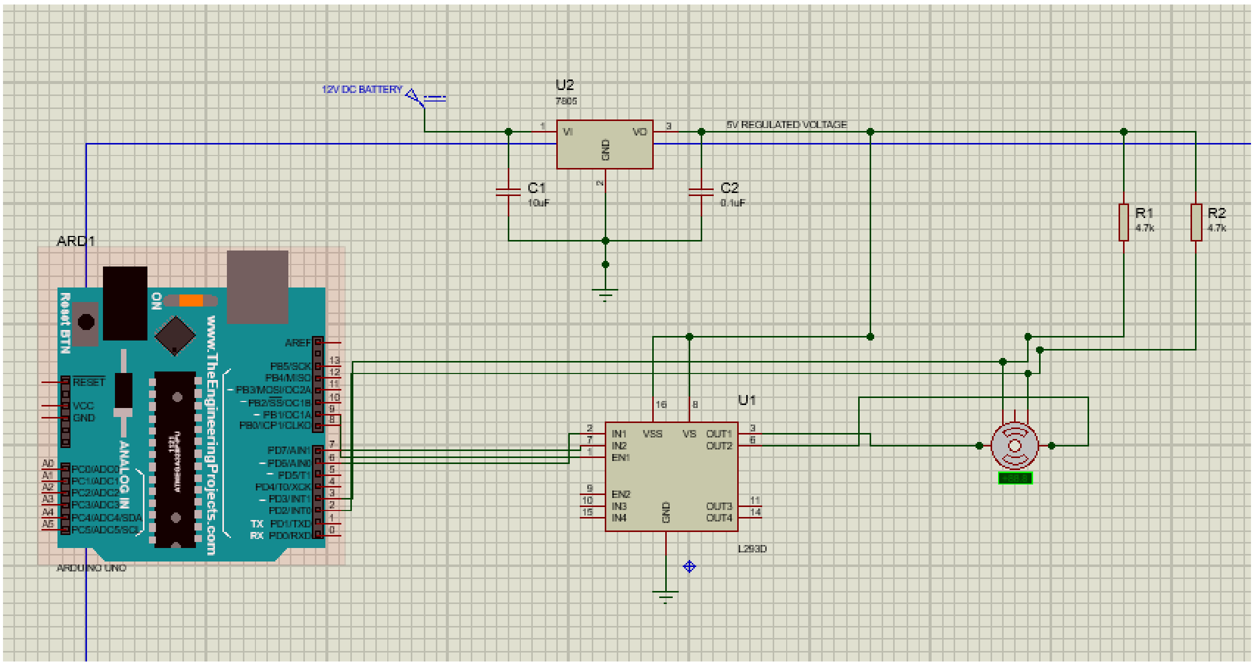
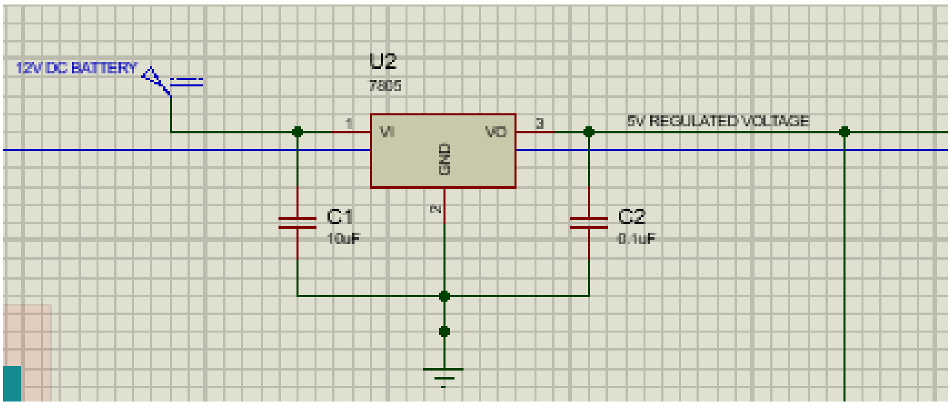
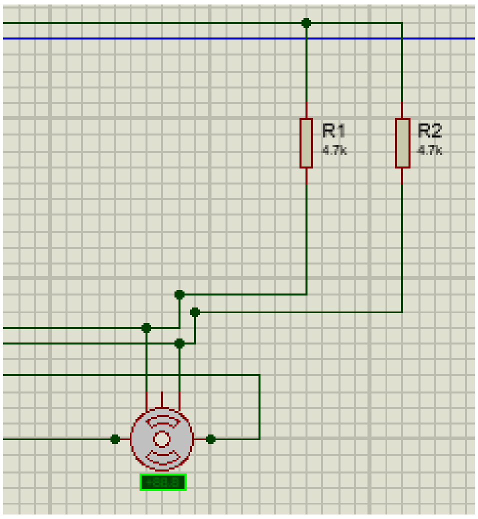


Figure 18: Proteus Design of the Motor Control Circuit

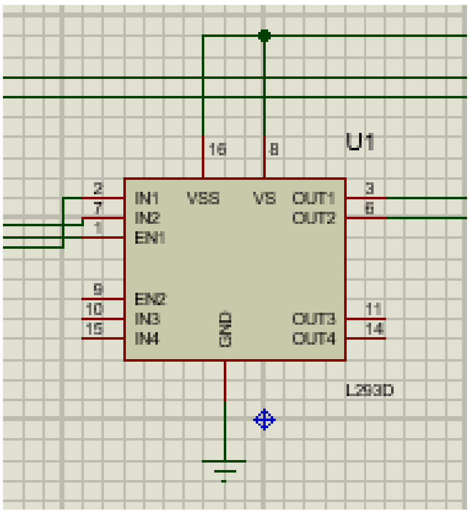
The above circuit now incorporates a 5V DC regulated supply to stabilize Vcc. The motor now used is encoder based for feedback.



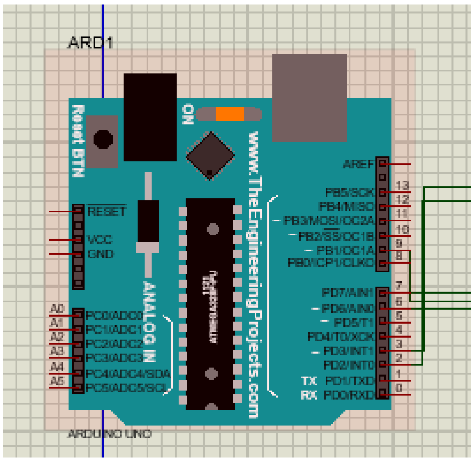
Our main input is 12V supplied through a DC battery which is then regulated to 5V using LM7805. Capacitors are used for noise reduction.



A magnetic disc and Hall effect sensors are used in quadrature encoder-based micro metal gearmotors to provide 12 counts every revolution of the motor shaft. The sensors have a voltage range of 2.7 to 18 volts and provide digital outputs to the microcontroller.



As mentioned before, motor driver L293D is used to control the motor’s speed and direction.



Arduino UNO or NANO is used to communicate between the motor, encoder, and the PC one at a time. The code is mentioned and explained below:

4.2.2.1 Encoder-Based Arduino Code

```
#include <Encoder.h>


//variable declaration

int output_1 = 0;

long int current_position = 0;

long int set_position = 1010;

int time_1 = 0; //previous time

int time_2 = 0; //currection time

bool status_a = 0; // status of channel a of the encoder

bool status_b = 0; // status of channel b of the encoder

float ki = 0.0008921;//0.0008921;//0.002;

float kp = 0.5098;//0.5097;//0.6345;

float kd = 0.05;//72.81;//00.05;

int p1 = 0; //previous position

int p2 = 0; //current position
```

```
int p = 0;

long int i = 0;

int d = 0;

int pid_op;

int change_position = 0;

 Encoder encode(3,2);

void setup() {

  //pin declaration

  pinMode(INPUT, 2);// interrupt pin 1 - reads B pulses

  pinMode(INPUT, 3);// interrupt pin 2 - reads A pulses

  pinMode(INPUT, 4); // home position

  pinMode(OUTPUT, 6); //Direction control A (6 high, 7 low)--> jbackward, (6 low, 7 high)--
> backward

  pinMode(OUTPUT, 7);//Direction control B

  pinMode(OUTPUT, 9); //Motor enable



  //interrupt

  //attachInterrupt(digitalPinToInterrupt(2), time1, RISING);

  //attachInterrupt(digitalPinToInterrupt(3), time2, RISING);


  Serial.begin(9600); // data transfer rate i.e. baud rate

}


void loop() {
```

```
//  if (set_position == current_position)
//  {
//    change_position = Serial.read(); // reads the incoming serial data in the Arduino
//    set_position = set_position + change_position;
//    change_position = 0;
//  }
  current_position=encode.read();


  Serial.print(current_position);
  Serial.print("  ");
  Serial.print(set_position);
  Serial.print("  ");
  //Serial.print(micros());
  Serial.print("  ");
  pid_op = pid_calculation(current_position, set_position, time_1, time_2);
  Serial.println(pid_op);
  //  digitalWrite(7, LOW);
  //    digitalWrite(6, HIGH);
  //    analogWrite(9, abs(155));
  // runmotor(pid_op);
  if (pid_op > 0)
  {
    digitalWrite(6, LOW);
    digitalWrite(7, HIGH);
```

```
    analogWrite(9, abs(pid_op));
  }
  else if (pid_op < 0)
  {
    digitalWrite(6, HIGH);
    digitalWrite(7, LOW);
    analogWrite(9, abs(pid_op));
  }
  else if (pid_op == 0)
  {
    digitalWrite(6, LOW);
    digitalWrite(7, LOW);
    analogWrite(9, 0);
  }

}
void time1()
{
  time_1 = micros(); //  Returns the number of microseconds since the Arduino board began running the current program
  status_a = digitalRead(3); //check status of channel b
  p1 = current_position;
  if (status_a == 1)
  {
    current_position--;
```

```
  }
  else
  {
    current_position++;

  }

}
void time2()
{ time_2 = micros();
  status_b = digitalRead(2); //check status of channel a
  p2 = current_position;
  if (status_b == 1)
  {
    current_position++;

  }
  else
  {
    current_position--;

  }
```

```
}
void runmotor(int pid)
{
  if (pid > 0)
  {
    digitalWrite(6, LOW);
    digitalWrite(7, HIGH);
    analogWrite(9, abs(pid));
  }
  if (pid < 0)
  {
    digitalWrite(6, HIGH);
    digitalWrite(7, LOW);
    analogWrite(9, abs(pid));
  }
  else
  {
    digitalWrite(6, LOW);
    digitalWrite(7, LOW);
    analogWrite(9, 0);
  }
}
int pid_calculation(int feedback, int setpoint, int t1, int t2)
{ long int op;
```

```
  int error = (setpoint - feedback);

  i = i + error;

// d = (p2 - p1) / (t2 - t1);

  p = error;

  if (setpoint == feedback)

  {

    i = 0;

  }

  op = (i * ki) + (p * kp) + (d * kd);

  return (op);

  //return (map(op,-27483648,27483647, -155, 155));


}
```

4.2.2.1 Including Library

```
#include <Encoder.h>
```

The Encoder Library is used for encoders to count pulses from quadrature encoded signals like those found on rotary knobs, motor or shaft sensors, and other position sensors.

4.2.2.2 Variable Declaration

```
//variable declaration
int output_1 = 0;
long int current_position = 0;
long int set_position = 1010;
int time_1 = 0; //previous time
int time_2 = 0; //currection time
bool status_a = 0; // status of channel a of the encoder
bool status_b = 0; // status of channel b of the encoder
float ki = 0.0008921;//0.0008921;//0.002;
float kp = 0.5098;//0.5097;//0.6345;
float kd = 0.05;//72.81;//00.05;
int p1 = 0; //previous position
int p2 = 0; //current position
int p = 0;
long int i = 0;
int d = 0;
int pid_op;
int change_position = 0;
 Encoder encode(3,2);
```

- Intermediate results are stored in output_1
- The current_position gives the current position of the motor as feedback by the encoder through which the error has to be calculated
- The input is stored in set_position and this is the required position of motor to be obtained
- The previous and current time is stored in time_1 and time_2
- The states of the encoder channels A and B are stored in status_a and status_b
- The calculated values of kp, ki and kd through the control systems are also stored
- For loops the variables p1 and p2 are used for position
- Further loop variables involve p, i and d
- The error correction is stored in pid_op

4.2.2.3 Pin Declaration

```
void setup() {
  //pin declaration
  pinMode(INPUT, 2);// interrupt pin 1 - reads B pulses
  pinMode(INPUT, 3);// interrupt pin 2 - reads A pulses
  pinMode(INPUT, 4); // home position
  pinMode(OUTPUT, 6); //Direction control A (6 high, 7 low)--> jbackward, (6 low, 7 high)--> backward
  pinMode(OUTPUT, 7);//Direction control B
  pinMode(OUTPUT, 9); //Motor enable


  //interrupt
  //attachInterrupt(digitalPinToInterrupt(2), time1, RISING);
  //attachInterrupt(digitalPinToInterrupt(3), time2, RISING);

  Serial.begin(9600); // data transfer rate i.e. baud rate
}
```

- The Arduino pins 2,3 are interrupts which input the channel A and B pulses of the encoder
- Pins 6,7 are set as output pins to give directional input to the motor driver i.e., if pin 6 is HIGH and 7 is LOW then motor would move clockwise and if vice versa then the motor would move counter clockwise, and if both HIGH or both LOW then we know that the desired point is achieved and the motor stops.
- Pin 9 which corresponds to the motor enable which controls the motor's speed in the form of pulses.

4.2.2.4 Main Motor Control

```
void loop() {
  current_position=encode.read();
  Serial.print(current_position);
  Serial.print("  ");
  Serial.print(set_position);
  Serial.print("  ");
  //Serial.print(micros());
  Serial.print("  ");
  pid_op = pid_calculation(current_position, set_position, time_1, time_2);
  Serial.println(pid_op);
  if (pid_op > 0)
  {
    digitalWrite(6, LOW);
    digitalWrite(7, HIGH);
    analogWrite(9, abs(pid_op));
  }
  else if (pid_op < 0)
  {
    digitalWrite(6, HIGH);
    digitalWrite(7, LOW);
    analogWrite(9, abs(pid_op));
  }
  else if (pid_op == 0)
  {
    digitalWrite(6, LOW);
    digitalWrite(7, LOW);
    analogWrite(9, 0);
  }
}
```

- The current position of the motor is first read through the feedback system of encoder
- If interfaced to an LCD or mobile application, it is printed as the current position, also the required position is also displayed highlighting the deviation
- The error correction program pid_calculation is called with the inputs being the current and desired set point of motor, and the corrected value gets stored in pid_op, which is also displayed
- Now according to the value of pid_op the motor changes its direction
- If pid_op is positive, Arduino pin 6 is LOW and 7 is HIGH making the motor move counterclockwise and the speed is managed by the absolute value of pid_op
- If pid_op is negative, Arduino pin 6 is HIGH and 7 is LOW making the motor move clockwise and the speed is managed by the absolute value of pid_op
- If pid_op is zero, it means that the current position has reached the set position and then both the Arduino pin 6,7 are LOW making the motor stop and the speed is set to zero.

