Design of Autonomous Mobile Robot

A thesis submitted in partial fulfillment of the requirements for
the award of the degree of

B.E

in

Mechanical Engineering

By

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NOVEMBER 2022

BONAFIDE CERTIFICATE

This is to certify that the project titled **Design and Development of Autonomous Mobile Robot** is a bonafiderecord of the work done by

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in partial fulfillment of the requirements for the award of the degree of **Bachelor of Engineering** in **Mechanical Engineering** of the **KLE TECHNOLOGICAL UNIVERSITY, HUBBALLI**, during the year 2020-21.

PROJECT GUIDE

Guide

DEPARTMENT HOD

Head of the Department

Project Viva-voce held on ________________________

Internal Examiner

External Examiner

ACKNOWLEDGEMENTS

The successful completion of any task would be incomplete without mentioning the people who made it possible and whose guidance and encouragement has made our efforts successful.

At the outset, we would like to express our deep sense of gratitude for our guide **Prof. Shivaprasad M Mukhandmath** for making this project report successful through their invaluable guidance at every stage of the project report.

We thank **Dr. Sachin Karadagi** for giving us this chance to work with him on this interdisciplinary project that was financed by the La Foundation. It was certainly a wonderful opportunity for us to learn and gain abundant knowledge.

We also thank **Dr. B. B. Kotturshettar** for his encouragement in undertaking the task of this project.

We express our sincere regard and gratitude to our project coordinators **Prof. Santosh Billur and Prof. Shivangouda Patil,** School of Mechanical Engineering, KLE Tech, Hubli.

We are also thankful to all faculty members of the Mechanical Engineering Department of KLE Technological University, for helping us directly or indirectly in different stages of our project work.

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ABSTRACT

An autonomous mobile robot is a type of robot that can understand and move through its environment independently. AMRs dynamically assess and respond to their surroundings while completing a variety of tasks all without the supervision of an operator. If they come across an unexpected obstacle while navigating, like a fallen box or a crowd of people, they will use sophisticated navigation collision avoidance systems to slow down, stop, or reroute their path around the object and then carry out the rest of their task. AMRs can be used everywhere. AMRs are mainly suitable for applications having multiple and variable destinations where the freedom of navigation and autonomous skills make the difference. AMRs are widely used in e-commerce, hospitals, grocery, and pharmaceutical industries, and for access to dangerous areas without guiding infrastructure such as fire nuclear, and military applications.[1]

Some of the main advantages of AMRs are that they help reduce the cost of day-to-day operations, provide improved safety to the operators, increase performance and productivity, are versatile and flexible to perform multiple tasks, and provide a better return.

There are very few AMRs currently available in the market and have similar properties in terms of load capacity, and runtime among others and are on the costlier side, tending to a niche market that is not accessible to all. We aim to solve this and make the bot accessible to a more widespread customer base, by reducing the size and cost significantly.[2]

To design a compact and cost-effective AMR, we decided to go with a lower run time and payload capacity, while ensuring it was in a range where it would still be useful in the industries. The design goals were set to achieve a bot that would be able to lift a 3kg payload and have a run time of 1 hour, while working at a speed of 0.5m/s.

The analysis of our designed AMR, should us that it was able to successfully carry a payload of 3kg with deformation of only 0.0094mm. Two battery packs of 24V 15 Ah and 12V 10Ah has been used to run the control system and the actuators independently ensuring a runtime of 1hour.[3]

Chapter 1

Introduction

1.1 What is an AMR?

AMR stands for Autonomous Mobile Robot. These Mobile Robots can be used for Automated Storage and Retrieval System (ASRS). Autonomous Mobile Robots can also be used in disaster recovery, military and exploration application. Autonomous Mobile Robots have the ability to operate without human surveillance which guarantees a robust and a resilient system.

The Decentralized decision-making allows the system to react dynamically to changes in the state and environment. The guiding system has evolved along various stages into today's vision-based system. The vision-based system uses Artificial Intelligence (AI) and Simultaneous Location and Mapping (SLAM) technology which enables the device to locate its facilities without the need of reference points or human surveillance.

In an Automated Guided Vehicle (AGV), a central unit takes control decisions such as routing and dispatching for all AGVs. On the other hand, AMRs can communicate and negotiate independently with other resources like machines and systems such as material handling assessment and control software, and take decision themselves.[4]

Requirements include –

- The AMR should be able to carry the payload to a certain prescribed height.
- The AMR should place the payload at the desired location within stipulated time thereby achieving the minimum given speed.
- The AMR, unlike an AGV, should be flexible enough to travel and not just on a fixed path.
- The AMR has to take decisions on its own thereby risking occurrence of collision.
- The AMR has to self-dock to recharge.
- The AMR has to travel with a minimum velocity of 0.5 m/s.

The decision-making strategies, problem solving and undertaking mission objectives form whole intelligence of the Autonomous Mobile Robot system. The AMR can create the map of an indoor environment.[5]

Chapter 2

Literature Survey

2.1 Analyzing the Need

Autonomous mobile robots are becoming more prominent in recent time because of their relevance and applications to the world today. Their ability to navigate in an environment without a need for physical or electro-mechanical guidance devices has made it more promising and useful.[6]

The use of autonomous mobile robots is emerging in different sectors such as companies, industries, hospital, institutions, agriculture, and homes to improve services and daily activities.

Due to technology advancement, the demand for mobile robot has increased due to the task they perform and services they render such as carrying heavy objects, monitoring, search and rescue missions, etc. Various studies have been carried out by researchers on the importance of mobile robot, its applications and challenges.[7]

The study, therefore, gives good direction for further developments of designs of autonomous mobile robots.

2.2 Product Benchmarking

Product benchmarking is the process of tracking a product's performance relative to its competitors based on certain metrics. This allows one to identify opportunities to improve products and make data-driven business decisions.

According to Productcraft, “Product performance benchmarks exist so companies can find ways to improve their products. Benchmarking is an important part of a continuous improvement cycle that involves measuring, comparing results to competitors, and identifying opportunities for improvement”.[8]

The table 2.2 lists out various competitive products in current market with the best specifications which can help us better design our product.

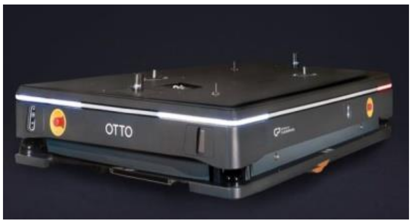
Products (Images or name)	Specifications
1.OTTO 750  Figure 2.2.1	i. 1837 x 1283 x 351 mm ii. Mass - 627kg iii. Max. Payload 1150 kg (2535 lbs) iv. Max. Speed 2.0 m/s. v. Battery Capacity 70 Ah vi. Runtime (10% to 90%) 10 hr.
2. BIDIBOT 2000  Figure 2.2.2	i. 2104 x 500 x 230 mm ii. Max. Speed 1.5 m/s. iii. Battery Li-Ion 48 V 40 Ah iv. Runtime (10% to 90%) 10 hr.
3. MiR 500  Figure 2.2.3	i. 1350 x 920 x 320 mm ii. Max. Speed – 2.0 m/s iii. Runtime – 8 hours continuous iv. Payload – 500kg

Table 2.2 – Product Benchmarking – Lists out the different currently available products along with its specifications

2.3 Competitive Benchmarking

Competitive benchmarking measures where and how your organization stands against your competitors. By using a set of predetermined metrics, benchmarking allows you to compare your company's performance against your competitors and other best-in-class brands.

According to Sprinklr, Competitive Benchmarking helps Rank brand performance of your competitors and helps to identify industry trends and top-performing content. In addition, helps gain visibility into competitors audience behaviours. [12]

The table 2.3 Compares three products Otto 750, Bidibot 2000, MiR 500 by using set of metrics to analyse the performance against competitors.

Sl. No.	Metric	Units	Competitive Products		
			Product 1 OTTO 750	Product 2 BIDIBOT 2000	Product 3 MiR 500
1.	Dimension	mm	1837 x 1283 x 351	2104 x 500 x 230	1350 x 920 x 320
3.	Mass	Kg	627	210	226
4.	Payload Capacity	Kg	750	2000	500
5.	Runtime	hr	10	10	8
6.	Speed	m/s	2	2	2
7.	Battery Capacity	Ah	70	60	55

Table 2.3 Competitive Benchmarking

In a nutshell, we can view our data in order to evaluate opportunities, threats, and strengths and weaknesses in the market (SWOT)

2.4 Literature Survey

A literature review is a comprehensive summary of previous research on a topic. Literary research includes scholarly articles, books, and other sources of information related to a particular field of study.

According to Bloomsburg University, "The review should list, describe, summarize, objectively evaluate and clarify this previous work. It should provide a theoretical basis for the study and help you (the author) judge the nature of the study. Literature reviews acknowledge the work of previous researchers and thus reassure readers that their work is well considered".[13]

The table 2.4 lists different Patents that we have considered as a part of our literature study.

Patent Name/ Number/ Date	Information
His Kao, Jian-An Su, Jau-Woei Perng, "Design of outdoor Autonomous Mobile Robot", International Conference on Recent Innovations in Biotechnology, 29 Jan 2022. [14]  Figure 2.4.1	- Six wheeled AMR. - Equipped with GPS, LiDAR, and High-Definition (HD) Camera. - 2D LiDAR based mapping helped robot to measure relative distance from robot to obstacle. - In order to avoid collision, the robot stops as soon as it detects an obstacle. - Use of fuzzy logic.
Dr. Ir. Dirk Lefeber , Autonomous Mobile Robot: Mechanical Design [15]	- Locomotion building mechanism
Shin'ichiYuta, Autonomous Mobile Robotics Research for Daily-Life Environment, IFAC Proceedings Volumes Volume 34, Issue 19, September 2001, Pages 31-38 [16]	Robustness in unstructured environments is very important and the length of time a robot can sustain his independence while acting for a particular mission, A reasonable measure of robot autonomy

Table 2.4 – Literature Survey of available Patents

CHAPTER 3

Problem Definition

3.1 Problem Statement

Design and Development of an Autonomous Mobile Robot (AMR), for an Automated Storage and Retrieval System (ASRS), which can carry a minimum payload of 3kg, and lift the payload to a height of 210 mm at a velocity of 0.5 m/s with a runtime of 1 hour.

3.1.1 Identifying End Customers

- Warehouses
- Hospitals
- Manufacturing
- Transportation
- Data Centre
- Research and Development

3.1.2 Identifying Customer Needs

- Place the payload at the desired location
- Achieve minimum speed
- Safety and Signal Interfacing
- Ability to take decisions on its own
- Docking for charging.

3.2 Objectives

Objectives	
Cost effective	Operations
Less maintenance cost	Material
Automated	Interactive
Portable	Low Power Consumption
Safety	

Table 3.2 – Lists different Objectives

3.2.1 Objective Tree and Affinity Diagram

According to WordPress, Objective trees are used to model the hierarchical nature of the requirements, or objectives, of a design problem. This is used primarily in the early stages of design in problem definition and clarification, though it should be revisited to ensure that the design team is kept on task. [17]

Objective tree Offers clear and useful format for the objective statement - Diagrammatic form showing the ways in which different objectives are related to each other.[18]

The below table 3.2.1 lists out the objectives and the different level of objectives for the same.

Sl. No.	Objectives	First level objectives
1	Portable	Light Weight
2	Efficiency	Achieving required speed
3	Easy to use	User- Interface
4	Safety	Emergency Button
5	Affordability	Inexpensive parts, less service cost
6	Automated	Mapping through LiDAR

Table 3.2.1 – Objective tree

Affinity Diagram

Affinity diagrams are tools used in design thinking to help organize ideas in brainstorming sessions. The goal is to have a large amount of information or insight and understand the essence behind its content. Suggestions are groupings of ideas based on affinity, similarity, dependency, or proximity.

According to ASQ Quality Press, “The affinity diagram organizes a large number of ideas into their natural relationships. It is the organized output from a brainstorming session. Use it to generate, organize, and consolidate information related to a product, process, complex issue, or problem”.[19]

The below figure 3.2.2 displays the primary and first level objectives.

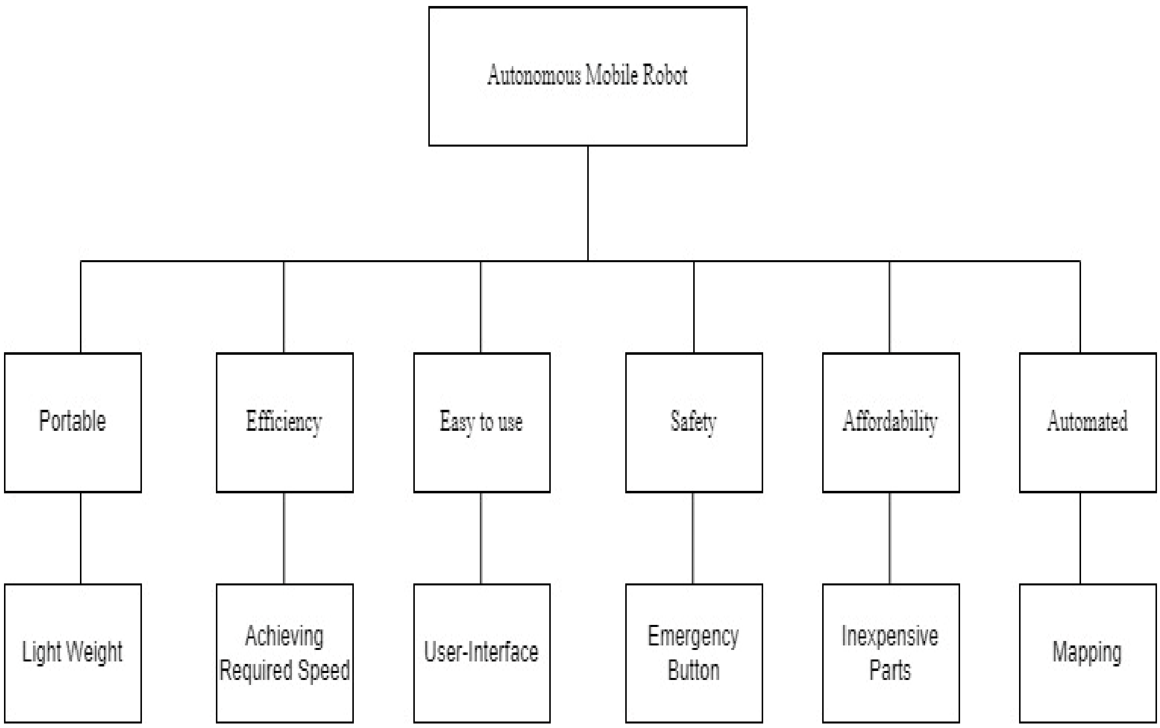


Figure 3.2.2 – Affinity Diagram

3.3 Morphological Chart

A morphological chart is a tool that represents a large qualitative design space. These charts list the functions identified for the design problem, and the means (solutions) that can perform each function.

Due to the difficulty of analyzing the long list of design solutions currently available There are no systematic design tools available for such analysis, systematic research. Morphological charts are studied in this work to provide a basis for the development of Future systematic exploration tools.[20]

The table 3.3 represents the different means to achieve a desired function.

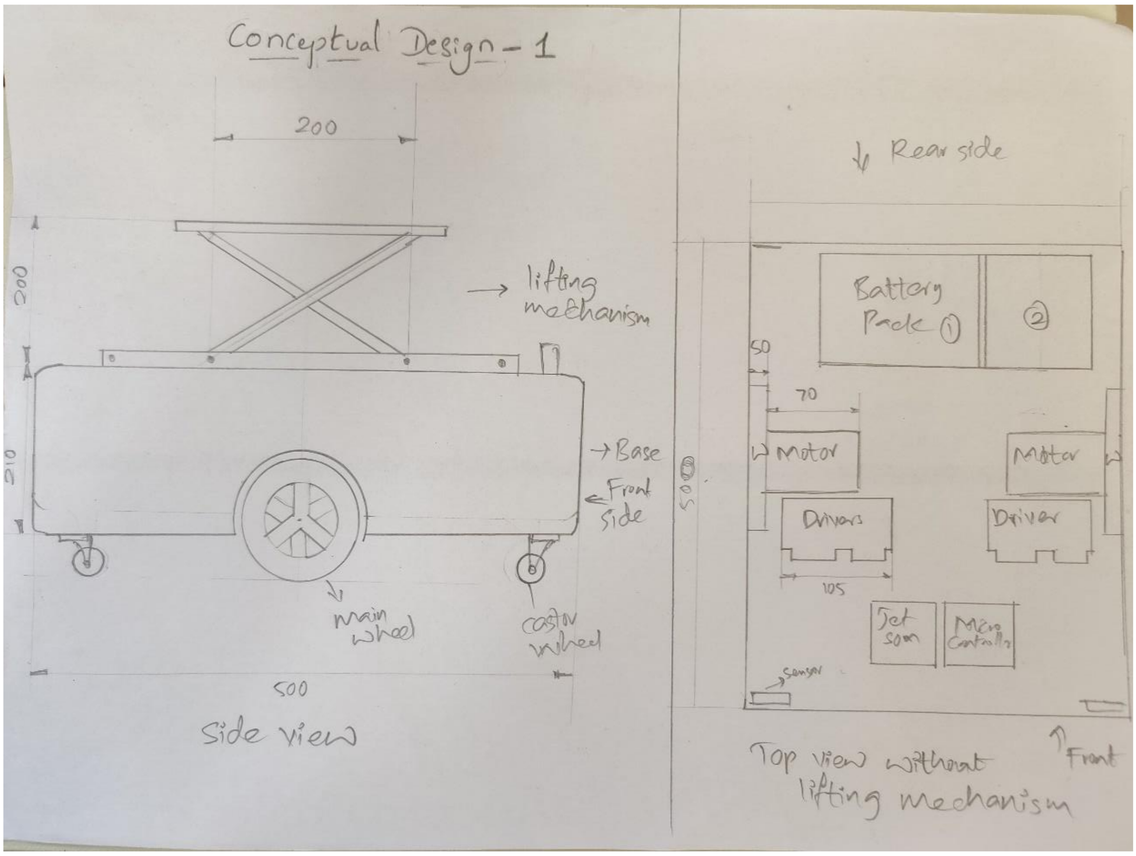
Start	Manual Button 	Application 	Voice 	
Sensing	LiDAR 	Ultrasonic 		
Lifting	Rack and Pinion 	Scissor 	Telescopic 	Jack 
Wheels	Mecanum 	Omni 	Castor 	

Table 3.3 – Morphological Chart: Explores different means to achieve a function.

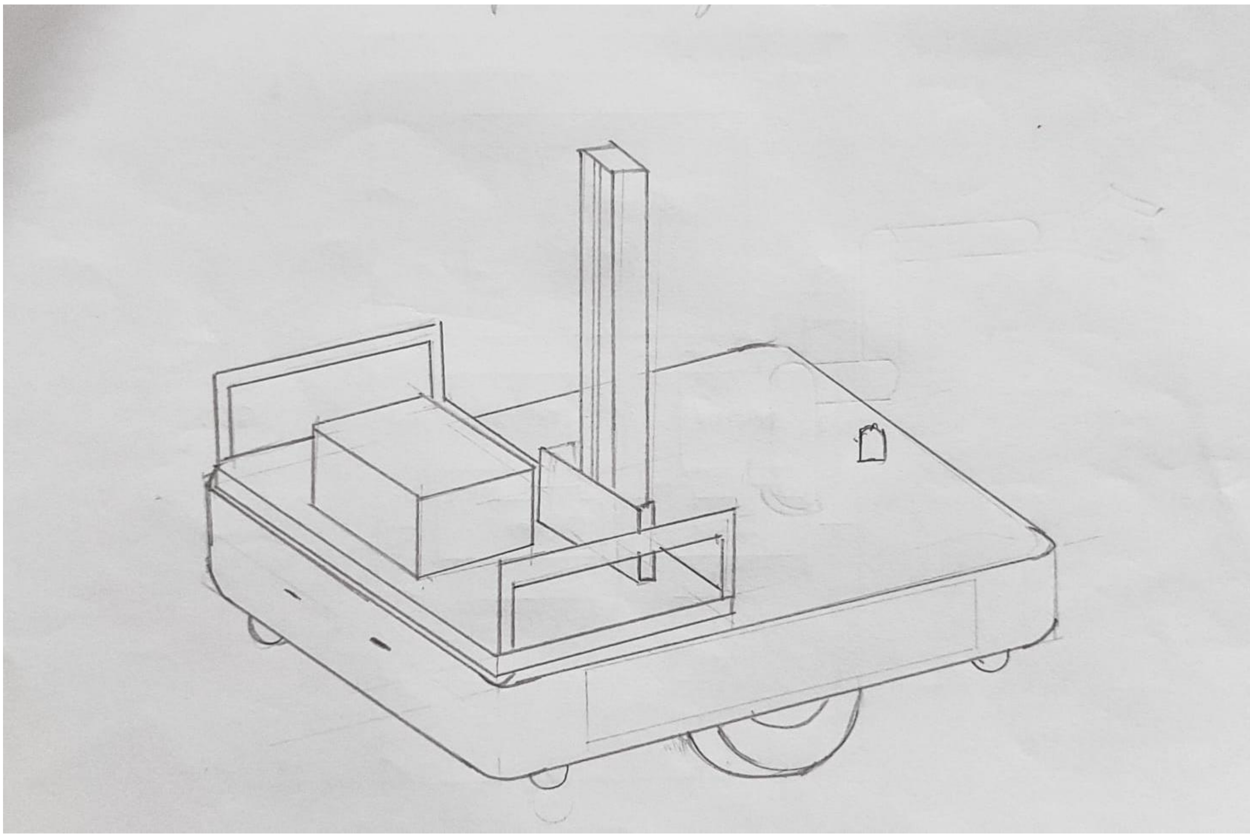
3.4 Identified Design Alternatives

CONCEPT GENERATION

Sketch of generated design concepts/ alternatives:

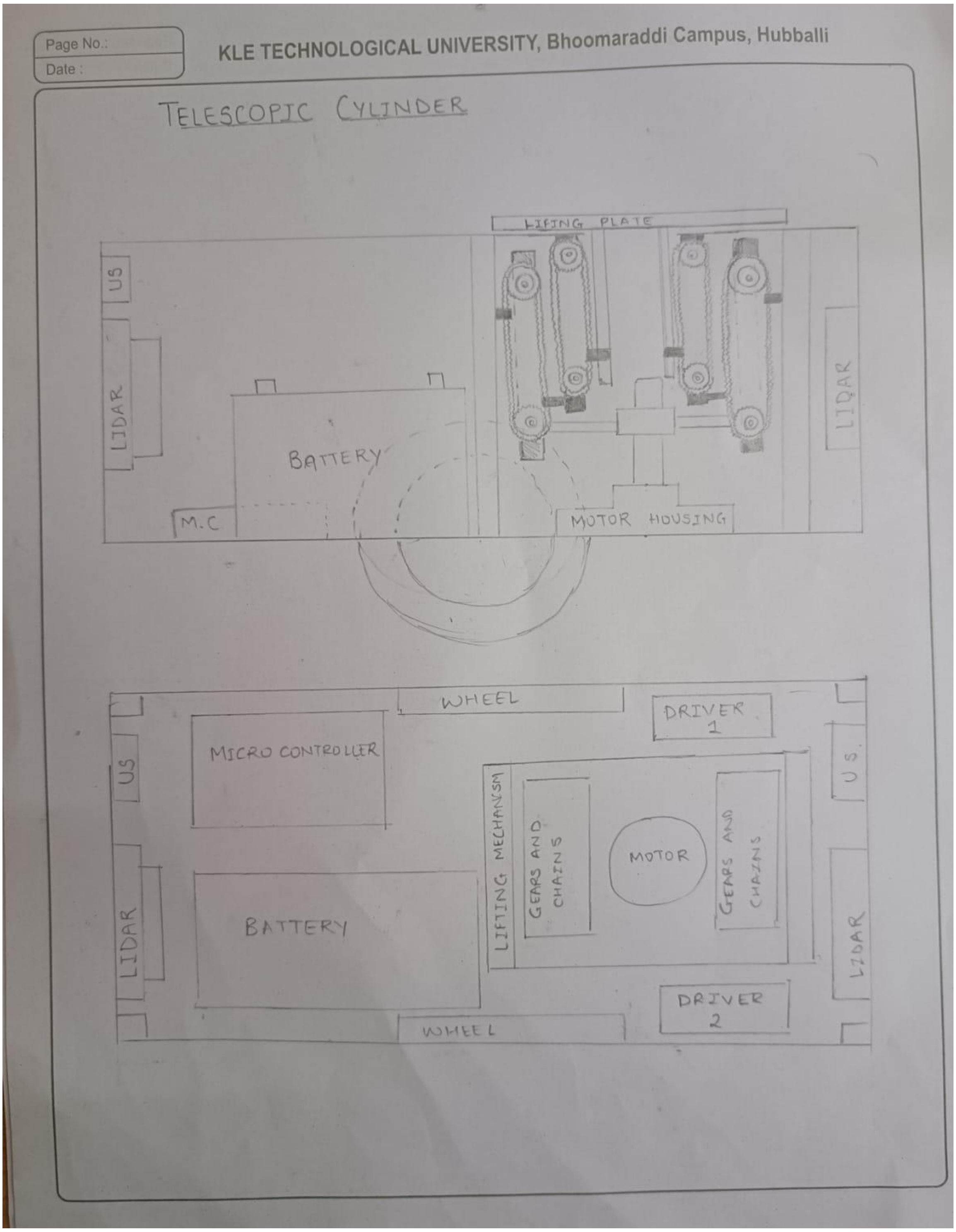
Design Alternative 1
 A scissor-lifting mechanism in which the DC motor rotates the threaded rod which forces the linked, folding supports to lift and platform. This is actuated by two powered wheels while the base is supported by four castor wheels.

