DEVELOPMENT OF MOBILE ROBOT FOR WAREHOUSE AUTOMATION

A Final Year Project Report

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In Partial Fulfillment
of the Requirements for the Degree of
Bachelor of Mechanical Engineering

by

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ABSTRACT

This project aims to address the need for an automated and efficient warehousing solution in Pakistan's booming e-commerce industry. We propose to design and fabricate an Autonomous Mobile Robot (AMR) that can transport packages weighing up to 2kg to a height of 4ft using a scissor lift and telescoping mechanism, reducing human intervention, and improving warehouse efficiency. Integrating this robot with conventional Warehouse Management Systems (WMS) will allow for efficient package storage and shorter order delivery times, while reducing electricity consumption and carbon footprint. The outcome of this project is an AMR capable of traversing a warehouse on its own, detecting and avoiding obstacles, and precisely picking and transporting packages. It will be able to operate in existing warehouses without extensive infrastructure changes.

ACKNOWLEDGMENTS

Above all, we are extremely thankful to Allah Almighty for blessing us with the strength, knowledge and persistence required to bring this project to fruition.

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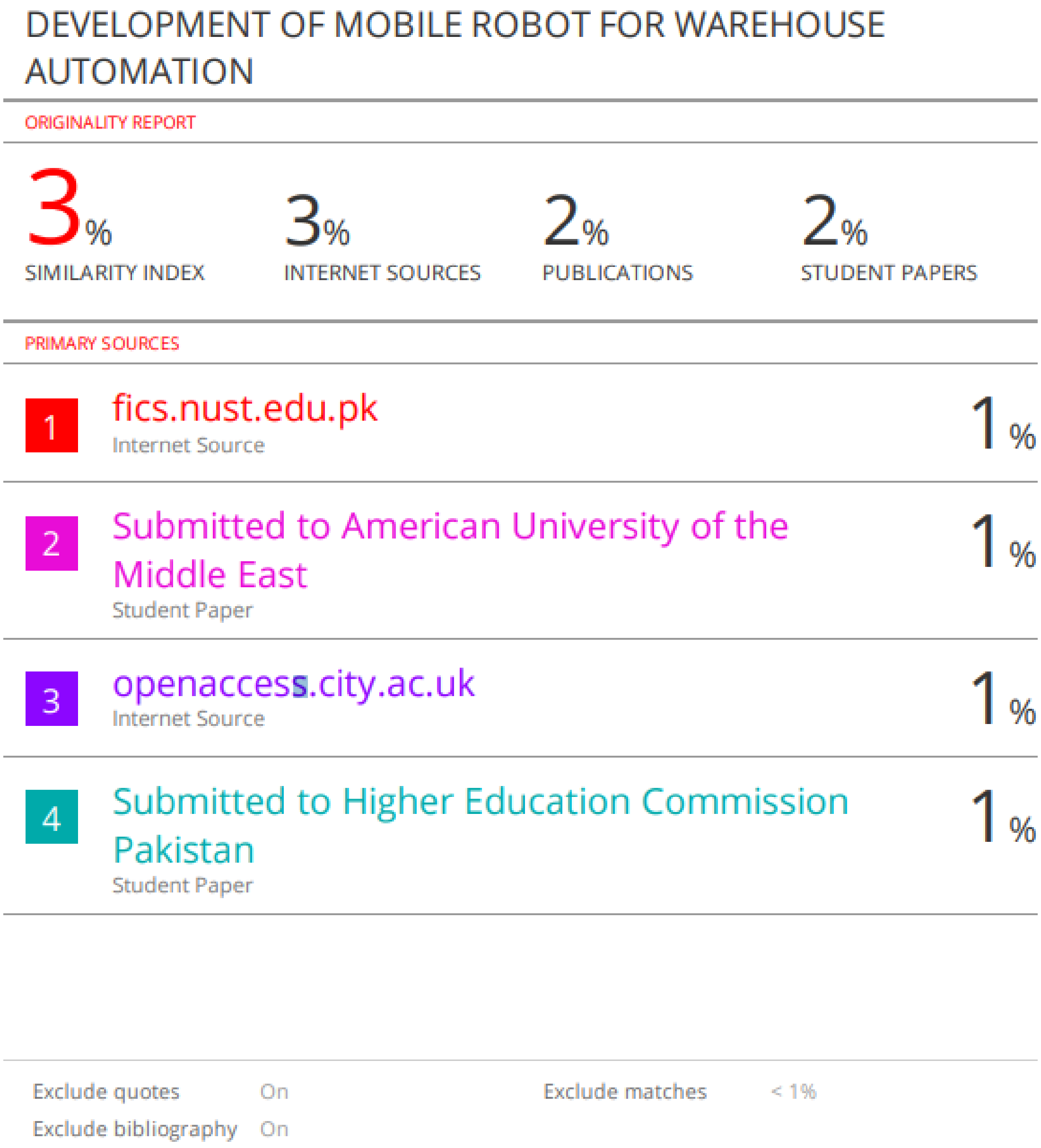
Finally, we are thankful to our parents who helped us throughout the four years journey, and our fellow batchmates who were there to help us with their precious guidance and skill.