4.2.2.5 Current Position Correction through Arduino Timing

```
void time1()
{
  time_1 = micros(); //  Returns the number of microseconds since the Arduino board began running the current program
  status_a = digitalRead(3); //check status of channel b
  p1 = current_position;
  if (status_a == 1)
  {
    current_position--;

  }
  else
  {
    current_position++;

  }

}
void time2()
{ time_2 = micros();
  status_b = digitalRead(2); //check status of channel a
  p2 = current_position;
  if (status_b == 1)
  {
    current_position++;

  }
  else
  {
    current_position--;
```

- Through the function micros() it returns the number of microseconds since the Arduino board began running the current program
- The status of the channel B is digitally read and stored
- The current position is stored in p1
- If the status of B is HIGH, the current position gets decremented
- If the status of B is LOW, the current position gets incremented
- In case of channel A, If the status of A is HIGH, the current position gets incremented
- In case of channel A, If the status of A is LOW, the current position gets decremented

4.2.2.6 Feedback Error Correction

```
int pid_calculation(int feedback, int setpoint, int t1, int t2)
{ long int op;
  int error = (setpoint - feedback);
  i = i + error;
 // d = (p2 - p1) / (t2 - t1);
  p = error;
  if (setpoint == feedback)
  {
    i = 0;
  }
  op = (i * ki) + (p * kp) + (d * kd);
  return (op);
  //return (map(op,-27483648,27483647, -155, 155));

}
```

- The current position is stored in feedback, the desired position is setpoint, and the current position correction through timing of Arduino is stored in t1 and t2
- The deviation is the difference between the desired and the current position
- Multiple errors are stored in the integral variable ‘i’
- Derivative variable ‘d’ stores the slope calculated through p1, p2 (calculated from the timer programs to modify current positions) and t1, t2 (previous and current time)
- The proportional variable ‘p’ is the error
- The feedback error correction is calculated through PID controller calculated values through the formula used

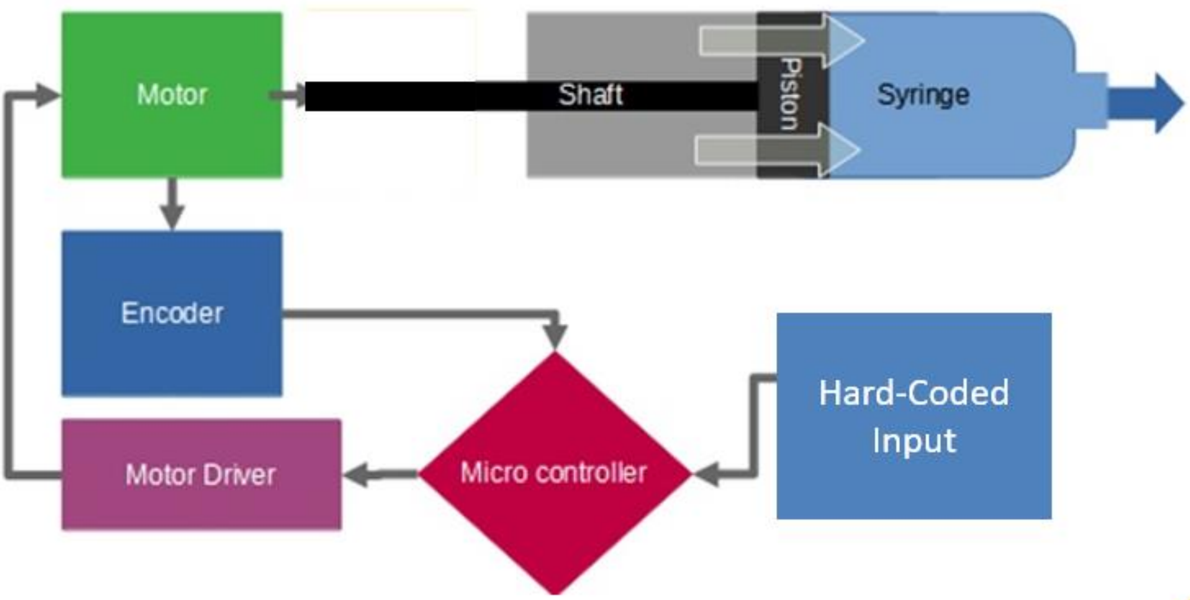


Figure 19: Basic Block Diagram of the Working Principle

4.3 Control Systems

The feedback control algorithm for our project utilizes PID Control System to calculate the values of kp, ki, and kd that were used in the controller programming.

4.3.1 Transfer Function of Motor

Equation used to calculate the transfer function of the motor:

$$P(s) = \frac{\dot{\Theta}(s)}{V(s)} = \frac{K}{(Js+b)(Ls+R)+K^2} \qquad \left[\frac{rad/sec}{V}\right]$$

The physical parameters for the DC geared motor are: (from parameter estimation)

- (J) moment of inertia of the rotor 0.01139365151 kg.m^2
- (b) motor viscous friction constant 0.0369898012 N.m.s
- (Ke) electromotive force constant 1.317141277 V/rad/sec
- (Kt) motor torque constant 0.3408978333 N.m/Amp
- (R) electric resistance 150 Ohm
- (L) electric inductance 4.412 H

Simulink Model of the DC Motor:

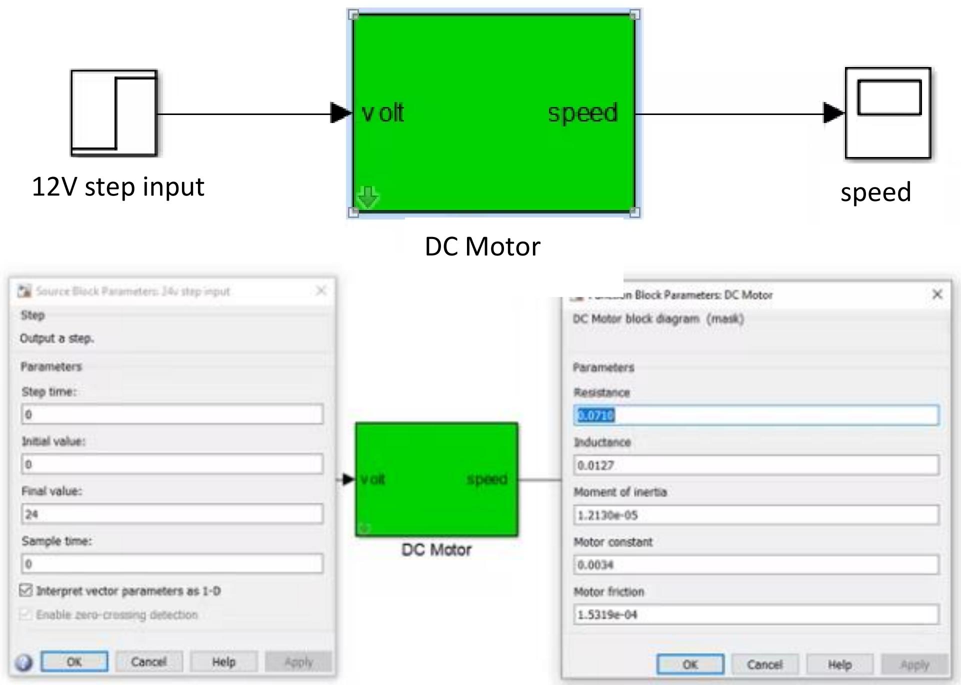


Figure 20: Simulink Model of DC Motor

Step Input 12V Response:

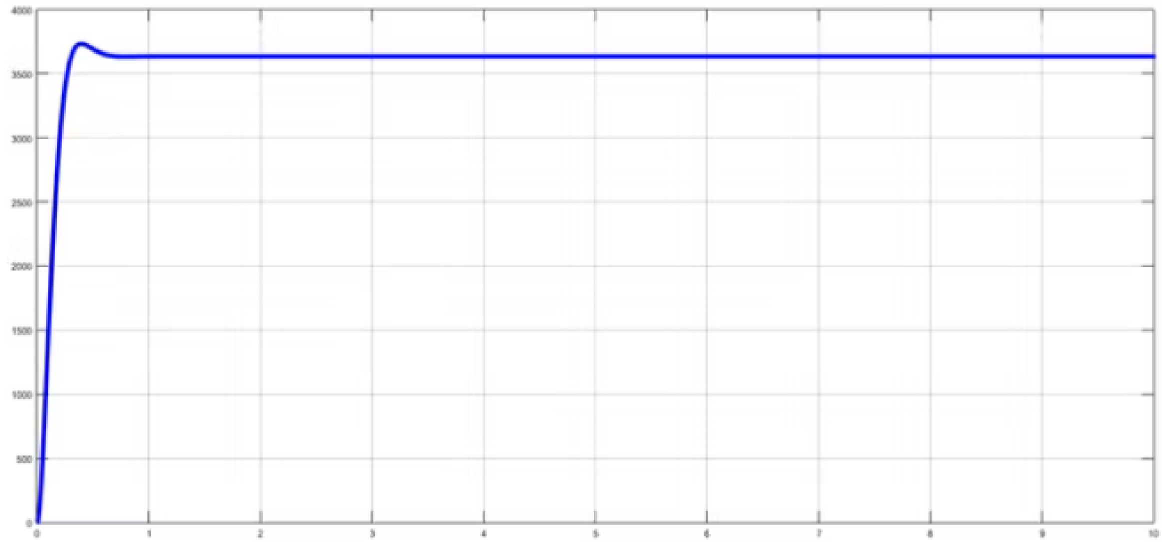
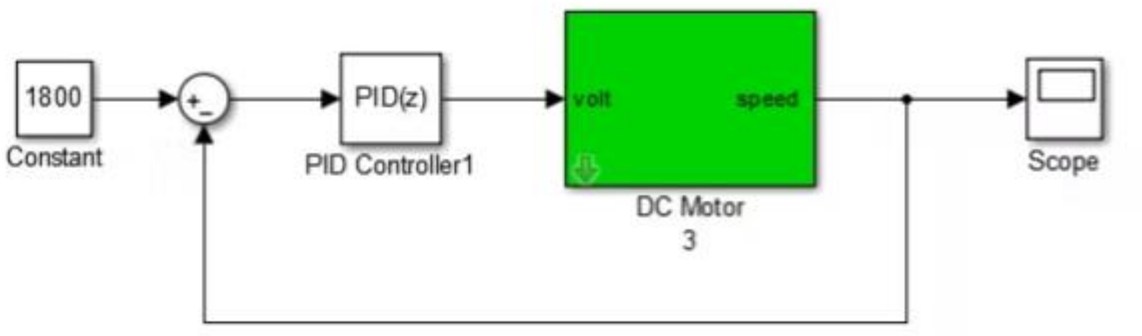
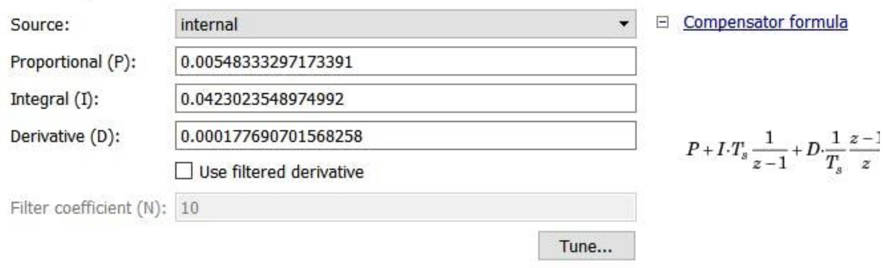


Figure 21: Step Input 12V Response

4.3.1 Calculation of Controlling Variables kp, ki, & kd

- To control speed of DC Motor
- Output signal consisting of three terms: ‘p’ proportional to error signal, ‘i’ proportional to integral of error signal and ‘d’ proportional to the derivative of the error signal.
- The proportional controller stabilizes the gain but produces a steady state error.
- The integral controller reduces or eliminates the steady state error.
- The derivative controller reduces the rate of change of error.
- PID controllers have higher stability, no offset and reduced overshoot.





After several tunings our final values came out to be:

- kp = 0.5098
- ki = 0.0008921
- kd = 0.05

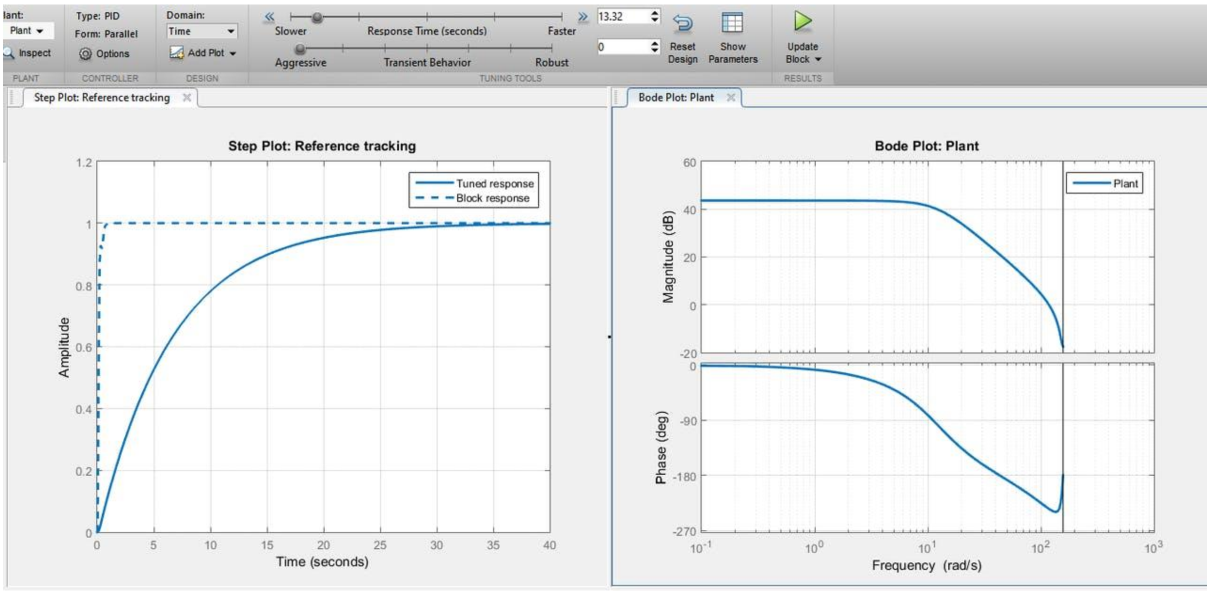


Figure 22: Response through controlling variables

CHAPTER 5: HARDWARE ASSEMBLY

5.1 Introduction

As previously designed in our software circuit, the main hardware components that our project uses are mentioned below each with their detailed description showing their essential match to our requirements.

5.2 Micro Metal Gearmotor HPCB 12V with Extended Motor Shaft

This gearmotor has a metal gearbox and a 12 V brushed DC motor with long-life carbon brushes with a ratio of 297.92:1. The D-shaped gearbox output shaft is 9 mm long and 3 mm in diameter, with a cross section of 10 x 12 mm. The motor shaft is also 4.5 x 1 mm longer in this variant.