Design Alternative 2



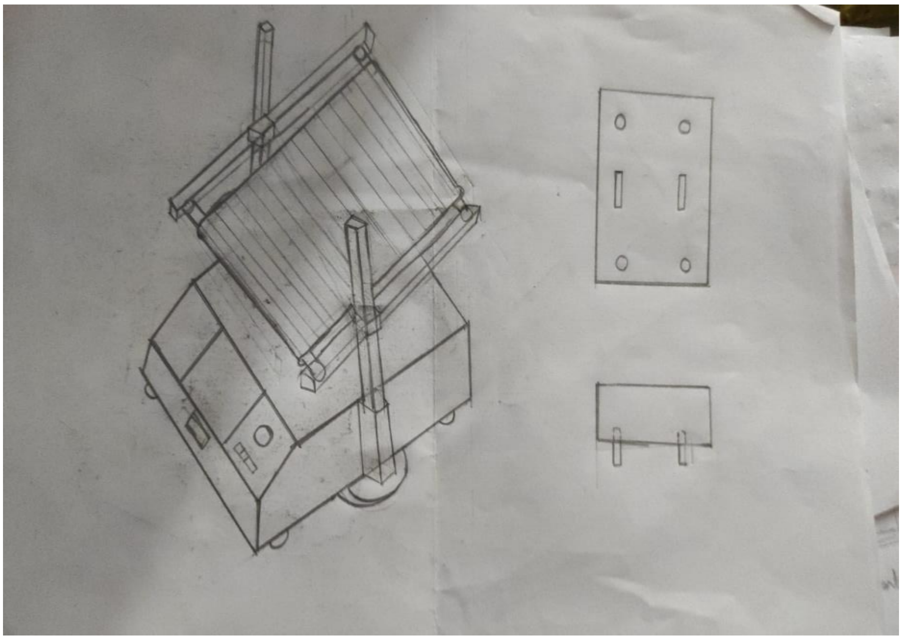
A hydraulic forklift is used to help lift the platform which requires a high-pressure fluid to exert the necessary force.

Design Alternative 3



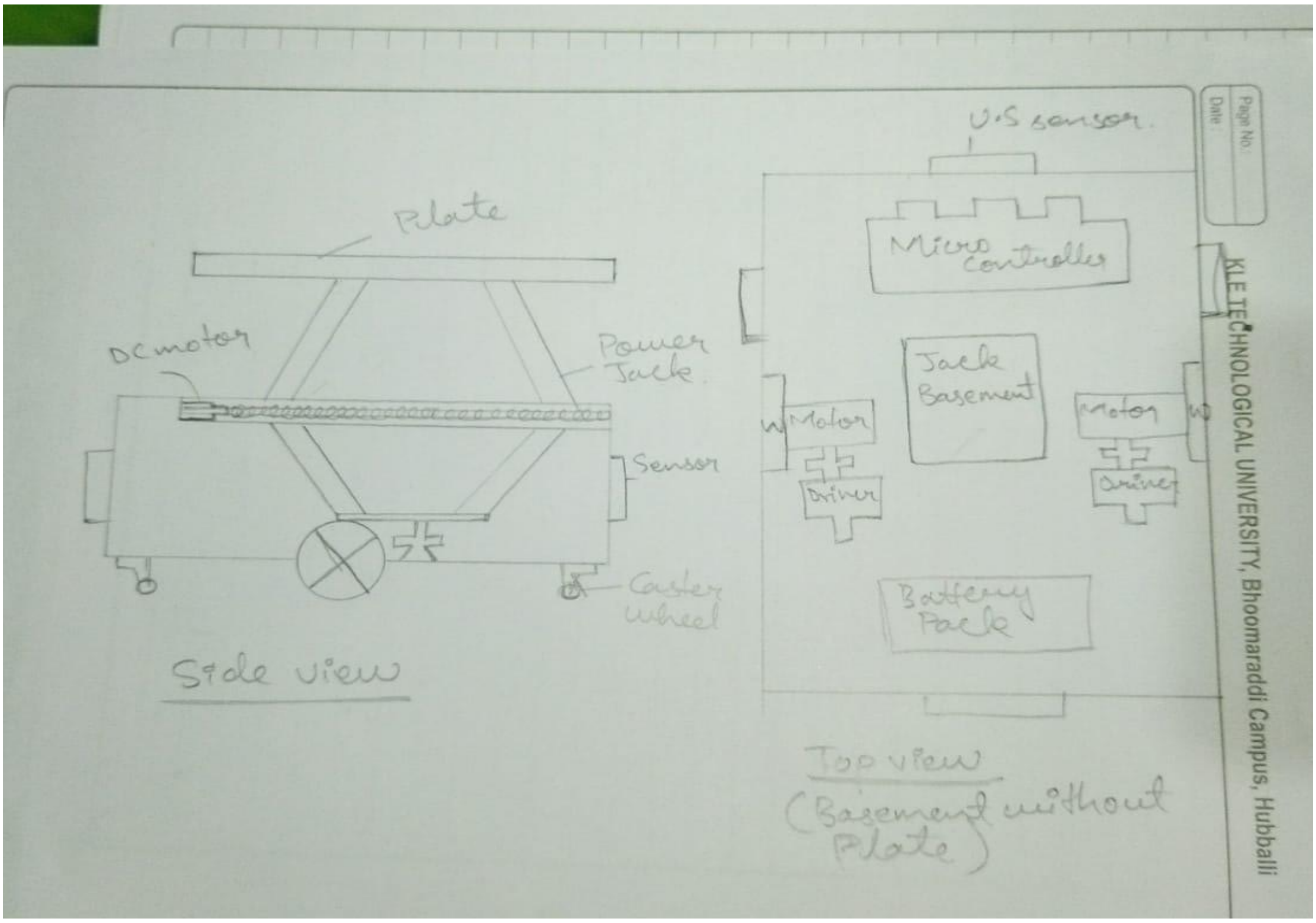
A combination of gears setup is used to provide telescopic lifting for the lifting platform with a motor housing at the base.

Design Alternative 4



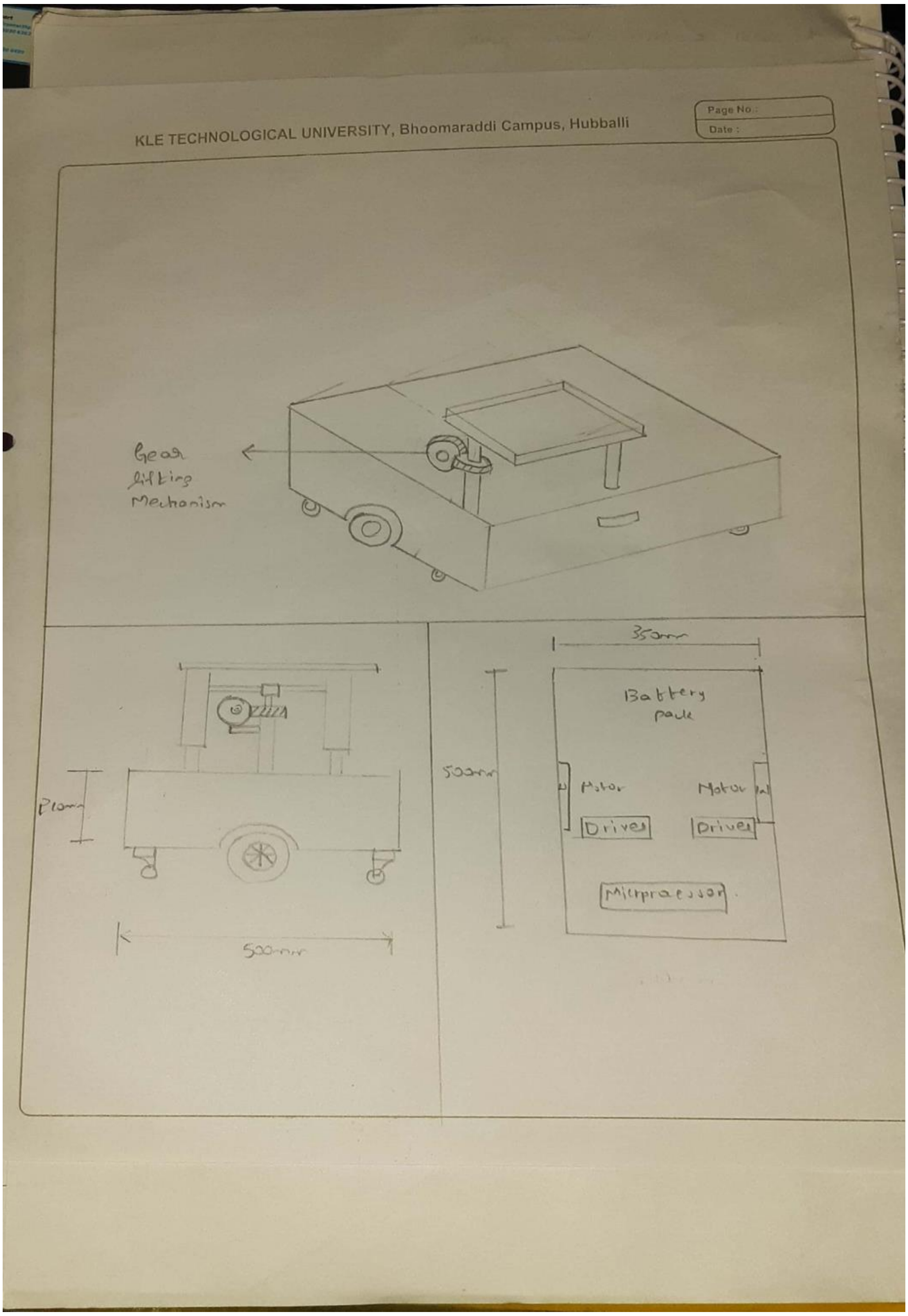
A telescopic lifting mechanism powered by a Stepper motor which when rotated provides the interlocked steps upward movement for the platform fixed at the top to lift.

Design Alternative 5



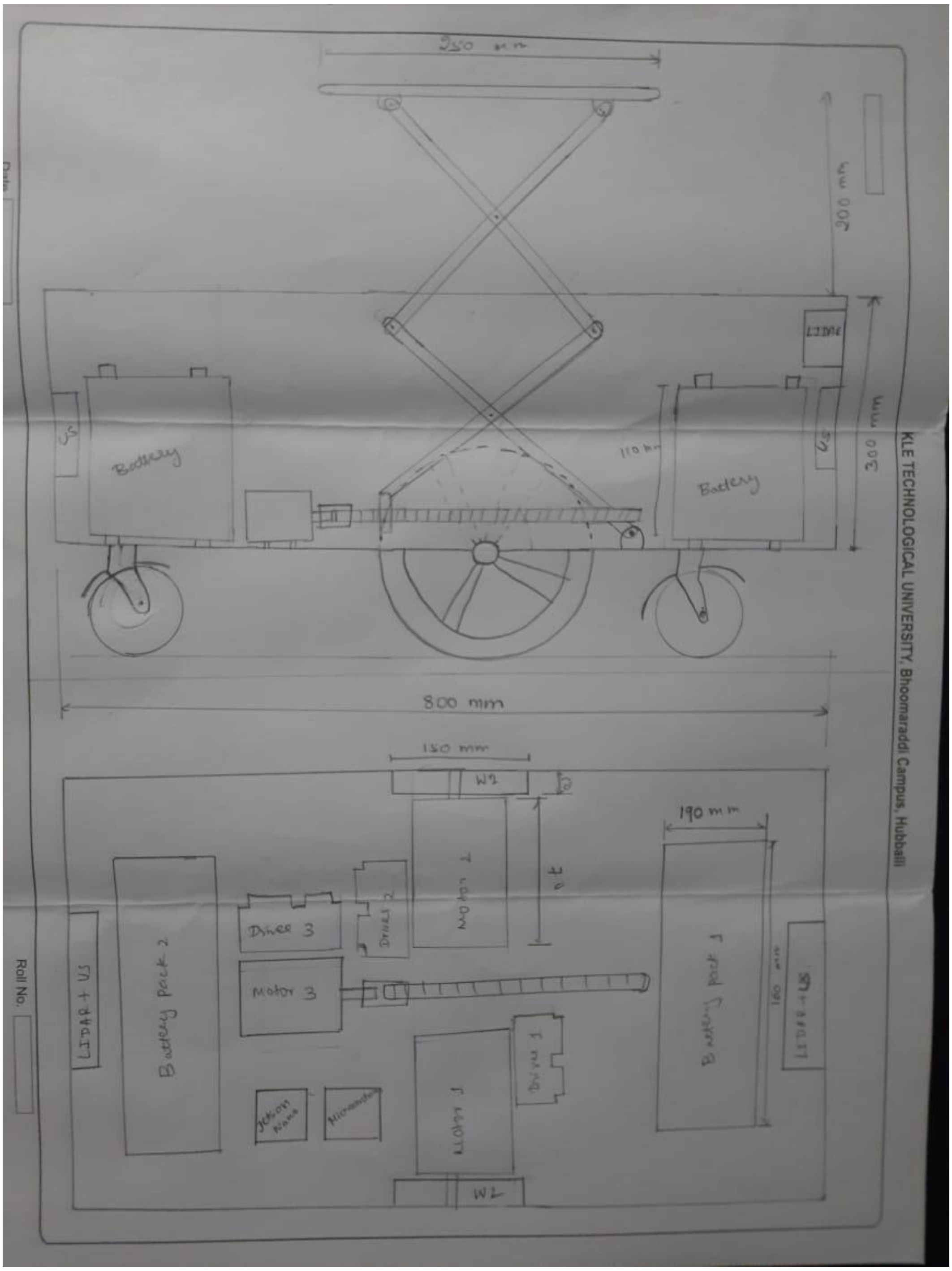
A DC motor is used to rotate the threaded rod which will help lift the jack and in turn the plate. Two-wheel powered actuation is used with castor wheels to provide the necessary support.

Design Alternative 6



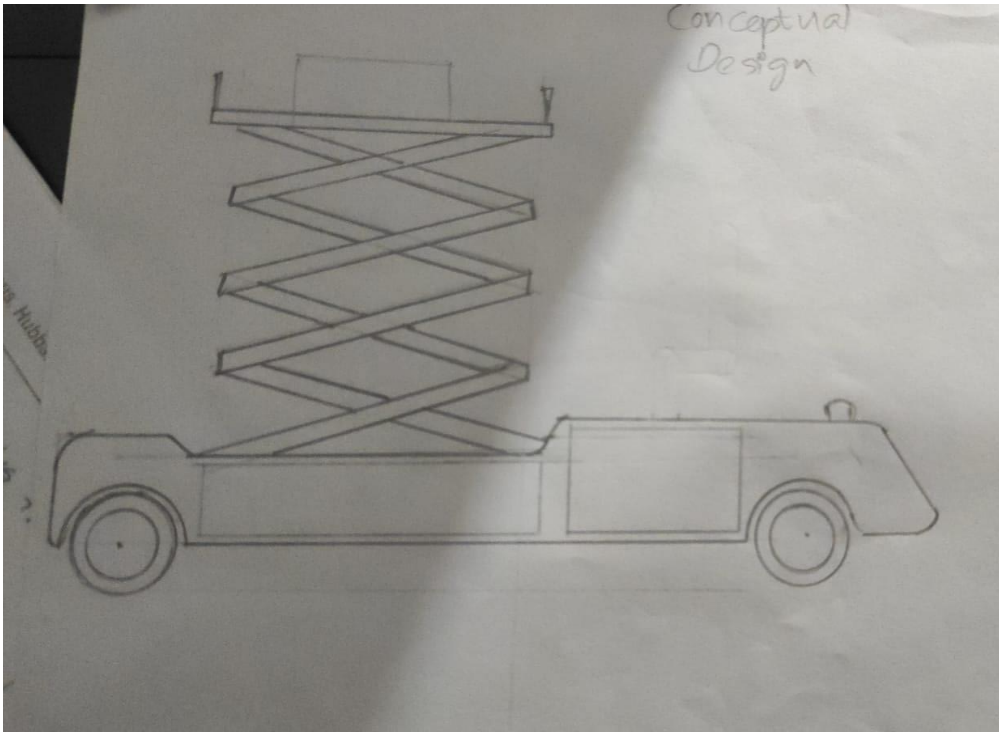
The platform is raised to the necessary height using a bevel gear configuration, with the base housing the entire control system and actuators.

Design Alternative 7



A scissor-lifting mechanism in which the DC motor rotates the threaded rod forcing the linked, folding supports to lift the platform. The platform recedes completely inside the base helping reduce the height of the bot. This is actuated by two powered wheels while the base is supported by two castor wheels.

Design Alternative 8



A Scissor lifting AMR design where all the wheels are powered to provide actuation and turning is obtained by providing power to a certain set of wheels while keeping others stationary.

3.5 Selecting Design Alternative (Using Phugh Chart)

Pugh Analysis Matrix is used to finalize the best concept. Pugh chart is done by narrowing the list of ideas using a matrix-based process to rank and compare draft concepts. [20]

The table 3.5 represents the Pugh Chart which helps to select the final design based on the objectives by comparing it to reference.

Requirements	**Weight**	**Design1**	**Design 2**	**Design 3**	**Design4**	**Design5**	**Design 6**	**Design7**	**Reference**
Safety	10	+	=	-	+	+	-	-	0
Portable	7	+	-	=	+	+	=	-	0
Easy to use	5	=	=	=	=	-	=	=	0
Weight	7	=	-	+	-	-	-	-	0
Cost	8	+	-	-	=	-	-	-	0
Reliable	8	=	=	=	-	+	-	=	0
Aesthetics	5	-	+	=	-	=	=	=	0
Pluses		3	1	1	2	3	0	0	
Equal		3	3	4	2	1	4	3	
Minuses		1	3	2	3	3	3	4	
Overall Total		2	-2	-1	-1	0	-3	-4	
Weighted Total		20	-15	-11	-3	5	-33	-32	
Yes / No		**Yes**	No	No	No	No	No	No	

Table 3.5 – Pugh Chart

This Pugh Analysis has considered objectives namely safety, portable, weight, reliability. We have assigned certain weightage to each objective depending upon the level of objectives. Based upon this we have evaluated the best design to be the first design.[21]

Since the primary objective of our design is safety, we have assigned the maximum weightage to safety i.e., 10. In addition, we have assigned weightages of 8 to on our objectives to cost, reliability. Then, we weightage of 7 is assigned to portability and weight and weightage of 5 to aesthetics and easy to use.

Further we have compared single design with the reference and have given the score by doing the same.

We have finalized Design 1 amongst the 8 designs.

Chapter 4

Design Calculations

4.1 Battery Sizing

4.1.1 Battery Sizing for Actuators

Power Consumption - Motion
= Voltage*Current*Quantity*Runtime
= 24*4*2*0.75
= 144W

Power Consumption - Lifting
= Voltage*Current*Quantity*Runtime
= 24*4*1*0.5
= 48W

Power Consumption – Conveyor
= Voltage*Current*Quantity*Runtime
= 12*0.3*1*0.5
= 1.8W

Total Power Consumption
= 144+48+1.8
= 193.8W

Required Ah at 12V
= 8.08

Factor of Safety
=1.5

Battery Rating Ah considering Factor of Safety
= 8.1*1.5
= 12.15Ah

Battery Specifications
= 24V 15Ah

4.1.2 Battery Sizing for Control System

Power Consumption – Ultrasonic Sensor HC-SR04
= Voltage*Current*Quantity*Runtime
= 5*1*2*1
= 10W

Power Consumption – LiDAR
= Voltage*Current*Quantity*Runtime
= 5*2*1*1
= 10W

Power Consumption – Raspberry Pi
= Voltage*Current*Quantity*Runtime
= 5*3*1*1
= 15W.

Power Consumption – Jetson Nano
= Voltage*Current*Quantity*Runtime
= 5*4*1*1
= 20W

Total Power Consumption
= 10+10+15+20
= 55W

Required Ah at 12V
= 4.583

Factor of Safety
=1.5

Battery Rating Ah considering Factor of Safety
= 4.583*1.5
= 6.875 Ah

Battery Specifications
= 12V 10Ah

4.2 Motor Sizing

4.2.1 Sizing for Wheels

Torque = Force * Perpendicular distance * co-efficient of friction
= 18*9.81*0.075*0.03
= 0.397 N-m

Torque Considering Factor of Safety
= 0.397*1.5
= 0.5955 N-m

Selected Motor
Leadshine Closed Loop Stepper Motor CS-M22313 NEMA 23
Selected Driver
Leadshine Closed Loop Stepper Drive CS-D508

DC Motor

Torque = Force * Perpendicular distance
= 3*9.81*0.015*0.3
= 0.132 N-m

Factor of Safety = 1.5

Torque considering factor of safety
= 0.132*1.5
= 0.198 N-m

Selected Motor = 60 RPM

Chapter 5

Cad Modeling

5.1 3D Model

1) Base – The base in Figure 5.1.1 of Autonomous Mobile Robot is designed considering the Aluminium material. The details of the material is provided in the following chapter of FEM analysis.