ORIGINALITY REPORT



DEVELOPMENT OF MOBILE ROBOT FOR WAREHOUSE AUTOMATION

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ABBREVIATIONS

AMR	Autonomous Mobile Robot
MHE	Material Handling Equipment
WMS	Warehouse Management Solution
RRT	Rapidly Exploring Random Tree

INTRODUCTION

1.1 Problem Statement

The aim of this project is to design and fabricate an Autonomous Mobile Robot (AMR) capable of transporting packages of 2 kg up to a height of 4 ft using a scissor lift and telescoping mechanism. The objective of the project is to reduce human intervention and improve efficiency of warehouse systems, thereby reducing human risk and decreasing the carbon footprint and power consumption of warehouses. The robot should be able to operate in existing warehouses without extensive change in its infrastructure and should be able to navigate intelligently through the dynamic environment of a warehouse.

1.2 Motivation

Pakistan has a booming e-commerce industry with an ever-increasing demand for speed and accuracy in warehousing. This industry is in dire need of an automated, scalable warehousing solution that is quick, precise, and more importantly, cheaper than conventional practices. The future of warehousing in Pakistan is in the adoption of Industry 4.0 practices to eliminate human intervention and efficiently optimize Warehouse Management Systems (WMS). Typically, the order picking process involves manual labor, where a person reads the order from the system, walks around the warehouse and retrieves the package by hand. He/she may also need to use a ladder to reach the higher shelves in the warehouse, which poses risk. The weight of the package is limited to the carrying ability of the worker, and usage of Material Handling Equipment (MHE) will lead to a further increase in time. As opposed to this, an automated mobile robot will be constantly in communication with the WMS while navigating the warehouse. It knows the exact location of every package with 100% accuracy and can transport and retrieve heavier packages from a higher shelf height without need of additional MHE. Using robots instead of humans in warehouses allows you to pack your shelves more efficiently, leading to 95% storage utilization and five times more storage density than wide aisle warehouses[i].

The environmental impact of the booming e-commerce industry in Pakistan has never greater than before. With redundant packaging made of plastic and the carbon cost involved in global transportation, the logistics and supply chain of the e-commerce industry has a huge carbon footprint which goes unconsidered. it is estimated that between 5.5% and 13% of the global GHG emissions are caused by logistic activities in supply chains[ii]. A vast amount of research is focused on reducing emissions from transport, yet warehouse-related emissions have been ignored. carbon emissions caused by material handling activities in logistics buildings, comprising warehouses and sortation facilities, are significant and account for 13% of overall supply chain emissions[iii]. In the UK, for example, it is estimated that warehouses are responsible for approximately 10.2 million tons of CO_2, while 1.5 million tons could easily be saved just by making simple changes[iv].

However, these solutions are not feasible to be implemented in Pakistan due to their high installation costs in addition to custom duties. From this proposed research and project, we aim to not only increase awareness of warehouse automation and its sustainable benefits but also to provide a cheap and effective solution that can be adopted in large-scale within Pakistani industries. The indigenous designing and manufacturing of this robot will not only help the local economy, but it will also promote the adoption of sustainable and automated solution in other segments and processes of the industry as well. Moreover, the advent of dark warehouses within Pakistan will also lessen the electricity consumption of storage facilities and alleviate the energy shortfall problem, especially during summers since dark warehouses have less lighting and HVAC consumption.

1.3 Objectives

The deliverables of our project are as follows:

1. **Design and fabricate a working prototype.**

The design and assembling of a working Autonomous Mobile Robot (AMR) that employs a scissor lift and telescoping mechanism. The mechanisms should be fully working and capable of vertical and horizontal motion within the considered ranges. The robot should be able to navigate an environment using its differential drive.

2. **Perform FEA and relevant simulation.**

Perform Finite Element Analysis of the designed structure to ensure reliable working within a factor of safety. Simulations include rigid body dynamics, transient structural analysis, and motion studies.

3. **Lift packages up to a height of 4 ft.**

The robot should be able to lift packages to a maximum height of 4 ft or 1.21 m.

4. **Transport packages weighing up to 2 kg.**

The robot should be able to lift standard-sized packages weighing at least 2 kg.

Most companies in Pakistan opt for conventional practices involving manual labor which not only has more margin for error but also poses a risk from a safety standpoint in hazardous environments such as warehouses. This is why Amazon, the largest e-commerce retailer in the world, is moving towards the concept of dark warehouses which completely automates warehouse management end-to-end i.e. those warehouses in which automated machinery and robots are guided by system commands to perform actions such as loading and packing of the goods or products. The scope and outcome of this project is to design an automated solution for local industries to reduce their dependency on manual human labor and increase the order processing efficiency of a warehouse. Implementing this solution will eliminate human intervention entirely, saving payroll costs and improving the workplace safety of a warehouse.