Key specifications:

Voltage	No-load performance	Stall extrapolation
12 V	110 RPM, 80 mA	3.3 kg·cm (46 oz·in), 0.75 A

Figure 23: A general 12V DC Motor

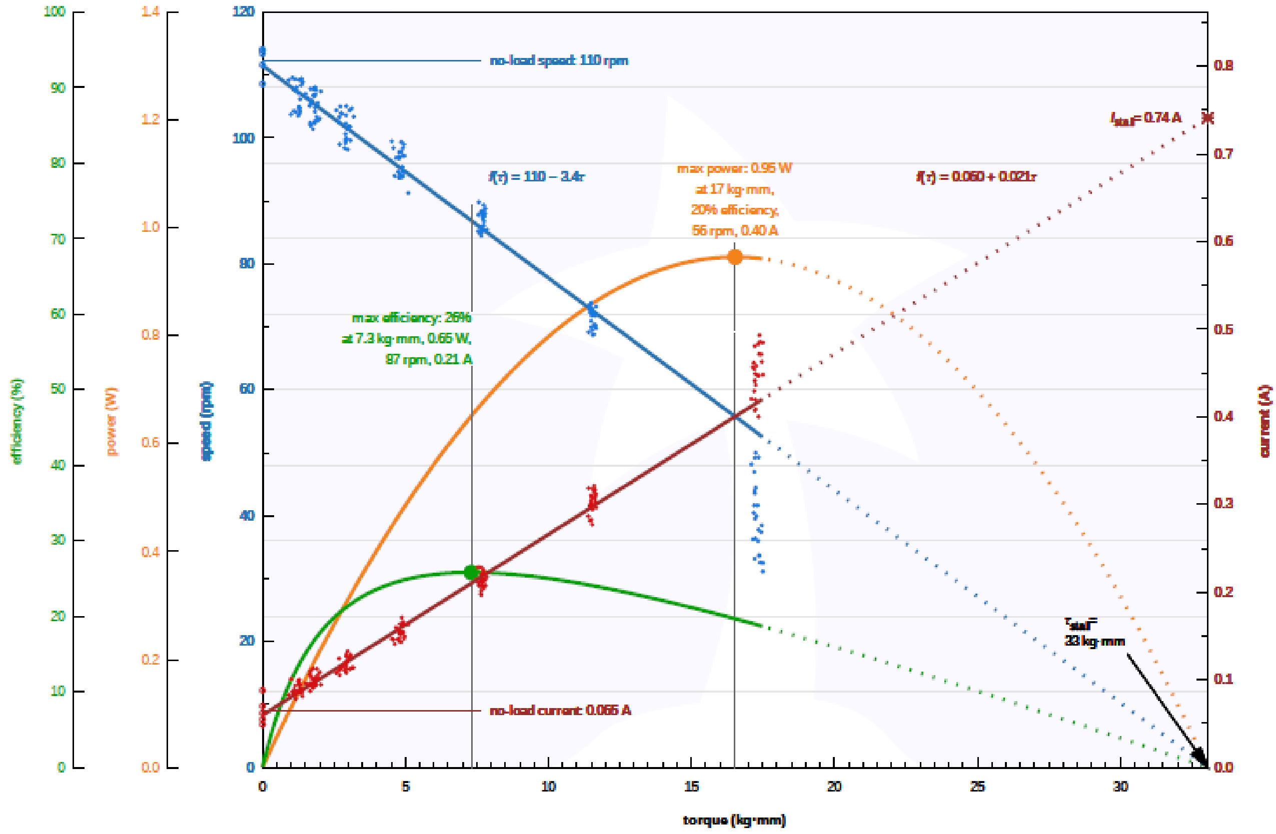


Figure 24: Working graph of a DC Motor

5.2.1 Gearmotor Dimensions

These gearmotors are quite close in size to Sanyo's popular 12 mm NA4S DC gearmotors, and gearmotors of this size are sometimes referred to as N20 motors. The terminal and end-cap dimensions of the variants with carbon brushes (HPCB) differ somewhat from those of the varieties with costly metal brushes, but all other measurements are the same. [13]

5.2.2 Versions with dimensions of carbon brushes (HPCB)

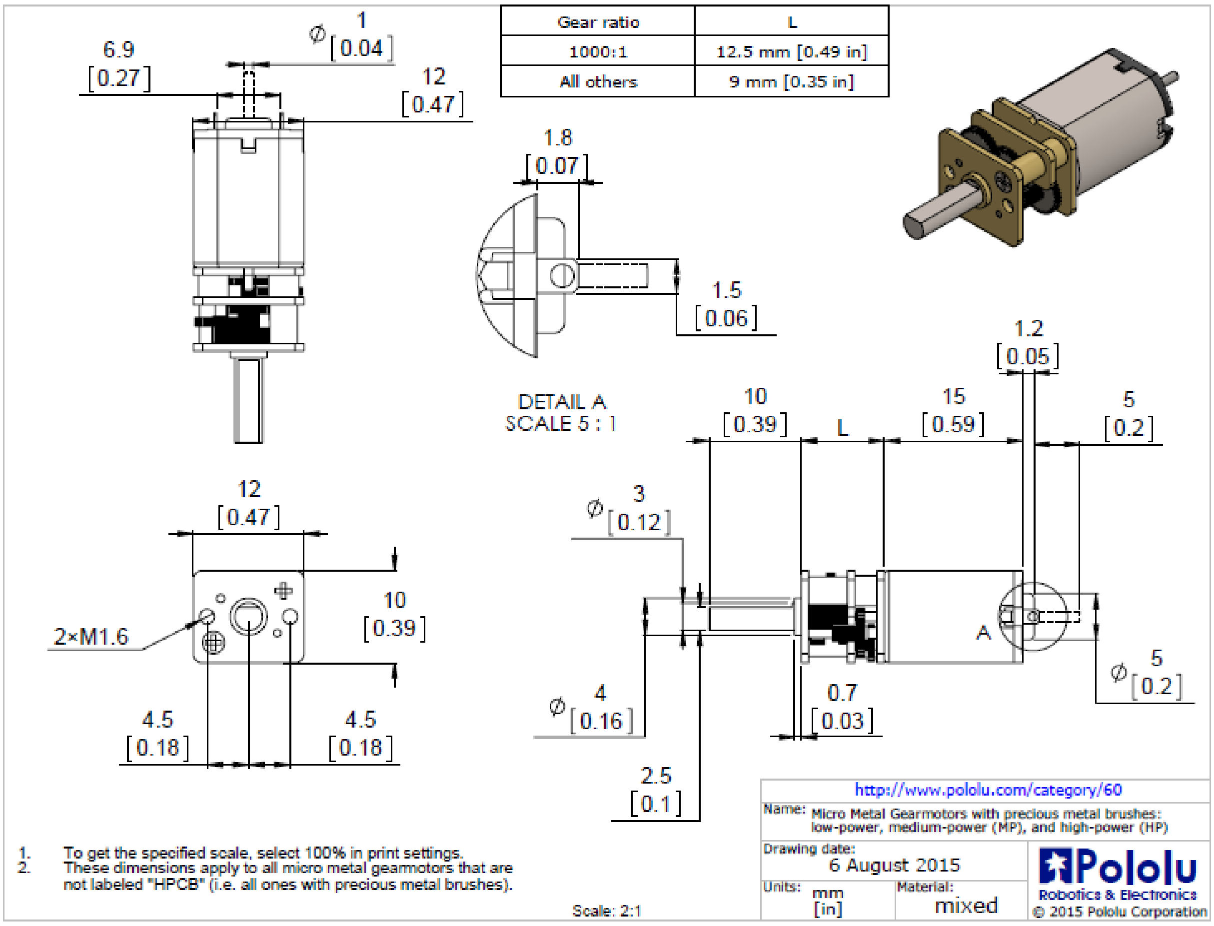


Figure 25: Dimensions of carbon brushes (HPCB)

5.2.3 Accessories of Motor

1. Wheels and hubs

The output shaft of the micro metal gearmotor can be used to mount custom wheels and mechanisms, and the 12mm hex wheel adapter can also be used to utilise this motor with many typical sideline RC wheels.

Figure 26: Wheel Adapter on a Micro Metal Gearmotor

2. Mounting Brackets

The mounting bracket and extended mounting bracket are meant to hold the gearmotor while also enfolding the uncovered gears. For wheels with recessed hubs, the extended mounting bracket is highly recommended. The 15.5D mm metal gearmotor bracket pair will also work with the micro metal gearmotors.

Figure 27: Mounting Bracket Pair including nuts and screws

3. Motor Controllers and Drivers

A variety of motor controllers, motor drivers, and robot controllers are available to make driving these miniature metal gearmotors simple. Consider the DRV8838 single-channel motor driver carier, DRV8833 dual motor driver carrier, and DRV8835 dual motor driver carrier for 6 V micro metal gearmotors (or DRV8835 shield for Arduino). Consider the MAX14870 single-channel motor driver carrier, DRV8801 single-channel motor driver carrier, and A4990 dual motor driver carrier for 12 V micro metal gearmotors (or A4990 shield for Arduino).

Figure 28: Different types of DC Motor Driver Carriers

4. Current Sensors

For individuals when monitor motor current needs to be monitored, there are a variety of Hall effect-based current sensors to pick from.

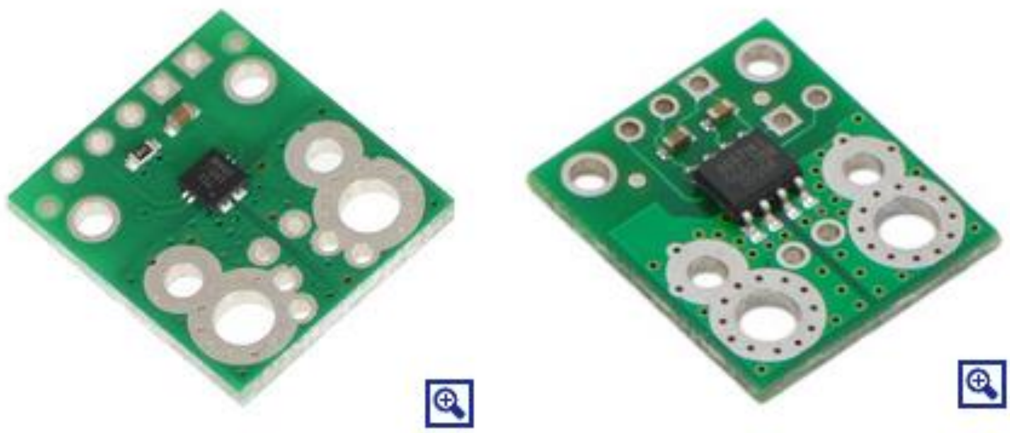


Figure 29: Current Sensor Carriers

5.2.4 Selection of the Right Gearmotor

There are a varied range of metal gearmotors that provide us with various combinations of speed and torque.

Figure 30: Varied Range of Metal Gearmotors

5.3 Magnetic Quadrature Incremental Encoder

Two dual-channel Hall effect sensor boards and two 6-pole magnetic discs are included in this kit, which can be used to encode two micro metal gearmotors with extended rear shafts in quadrature. When counting both edges of both channels, the encoder board detects the rotation of the magnetic disc and offers a resolution of 12 counts per revolution of the motor shaft. Multiply the gear ratio by 12 to get the counts per revolution of the gearbox output shaft. On three of the four sides, this tiny encoder solution fits within the 12 mm 10 mm cross section of the motors, and it extends 2.8 mm past the border of the fourth side.

The encoders have a 6-pin male JST SH-type connector on the top. We also have a side-entry version of this encoder.

The following images show the differences between the top-entry and side-entry versions:

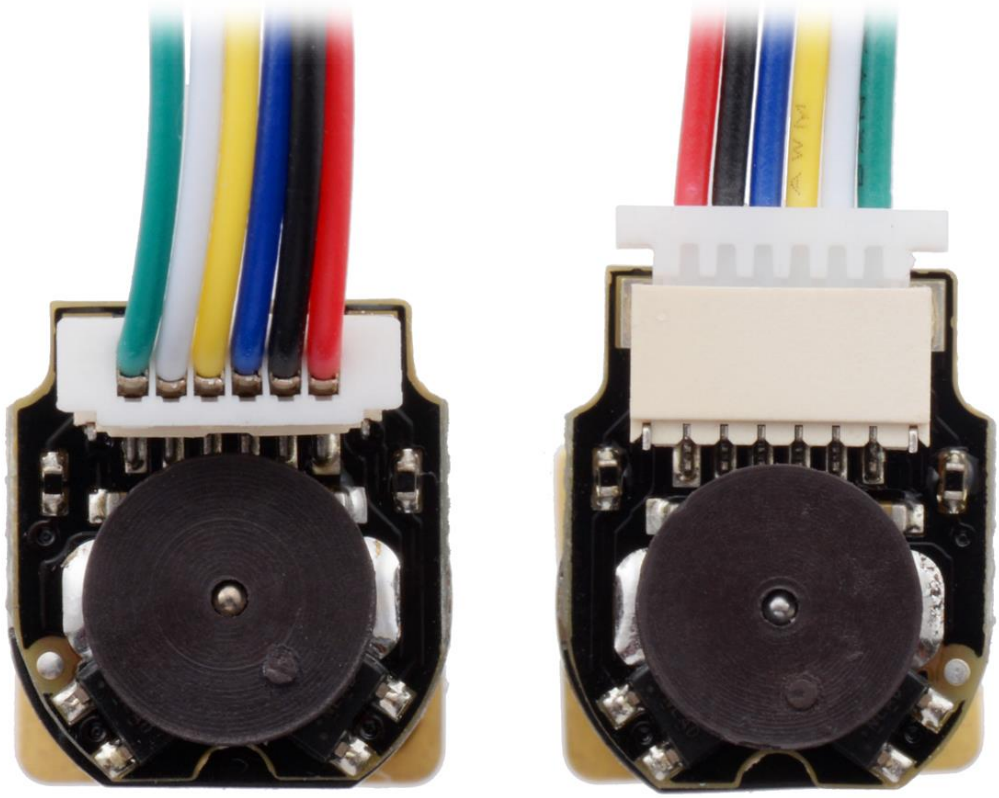


Figure 31: Magnetic Encoders

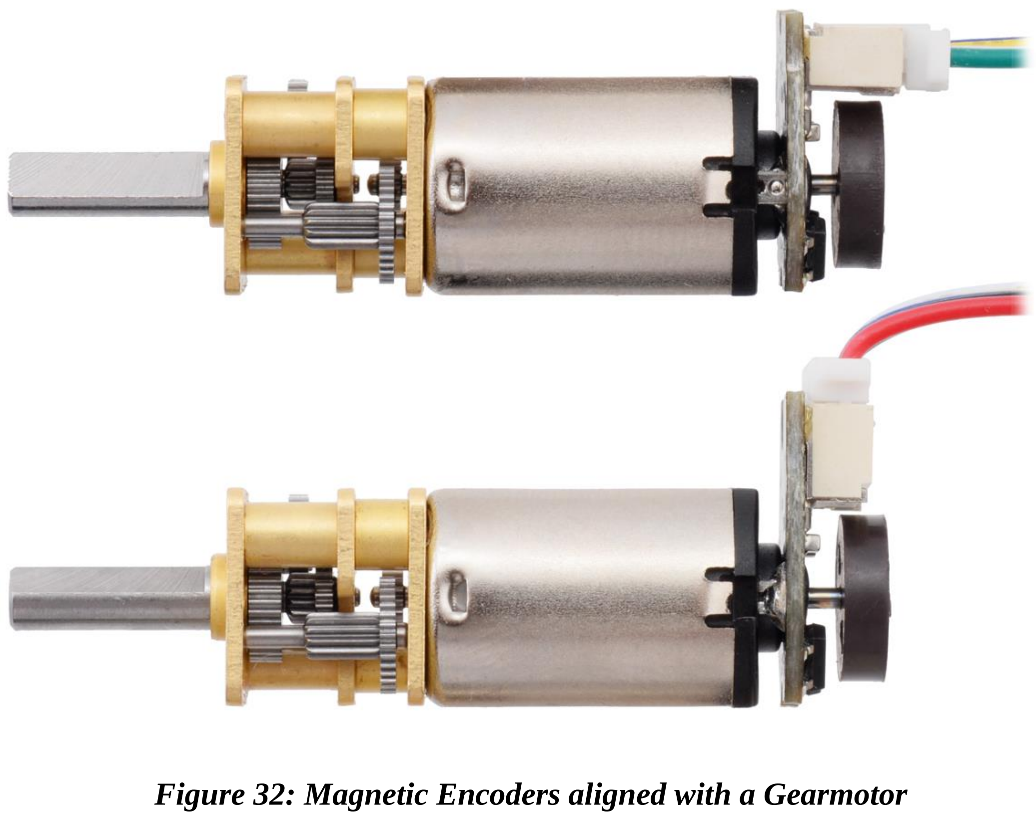


Figure 32: Magnetic Encoders aligned with a Gearmotor

5.3.1 Cables

These encoders are compatible with two types of cables, both of which include JST SH-style connectors.