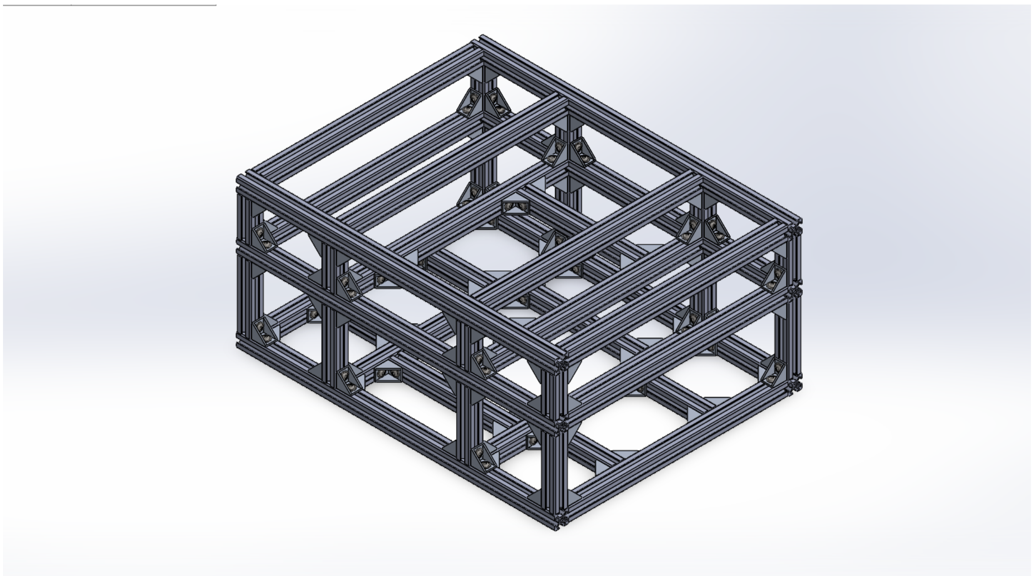


Figure 5.1.1 – 3D Model of Base

2) Caster Wheel - A caster (or castor) is a type of undriven wheel that is intended to be fastened to the bottom of a bigger object (the "vehicle") to allow for the movement of that object.
Shopping carts, office chairs, toy wagons, hospital beds, and material handling equipment are just a few of the items that require casters. Many industrial uses, including platform trucks, carts, assembly, and tow-lines in factories, employ high capacity, heavy-duty casters. The figure 5.1.2 represents the 3D model of Caster Wheel carried out in Solidworks. The diameter is 150mm.

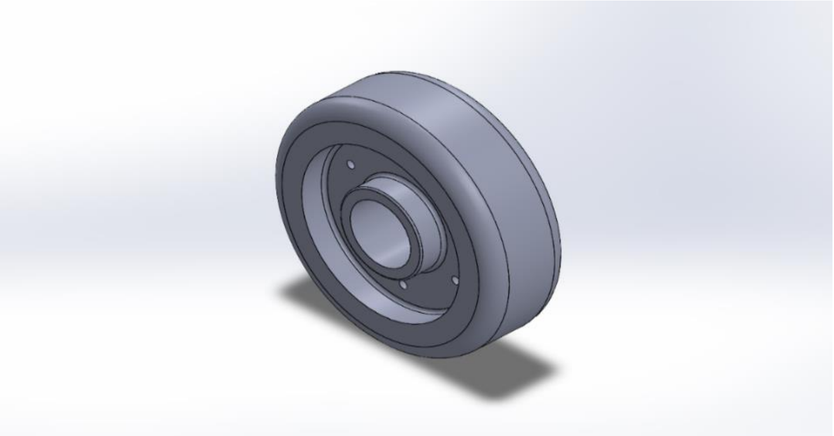


Figure 5.1.2 – 3D Model of Caster Wheel

3) Emergency Button – Figure 5.1.3 represents the Emergency Button. An emergency stop button is a fail-safe control switch that provides safety for both the machine and the person operating the machine. Emergency stop buttons are used to quickly stop the machine if there is a risk of injury or if the work process requires a stop.

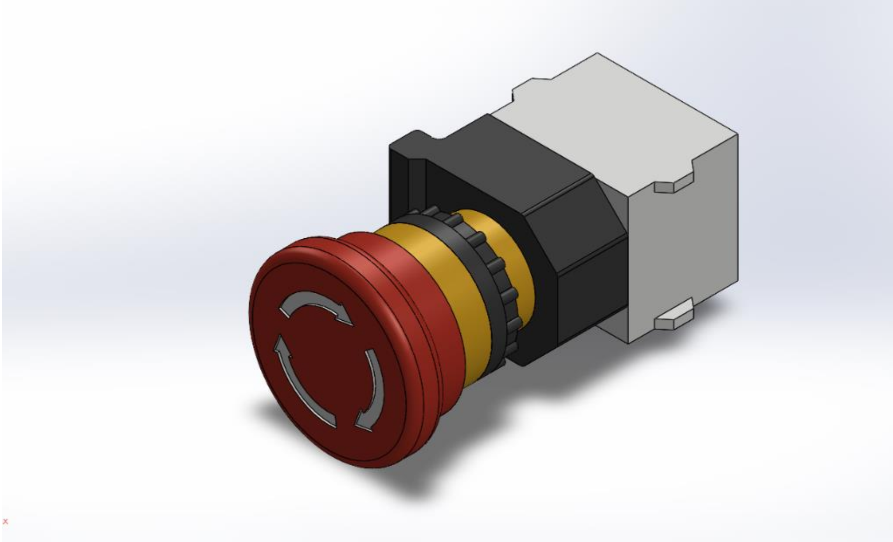


Figure 5.1.3 - 3D model of Emergency Button

4) Caster Wheels – These wheels are used in variety of applications including office chairs, hospital beds, shopping malls. The below figure represents the 3D model of Caster Wheel.

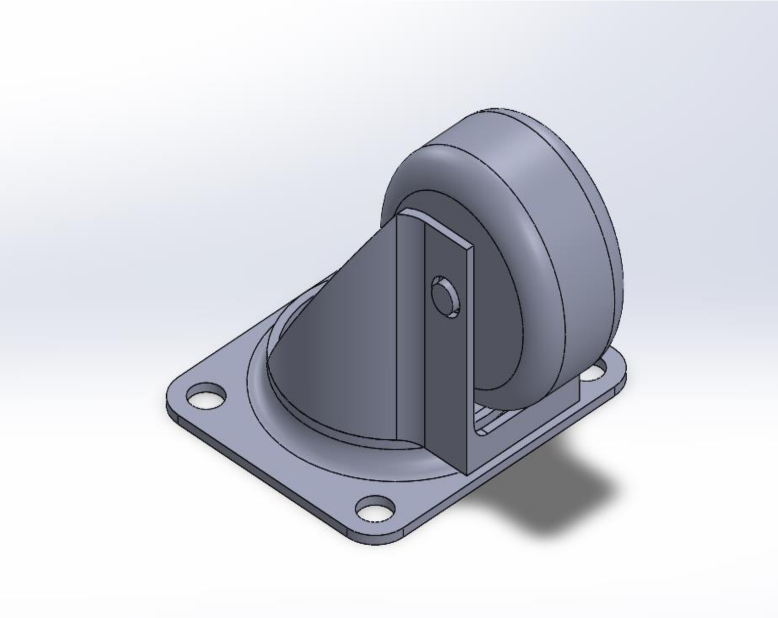


Figure 5.1.4 – 3D model of Caster Wheel

5) LIDAR - A typical lidar sensor emits pulsed light waves into the surrounding environment. These pulses bounce off surrounding objects and return to the sensor. The sensor uses the time it took for each pulse to return to the sensor to calculate the distance it traveled. An A2M8 LiDAR is used in implementing the project. [23]

Figure 5.1.5 – 3D Model of LiDAR Sensor – A2M8 18M

6) Rexroth Aluminum – Rexroth Aluminium is used to construct the base of Autonomous Mobile Robot. These are not only robust, but are also reliable as they can withstand heavy loads. The below figure represents the 3D mode of Bosch Rexroth Aluminium.

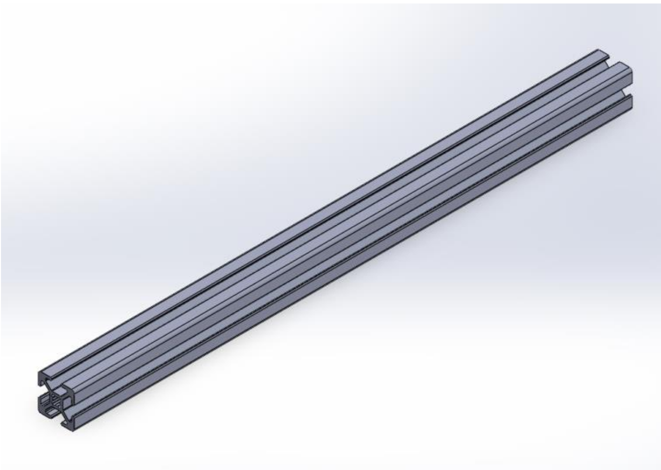


Figure 5.1.6 - 3D Model of Rexroth Aluminium

7) Stepper Motor Driver with encoder – A stepper motor, also known as step motor or stepping motor, is a brushless DC electric motor that divides a full rotation into a number of equal steps. The motor's position can be commanded to move and hold at one of these steps without any position sensor for feedback (an open-loop controller), as long as the motor is correctly sized to the application in respect to torque and speed.
An encoder is a rotary device that can be mounted onto an electric motor. It provides closed loop feedback signals, tracking the motor shaft's position, speed, or both. [24]

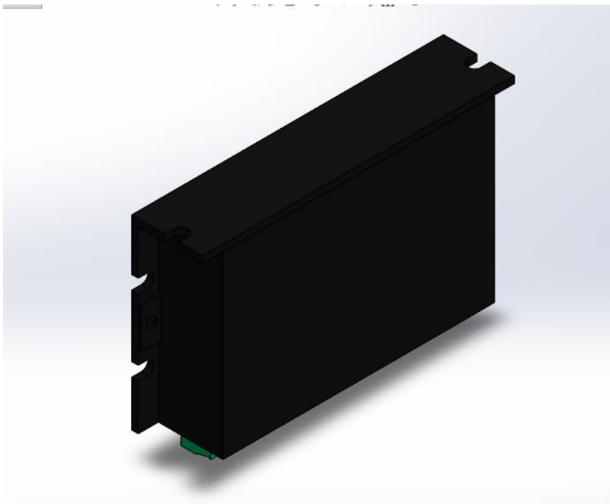


Figure 5.1.7 – 3D Model of Stepper Motor with Encoder

8) Raspberry Pi - The Raspberry Pi Foundation and Broadcom collaborated to create the Raspberry Pi line of compact single-board computers in the UK. The initial focus of the Raspberry Pi project was to encourage the study of fundamental computer science in classrooms and in underdeveloped nations. [25]

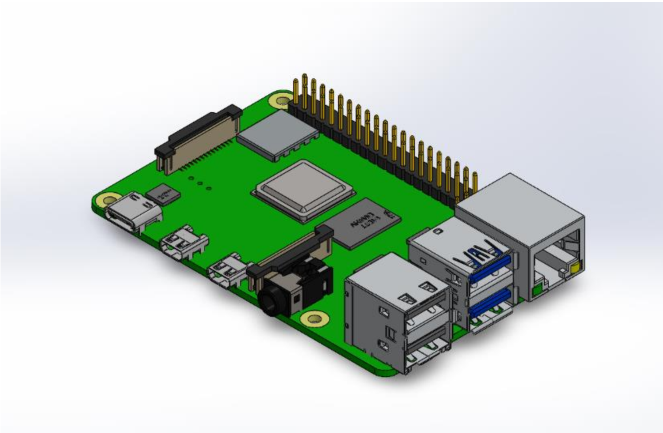
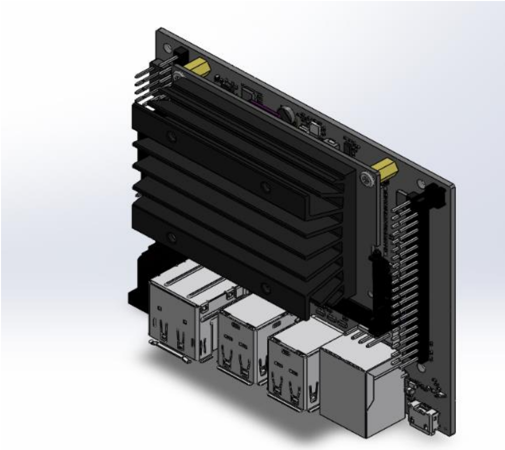


Figure 5.1.8 – 3D Model of Raspberry Pi

9) Jetson Nano - Jetson Nano is a small, powerful computer designed to power entry-level edge AI applications and devices. Get started quickly with the comprehensive NVIDIA SDK, which includes accelerated libraries for deep learning, computer vision, graphics, multimedia, and more. [26]



5.1.9 - 3D Model of Jetson Nano

10) Ball Bearing - A bearing is a component of a machine that limits relative motion to only that motion that is intended and lessens friction between moving elements. The bearing's design may, for instance, permit free rotation around a fixed axis or free linear movement of the moving part. It may also serve to prohibit motion by managing the vectors of normal forces acting on the moving parts. Most bearings reduce friction in order to enable the desired motion. According to the type of operation, the motions permitted, or the directions of the loads (forces) applied to the parts, bearings can be broadly categorized.

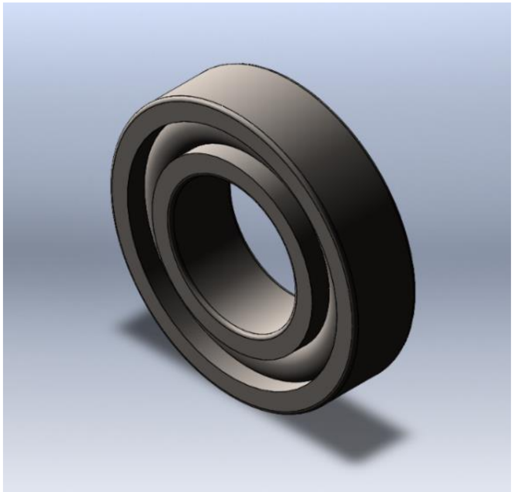


Figure 5.1.10 – 3D Model of Ball Bearing

12) Scissor mechanism attachment - The power source is turned on and begins to fill the cylinder(s) with hydraulic fluid or compressed air. Hydraulic fluid or compressed air is pushed from one area to another. The cylinder is pushed outwards and causes the legs to push apart. The platform is raised.

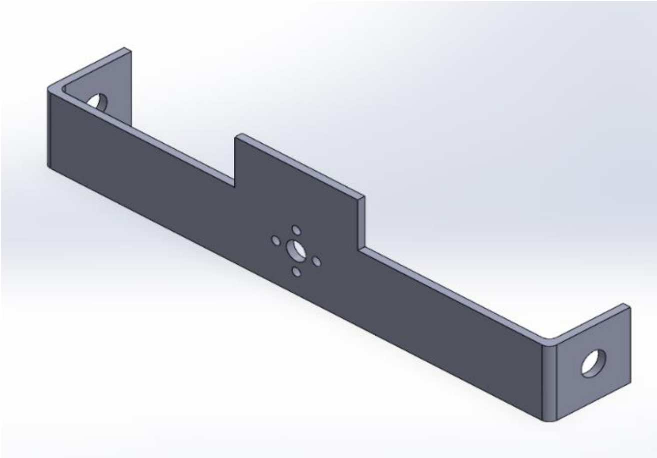


Figure 5.1.12 – 3D Model of Scissor Mechanism Attachment

13) Motor Clamp - clamp is a fastening device used to hold or secure objects tightly together to prevent movement or separation through the application of inward pressure. In the United Kingdom the term cramp is often used instead when the tool is for temporary use for positioning components during construction and woodworking; thus a G cramp or a sash clamp but a wheel clamp or a surgical clamp.

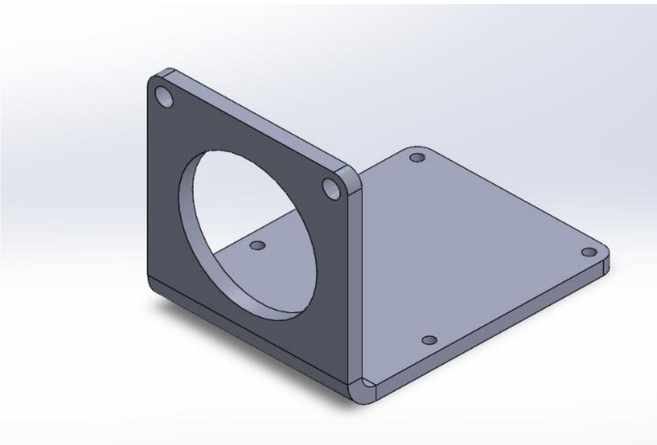


Figure 5.1.13 – 3D Model of a Motor Clamp

14) Bearing Block - SKF pillow block ball bearing units consist of an insert bearing mounted in a housing, which can be bolted to a support surface. The SKF assortment includes units compliant with ISO standards, North American standards, or Japanese Industrial Standards (JIS). Within the SKF assortment, you can find units for nearly all requirements.

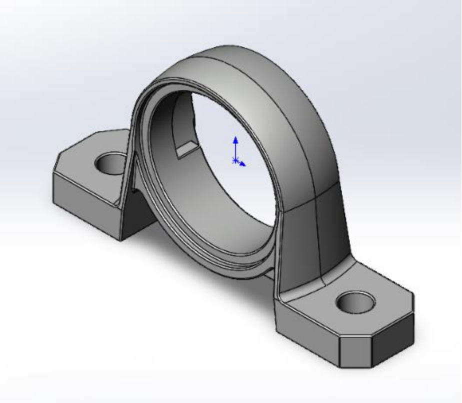


Figure 5.1.14 – 3D model of Bearing Block

15) Link - The scissor lift mechanism appears as a series of connected parallelograms with hinged pivot crossings. This allows the operator to extend and retract the mechanism while maintaining geometric integrity and keeping the platform stable and parallel to the base. The figure 5.1.15 represents a scissor link in 3D view.