CHAPTER 2: LITERATURE REVIEW

With the development of apps like Daraz, Alibaba etc., warehouse operations throughout Pakistan have grown large. As a result, the warehouse owners require accurate and timely delivery of items to the customers by the warehouses. The aim of this project is to introduce robots in warehouses to perform storage and retrieval operations with accuracy and to improve the supply chain management of a warehouse. The paper will examine the necessary and possible mechanisms required to build an autonomous robot to perform warehouse operations. The paper also discusses the different warehouse robots manufactured to date and the mechanisms they used to perform these operations.

The warehouse robot is made of different mechanisms performing different tasks. The vertical movement, the horizontal movement, the movement of the robot and the obstacle detection and avoidance, all require different mechanisms to carry out the specified operations.

2.1 Existing Products

2.1.1 Kiva Robotics

The Kiva Robots use a combination of electronic, mechanical, and software components to function. The software system chooses the best path for each Kiva robot to take to retrieve the required items when an order is received.

Some of the key electrical components used in Kiva robots include:

- **Battery:** These robots use lithium-ion batteries. These batteries provide high energy density and long-life cycle. Hence, the robots can work for a greater time before recharging is required.

- **Sensors:**
  1. The LIDAR sensor is used to create a 3D map of the surrounding.
  2. Cameras are used to navigate through the warehouse.
  3. Infrared sensors are used to detect obstacles and objects.
  4. Wheel encoders track the movement of the wheels.
  5. Bump sensors to detect if the robot has collided with anything.
  6. Floor sensors are used to locate charging stations and used for navigation.
- **Microcontrollers:** The Kiva robot uses different microcontrollers depending on the capacity of the robot. They use Raspberry Pi, which is used to control sensors, actuators, processing sensor data, controlling motors and communicating with other devices.

The mechanical components of these robots are:

- **Casters:** Kiva robots also use casters to help them turn and maneuver in tight spaces. These casters are typically mounted on the underside of the robot and provide additional stability and maneuverability. These wheels are made of durable hard plastic material.

- **Robotic arms:** Kiva robots are equipped with robotic arms that are used to pick up and move items around the warehouse. A gripper is attached to the robotic arms end to grip the object desired. These arms are typically made of lightweight materials, such as aluminum or carbon fiber, and are designed to be strong and durable.
- **Scissor lift:** The scissor lift can move the gripper up or down to reach pods or shelves located at different heights.

A grid of floor markings that are picked up by sensors on the robot's underside serves as the robot's movement guides. The robot lifts the storage pod and moves it to the desired spot once it has reached the correct storage pod using its mechanical lifting mechanism[v] that is situated on the base.

2.1.2 Skypod Exotec

Figure 1 Exotec Skypod warehouse robot

Another warehouse robot, namely “Skypod” navigates the warehouse and retrieves items for order picking. Key electrical components of the robot are as follows:

- **LED lights:** The Skypod Exotec robot is equipped with LED lights that provide visual feedback on the robot's status and operation.
- **Motors:**
    1. Brushless DC motors are used for the main drive motors. These provide high energy, torque and are efficient and reliable.
    2. Gear motors are to reduce the speed and increase the torque of the main drive motors.
    3. Servo and stepper motors are used for the precise movement of robotic arm or gripper.
- **Sensors:**
    1. Inertial measurement units (IMU) are used to sense bodies motion, velocity, acceleration.
    2. Force sensors are used to measure force applied on the gripper and other components.
    3. Cameras are used for object recognition and navigation.
    4. Proximity sensors are used to detect objects and obstacles to avoid collisions.

5. LiDAR sensor is used to create a 3D map of the environment.

- **Communication system:** Skypod Exotec robots are equipped with wireless communication systems that allow them to communicate with other robots and with the central control system.
- **Batteries:** These bots use rechargeable lithium-ion batteries.

The main features of this robot are as follows:

1) **3D navigation**: The Skypod Exotec robot uses 3D cameras and sensors to navigate through the warehouse, enabling it to operate safely and efficiently even in complex environments.
2) **High speed**: The robot can travel at speeds of up to 4 meters per second, making it one of the fastest ASRS solutions on the market.
3) **Modular design**: The Skypod Exotec system is made up of modular units that can be combined and configured to fit a wide range of warehouse layouts and requirements.
4) **Dual gripper technology:** Each robot is equipped with two grippers that can handle multiple items simultaneously, allowing for faster and more efficient order fulfillment.

5) **Scalability:** The Skypod Exotec system can be easily scaled up or down to meet changing business needs, making it a flexible and future-proof solution for warehouse automation.