Single-ended cables come in three lengths, with a connector on one end and unterminated wires on the other:

- 12 cm (4.5")
- 30 cm (12")
- 75 cm (30")

Figure 33: Single-ended Cables with Dimensions

Five lengths of twisted female-female cables with connections on both ends are available:

- 10 cm (4")
- 16 cm (6.3")
- 25 cm (10")
- 40 cm (16")
- 63 cm (25")

Figure 34: Twisted Female-Female Cables with Dimensions

Using these double-ended cables with the JST SH-style connector breakout boards to access the motor and encoder pins on a conventional solderless breadboard (available in top-entry and side-entry versions)

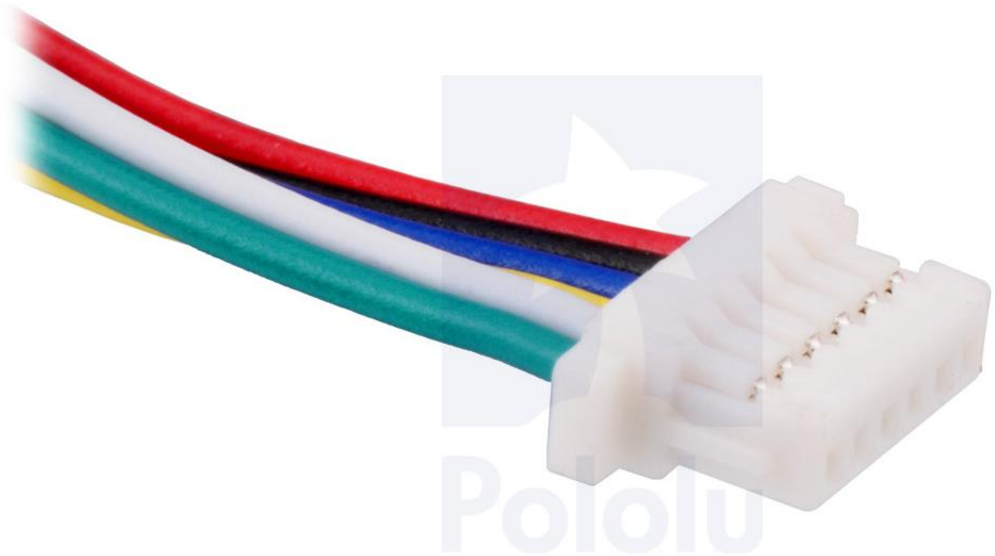


Figure 35: A 6 pin Female JST Cable

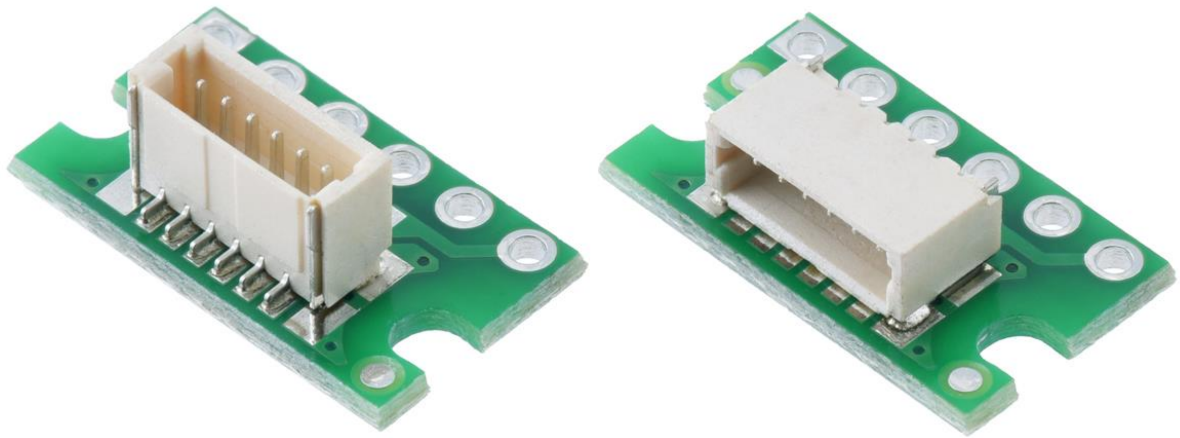


Figure 36: Breakout Boards for JST Connectors

5.3.2 Installation and Pinout

The encoder board is intended to be soldered directly to the back of the motor, with the motor's back shaft protruding through the circuit board's middle hole. Tacking the board to one motor pin and soldering the other pin only when the board is flat and properly aligned is one approach to obtain good arrangement between the board and the motor. Avoid overheating the motor pins, since this may cause the plastic end cover of the motor to distort, as well as the motor brushes.

The motor leads are connected to the M1 and M2 connection pins as labelled below when the board is soldered down to the two terminals, and they can be accessible via the red and black wires when using our appropriate JST cables. The sensors are powered and the two quadrature outputs are accessed via the remaining four connector pins:

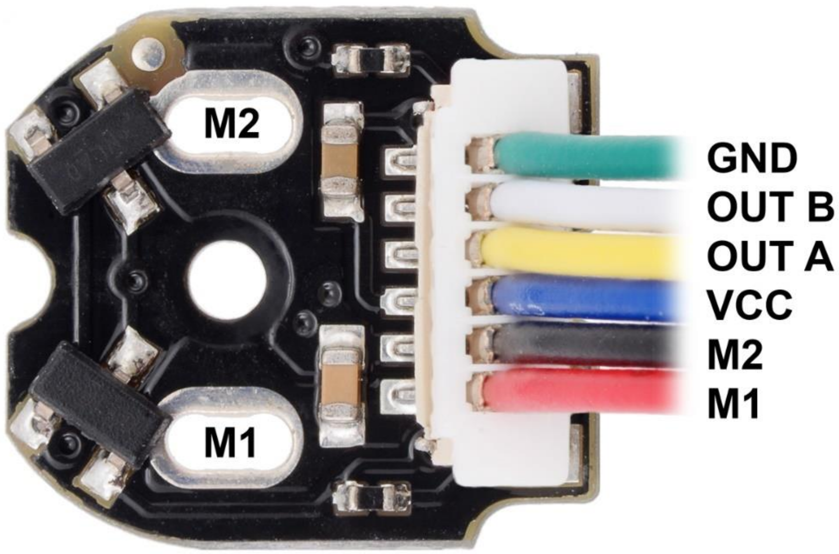


Figure 37: Magnetic Encoder alongwith the Connector Pins

The VCC (blue wire) and GND (green wire) pins provide electricity to the sensors. The quadrature outputs A and B (yellow and white wires) are digital signals that, depending on the applied magnetic field, are either driven low (0 V) by the sensors or pulled to VCC using 10 k pull-up resistors. In circumstances where the motor stops near a transition point, the sensors' comparators contain built-in hysteresis, which prevents erroneous signals.

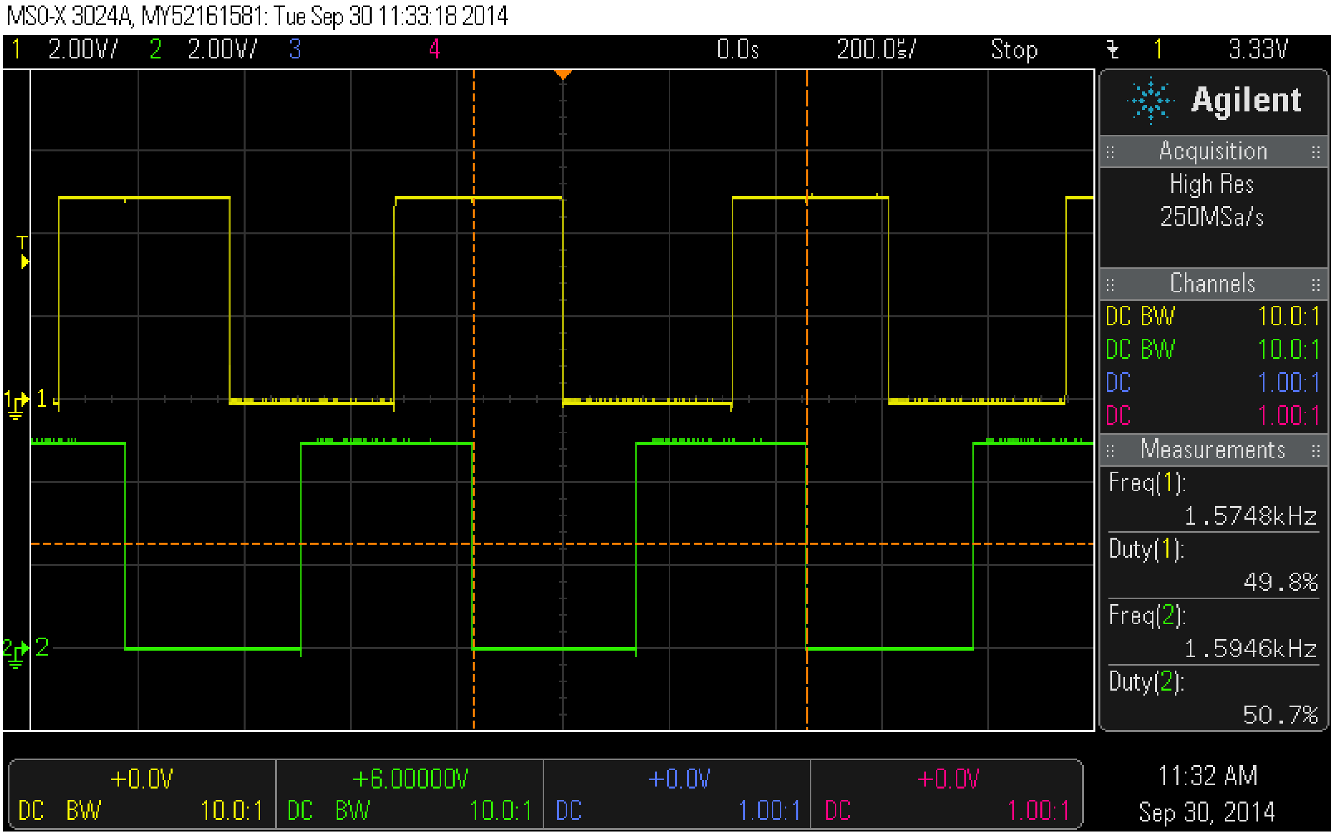


Figure 38:Encoder Outputs using Micro Metal Gearmotor of a Magnetic Encoder

5.3.3 Schematic Diagram

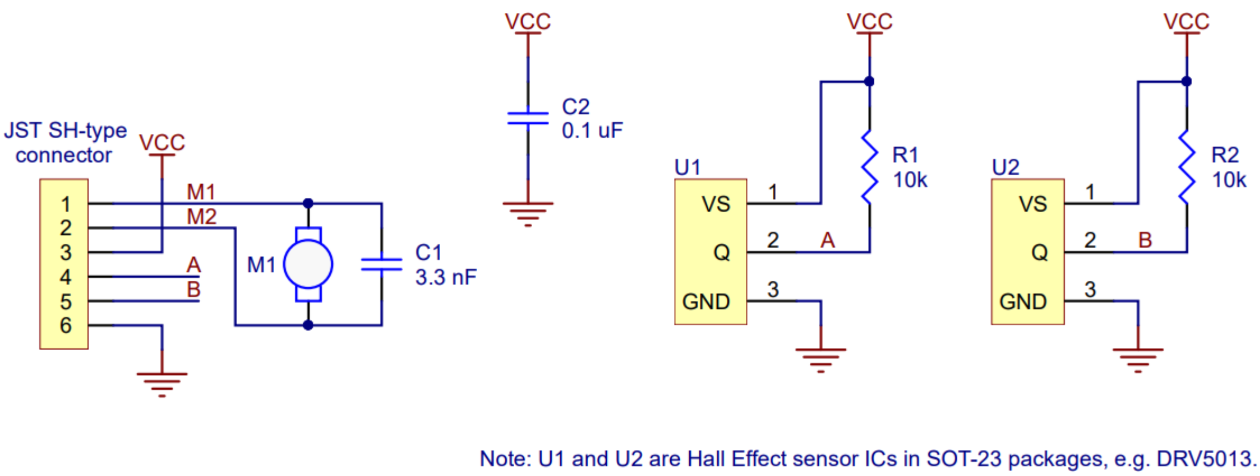


Figure 39: Schematic Diagram of Magnetic Encoder

5.4 Arduino Nano

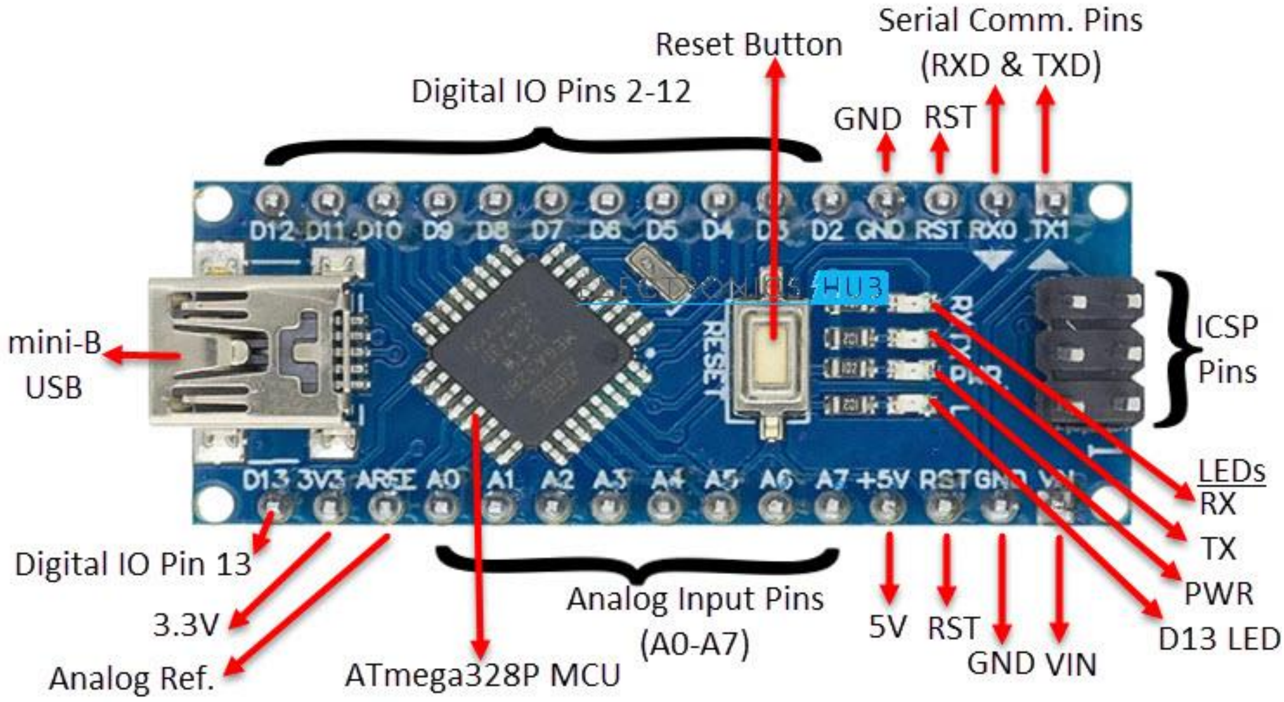


Figure 40: An Arduino Nano including the Connector Pins

The Arduino Nano is a compact, flexible, and breadboard-friendly microcontroller. There are 14 digital pins, 8 analogue pins, 2 reset pins, and 6 power pins on the Arduino Nano.

The Arduino IDE is used to programme it.

It has a 5V operational voltage, although the input voltage can be anywhere between 7 and 12V.

The maximum current rating of the Arduino Nano is 40mA, so the load connected to its pins should not draw more than that.

Digital pin operations are controlled by functions like pinMode() and digitalWrite(), whereas analogue pin actions are controlled by analogRead(). [14]

The analogue pins have a total resolution of 10-bits, measuring values from 0 to 5V.

The device's small size and breadboard-friendly nature make it a good choice for most applications where electrical component size is a major consideration.