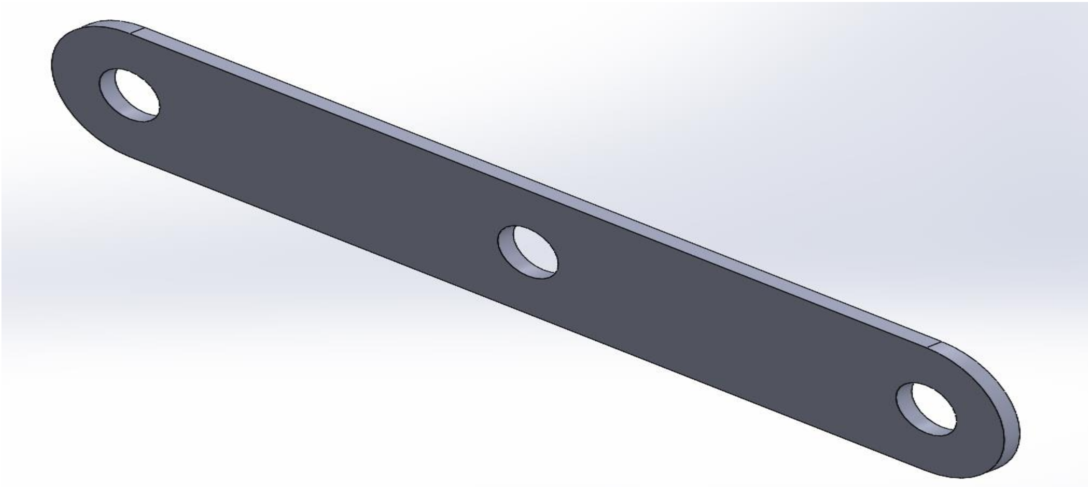


Figure 5.1.15 – 3D model of Scissor Link

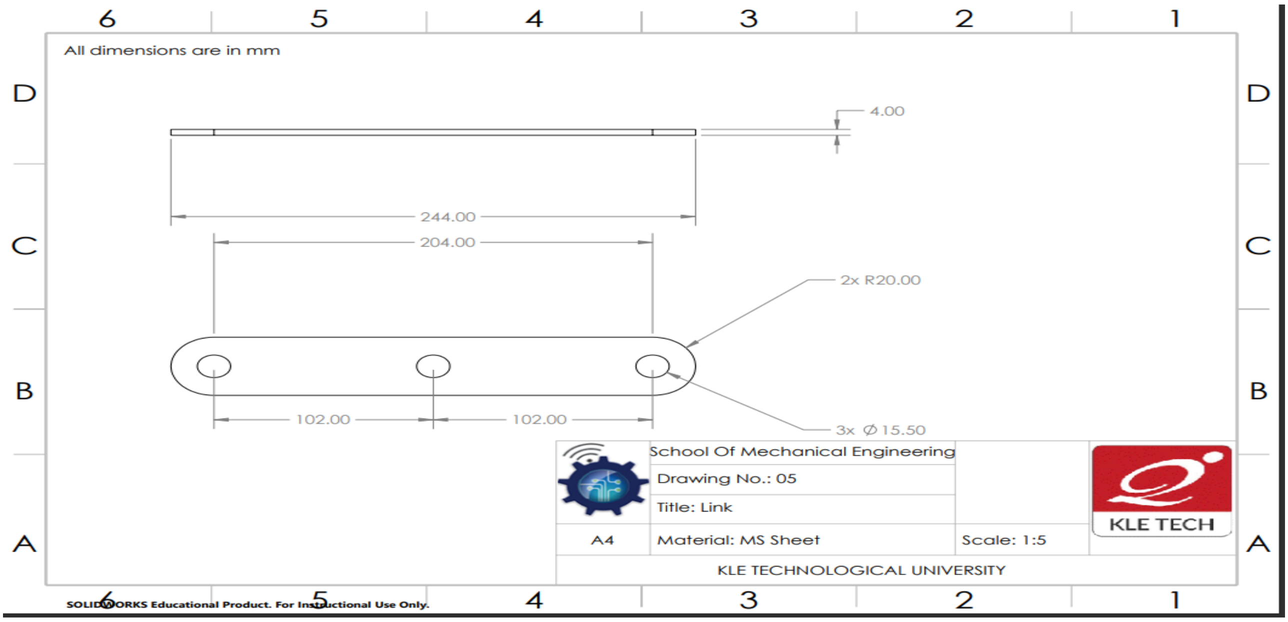


Figure 5.1.15b – 2D Drafting of Scissor Link

16) Acrylic Plate

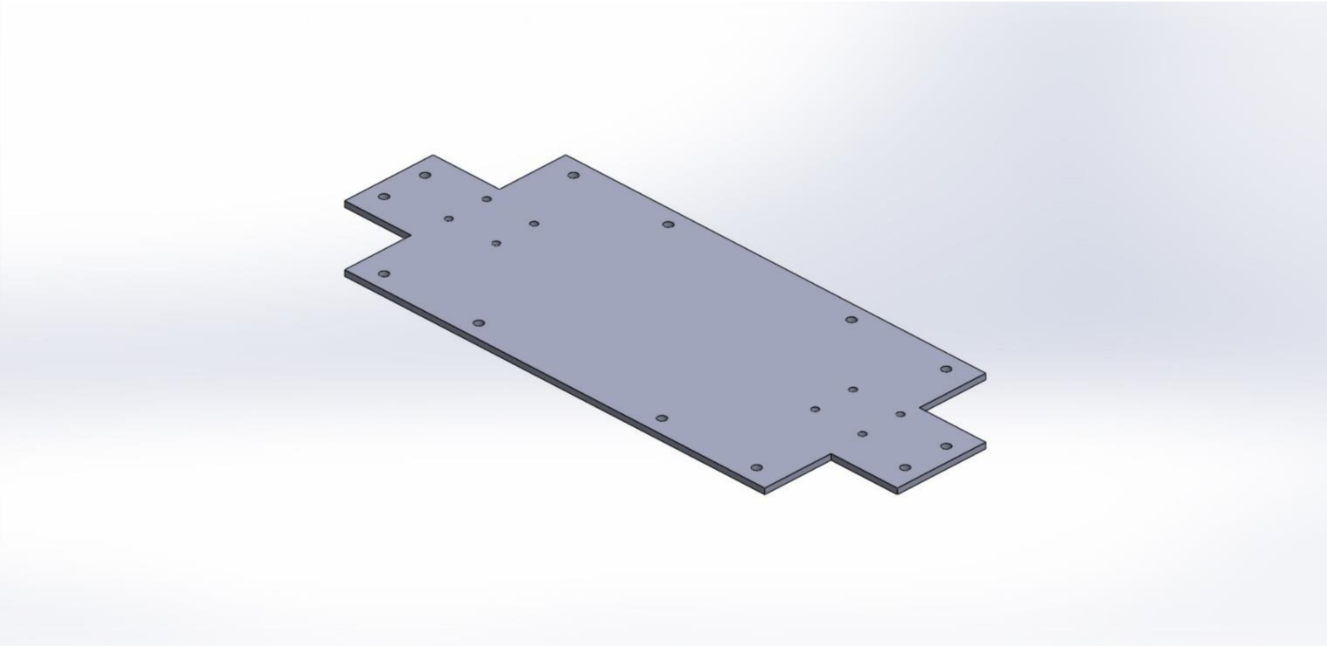


Figure 5.1.16 – 3D model of Acrylic Plate

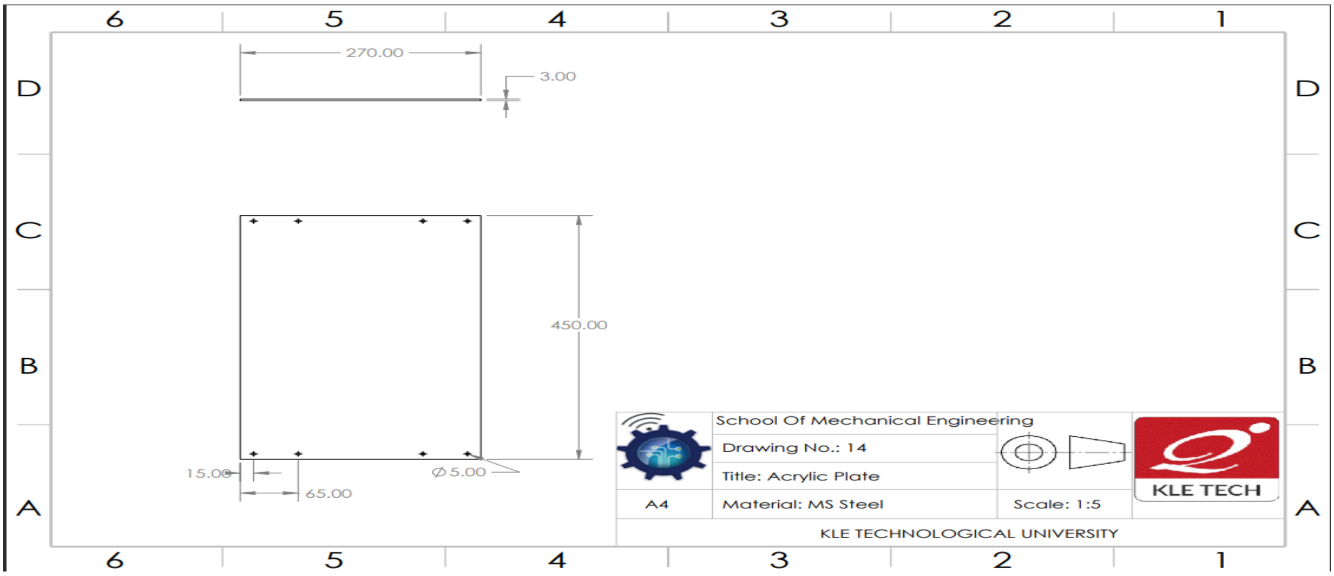


Figure 5.1.16b – 2D Drafting of Acrylic Plate

17) Ball Screw Support - The Support Unit comes in six types: models EK, FK, EF, and FF, which are tailored to model BNK precision Ball Screw with finished shaft ends, and models BK and BF, which are standardized for general Ball Screws. The Support Unit on the fixed side includes a JIS Class 5-compliant angular bearing provided with an adjusted preload. [27]

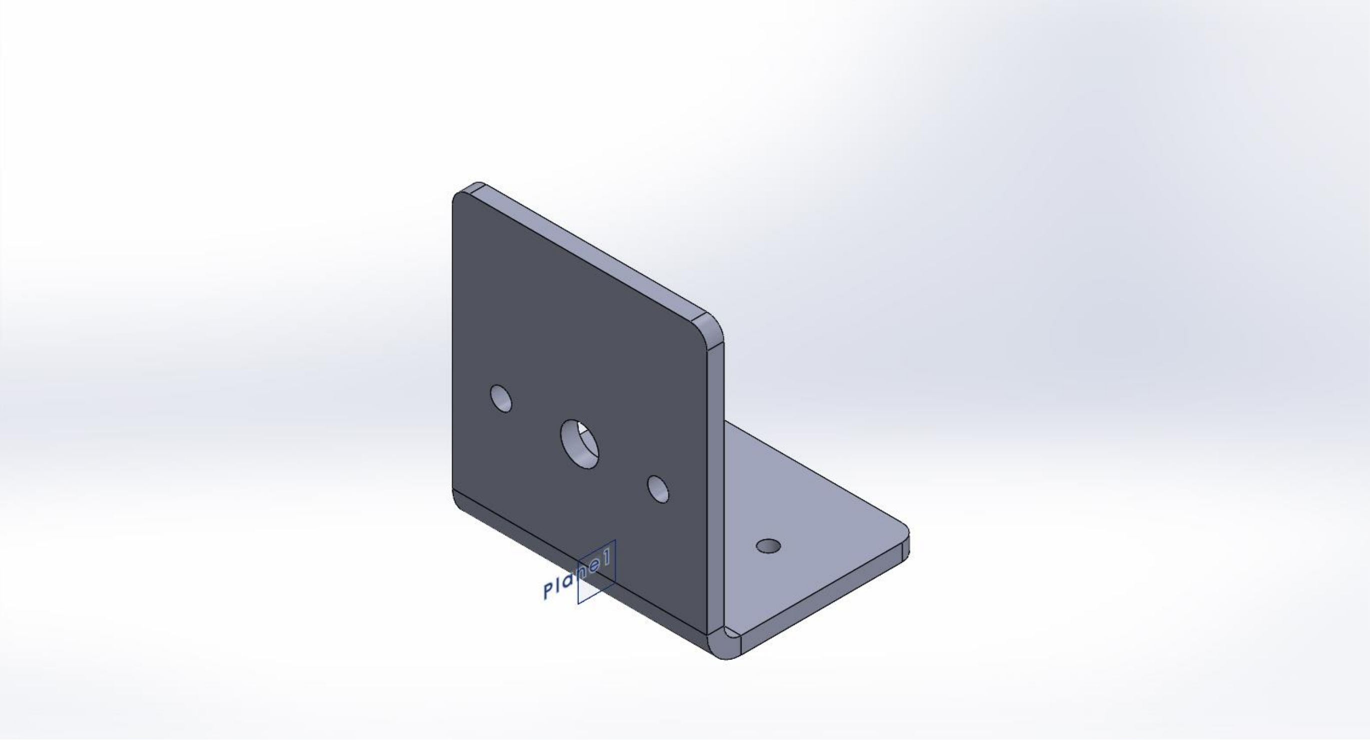


Figure 5.1.17 – 3D Model of Ball Screw Support

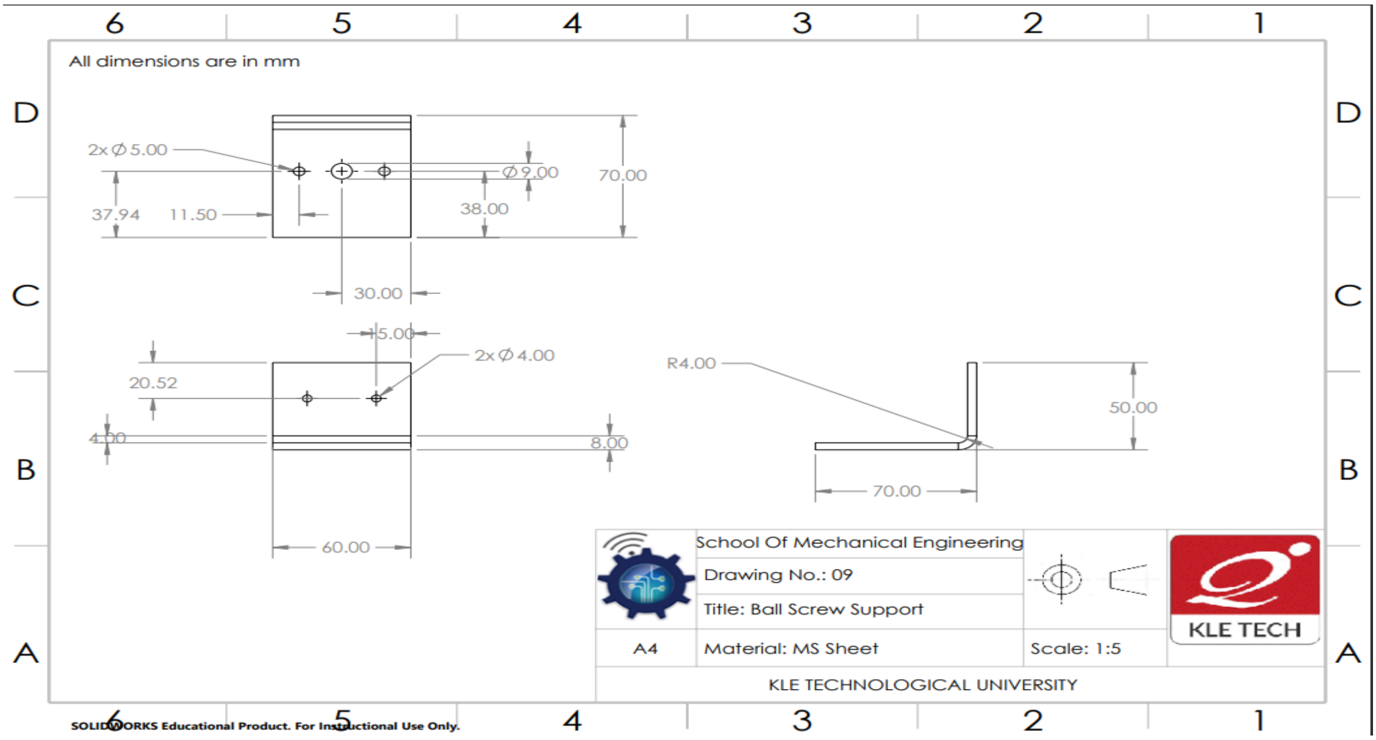


Figure 5.1.17b – 2D Drafting of Ball Screw Support

18) Conveyor Frame - In order to connect the inventories on a small-grid ship or station into a network, the Conveyor Frame is used together with several other comparable components. Once created, the conveyor network makes it simple to transfer objects between blocks and moves them automatically as required. The figure 5.1.18 displays the conveyor frame in 3D view.

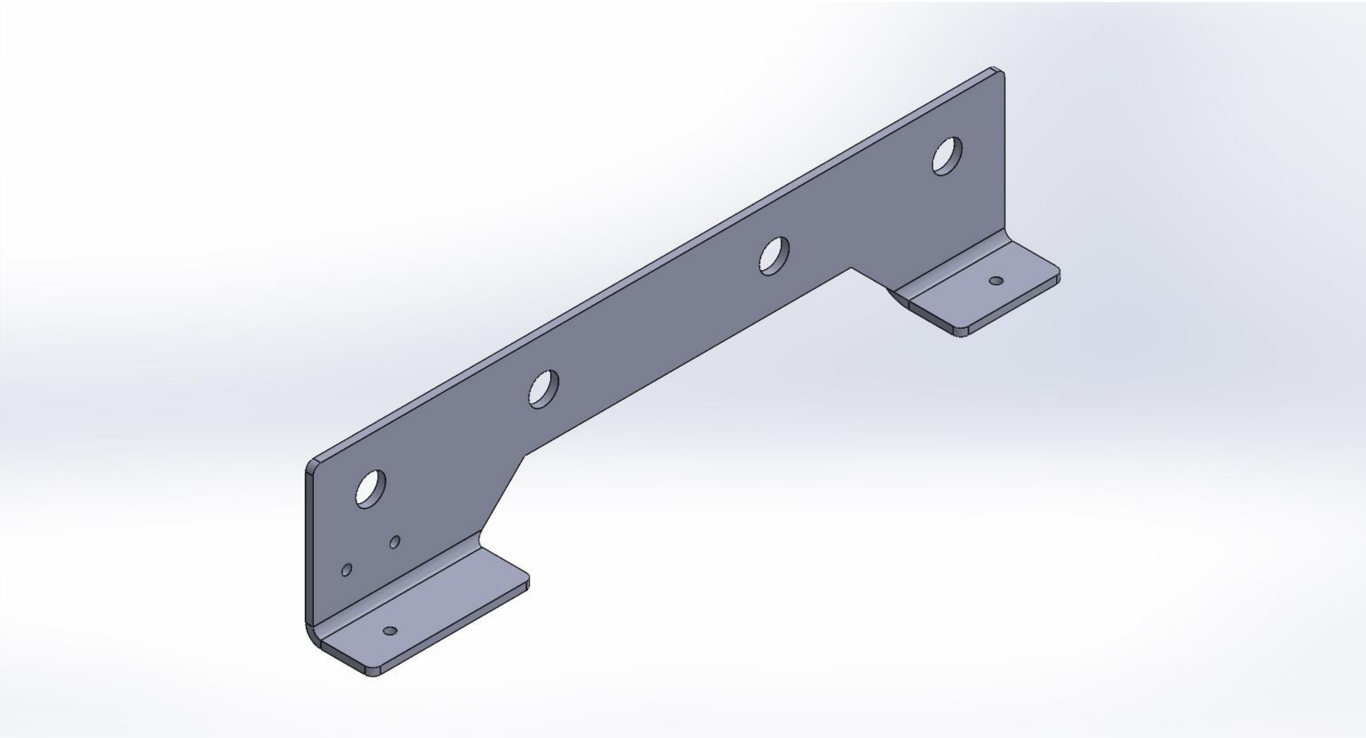


Figure 5.1.18 - 3D model of Conveyor Frame

The below figure 5.1.18b shows the Drafting of Conveyor Frame which is carried out in Solidworks.

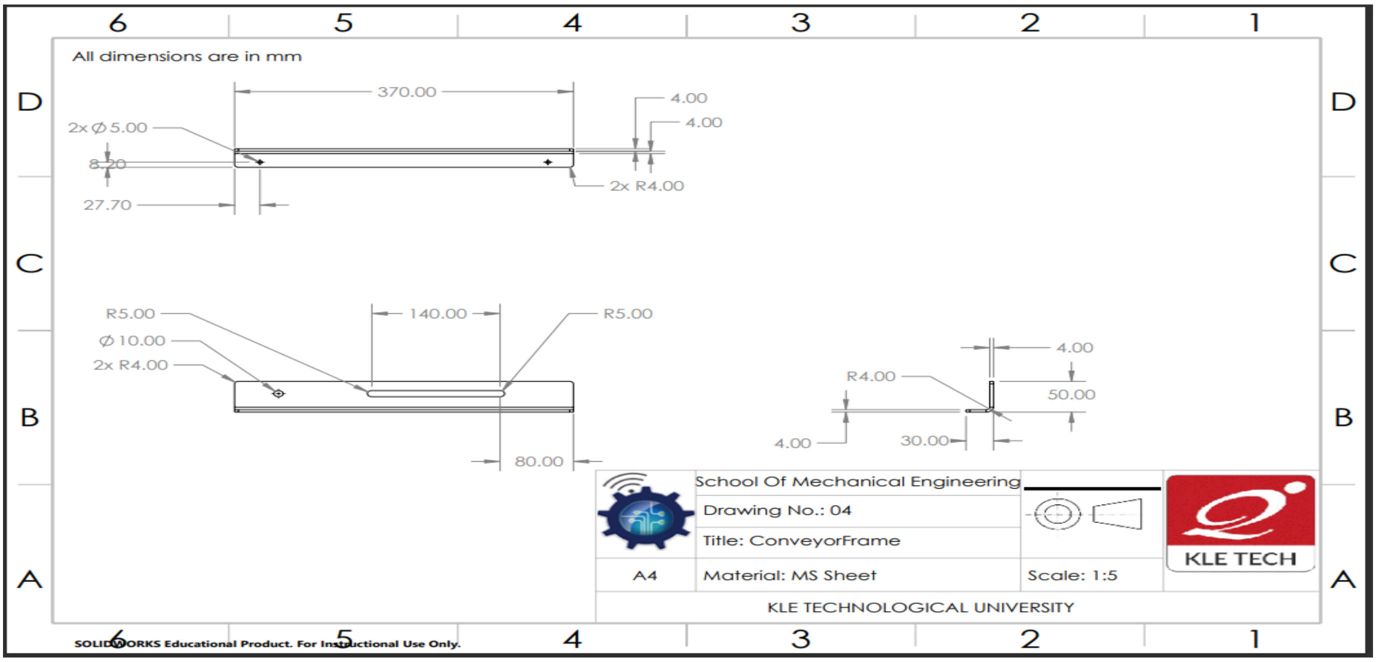


Figure 5.1.18b – Drafting of Conveyor Frame

19) Roller for Conveyor - Roller conveyors are a form of conveyor belt that has evenly spaced, rotating cylinders called rollers that allow things to skate on their surface. They usually use gravity or small engines to move objects from one place to another. The figure 5.1.19 displays the roller for conveyor.

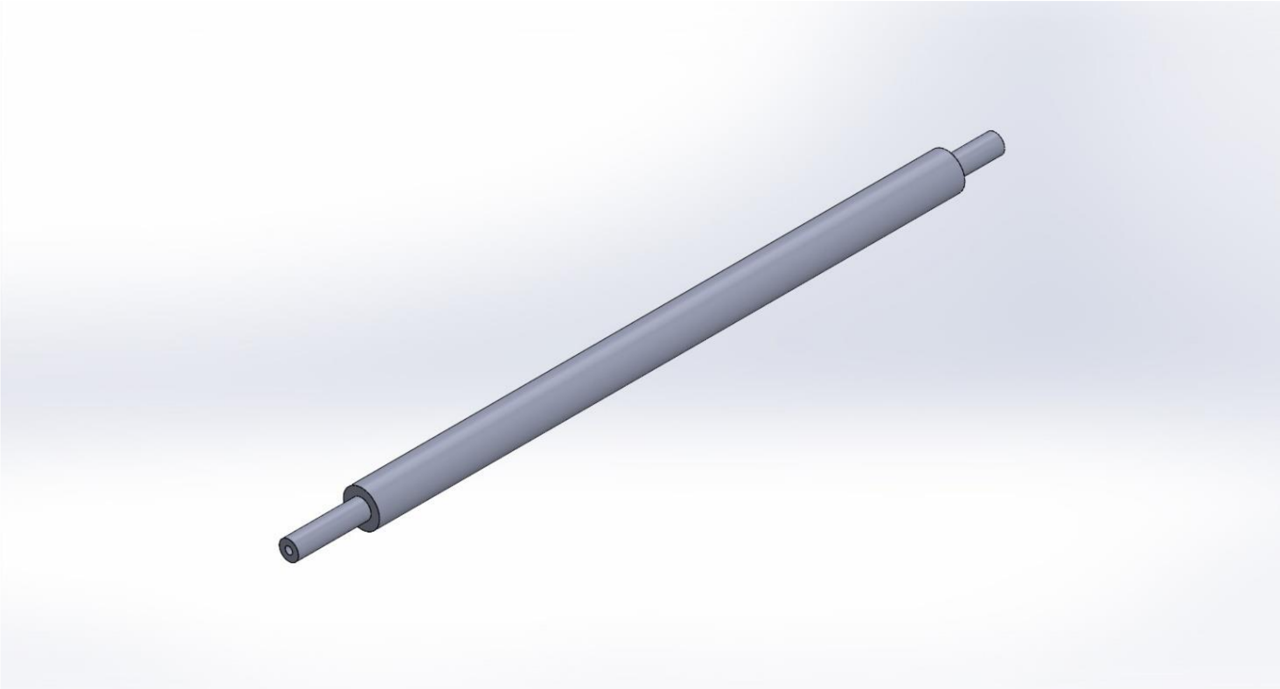


Figure 5.1.19 - Roller for Conveyor in 3D view

The figure 5.1.19b shows the 2D Draft sheet for roller with a scale of 1:5.