6) **Real-time monitoring:** The system includes real-time monitoring and reporting tools that enable warehouse managers to track inventory levels, order status, and other key metrics in real-time.

2.1.3 SqUID bot

Figure 2 SquidBot rack climbing robot

Another warehouse robot is "SqUID." SqUID (Synchronous Quadruple Independent Drive) robot is made to move items throughout a warehouse or distribution facility. It is a nimble robot with great versatility that can move in any direction and squeeze through small areas.

The four-wheel drive system that underpins the SqUID robot's working mechanism enables it to travel in any direction with equal ease. Electric motors within the robot allow it to move rapidly and effectively throughout the warehouse. With the aid of a number of sensors and cameras, the SqUID robot can move around the warehouse and avoid obstructions. In order to avoid collisions, the sensors recognize things in its route, such as walls, pallets, and other machinery, and change its course accordingly. The SqUID robot uses a variety of mechanisms to carry and move objects in addition to navigating. Some models feature a conveyor system that enables them to transfer objects on flat surfaces, while other models might have a gripper or clamp mechanism for lifting and moving objects. In order to improve the flow of supplies and goods, the SqUID robot collaborates with other robots in the warehouse via communication. This increases the effectiveness of the warehouse operation and aids in lessening bottlenecks.

Literature Review of Research Papers:

Authors	Focus	Content
Belotserkovsky et al. (2021)[vi]	Warehouse robot	Aims to simplify and reduce the cost of robot design by using existing warehouse video surveillance infrastructure. Proposes a digital twin of the warehouse to verify and test the algorithms for managing the robots.

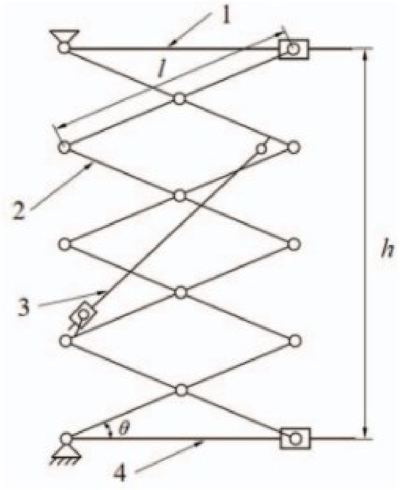
McNulty et al. (2022)[vii]	Power system	Reviews the energy requirements of AMRs and the battery packs currently being used in them. discusses the operation of Li-ion batteries, proposes alternative electrode materials, and recommends electrode pairings
Zhang et al. (2015)[viii]	Scissor Lift	Analyzes the static stability of six different types of scissor lifts with one input force of hydraulic actuator. The stability of single scissor arms is studied using energy and modeling methods, with results compared.
Hanafusa et al. (2022)[ix]	Telescoping mechanism	Proposes a design for a compact telescopic arm that can be mounted on a mobile robot and generate space-saving motions using multi-stage expansion and contraction by a lead screw, and folding wires in the telescopic link shells.
Liang et al. (2015)[x]	Warehouse robot	Presents an automated robot picking system for e-commerce fulfillment warehouses. The system includes a lightweight robot manipulator, a 3D camera system, and a custom-built robotic gripper.
Dengiz et al. (2018)[xi]	Scissor Lift	Presents the design and analysis of a scissor lift system using finite element method. The system has a load

		carrying capacity of 500kg and working height of 2m.
Lee et al. (2011)[xii]	Telescoping Mechanism	Presents a wire-driven bidirectional telescopic mechanism for workspace expansion.
Ries et al. (2017)[xiii]	Warehousing Operations	Highlights the environmental impact of warehousing operations and proposes a systematic assessment approach to measure the carbon footprint of warehouses. Identifies effective mitigation strategies
Ozbaran et al. (2020)[xiv]	Warehouse robot	Presents a mechatronic system design of a smart mobile warehouse robot for automated storage/retrieval systems.
Reid et al. (2013)[xv]	Path Planning	Presents WAMbot, a modular multi-robot system designed to navigate, explore and map large-scale urban environments while performing visual object recognition.
Zhao et al. (2021)[xvi]	Obstacle Avoidance	Proposes an intelligent obstacle avoidance design for a mobile robot that uses ultrasonic and infrared sensors to detect obstacles and potholes, and road sign detection to follow additional information.
Adarsh et al.	Obstacle	Compares the performance of Infrared and Ultrasonic

(2016)[xvii]	Avoidance	sensors for obstacle detection in vehicle and robot navigation applications. The sensors are tested on obstacles made of different materials and their detection range and properties are analyzed
Sun et al. (2020)[xviii]	Warehouse robot	Presents the design and simulation of an intelligent logistics warehouse handling robot for pharmacy warehouses. The robot's fork-scissor lifting mechanism, rotating device, telescopic device, and gripper, is designed and simulated using CAD & FEA.
Qing et al. (2017)[xix]	Path Planning	Proposes an improved Dijkstra algorithm for path-planning in rectangular environments of automated storage and retrieval systems (AS/RS) to find all equidistant shortest paths and choose the optimal path based on turn time, improving AGV efficiency.
Prabhu et al. (2021)[xx]	Path Planning	Explores motion planning solutions for AMRs in smart warehouses. It compares RRT and VFH techniques for single AMRs, and leader follower, and multi-robot collision avoidance for multi-agent AMRs.