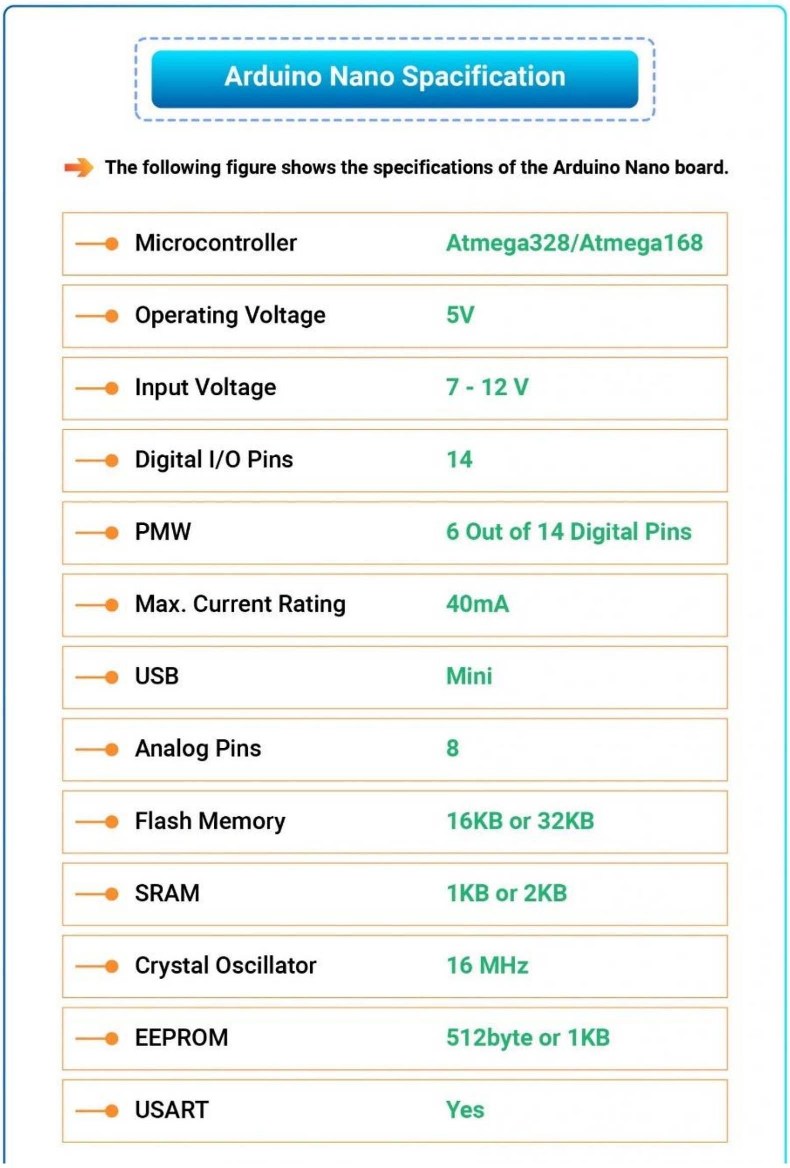


Figure 41: Specifications of Arduino Nano

5.5 L293D Motor Driver IC

The extensively used motor driver IC is a 16-pin L293D. It is mainly used to drive motors, as the name suggests. At the same time, a single L293D IC may drive two DC motors, and the two motors' directions can be regulated individually. If there are motors with an operating voltage of less than 36V and a current of less than 600mA that need to be controlled by digital circuits such as Op-Amps, 555 timers, digital gates, or even Microcontrollers such as Arduino, PIC, ARM, and so on, this IC is the correct solution for you.

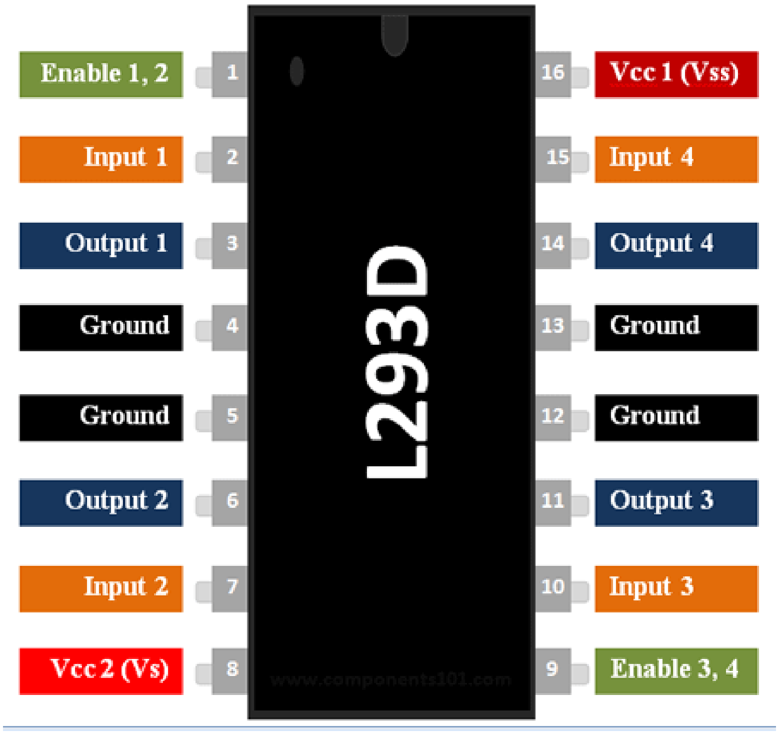


Figure 42: L293D Motor Driver IC

5.6 Voltage regulator LM7805

The 7805 Voltage Regulator IC is a common voltage regulator found in a variety of electronic designs. It produces a constant +5V output voltage from a variable input voltage supply. This is an application circuit for the 7805 integrated circuit. We only need two capacitors with values of 33uf and 0.1uf to get this IC operating. The input capacitor is a 0.33uF ceramic capacitor that eliminates the problem of input inductance, and the output capacitor is a 0.1uF ceramic capacitor that increases the circuit's stability. These capacitors should be put close to the terminals in order to function effectively. Ceramic capacitors should also be used, as they are faster than electrolytic capacitors.

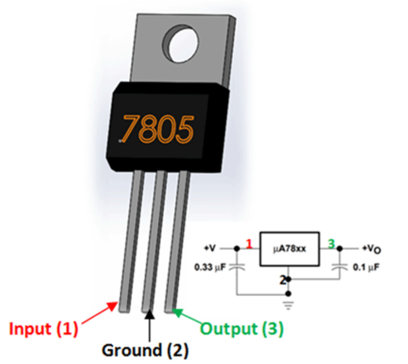


Figure 43: LM7805 Voltage Regulator

CHAPTER 6: MECHANICAL ASSEMBLY

6.1 Introduction

Mechanical assembly was required to hold the syringe, house the gearing, piston and position sensor. The assembly was to custom designed. The syringe was stock, available in the market. It was necessary to design the mechanical assembly before the control system could be designed.

The syringe is shown below:

Figure 44: Syringe available in Market

The measurements of the syringe are as follows:

External Diameter = 13.73mm

Internal Diameter = 11.71mm

External Height = 36mm

Internal Height = 27mm

Plunger Internal Diameter = 7.5mm

6.2 Design of mechanical assembly

6.2.1 Design Requirements

The assembly had to accomplish the following:

- The assembly had to fit the syringe.
- Allow the syringe to be swapped out/ replaced.
- Enough space and rigidity to handle mechanical stresses.

- Allow placement of position sensor.
- Have stops integrated in its design as not to prevent the piston from rotation and only allow linear motion.
- Light weight.

6.2.2 Working Principle of Injection Mechanism

A threaded rod is coupled with the motor through a gear box, the rod spins and if a body connected to the threaded rod, via threads of its own and it is not allowed to rotate via external stops. The body will move linearly along the threaded rod.

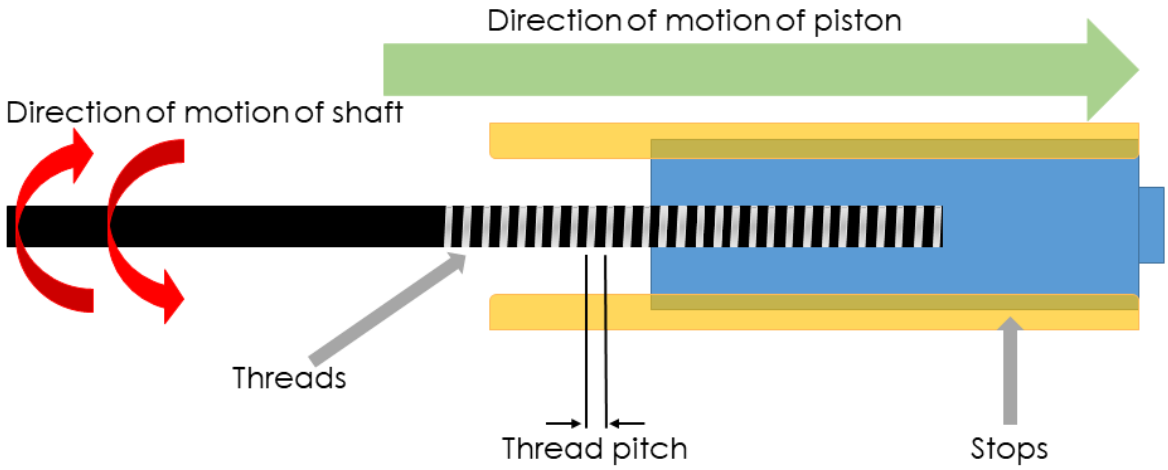


Figure 45: Working Principle of Injection Mechanism

The amount of linear displacement of the piston per rotation of the shaft is equal to the pitch of the threads of the shaft. Pitch of a thread is defined as "The distance between two adjacent threads".

For this we choose a threaded rod of size M3, which means it has a diameter of 3mm and a pitch of 0.5mm.

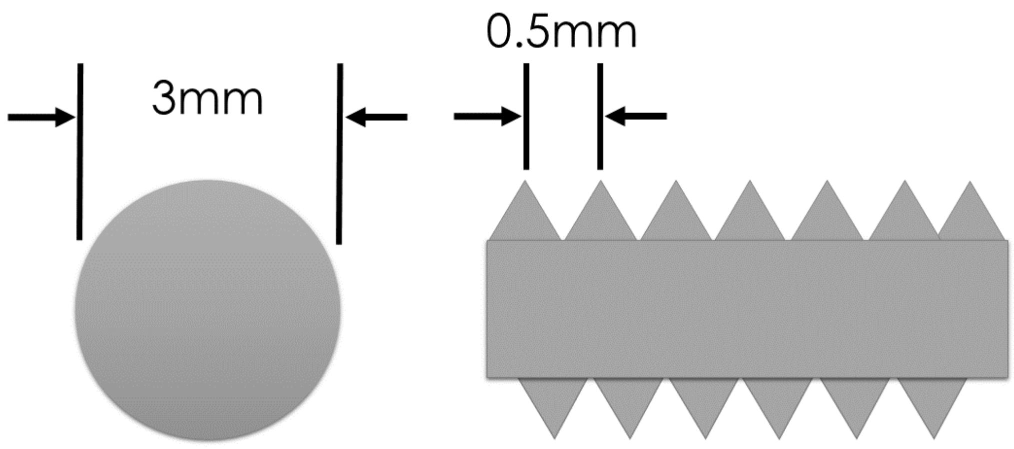


Figure 46: Dimensions of Threaded Rod

6.3 3D Modelling and Design

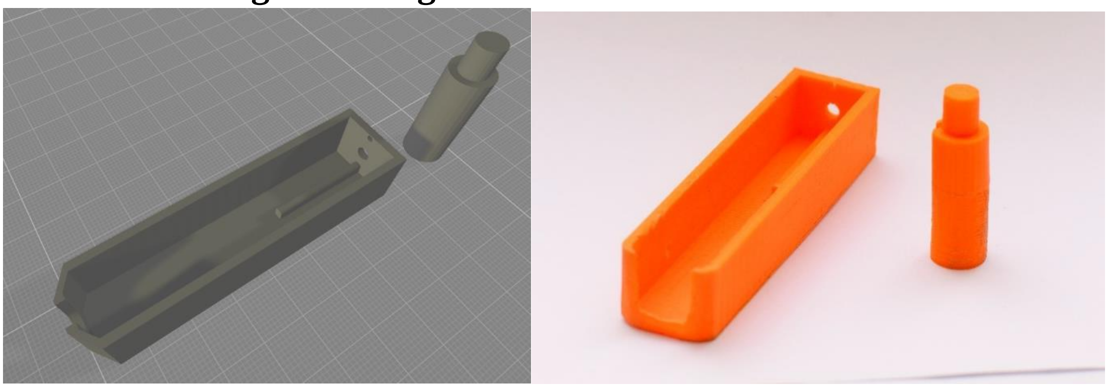


Figure 47:CAD Design (LEFT)– 3D Printed parts (RIGHT)

Engineering Schematics

(All measurements are in millimeters)

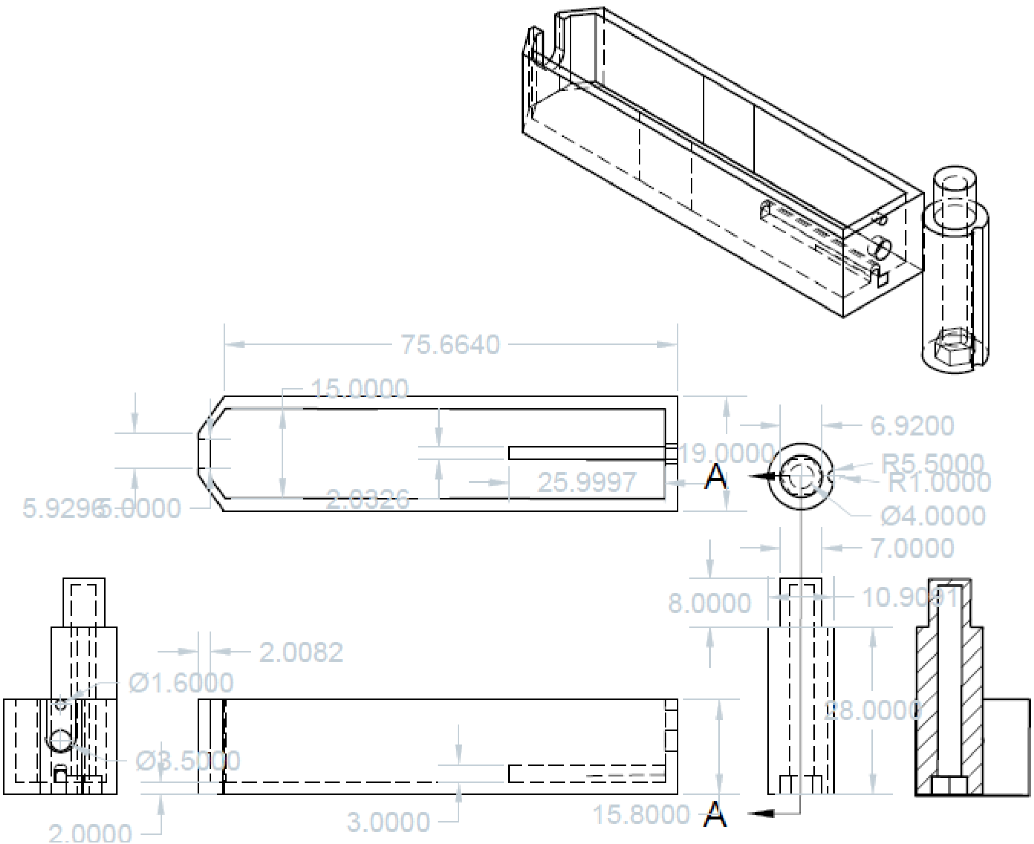


Figure 48: Mechanical Drawing of the Assembly

Following points were kept in mind when making the 3D design

- Better syringe retention.
- Rotation stops on all four sides.
- Mounting access for position sensor.

The assembly was designed to be top loading, with a cap to fix the syringe in place and to hold it in place while the piston was depressing the syringe.

For the parts to be printed with ease the individual components were separated and would be later joined together with screws and nuts (both M3).