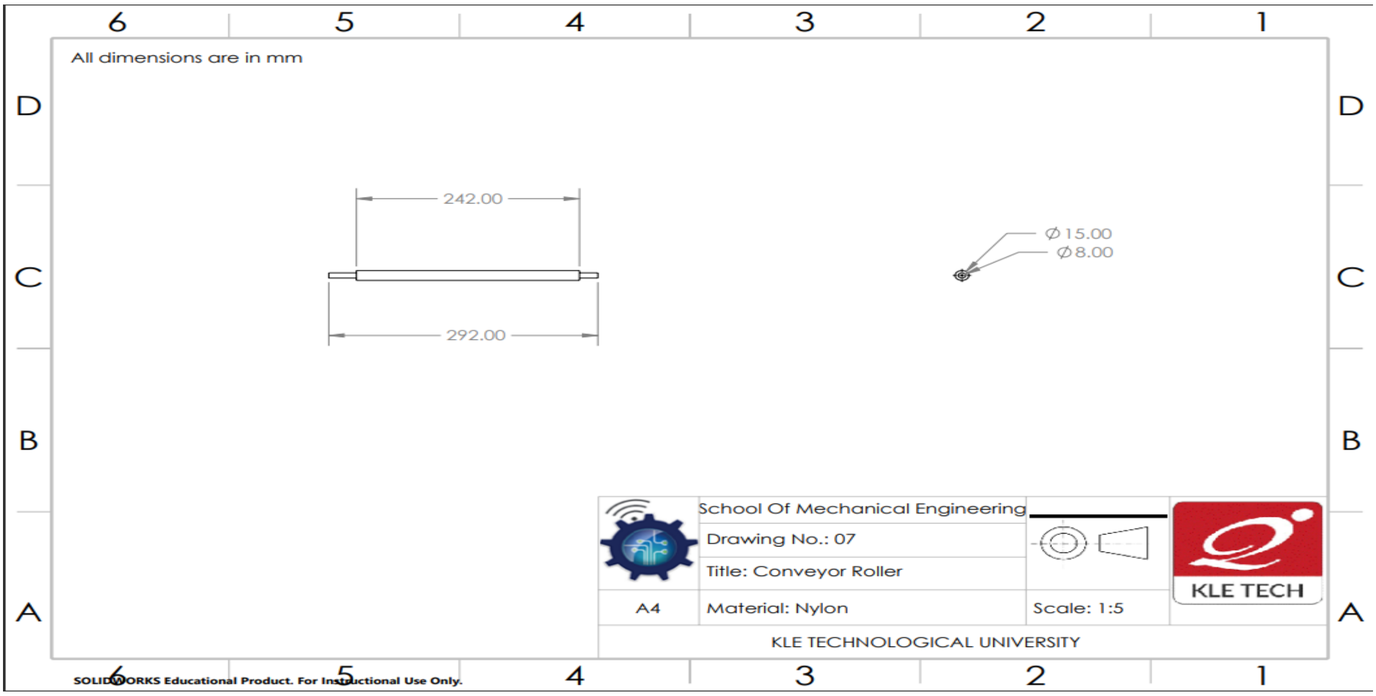


Figure 5.1.19b – Drafting of Conveyor Roller

20) Flange - A flange is a protruded ridge, lip or rim, either external or internal, that serves to increase strength (as the flange of an iron beam such as an I-beam or a T-beam); for easy attachment/transfer of contact force with another object (as the flange on the end of a pipe, steam cylinder, etc., or on the lens mount of a camera); or for stabilizing and guiding the movements of a machine or its parts (as the inside flange of a rail car or tram wheel, which keep the wheels from running off the rails). Flanges are often attached using bolts in the pattern of a bolt circle. The term "flange" is also used for a kind of tool used to form flanges. [28]

The below figure represents the 3D Model of Flange

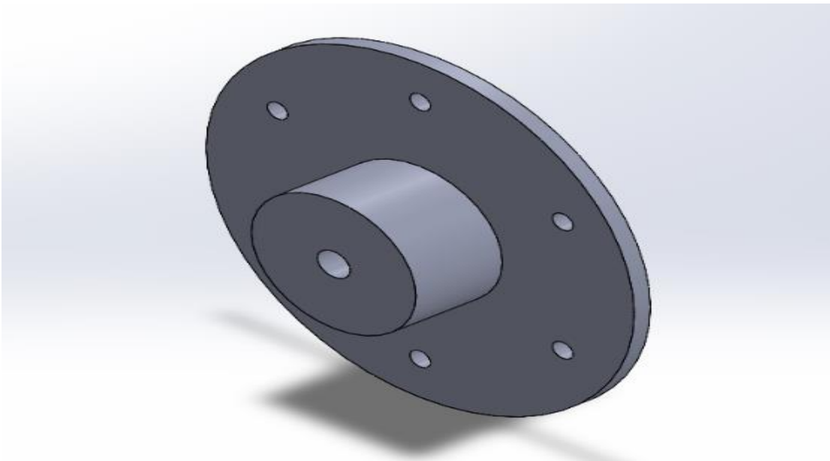


Figure 5.1.20 – 3D Model of Flange

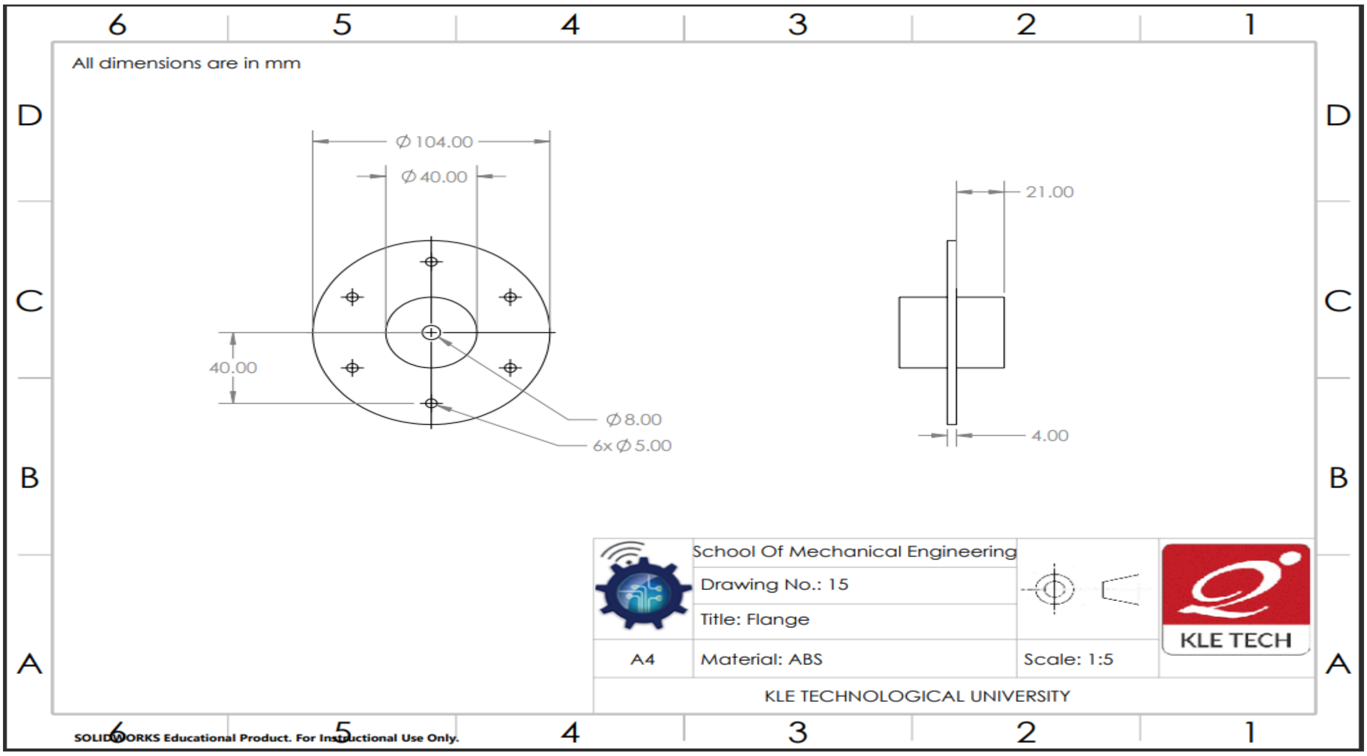


Figure 5.1.20b – 2D Drafting of Flange

21) Frame for Conveyor - The idlers, pulleys, and tension on the belt are supported by the belt conveyor frame, which is typically made of standard or stainless steel. The designed structure and manufacturing components of the frame determine its quality. Various types of steel structures are used in the belt conveyor frames' real application. The figure 5.1.21 shows the 3D model of Frame.

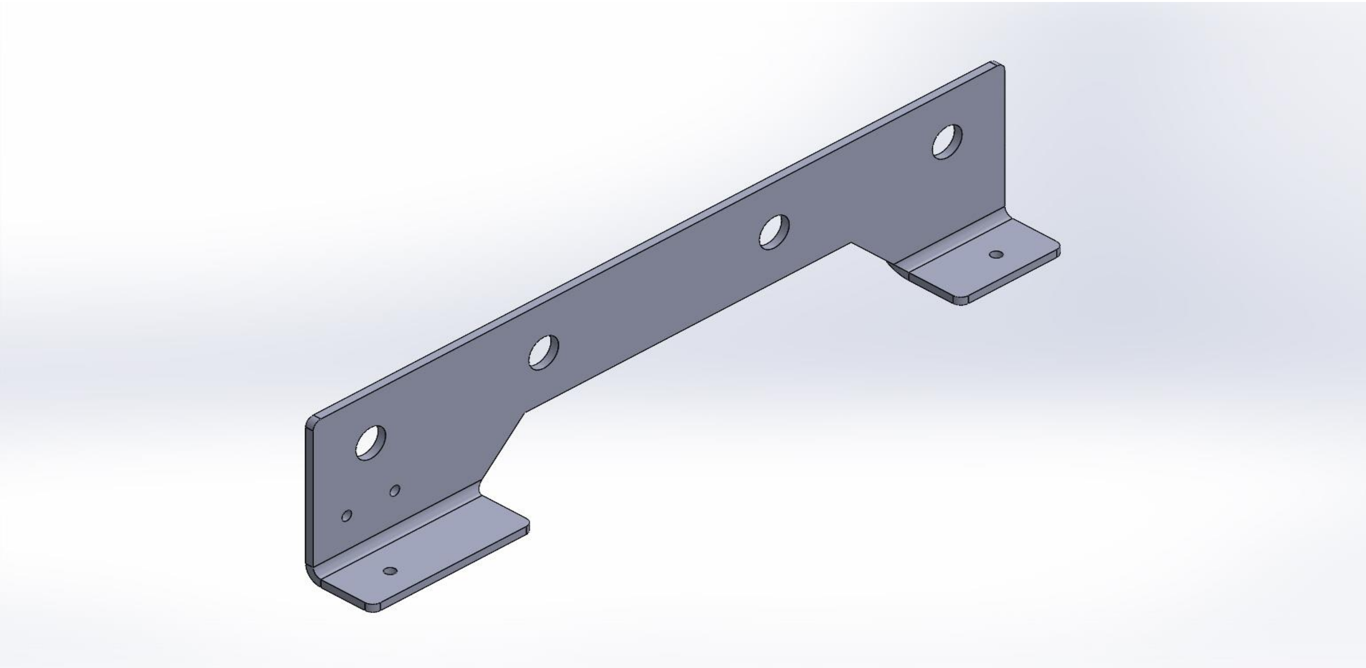


Figure 5.1.21 – 3D model of Frame

The below figure represents the 2D Draft of Frame.

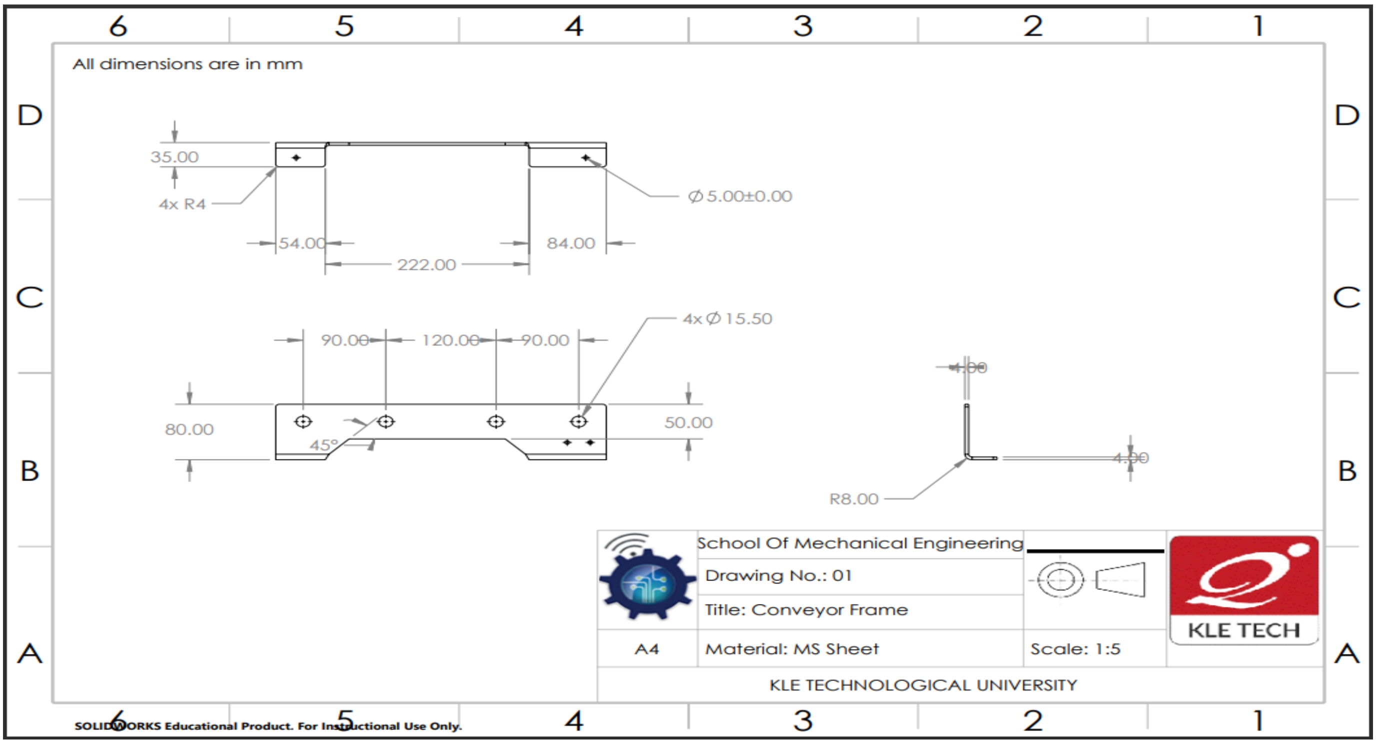


Figure 5.1.21b – 2D Drafting of Frame

22) Front Cover Plate - A sheet metal plate used for covering the front portion of the base to protect the components inside from any harm due to environmental or accidental factors. A small opening is been given for the placement of ultrasonic sensor.

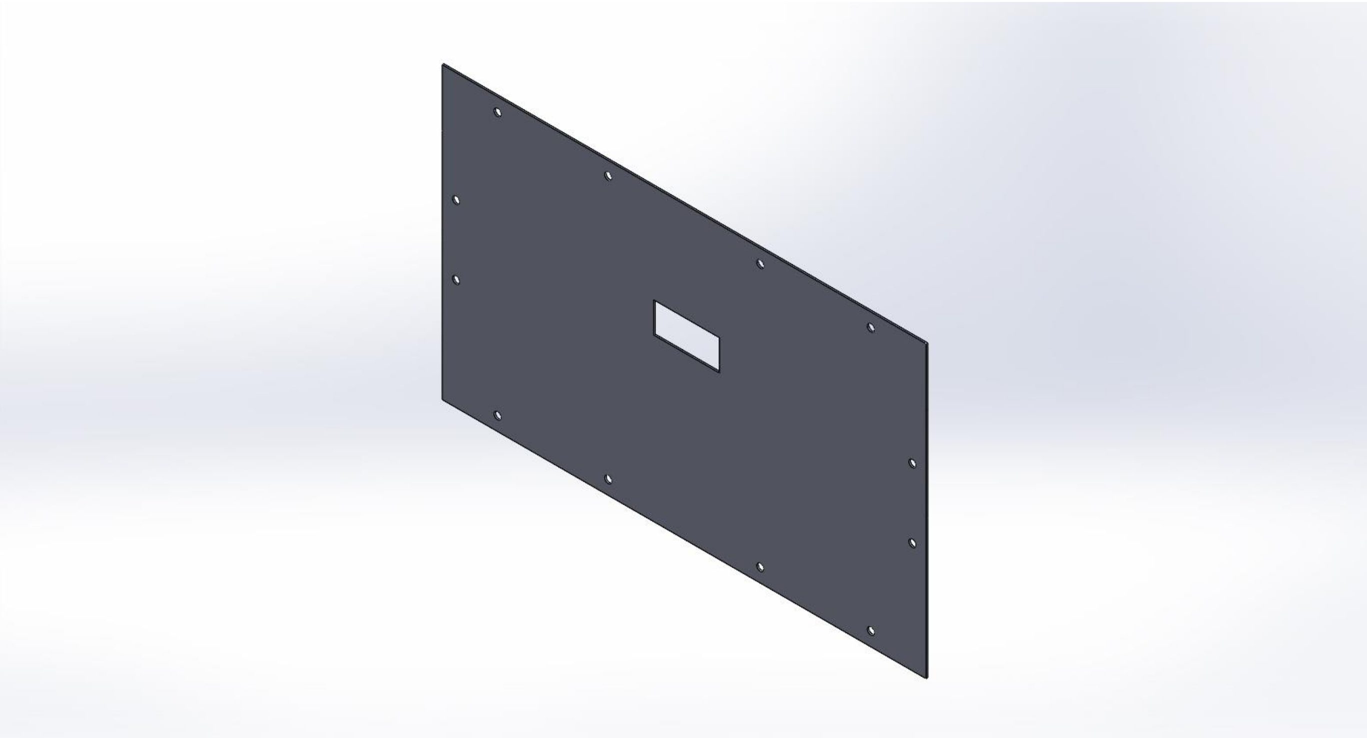


Figure 5.1.22 – 3D model of Front Cover Plate

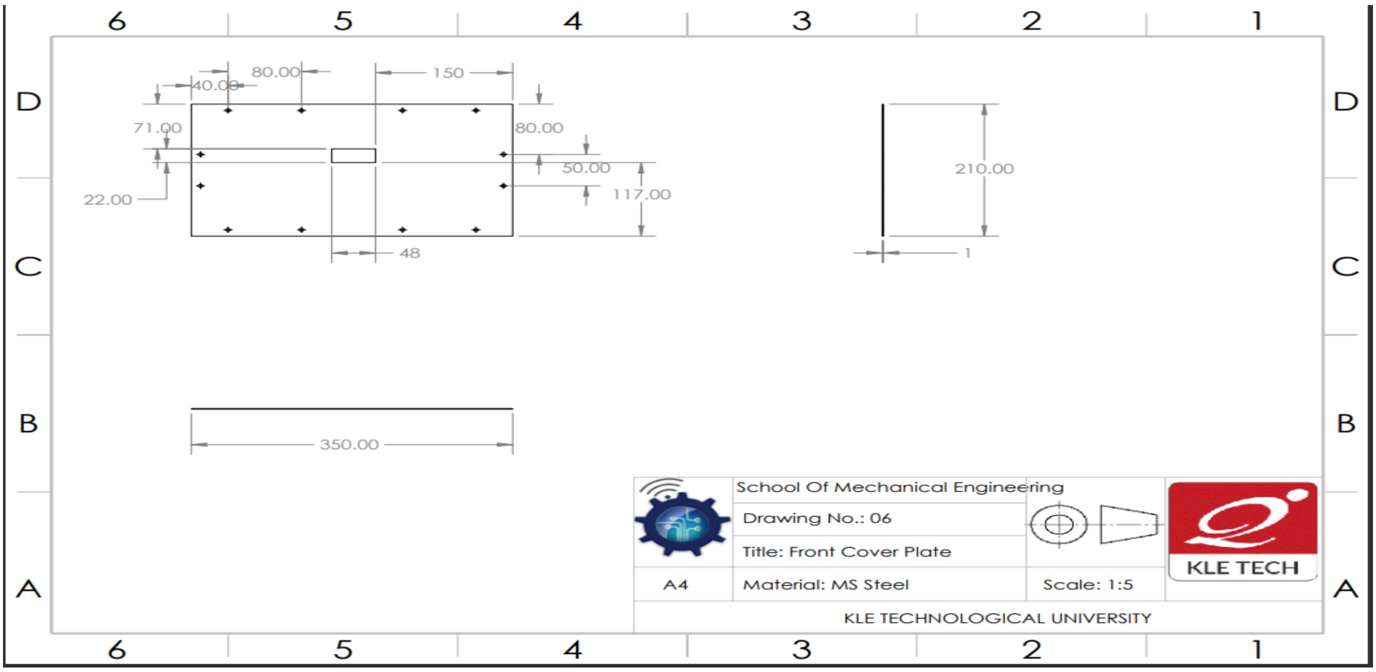


Figure 5.1.22b – Drafting of Front Cover Plate

23) Left Side Cover Plate - A sheet metal plate used for covering the side portion of the base to protect the components inside from any harm due to environmental or accidental factors.

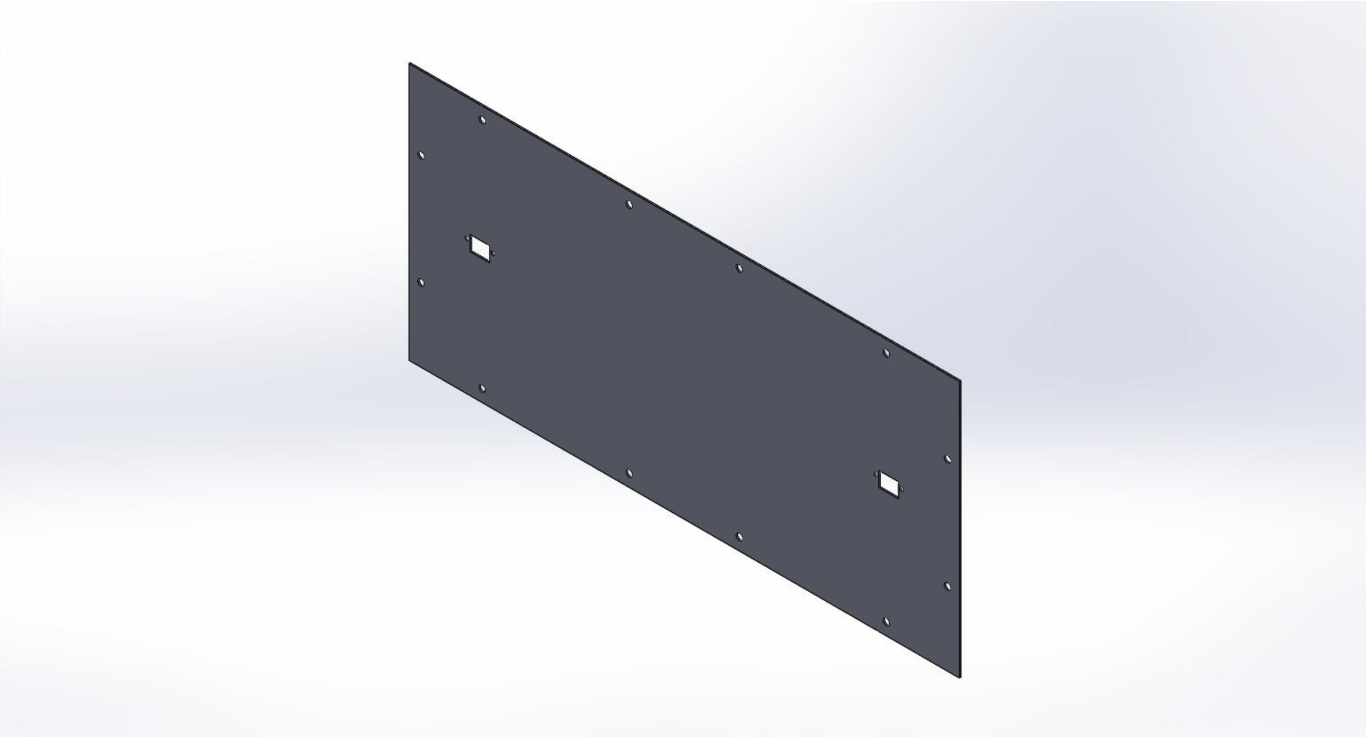


Figure 5.1.23 – 3D Model of Left Side Cover Plate

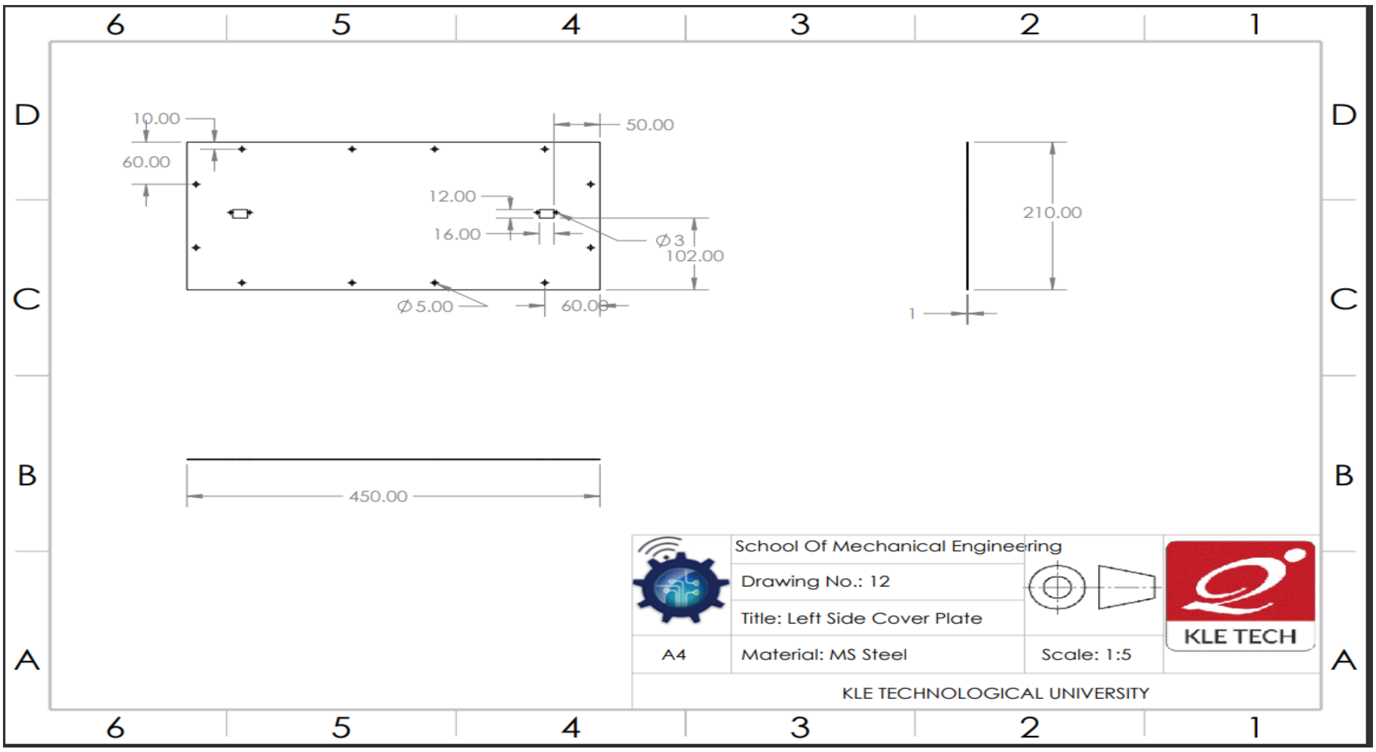


Figure 5.1.23b – 2D Drafting of Left Side Cover Plate

24) Link Connector - A MS rod used to connect the Link connector with the rollers and base.