2.2 Scissor Lift Mechanism

For the vertical motion of the robot to achieve the height of the rack or shelves there are a number of mechanisms. The design of scissor lift is a very important task to make the overall robot work. As, this mechanism helps the robot achieve the height of the shelf. The designing of scissor lifting mechanism is crucial to the angle of scissor leg with the horizontal. The greater the angle the angle will cause minimal change in the height and increase the stress on the upper platform. The angle hence should be between 10-50 degrees. The basic electric pushrod driven scissor lift diagram describing the parts of the scissor lift is as follows:



1. Upper platform 2. Scissor arm 3. Electric pushrod 4. Base frame

Figure 3 Scissor Lift links configuration

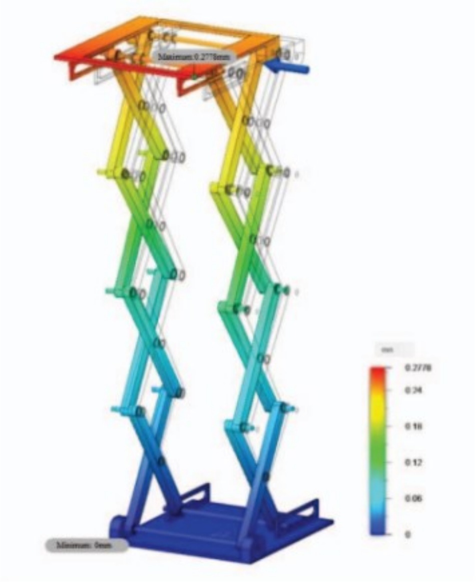


Figure 4 Scissor Lift FEA analysis.

One of the papers also discusses the effect of load on the strength of scissor arms. Different loads are applied to the upper platform of the scissor lift and the distortion in the scissor arms is observed with the help of FEA analysis. The scissor lift is first tested with 200N load which concludes a loss of 5mm displacement along with reduction in scissor arm strength. To reduce the weight on the scissor arm without weakening it, the scissor lift design is optimized, and the simulation results then show a 0.3mm maximum deviation. The results for a four-stage scissor lift are shown:

The stability of scissor arm can be calculated through energy method or the static equilibrium method.

The energy method

$$\boldsymbol{\Pi = U + V}$$

Static equilibrium method

$$\sum \mathbf{F_x = 0}$$

$$\sum \mathbf{F_y = 0}$$

Moreover, the scissor lift can be driven mechanically (lead screw or hydraulic pushrod) or electrically (electronic pushrod). The scissor lift is the least expensive and reliable mechanism for achieving height. The hydraulic driven scissor:

- Uses hydraulic fluid to power the lift mechanism, which typically consists of a pump, cylinders, and a valve system.
- Can lift heavier loads than lead screw driven scissor lifts.
- Can lift loads to greater heights than lead screw driven scissor lifts.
- Have a smooth and quiet operation due to the use of hydraulic fluid.
- Require more maintenance than lead screw driven scissor lifts due to the complex hydraulic system.
- Are more expensive than lead screw driven scissor lifts.

The other scissor lift driving mechanism is the electric pushrod.

Electrical pushrod driven scissor lift:

- **Electric actuation**: Unlike hydraulic scissor lifts, which use fluid power to lift and lower the platform, electric pushrod scissor lifts use electric motors to actuate the pushrods that drive the lifting mechanism.
- **Compact design:** Electric pushrod scissor lifts are often more compact than hydraulic scissor lifts, as they do not require bulky hydraulic cylinders or pumps.
- **Quiet operation**: Electric pushrod scissor lifts are generally quieter than hydraulic scissor lifts, as they do not produce the same level of hydraulic fluid noise.
- **Precise control**: Electric pushrod scissor lifts offer precise control over the lifting mechanism, allowing for fine adjustments in height.
- **Lower maintenance**: Electric pushrod scissor lifts require less maintenance than hydraulic scissor lifts, as they do not have hydraulic fluids that need to be regularly checked or replaced.
- **Lower weight capacity:** Electric pushrod scissor lifts typically have a lower weight capacity than hydraulic scissor lifts, as electric pushrods may not be as powerful as hydraulic cylinders.

Lead screw mechanism for scissor lift:

- **Mechanical actuation:** Unlike hydraulic or electric scissor lifts, lead screw driven scissor lifts use a threaded rod or lead screw that is manually or mechanically turned to actuate the lifting mechanism.