Following are the subparts for the assembly:

6.3.1 Piston:

Piston was modelled as to accept guides/stops from four sides to prevent rotation. (All measurements are in millimetres)

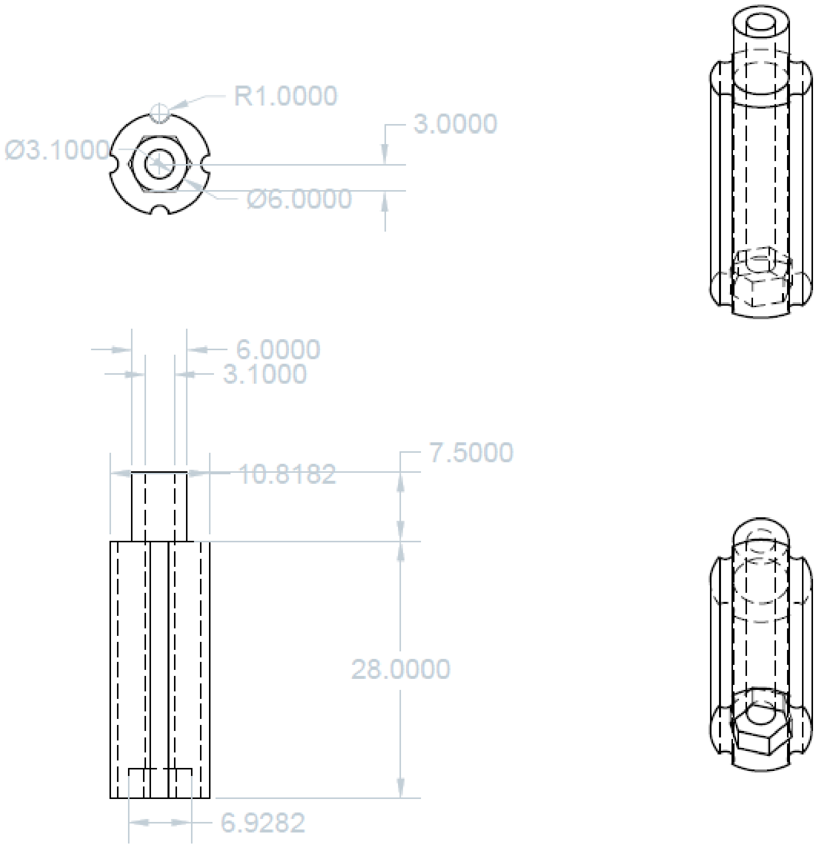


Figure 49: Piston Mechanical Drawing

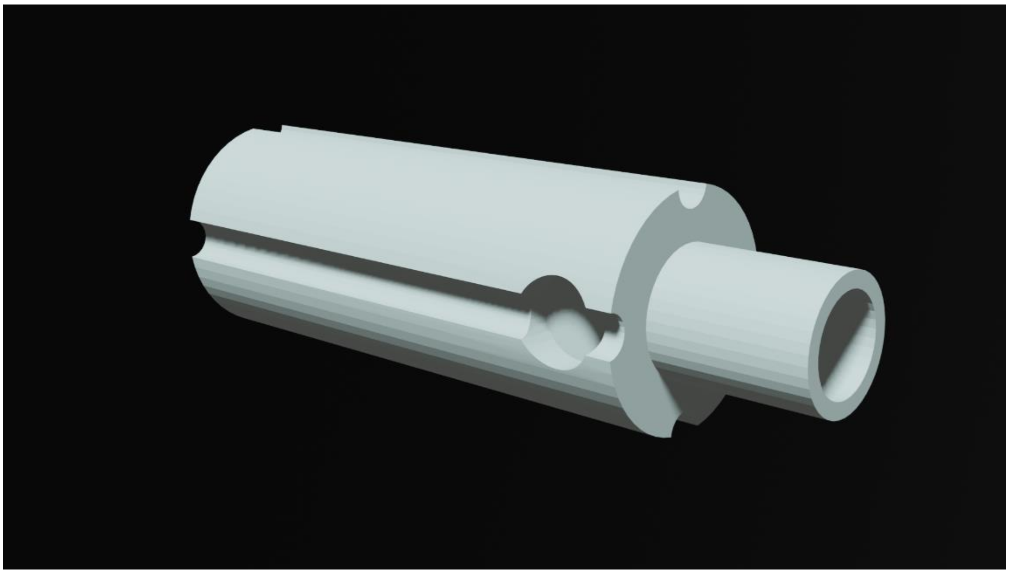


Figure 50: Blender Model of the Piston

The Bottom of the piston has a recess that an M3 nut can fit in to couple the piston with the M3 threaded rod.

6.3.2 Main Assembly:

The main assembly consisting of the syringe and piston housing units as well as the guides/stops for the piston. (All measurements are in millimeters)

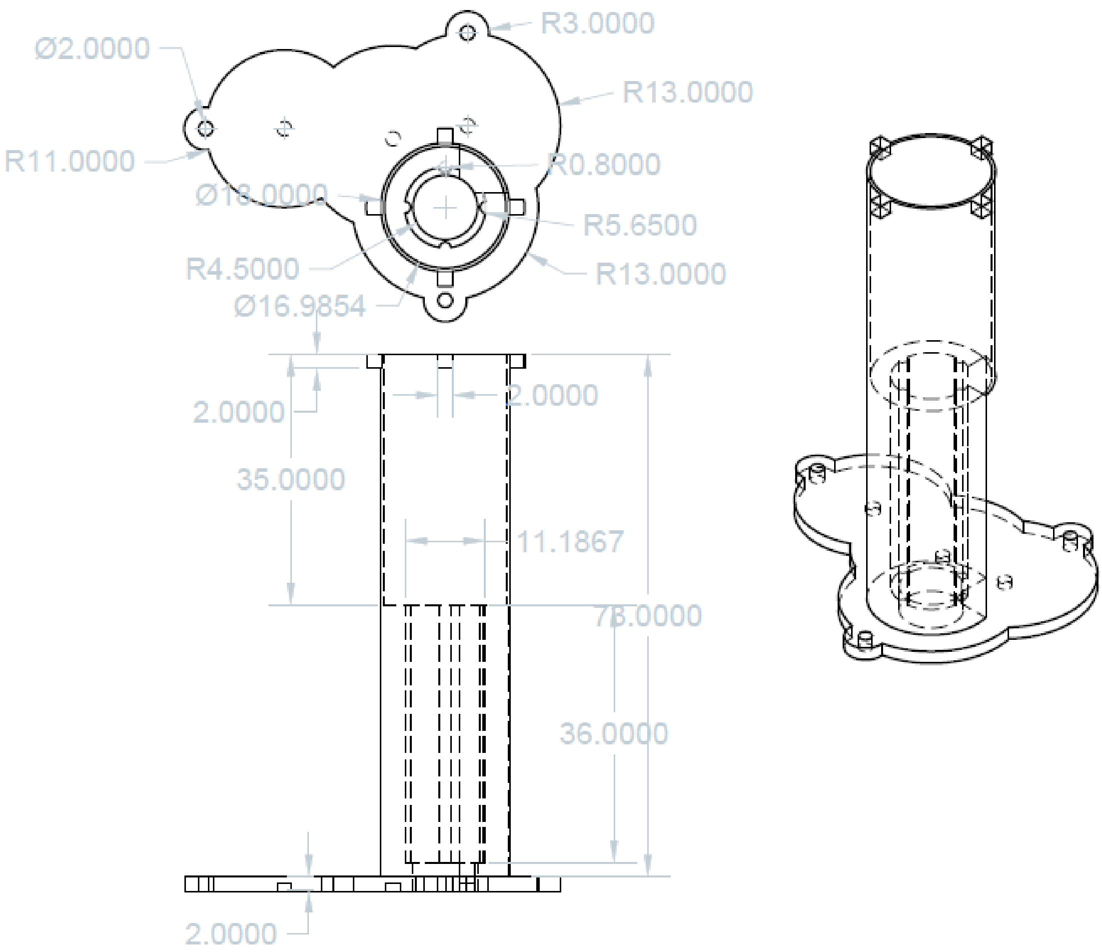


Figure 51: Main Assembly Mechanical Drawing

The assembly has a window where the position will be attached to the piston. Also, the housing has limiting stops to where the syringe will rest, preventing it from moving downwards.

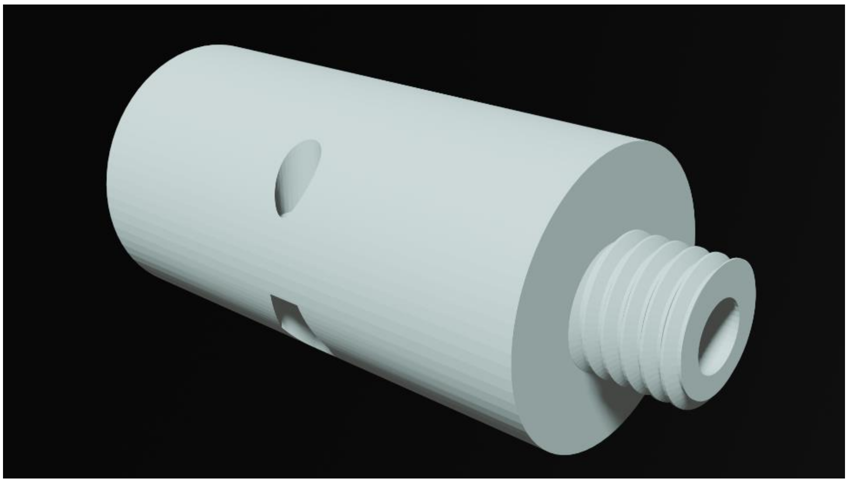


Figure 52: Blender Model of Motor Casing

6.3.3 Back Plate and Casing:

Back plate and the casing house the gearing mechanism and allow the motor to turn the threaded rod and in turn mode the piston forwards and backwards. (All measurements are in millimeters)

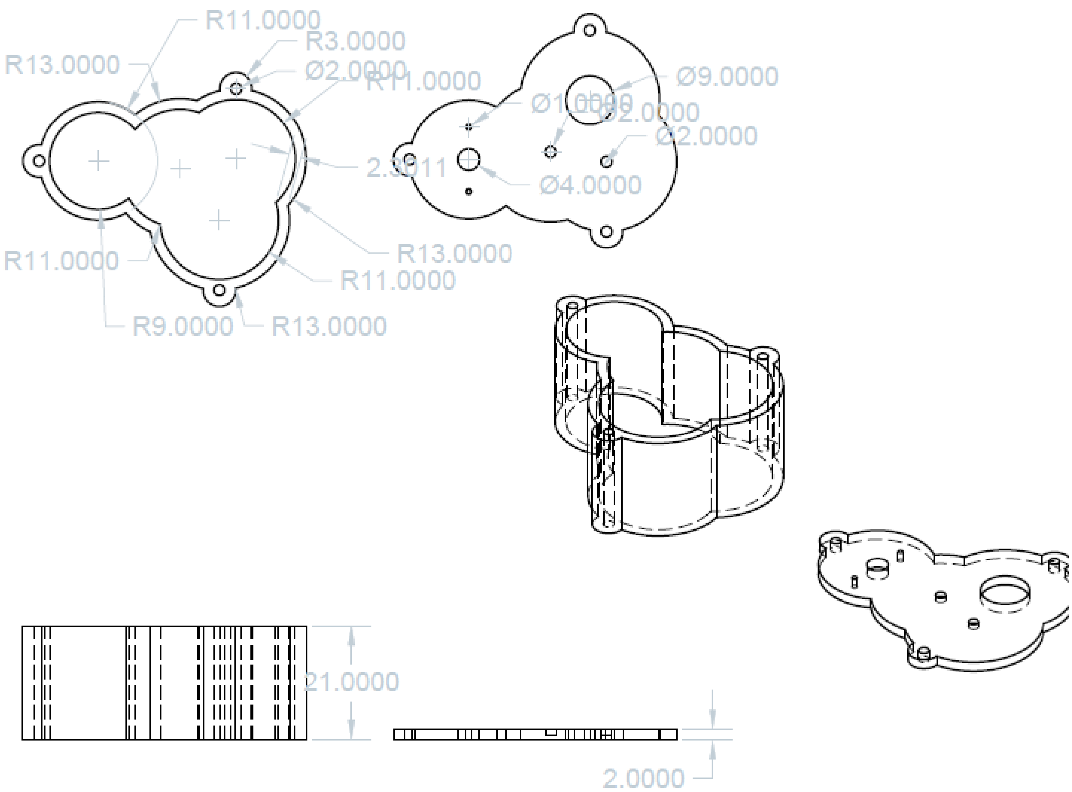


Figure 53: Back plate and Casing mechanical drawing

6.3.4 Cap:

Once the syringe is inserted, the cap will hold it in place serve the purpose of providing downward pressure and holding the syringe in place. (All measurements are in millimeters)