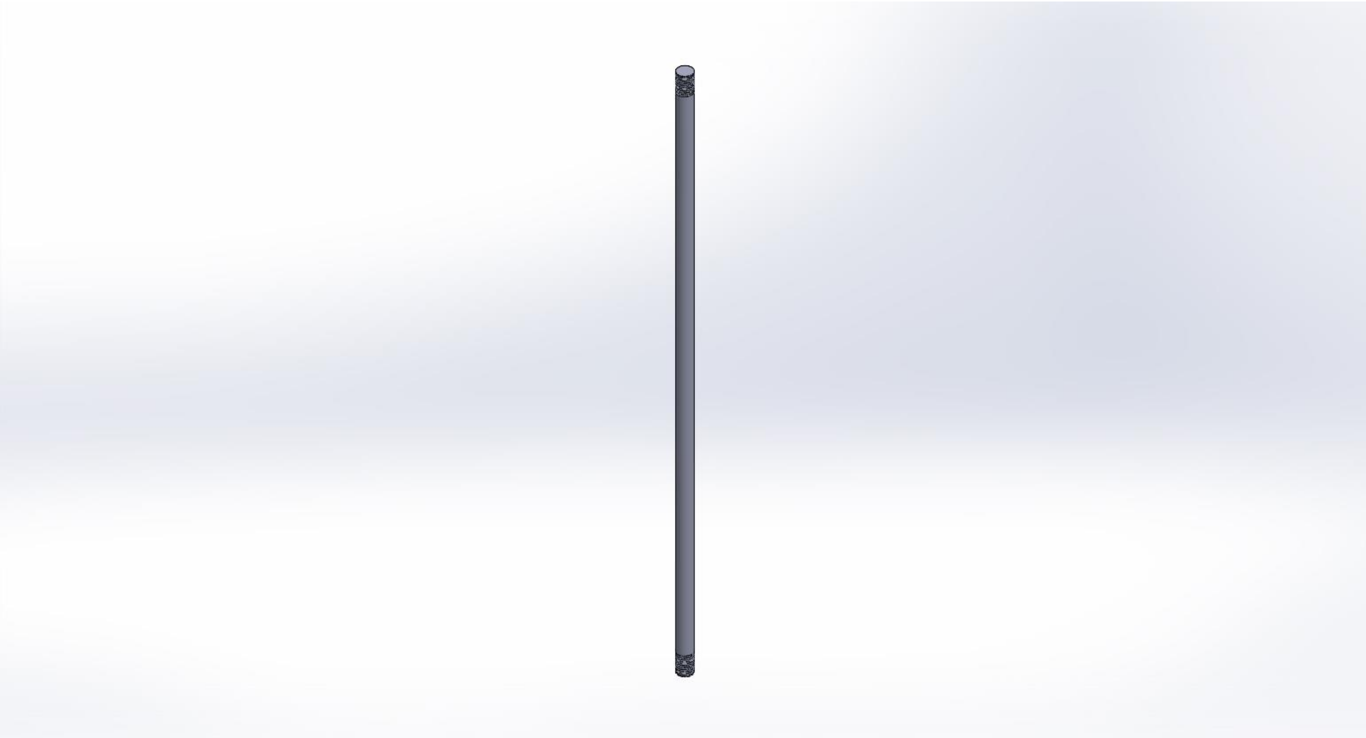


Figure 5.1.24 – 3D Model of Link Connector

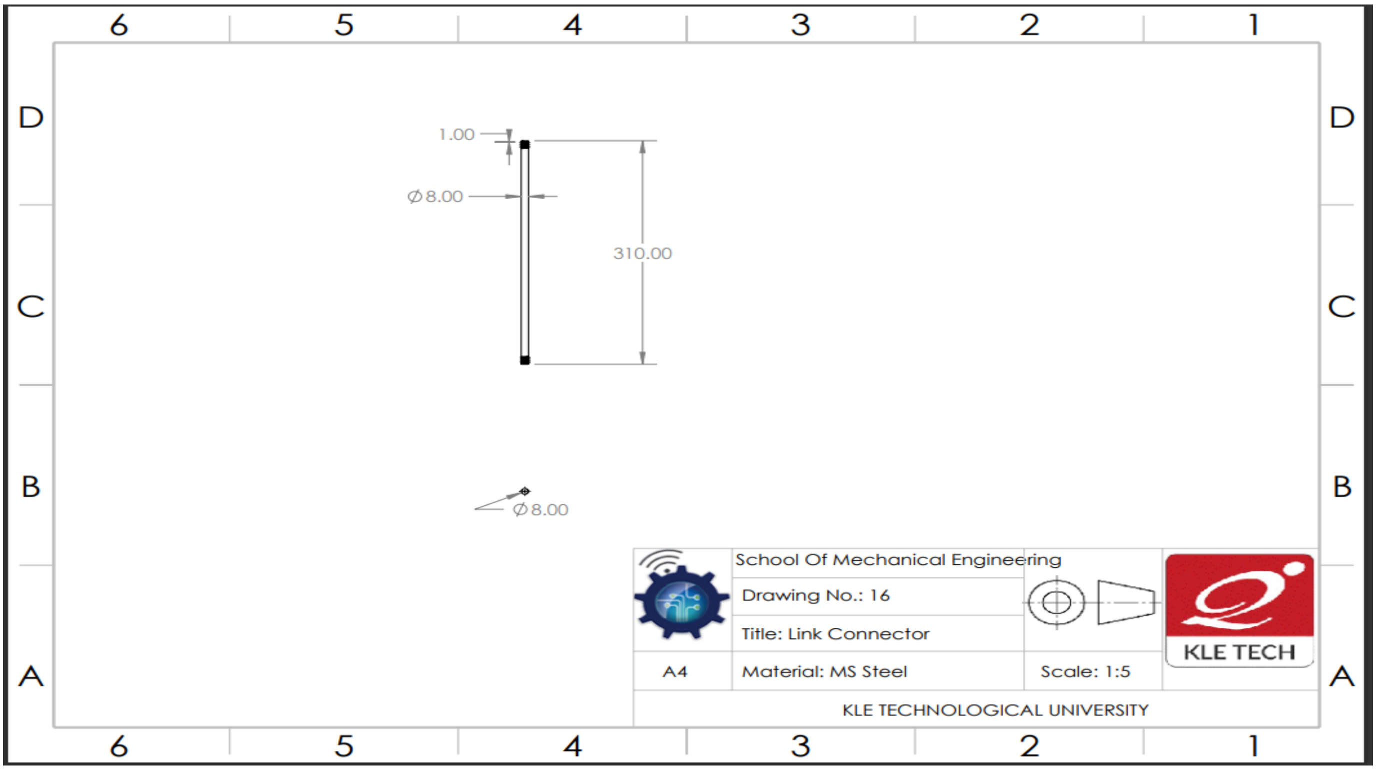


Figure 5.1.24b – 2D Drafting of Link Connector

25) Link Support - A 4mm thickness sheet metal used to transmit the force from the servo motor to the links of the scissor mechanism to help move the platform upwards.

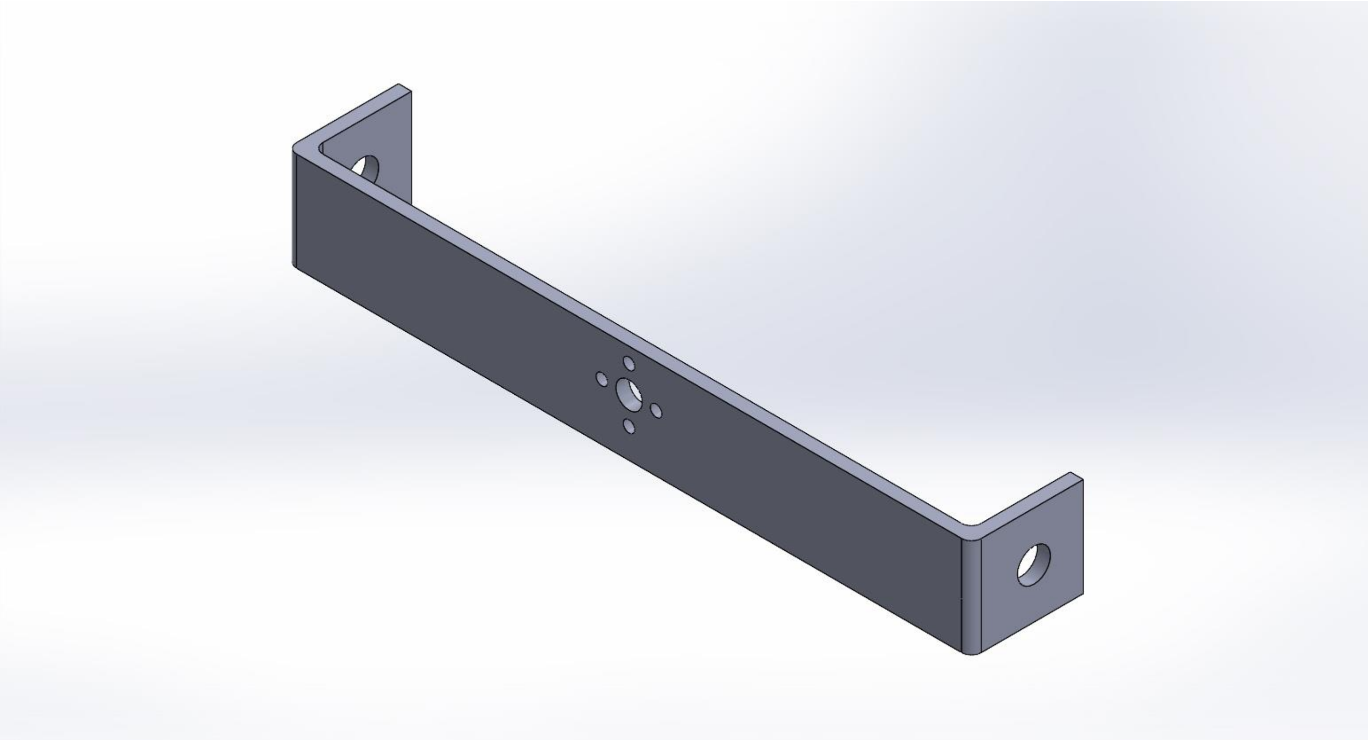


Figure 5.1.25 – 3D Model of Link Support

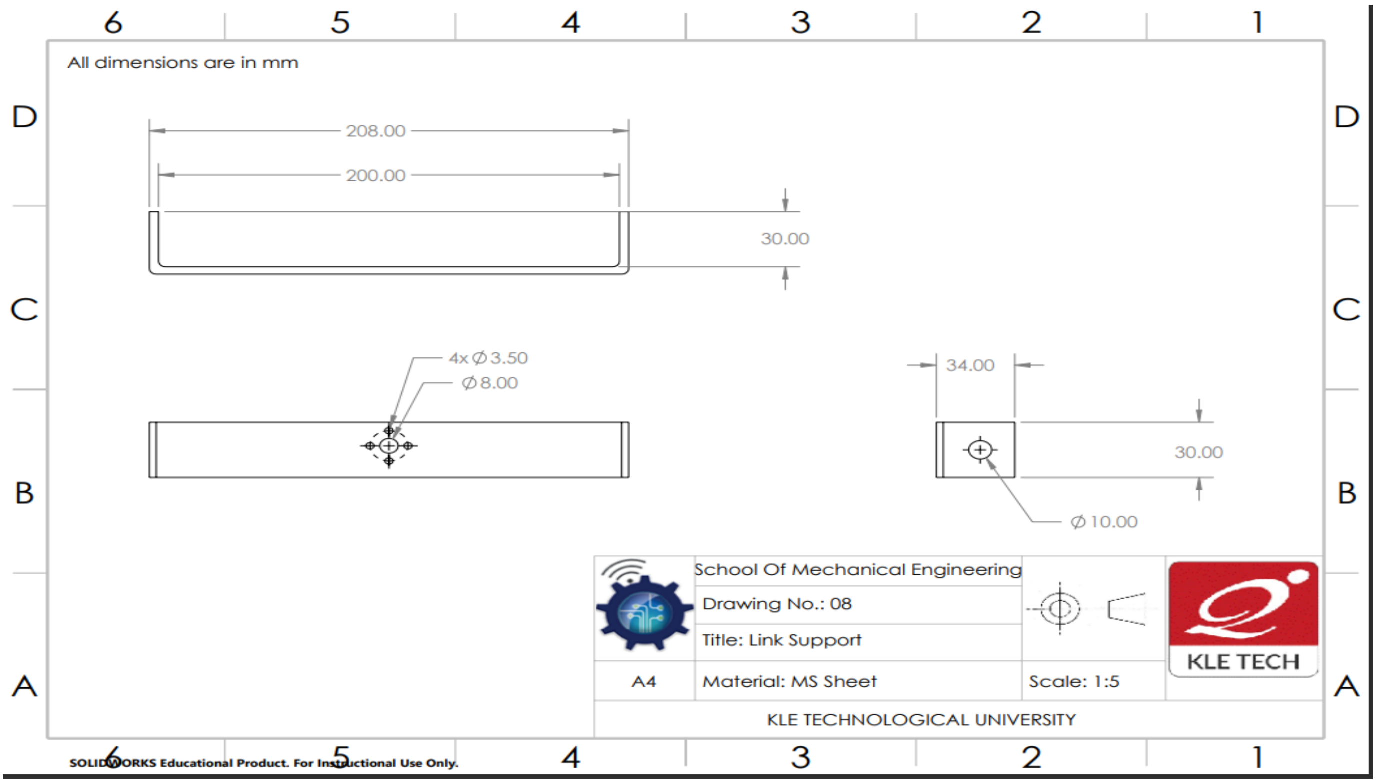


Figure 5.1.25b – 2D Drafting of Link Support

26) Motor Bracket - A bracket is an architectural element. It is a structural or decorative member. This motor mounting bracket provides easy and secure mounting for motors. Motors are mounted within HVAC units and other systems by motor mounting brackets. These brackets attach to (or within) the unit and hold the motor. [29]

Motors have frames that must meet certain NEMA standards and the shape of those frames will determine the applicable mounting bracket. Active Robots have a good range of DC motor brackets providing easy and secure mounting for motors. [30]

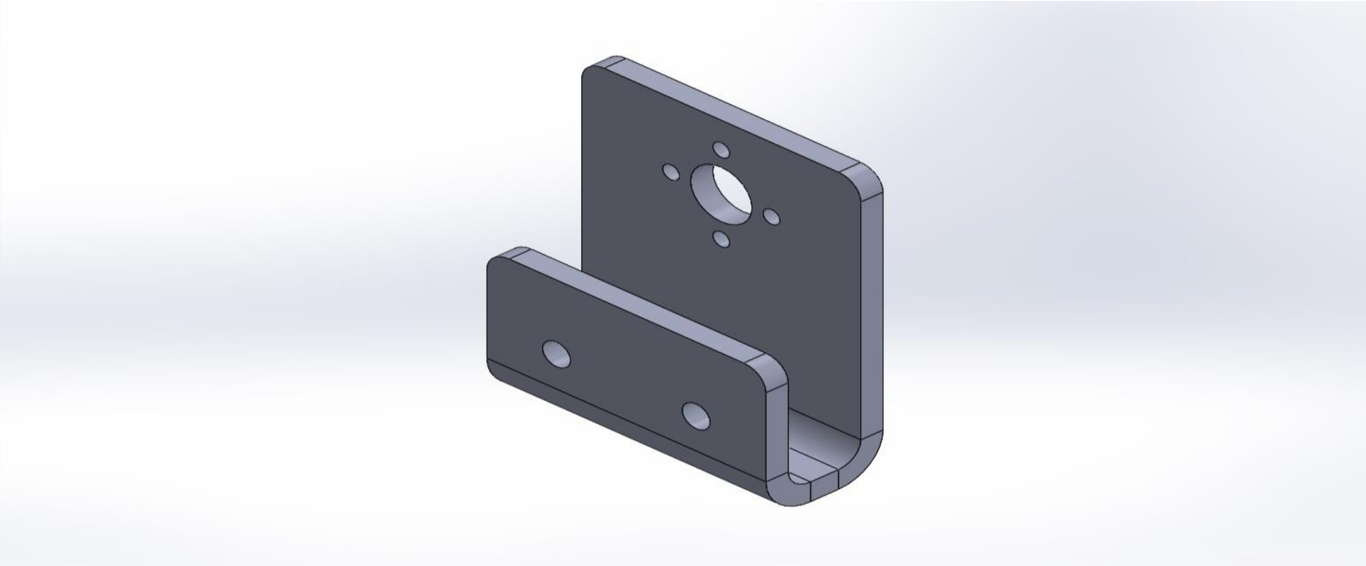


Figure 5.1.26b – 3D Model of Motor Bracket

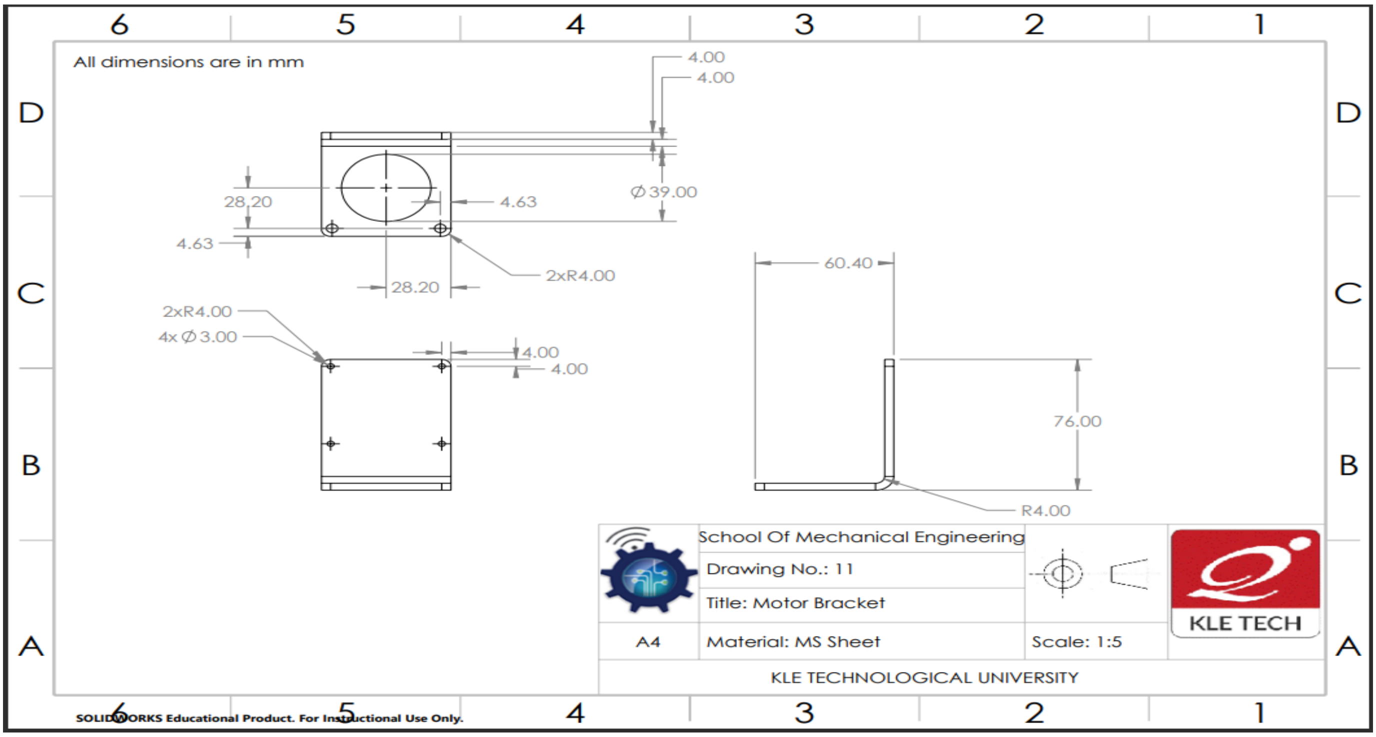


Figure 5.1.26b – 2D Drafting of Motor Bracket

27) Motor Mounting - To achieve top-notch functioning, effective performance, and optimum reliability, proper motor installation and mounting position are crucial. However, the numerous methods a motor can be placed can also cause difficulty.