- **Simple design**: Lead screw driven scissor lifts are relatively simple in design, consisting of a scissor lift mechanism that is driven by the lead screw.
- **Cost-effective**: Lead screw driven scissor lifts are typically less expensive than hydraulic or electric scissor lifts, as they do not require complex hydraulic or electrical systems.
- **Easy maintenance:** Lead screw driven scissor lifts require minimal maintenance, as the lead screw and associated components are relatively simple and easy to replace if necessary.
- **Slower operation**: Lead screw driven scissor lifts operate more slowly than hydraulic or electric scissor lifts, as the lead screw must be manually or mechanically turned to raise and lower the platform.
- **Limited weight capacity:** Lead screw driven scissor lifts typically have a lower weight capacity than hydraulic or electric scissor lifts, as the lifting mechanism may not be as powerful.

2.3 Telescopic Mechanism

The horizontal motion of the robot is achieved by a multistage telescopic mechanism. It allows for increased linear motion to further go into space to reach certain things that cannot be achieved by a human. The tubes of the telescopic mechanism are called stages.

This means a three-stage telescopic mechanism consists of three tubes. The largest tube is called the barrel and the smallest is called the plunger.

The other type of telescopic mechanism is bidirectional wire-driven telescope which consists of two nested tubes, one inside the other, which can be extended and retracted by wires attached to pulleys at each end. The design offers two-way mobility, meaning the tool can extend and retract in any direction.

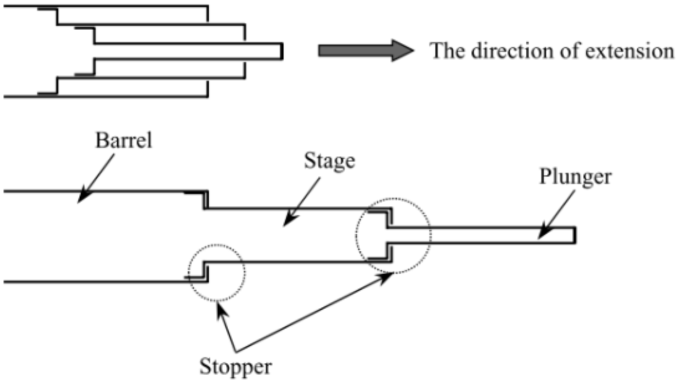


Figure 5 Telescopic Mechanism for ship building tasks

Some types of telescopic systems are larger due to some technical requirements in hydraulic telescopic mechanisms, such as pipes for transmitting the oil pressure and safety devices for preventing unintentional discharge due to excessive pressure.

The main features of a hydraulic driven telescopic mechanism include.

- **High reach and height**: Hydraulic driven telescopic mechanisms can extend to great heights and reach long distances, making them suitable for applications where vertical or horizontal reach is required.

- **Precise control:** The hydraulic system allows for precise control over the telescopic arm, enabling fine adjustments to be made to achieve the desired position.
- **Heavy load capacity**: Hydraulic driven telescopic mechanisms can typically lift and transport heavy loads due to the power of the hydraulic system.
- **Maintenance:** Hydraulic driven telescopic mechanisms require regular maintenance, including fluid checks and replacements, to ensure proper operation.
- **Cost**: Hydraulic driven telescopic mechanisms can be more expensive than other types of lifting mechanisms due to the complexity of the hydraulic system.

The main features of gear-driven telescopic mechanisms include:

- **Simple design**: Gear-driven telescopic mechanisms have a relatively simple design compared to hydraulic systems, as they do not require complex fluid systems.
- **High precision:** Gear-driven telescopic mechanisms can be precisely controlled to achieve the desired height or reach, making them suitable for applications where precise positioning is required.
- **Low maintenance:** Gear-driven telescopic mechanisms require minimal maintenance, as there are no fluids or hydraulic systems to maintain.
- **Lightweight**: Gear-driven telescopic mechanisms are often lighter than hydraulic systems, making them easier to install and transport.

- **Limited load capacity**: Gear-driven telescopic mechanisms are typically designed for light to moderate loads and may not be suitable for heavier lifting applications.
- **Limited reach**: Gear-driven telescopic mechanisms typically have a shorter reach than hydraulic systems.

The main features of cable driven telescopic mechanism is:

- **Telescopic design:** The mechanism features a telescopic design that allows for the extension and retraction of its sections, making it adjustable to varying heights and lengths.
- **Cable-driven:** The mechanism is driven by cables or wires, which are used to pull the sections apart or push them together. The cables are typically made of high-strength materials, such as steel or synthetic fibers, to ensure durability and reliability.
- **Lightweight:** Cable-driven telescopic mechanisms are designed to be lightweight, which makes them easy to transport and install. This feature also makes them suitable for applications where weight is a critical factor, such as in aerospace or marine engineering.
- **High load capacity:** Despite their lightweight construction, cable-driven telescopic mechanisms are capable of supporting heavy loads. This is achieved through the use of high-strength materials and precise engineering of the mechanism's components.