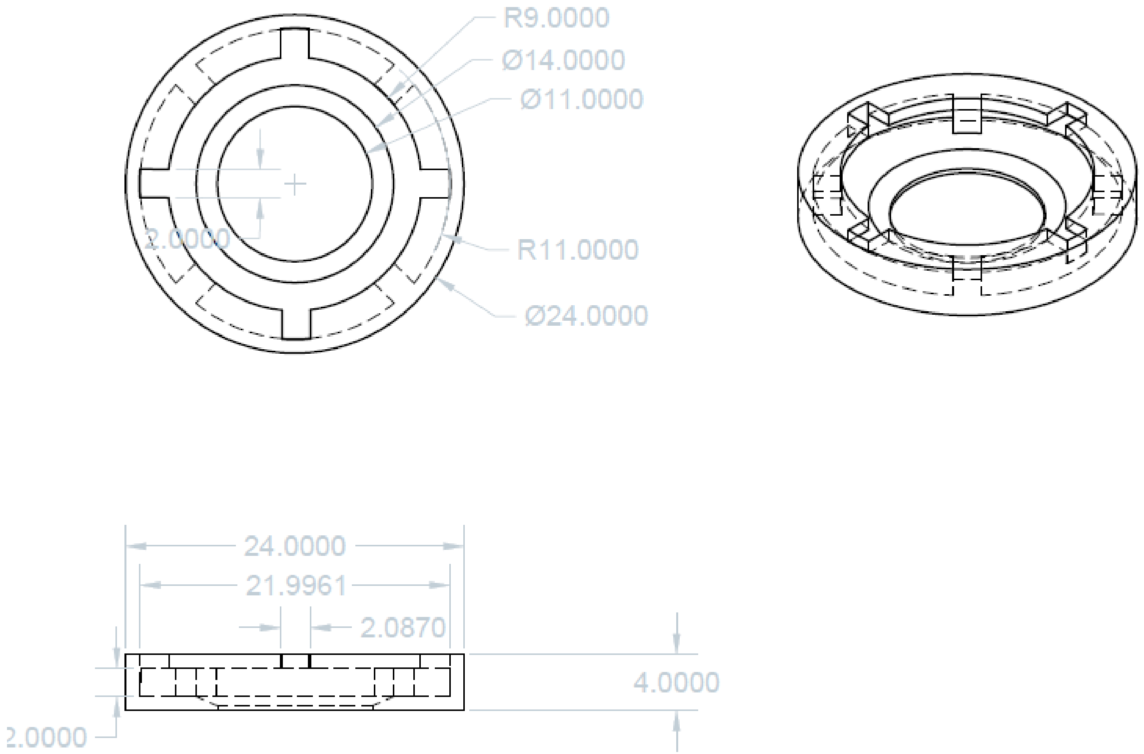


Figure 54:Cap mechanical drawing

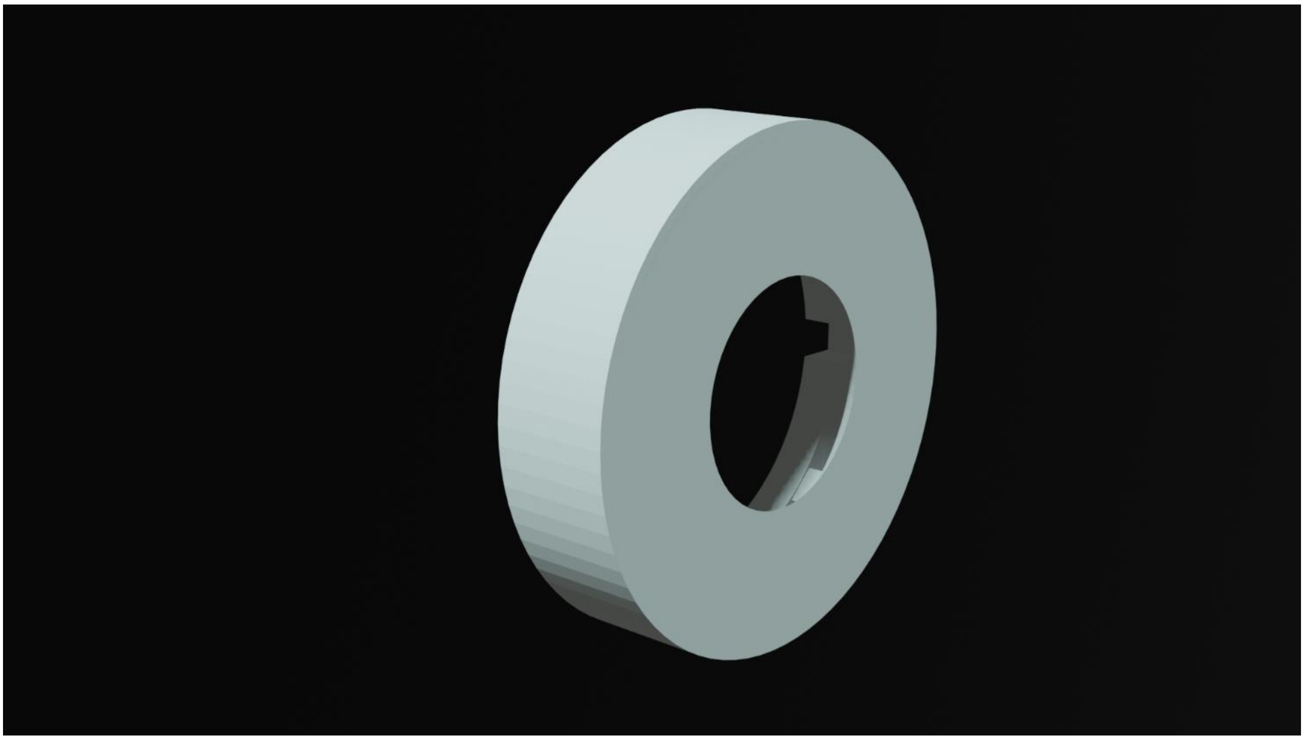


Figure 55: Blender Model of Cap

6.3.5 Bushings and Shaft:

The bushings hold he shaft in place, prevent twisting along its axis. The piston moves linearly along the line of the shaft along the threaded portion

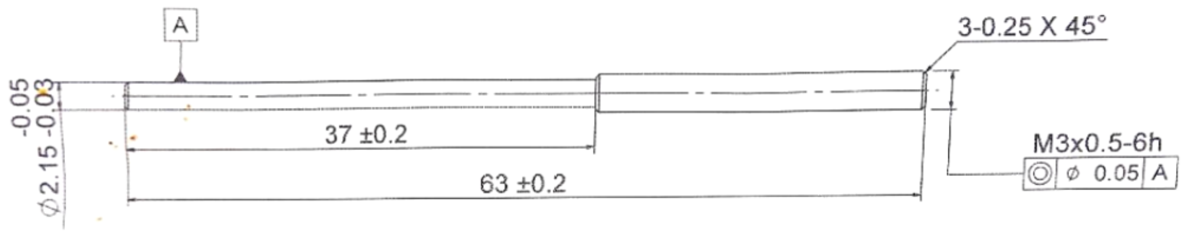


Figure 56: Shaft

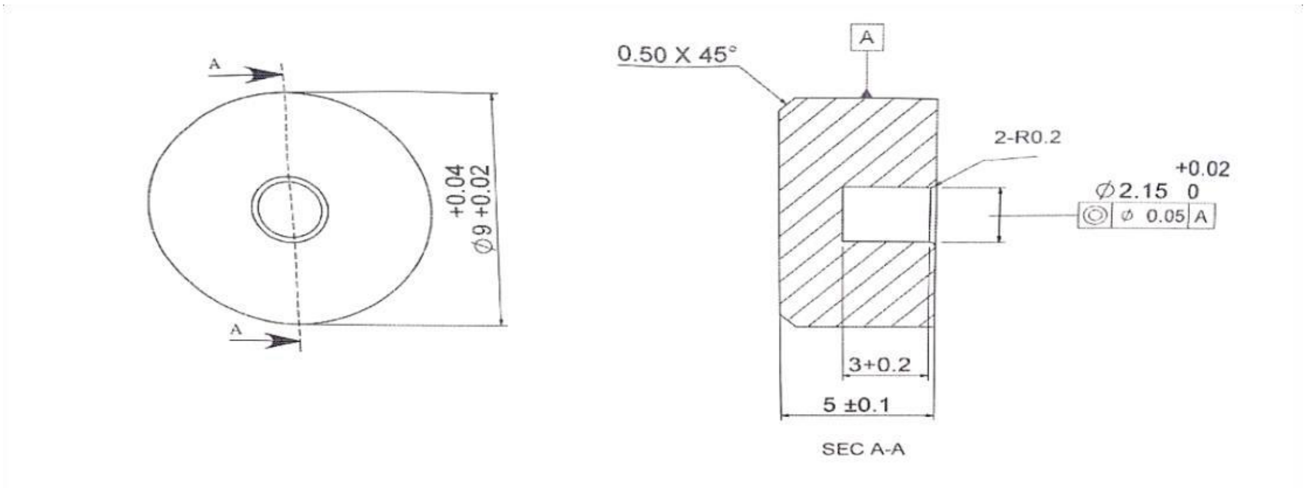


Figure 57: End Bushing

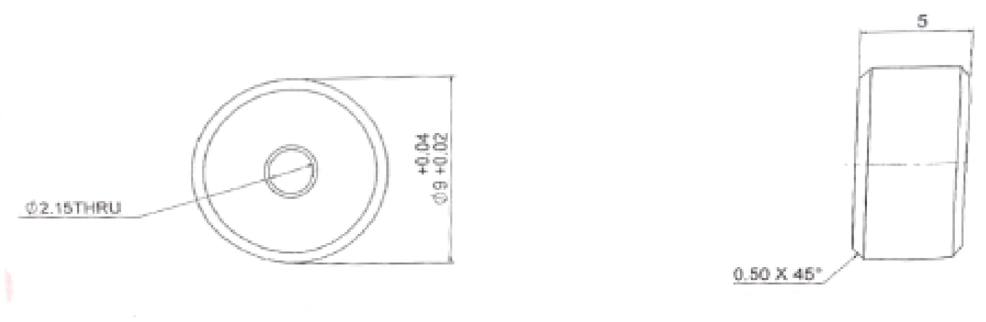


Figure 58: Support Bushing

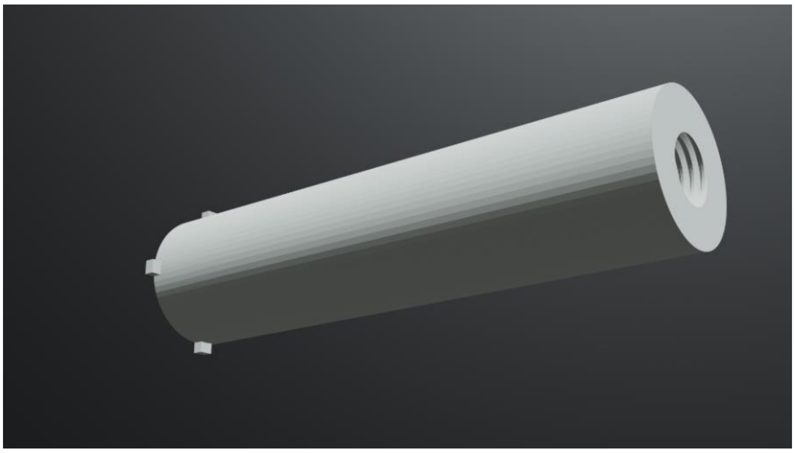


Figure 59: Blender Model of Syringe Tube

6.3.6 Assembled 3D Model:

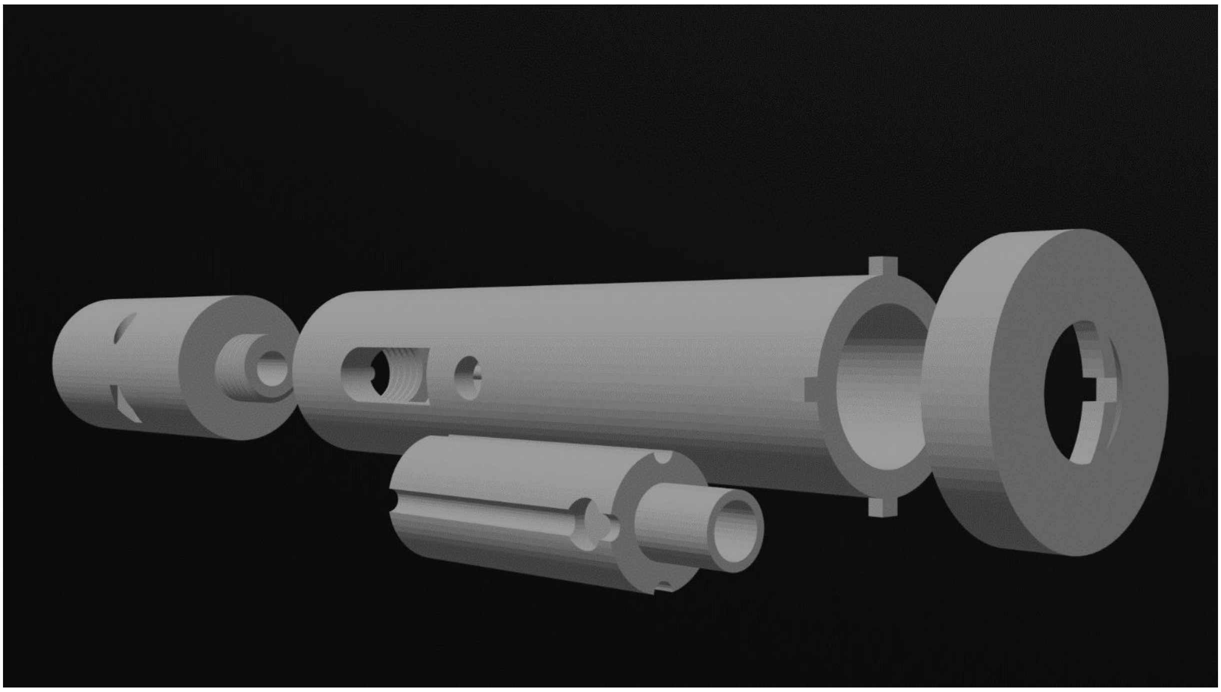


Figure 60: Assembled 3D Model

6.4 Gear Reduction and Minimum Dose Calculation

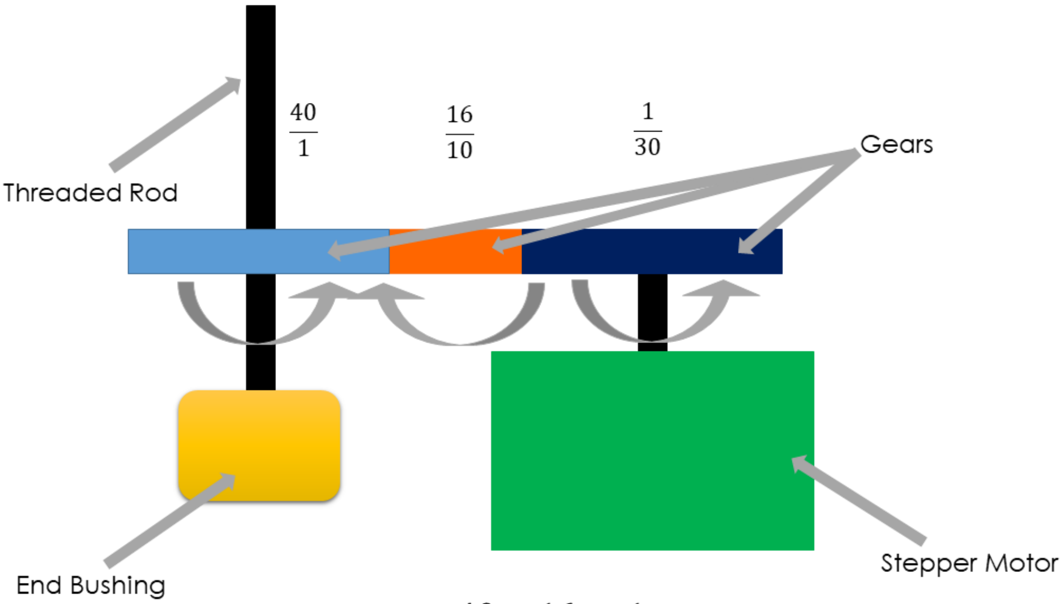
Minimum discretization of dose = 0.25

Stepper motor chosen for the design does 1000 steps per rotation.

Pitch of threaded rod = 0.5mm

Minimum dose of insulin (by volume) = 0.01ml (One Unit)

Gearing ratios = $\frac{40}{1} \times \frac{16}{10} \times \frac{1}{30} = 2.133$



$$\text{Gear ratio} = \frac{40}{1} * \frac{16}{10} * \frac{1}{30} = 2.1333$$

Figure 61: Gear Ratios

Overall reduction = Motor reduction x gearing ratio

= 2.133*1000

= 2133 times reduction in speed

i.e.

$$\frac{Rotations\ of\ Threaded\ Rod}{Rotation\ of\ Motor\ Shaft} = \frac{1}{2133}$$

That is, one rotation of the motor shaft will equal a 1/2133th rotation of the treaded rod. Since per rotation of the threaded rod the piston moves by a distance equal to the pitch of the treads, i.e. 0.5mm, so per step of the motor it moves a distance $= \frac{0.5mm}{2133} =$ $0.00023441163mm$

The volume of insulin delivered per step of the motor =

$\frac{\pi \times (internal\ diameter)\hat{}2 \times (distance\ moved\ by\ piston\ per\ step)}{4}$ = Volume per step

$$\pi \times \left(\frac{11.71}{2}mm\right)^2 \times (0.00023441163mm) = 25.2446 \times 10^{-12} m^3$$

$$\mathbf{0.025244688241}\ \boldsymbol{\mu L\ per\ step}$$

$$\text{Steps per minimum discretization} = \frac{0.25}{0.025244688241} = 9.9022127 \text{ steps}$$

$$\text{Steps to deliver 1 unit} = \frac{0.01\text{ml}}{0.025244688241\ ul/step} = 396.122935032289\ steps$$

CHAPTER 7: VEROBOARD PROTOTYPE AND PCB

7.1 Veroboard Prototype

The system is supposed to integrate the mechanical assembly with the control circuitry.

The system must have the following components:

- Driver circuit.
- Microcontroller.
- BMS (Battery Management System) and Battery
- Position sensor.