When examining the mounting positions for electric motors, we can notice that NEMA and IEC are two different standards. Despite having some minor differences, they are comparable in general. [31]

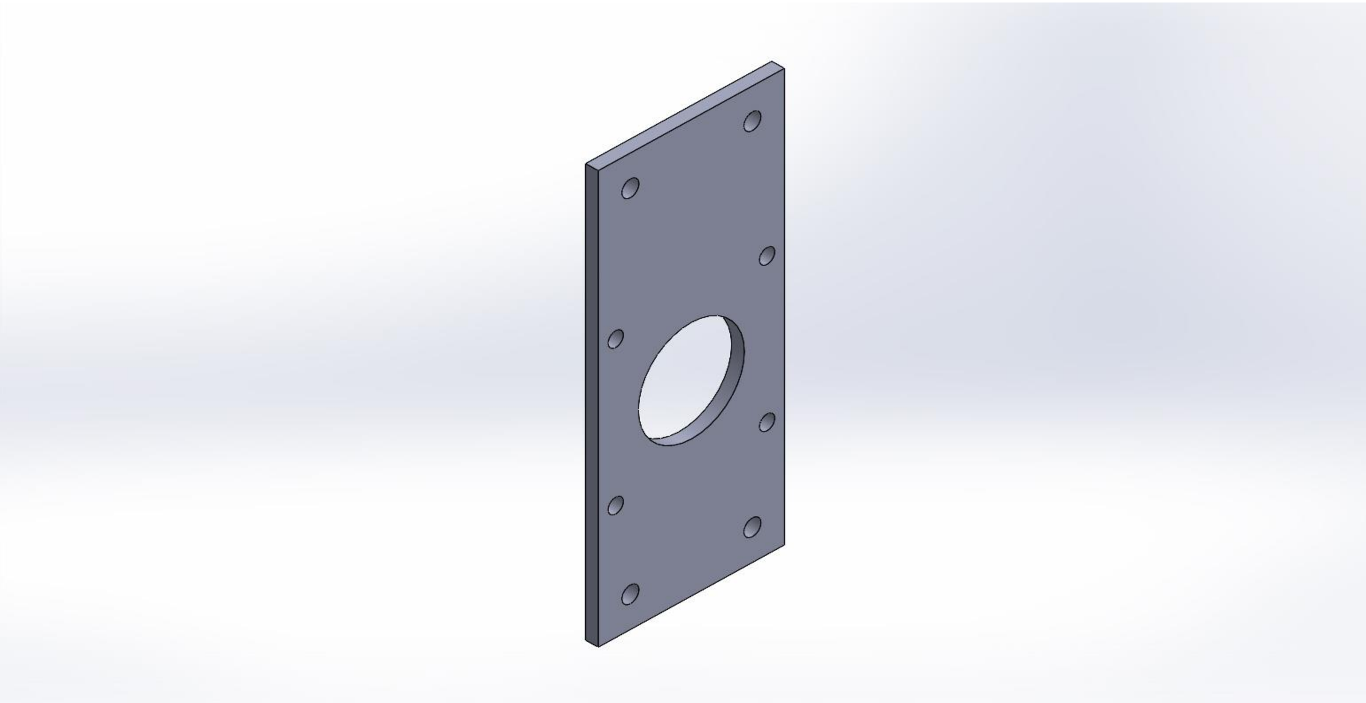


Figure 5.1.27 – 3D model of Motor Mounting

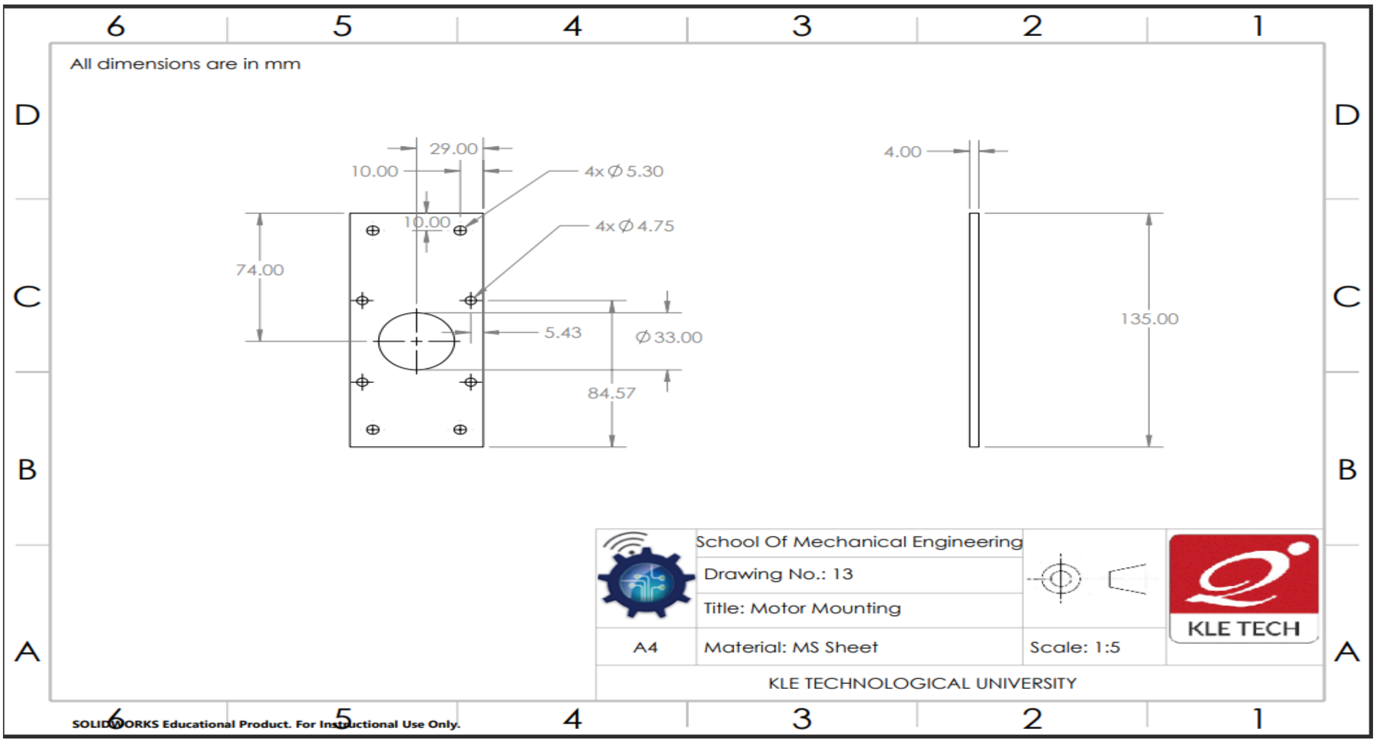


Figure 5.1.27b – 2D drafting of Motor Mounting

28) Right-Side Cover Plate - A sheet metal plate used for covering the side portion of the base to protect the components inside from any harm due to environmental or accidental factors.

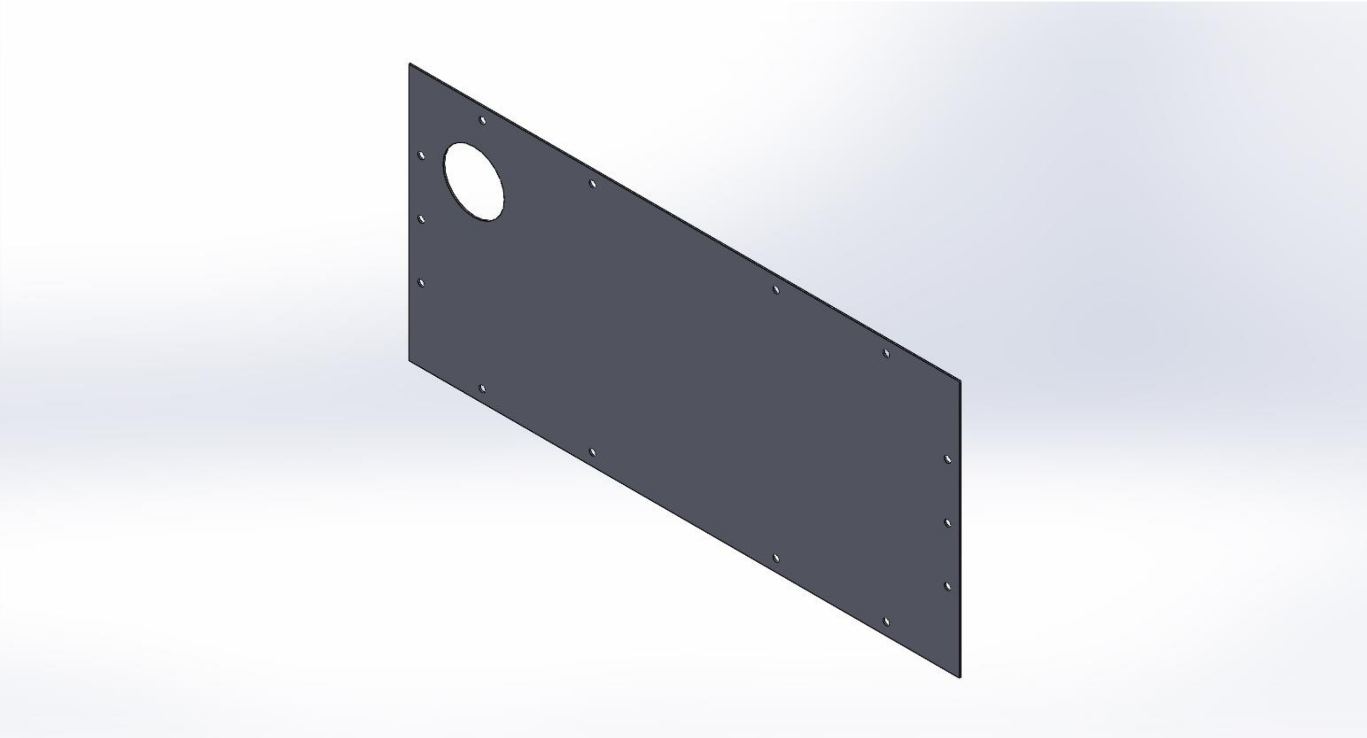


Figure 5.1.28 – 3D model of Right-Side Cover Plate

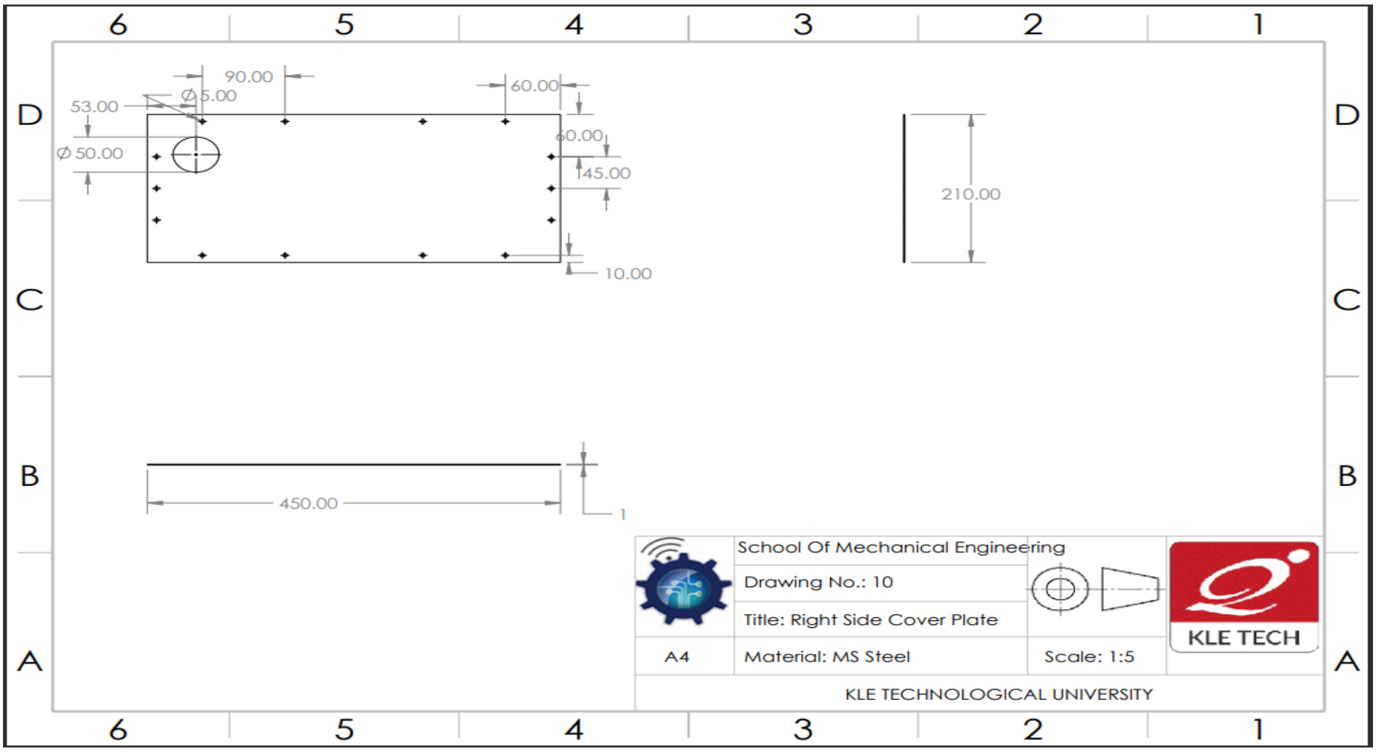


Figure 5.1.28b – 2D Drafting of Right Side Cover Plate

29) Top Cover Plate - A sheet metal plate used for covering the top portion of the base to protect the components inside from any harm due to environmental or accidental factors. It also acts as a base to support the scissor lifting mechanism and its components placed on top of it.

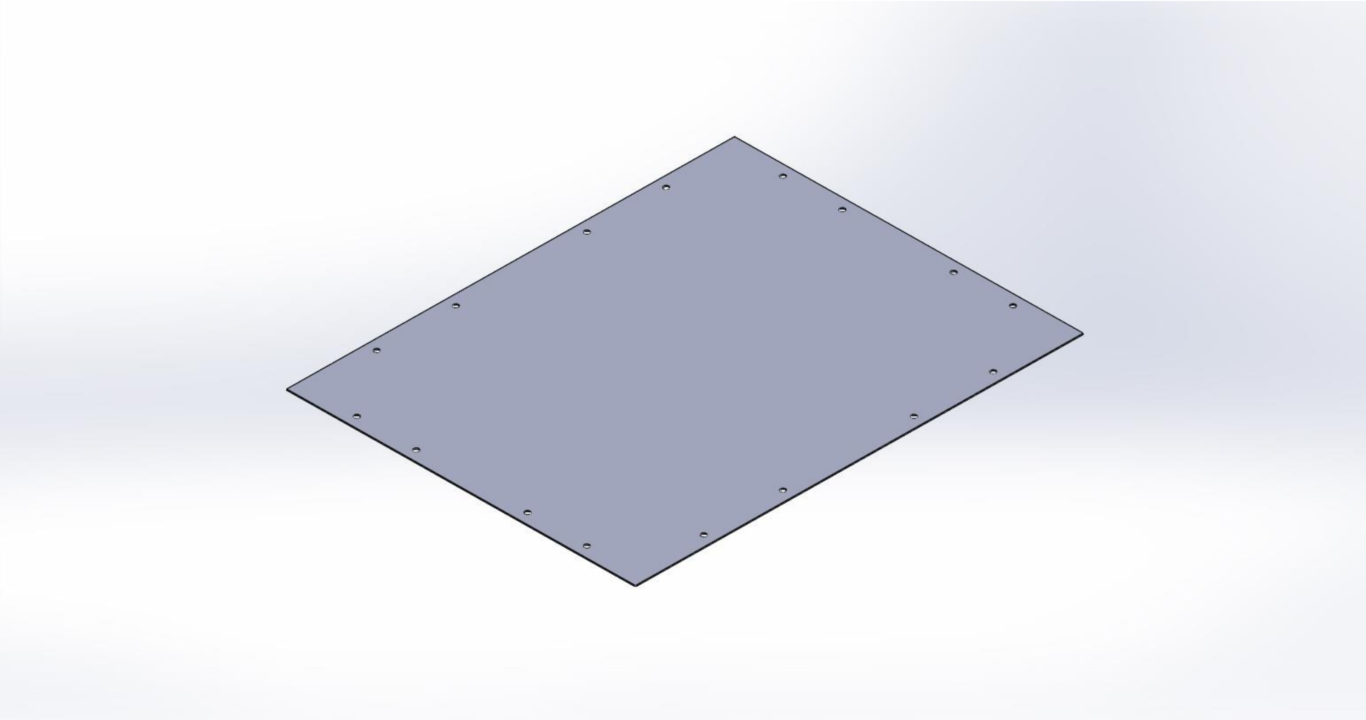


Figure 5.1.29 – 3D model of Top Cover Plate

The below figure shows the Drafting model of Top Cover Plate

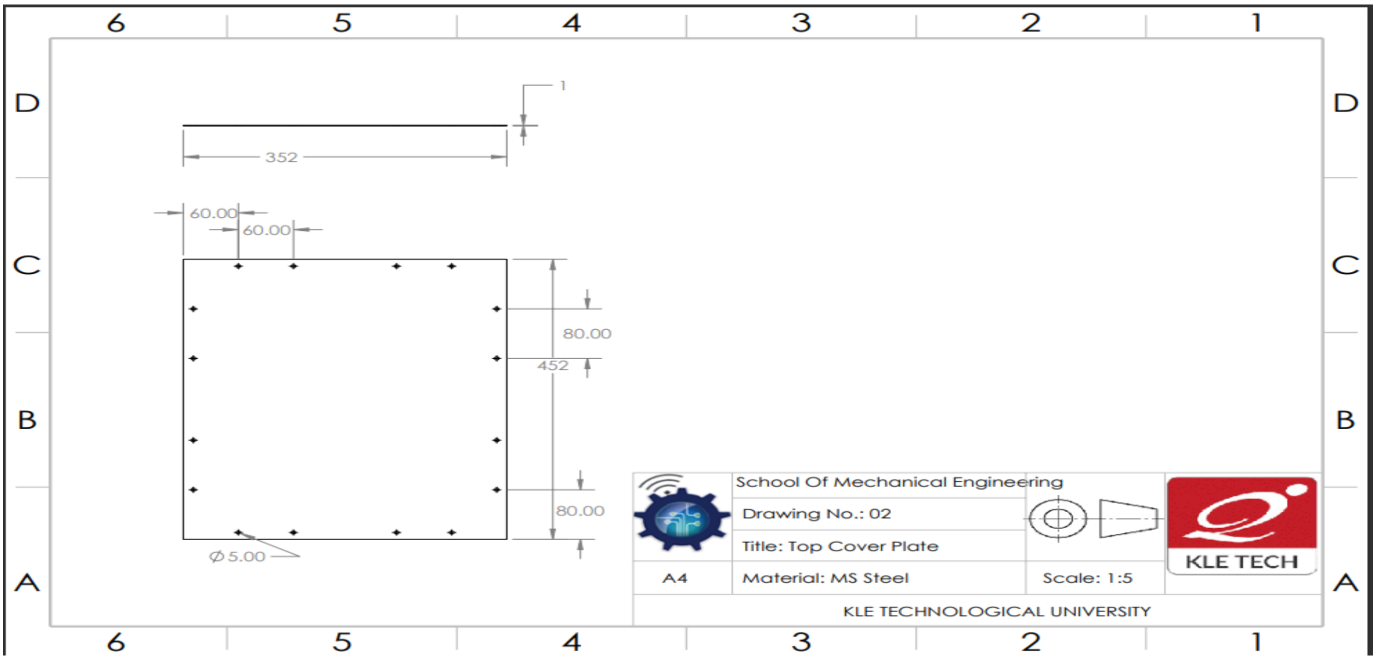


Figure 5.1.29b – Drafting model of Top Cover Plate

5.1.2 Assembly

The Assembly model consists of all the sub-systems put together to form the final model. The entire model was built and drafted using the Solidworks 3D Software which provides hassle-free experience.

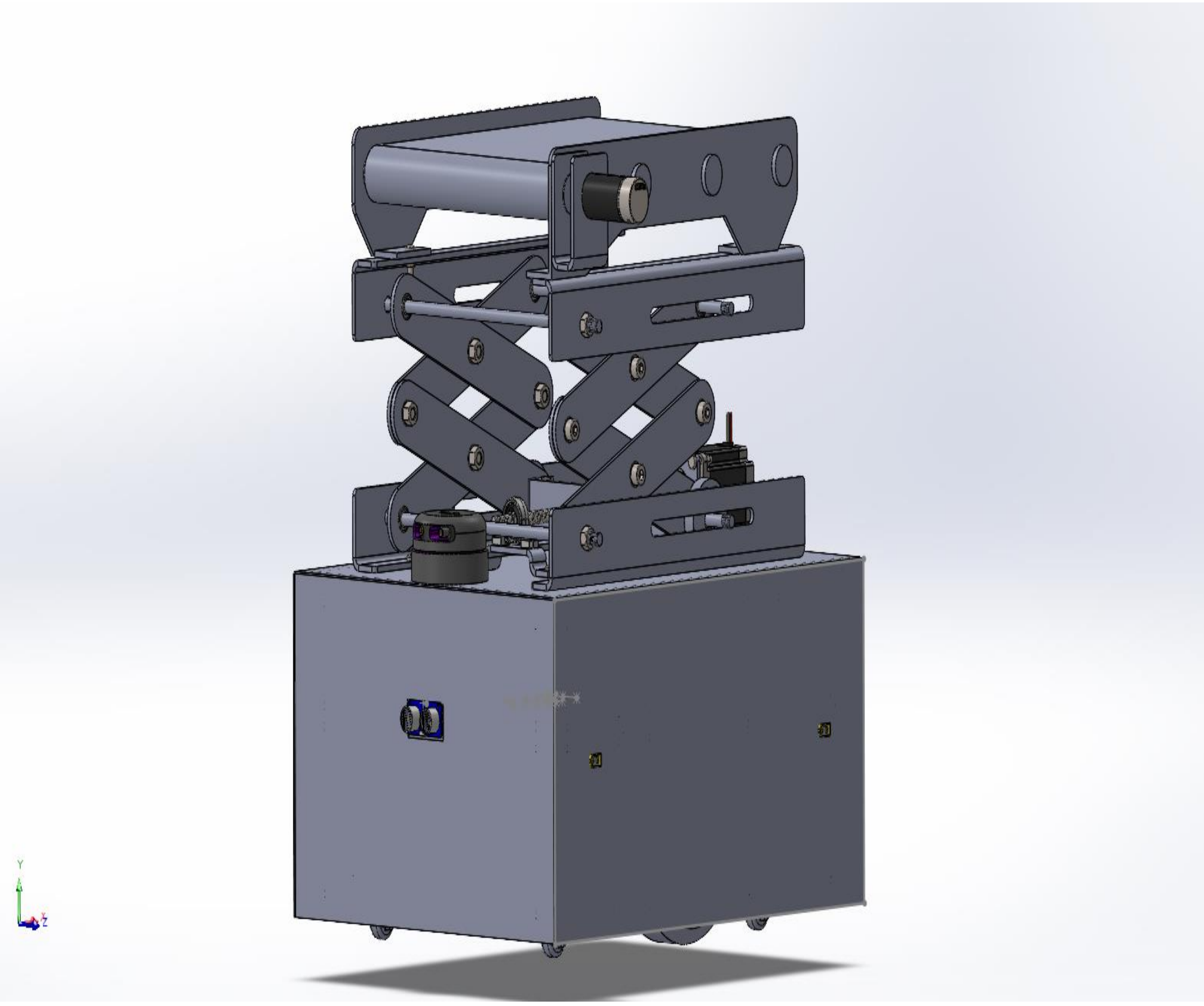


Figure 5.1.2

5.2 Exploded View

An exploded-view drawing is a diagram, picture, schematic or technical drawing of an object, that shows the relationship or order of assembly of various parts.

It shows the components of an object slightly separated by distance, or suspended in surrounding space in the case of a three-dimensional exploded diagram. An object is represented as if there had been a small controlled explosion emanating from the middle of the object, causing the object's parts to be separated an equal distance away from their original locations.