- **Smooth operation:** Cable-driven telescopic mechanisms are designed to operate smoothly, with minimal friction or resistance between the sections. This feature ensures that the mechanism can be extended or retracted with minimal effort, making it easy to use.
- **Versatile:** Cable-driven telescopic mechanisms are versatile and can be used in a wide range of applications. They are commonly used in cranes, hoists, lifts, and other lifting or loading equipment, as well as in telescopic camera stands, lighting rigs, and other applications where height adjust-ability is required.

CHAPTER 3: METHODOLOGY

The methodology chapter of this thesis report describes the design and development process of an autonomous mobile robot for warehouse automation. The robot consists of three modules: a telescopic gripper for box picking and placing, a scissor lift for vertical elevation, and an autonomous base for mobility. The focus of the project is to develop a reliable and efficient solution that meets the requirements and specifications for warehouse automation.

This chapter is organized into several sections, each describing the approach and methods used for the development of each module. The sections cover the design and development process, manufacturing methods and procedures, quality control and assurance measures, project management and scheduling methods, and validation and verification methods. The methodology used emphasizes a rigorous and systematic approach, ensuring that the final product meets the project requirements and specifications.

3.1 Design and Development Process

3.1.1 Prototype Parameters Selection

The selection of the initial prototype parameters for the autonomous mobile robot was based on the resources available and the project budget constraints. The parameters were carefully chosen to meet the requirements and specifications for warehouse automation while remaining within the project's budget limitations. These parameters served as starting point for our design and prototyping of a robot. Some additional parameters about robot base sizing were determined keeping in mind the space available at warehouse for a safe maneuver of a robot.

Table 1 Prototype parameters

Vertical Lift	4ft
Payload	2 kg
Box Dimensions	200 x 200 mm
Telescopic Extension	450 mm

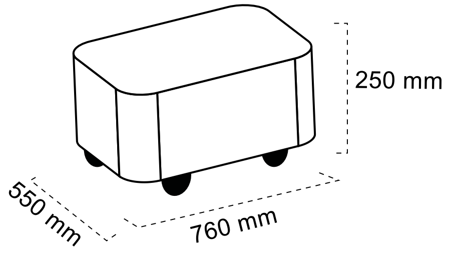


Figure 6 Parameters of robot base

To achieve these parameters, a detailed design and development process was undertaken, which involved the selection of cost-effective components and materials. Specialized mechanisms were also developed for box picking and vertical elevation, considering the cost implications of each design decision. Throughout the process, strict cost controls were maintained to ensure that the final product remained within the project's budget constraints.

3.1.2 Design of Telescopic Gripper

The telescopic gripper mechanism was selected for the box picking module due to its ability to pick boxes of varying sizes and shapes, while also allowing for a greater degree of precision and control. The mechanism consists of a series of extendable and retractable tubes, allowing for the gripping arms to adjust to the size of the box being picked. This versatility and precision make it a more efficient and effective solution compared to other gripper mechanisms, such as suction cups or clamp-style grippers, which may be limited by the size and shape of the boxes being picked. Additionally, the telescopic gripper mechanism is relatively lightweight and easy to control, making it a cost-effective and practical solution for the autonomous mobile robot.

3.1.2.1 Design

The telescopic mechanism for the box picking module of the autonomous mobile robot consists of two degrees of freedom for the gripping arms. The first degree of freedom allows the arms to extend along their length to reach the box, while the second degree of freedom enables the arms to adjust in a transverse or lateral direction to grip boxes of different sizes. The gripping arms also feature flaps at their ends to securely hold boxes during transportation.

The telescopic mechanism is mounted on a platform that extends with the arms to the start of the shelf, ensuring that boxes can be safely picked and placed onto the robot. The platform is also designed to be compatible with the scissor lift mechanism, which provides the vertical elevation required for the autonomous mobile robot to reach multiple levels of the warehouse. The resulting design enables the robot to efficiently and safely pick and transport boxes of various sizes and shapes, while also ensuring the safety of the surrounding environment.