A basic block diagram is given below:

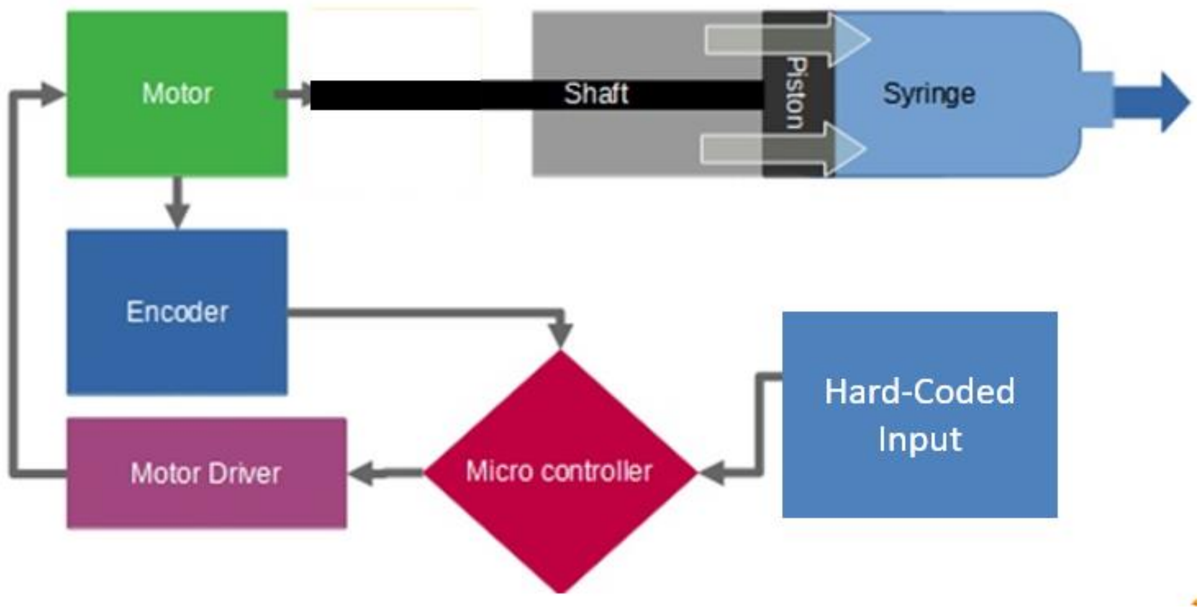


Figure 62: Basic Block Diagram of the System

Prototype of the system circuitry was constructed on Veroboard.

7.1.1 Schematic

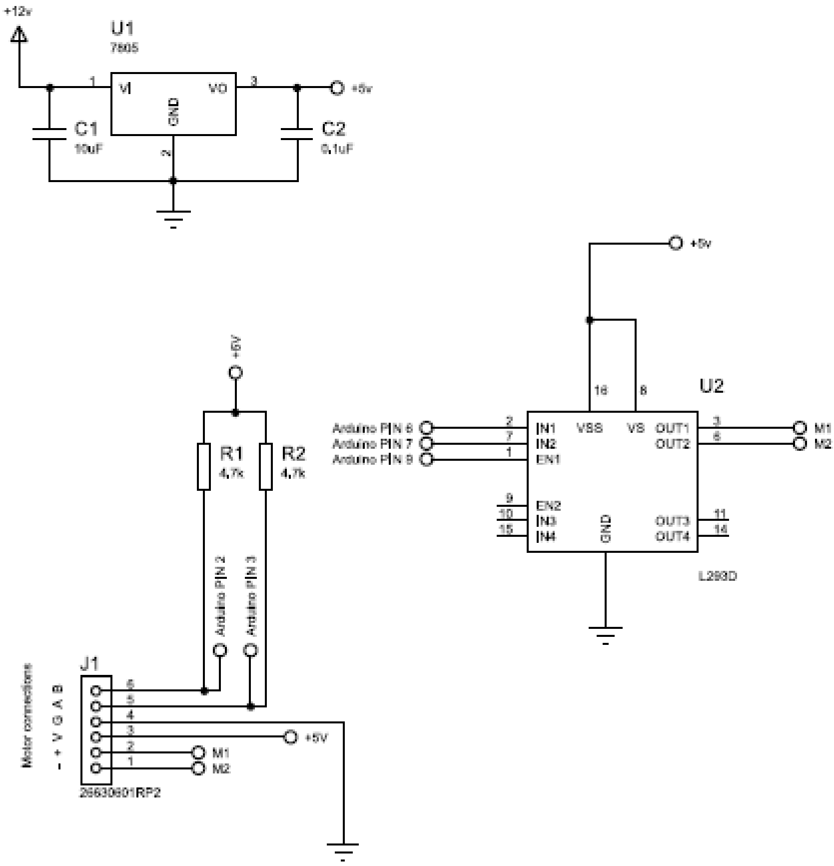


Figure 63: Veroboard Schematic

7.1.2 Assembled Circuit

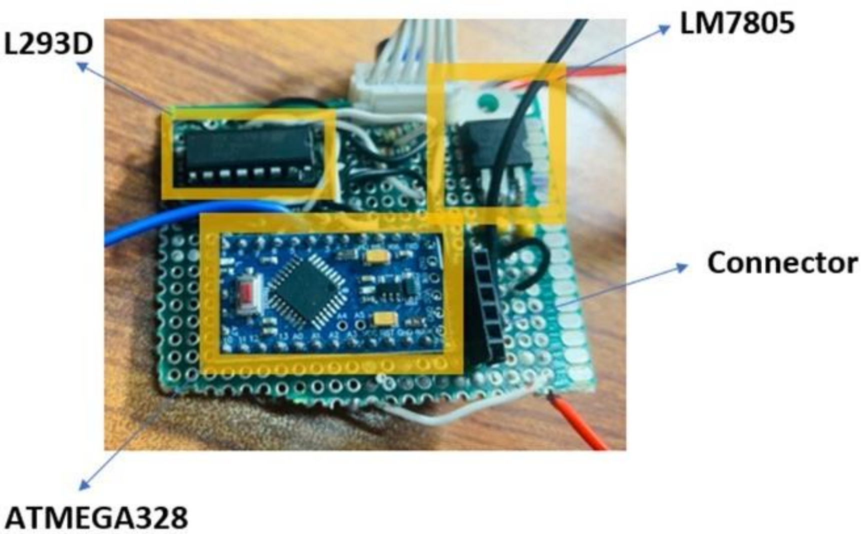


Figure 64: Veroboard prototype front

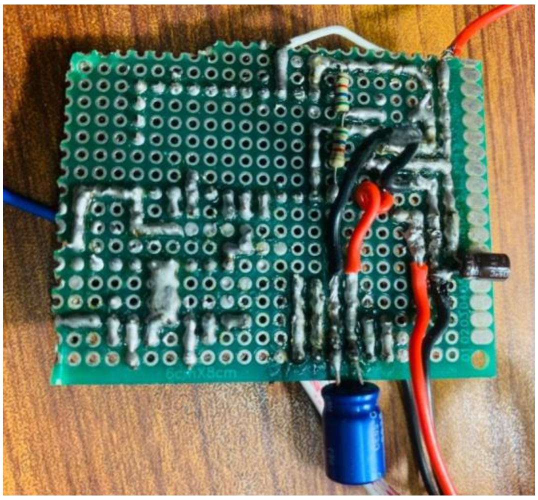


Figure 65: Veroboard prototype back

7.2 PCB

7.2.1 Design

7.2.1.1 Components used:

Following are the components used: -

- LM7805 5V Regulator
- L293D Motor Driver IC
- 4.7k Resistors
- 0.1uF Capacitors
- ATMEGA328
- DC 12V Lithium Battery

7.2.1.2 PCB

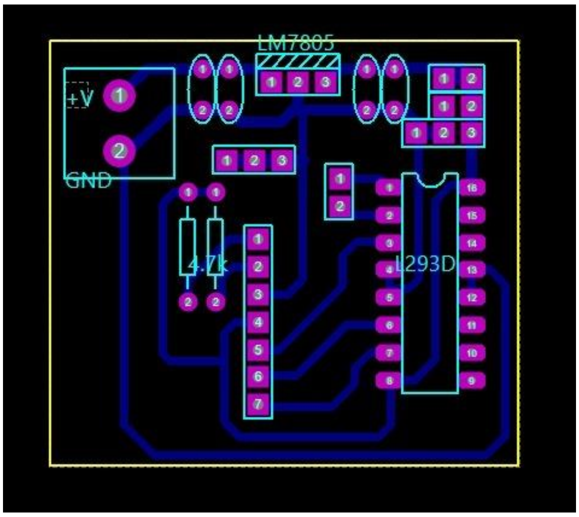


Figure 66: PCB Layout

7.2.1.3 Etched PCB

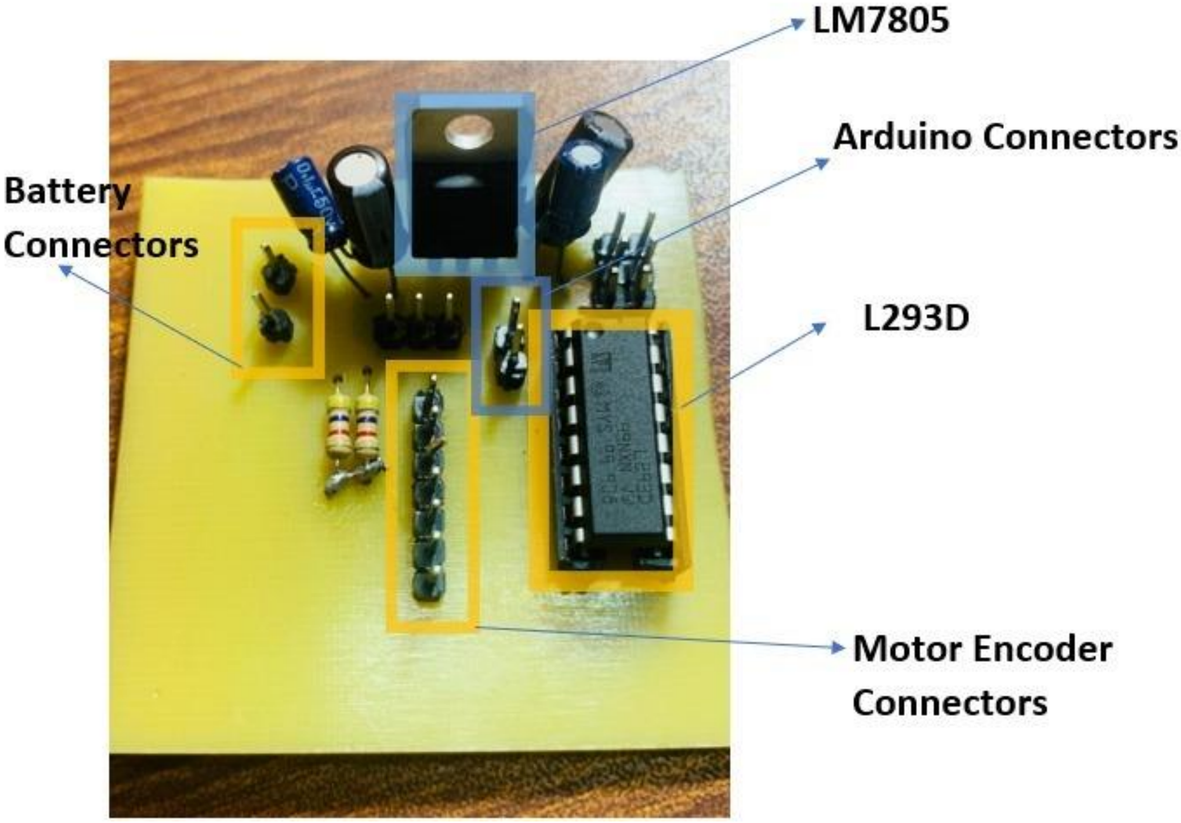


Figure 67: Assembled PCB front

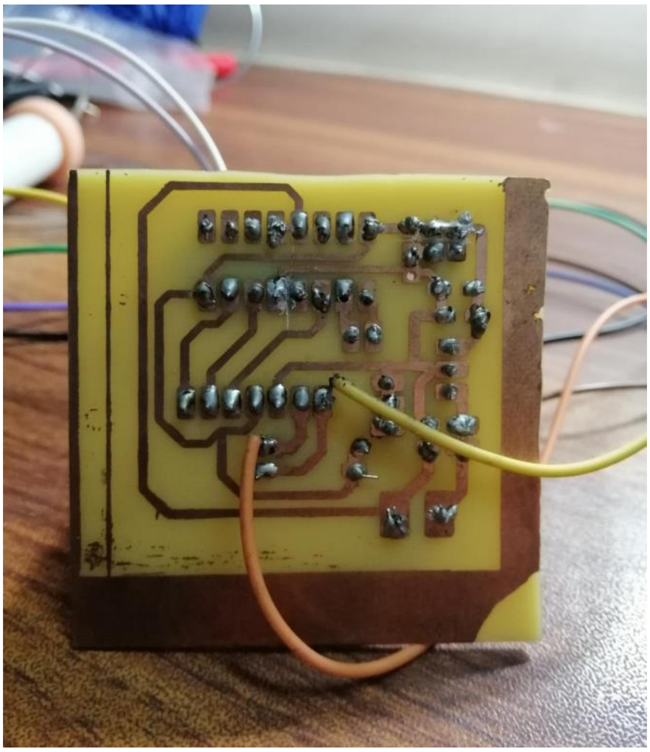


Figure 68: Assembled PCB back

7.2.2 Working

The 5V voltage regulator, powers the microcontroller and the motor. The encoder provides the necessary feedback and control for the motor's position and speed. Along with the microcontroller's programming involving the controlling variables, the required precision and accuracy is achieved. Which is then followed by the mechanical assembly for the rotational motion of the motor to be converted into linear motion of the shaft for the final fluid output.

CHAPTER 8: DISCUSSION AND CONCLUSION

8.1 Problems

- ### Soldering

The connections of the hardware keep getting disconnected due to weak soldering services. Also, the connections were not strong enough for stable current flow.

- ### Expertise for Mechanical Assembly

Mechanical design was not efficient due to lack of expertise.

- ### Testing and Feedback Sensor

Liquid flow measurement sensor was not available in the range of micrometres which was our project's minimum requirement for testing. Same problem was faced with feedback sensor.

- ### Viscosity based retracking

When the motor stopped working, the fluid didn't retrack resulting in excessive flow of fluid.

- ### Generic Design of Controller

The control system didn't give the best results.

8.2 Future Recommendations

- Model predictive controller instead of classical PID controller
- Further work on retracking the fluid should be done
- To increase accuracy and performance of pump use planetary gearbox with professional techniques
- MEMS based flow sensor to further increase accuracy
- Additional application as centrifugal pumps to be used in food and beverage manufacturing
- Reduction in size and user-friendly interface
- Mini Buck Converter for longer battery life

CONCLUSION

By looking at the results, it can be concluded that chemical pump was designed according to specification which can deliver a pumping rate with accuracy in mL. Controlling variables, magnetic encoder-based feedback with microcontroller programming, and circuit were designed and implemented to control motor. The automation and control were achieved through the position correction of the motor through the encoder loop, and the motor stopped once the setpoint was reached. The gearing of the motor and the mechanical assembly combined gave the desired volume of fluid as output as tested on hardware.

References

[1] "Advantages and Disadvantages of Syringe Pumps," Chemyx.

[2] K. H. Al-Sowdani and K. Al-Balaawi, "Lab–Built semi-automated Stop–flow System for Spectrophotometric Determination of Nitrite in Different water Samples," *Journal of Physics: Conference Series*, 2019.

[3] "Evaluation of automatic mixing versus manual mixing," 2020.

[4] "Automating Chemicals," 2020.

[5] J. Sabhadiya, "What Is A Dynamic Pump".

[6] C. Bipat, "Main Types of Pumps," 2021.

[7] H. ElKheshen, "Semi-automated self-monitore-syringe infusion pump," *2018 International Conference on Computer and Applications (ICCA),* 2018.

[8] T. a. L. S. Rayna, "The impact of 3D printing technologies on business model innovation," *Digital enterprise design & management. Springer,* 2014.

[9] Q. Ge, "Projection micro stereolithography based 3D printing and its applications," *International Journal of Extreme Manufacturing,* 2020.

[10] D. A. Zakoldaev, "Algorithm of choosing type of mechanical assembly production of instrument making enterprises of Industry 4.0," *Journal of Physics: Conference Series,* 2018.

[11] A. C. Siegel, "Foldable printed circuit boards on paper substrates," *Advanced Functional Materials 20.1 (2010),* 2010.

[12] K. S. Wenk, ""Allergic contact dermatitis from epoxy resin in solder mask coating in an individual working with printed circuit boards," *Dermatitis® 21.5 (2010),* 2010.

[13] M. Muhammad, "Linear Modeling of an Armature Controlled Geared DC Motor," *BRIDGING THE GAP BETWEEN ACADEMIA AND INDUSTRY IN NIGERIA– REFOCUSING THE ENGINEERING.*

[14] A. Kurniawan, Arduino Nano A Hands-on Guide for Beginner, PE press, 2019.