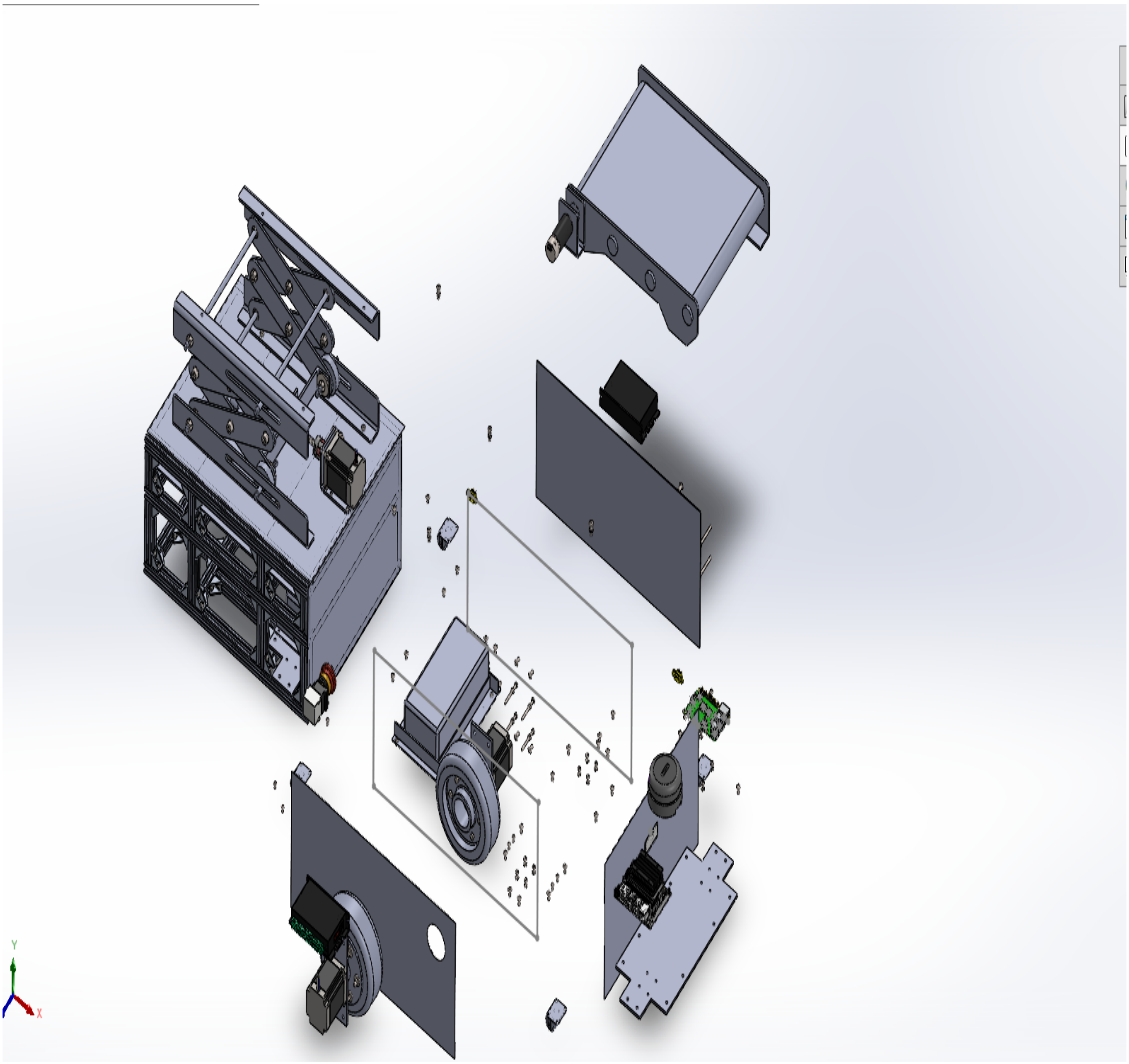


Figure 5.2 – Exploded view of Assembly Model

Chapter 6

FEM Analysis

Simulation is the emulation of operations that we tend to perform in the real world. Simulation is capable of answering fundamental questions like how? What if? etc. After completion of modeling in Solidworks software, it is converted into and then imported into ANSYS software. ANSYS is a software that uses FEM to solve the problem virtually and predict how safe or how the model behaves with respect to boundary conditions. [32]

6.1 Type of FEM Analysis and Justification

FEM Software used: ANSYS 2022 R2

1. Part 1: Base

Analysis type: Static structural

Justification: The Base is one of the critical load-carrying part which has all the components placed inside of it and has to bear all their loads. During a collision, it absorbs all the energy and protects all the other components which are present inside it. The Static structural analysis type is chosen for this part as the load acting due to the weight of components is static and the load acting due to the weight of the deliverable is static throughout the process.

6.2 FE Analysis Details

1. Part: Base

The table 6.2 lists out the analysis and element type along with the number of elements and the material assigned.

Analysis Type	Static Structural
Element Type	Tetrahedron
Elements	7114
Nodes	32617
Material	Rexroth Aluminium

Table 6.2 – Analysis Details [33]

Total Deformation

Deformation results generally can be in ANSYS WorkBench as total deformation or directional deformation. Both are used to obtain displacements from stresses. The main difference is the directional deformation calculates for the deformations in X, Y, and Z planes for a given system. In total deformation, it gives a square root of the summation of the square of x-direction, y-direction and z-direction. Let me know if you need more clarification. [34]

The figure 6.2.1 shows the total deformation for the load applied. The material assigned is Aluminium Alloy 6000 series composed of magnesium and silicon.

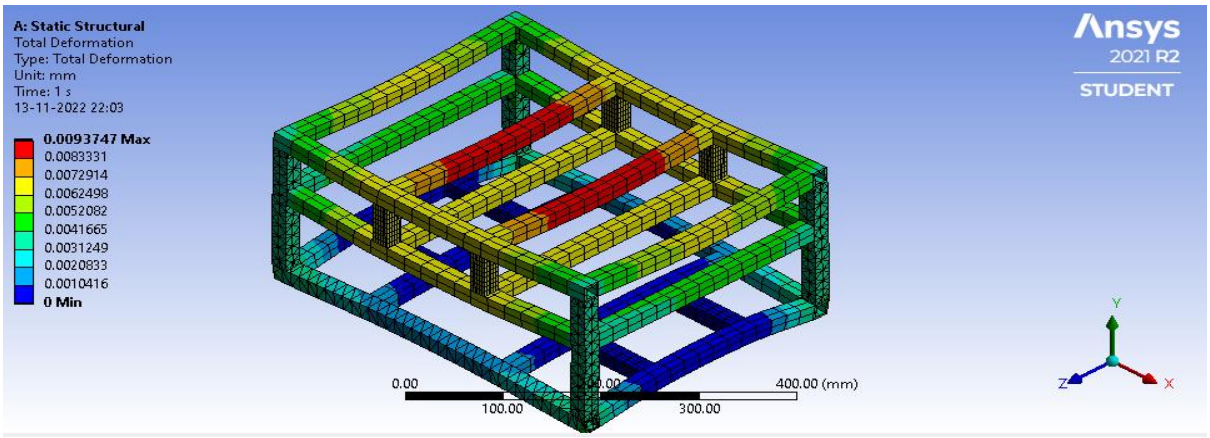


Figure 6.2.1 - Total Deformation for Aluminium

Equivalent Stress

Since aluminium is a ductile material, we can consider Von Mises stress for equivalent stress analysis. The von Mises stress is a value used to determine whether a particular material will yield or rupture. Mainly used for ductile materials such as metals. The von Mises yield criterion states that a material will yield if the von Mises stress of the material under load is greater than or equal to the yield point of the same material under simple stress. [35]

The table 6.2.2 represents the equivalent (von-Mises) stress.

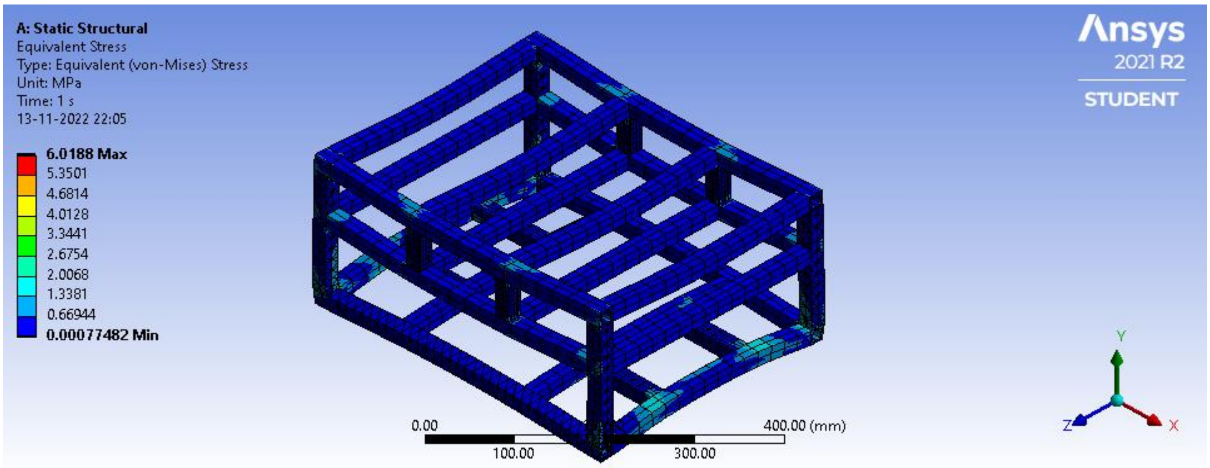


Figure 6.2.2 – Equivalent Stress

Boundary Condition

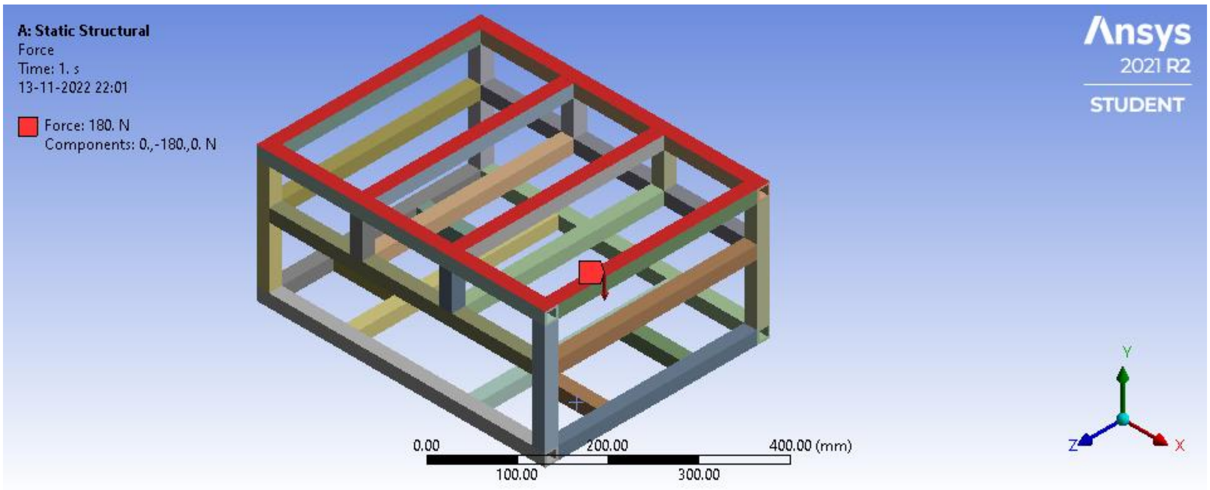


Figure 6.2.3 – Boundary Condition (Force)

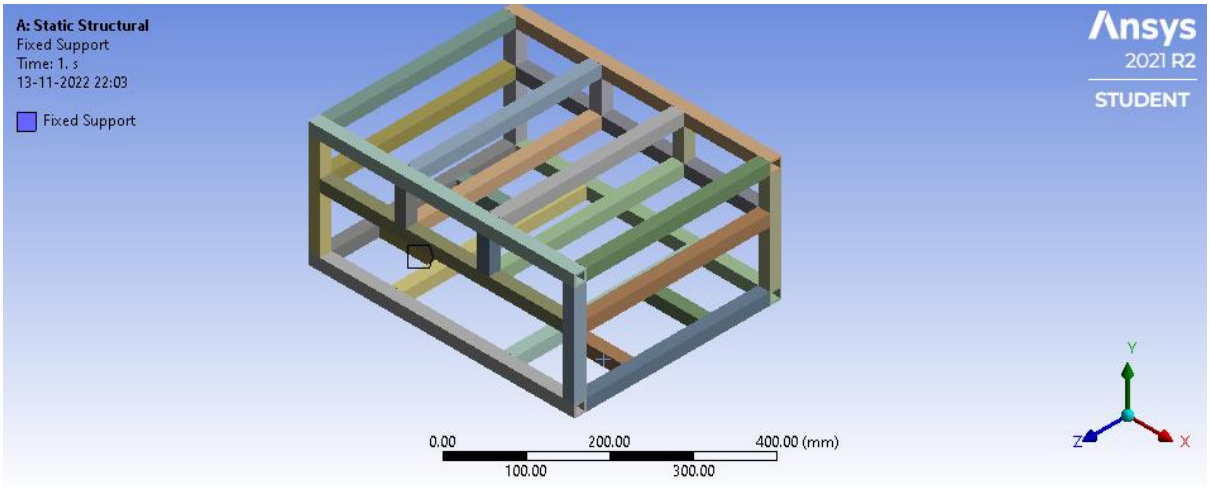


Figure 6.2.4 – Boundary Condition (Fixed Support)

6.3. Results and Discussions: 1. Part 1: Base Support

Total Deformation	0.0094 mm
Equivalent Stress	6.0188 MPa

Outcome of the Analysis: The result shows that the deformation achieved for the load is very small and the stress values are within the limits and are far less than the yield strength of the materials. Hence we can conclude that the design is safe. [36]

Chapter 7

Bill of Materials

Si No	Part Name	Quantity	Material Specification	Brought Out/ Manufactured Part
1	Light Detection and Ranging Sensor (LiDAR)	1	50cm * 50cm 5 mm thick acrylic sheet	Brought Out
2	Ultrasonic Sensor HC-SR04	1	45mm x 20mm x 15mm	Brought Out
3	Jetson Nano	1	20cm * 5cm Wrist band (vinyl material)	Brought Out
4	Leadshine Closed Loop Stepper Motor with Encoder	3	2 phase, NEMA 23 frame size 75 mm (2.95 inch) long	Brought Out
5	Leadshine Closed Loop Stepper motor Driver	3	2 phase, NEMA frame	Brought Out
6	DC Motor	1	60 RPM	Brought Out
7	Jumper wires	20	Thin plated Copper Wire	Brought Out
8	L Shape Aluminium Reinforcement Clamp	70	Straight Angle for 2020 Profile	Brought Out
9	T Type Nut	128	T Type Nut	Brought Out
10	Socket Head Cap Stainless Steel Bolt	128	M5 X 10mm	Brought Out
11	Socket Head Bolt	6	M8	Brought Out
12	Hex Nut	10	M8	Brought Out
13	Socket Head Bolt	16	M4 x 8	Brought Out
14	IS 1364 Bolt	16	M4	Brought Out
15	Hex Jam Nut	40	M5 x 8	Brought Out
16	Plain Washer	12	M5x50	Brought Out
17	Hex Bolt	12	M5	Brought Out
18	Hex Nut	12	5mm	Brought Out
19	Lithium-ion Battery	1	24V 15Ah	Brought Out
20	Lithium-ion Battery	1	12V 10Ah	Brought Out
21	Nylon Ball	2	50mm	Manufactured
22	Emergency Stop Button	1	16mm	Brought Out

23	Acrylic Sheet	1	3mm 100mm^2	Manufactured
24	Acrylic Sheet	1	1mm thickness, 100mm^2	Manufactured
25	Sheet Metal	1	1.2mm thickness, 800*210 mm^2	Manufactured
26	Sheet Metal	1	1.2mm thickness, 300*300 mm^2	Manufactured

Chapter 8

Manufacturing Process

i). Laser Cutting Process

Laser cutting is a technology that uses a laser to vaporize materials, resulting in a cut edge. While typically used for industrial manufacturing applications, it is now used by schools, small businesses, architecture, and hobbyists.

In the design of Autonomous Mobile Robot, we use the process of Laser Cutting for the manufacturing of Scissor links. Initially, the design is developed on 3D modeling software for example Solidworks. Then, the file is converted to a .dxf format. Then the converted file is fed into the Laser cutting machine through which we can obtain the final links.

ii). Sheet Metal Bending

Sheet metal bending is an operation that involves using forces to change the shape of a sheet. This is done to achieve the desired form or shape needed for a manufacturing process. The external force used alters only the external features of the sheet.

We use the sheet metal bending process to bend the sheets as support for scissor lifting mechanism.

iii). 3D Printing

3D printing or additive manufacturing is the construction of a three-dimensional object from a CAD model or a digital 3D model. It can be done in a variety of processes in which material is deposited, joined or solidified under computer control with material being added together (such as plastics, liquids or powder grains being fused), typically layer by layer.

The flange which is used to connect the stepper motor with the wheels is 3D printed to ensure accuracy and proper fitting to provide well designed light weight component.

Chapter 9

Simulation

9.1 Mechanical Simulation

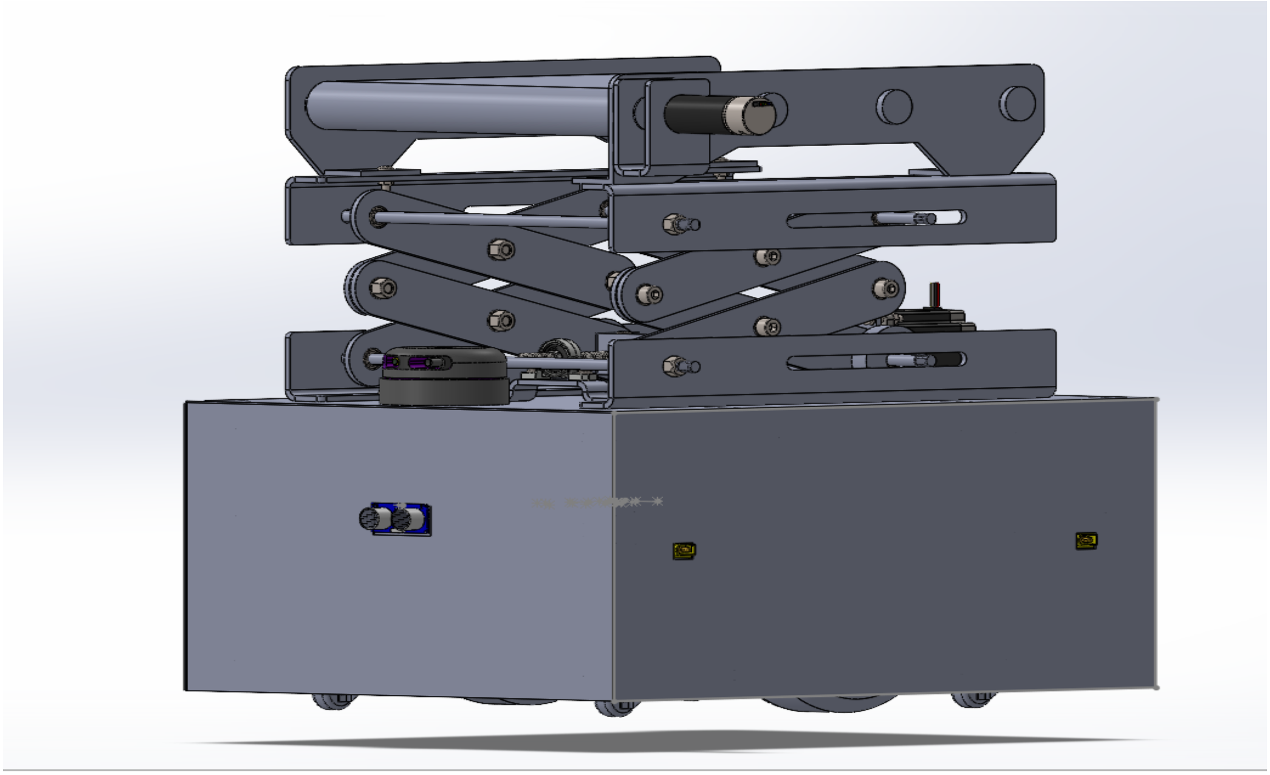


Figure 9.1.1 Model When Scissor Mechanism is Retracted

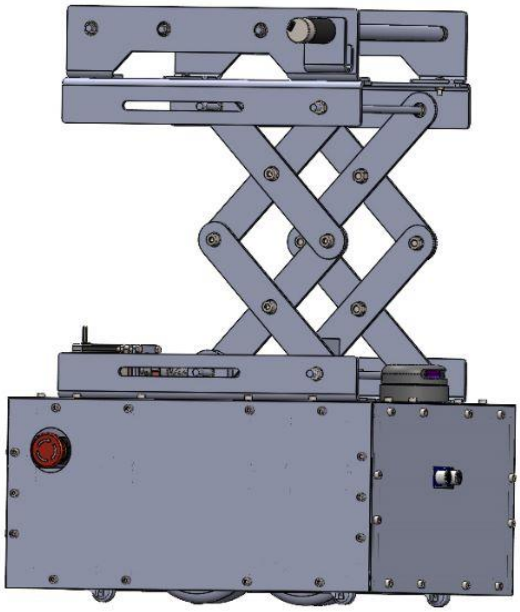


Figure 9.1.2 Model When Payload is being Lifted

The mechanical simulation showcases the scissor lifting mechanism in its extended and receded positions. When extended a height of 400mm is achieved and when retracted it is at a height of 180mm. Limiting switches have been placed to stop the servo motor at the top and bottom positions.

Chapter 10

Conclusion and Future Scope

The technological advances of Autonomous Mobile Robots have helped to achieve operational flexibility and to increase productivity, quality, and cost efficiency. Taking decisions autonomously thanks to Artificial Intelligence promotes the decentralization of activities involving AMRs.

The system uses Light Detection and Ranging sensor along with an Ultrasonic sensor, visual road line detection, front obstacle detection, and safety features in an interactive environment. We have structured and analyzed the literature, given a definition of AMRs, and proposed a design and development framework.

Based on our literature survey of existing designs and products in the market we were able to find AMRs which were able to lift large payloads and have a long runtime but there weren’t any which would cater to the smaller industries’ needs, so a goal to design an AMR with a payload capacity of 3kg and runtime of minimum 1 hour was set.
To meet this goal after various design iterations we were able to develop a design using a split battery setup which ensured that the control system would remain working even if the lifting mechanism ran out of battery, ensuring it to be able to reach the docking station to charge again.
A Scissor Lifting mechanism was used for the lifting mechanism to as it helped reduce the weight, and cost and provided scope for modification in height achieved.
The static structural analysis of the design was carried out in Ansys which showcased the successful ability of it to carry the load of 3kgs, with deformation of just 0.0094mm showcasing the ability of the AMR to carry a load beyond 3kgs.

The use of AMRs will be vast in the future and to cater to that we have to ensure further development of the design to provide better value-for-money products. Two considerations- Longer run time and more efficient packaging are the important factors that can help develop the design further. Longer run time would require a larger battery pack and hence more storage space on the robot, alternatively, the weight can be significantly reduced to help draw less power and help it run longer. Efficient packaging is needed in order to make the bot smaller in dimensions and help reduce the cost.

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