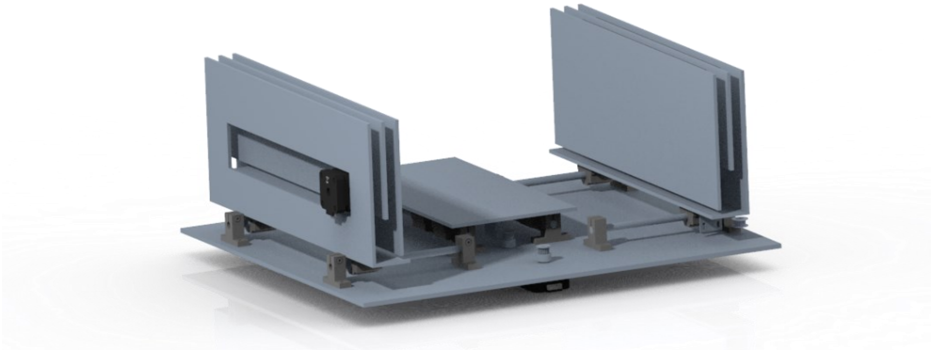


Figure 7 Telescopic mechanism 3D model in retraced form

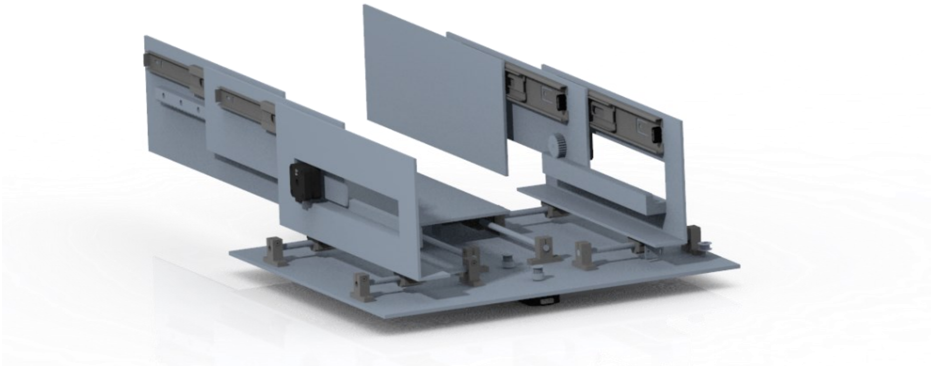


Figure 8 Telescopic mechanism 3D model in extended form

3.1.2.2 Driving Mechanisms

The linear arm motion of the telescopic mechanism is driven by rack and pinion drive that permits bi-directional movement of the arms. This model configuration is presented in a picture, alongside the two stages of a single arm that are driven by a single NEMA 17 motor. The lateral motion of the arms is driven by a motor and GT2 belt connection that is mounted with arms.

Additionally, the platform for placing boxes is actuated using a belt drive mechanism, which allows for precise control and adjustment of the platform height. The flaps located at the end of the gripping arms are operated by small MG-90S servo motors, which enable the arms to securely grip boxes of different sizes and shapes. Overall, this mechanism ensures that the telescopic mechanism can accurately and reliably pick and transport boxes within the warehouse environment.

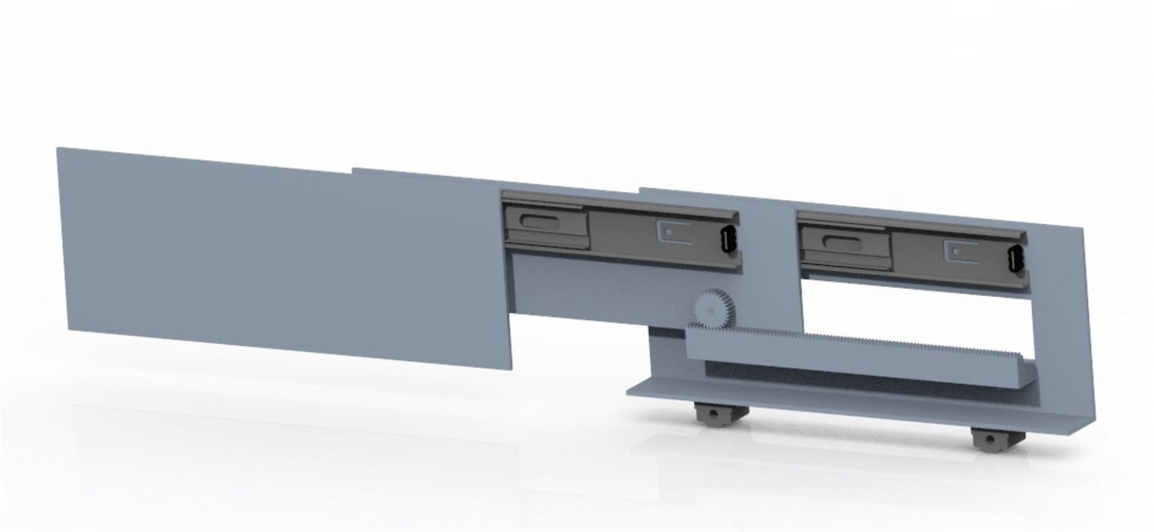


Figure 9 Drive Configuration of Telescopic Arm

3.1.2.3 Sensors and Control System

The stepper motors on the telescopic mechanism are driven through A4998 drivers and are controlled by an Arduino MEGA microcontroller. The Arduino MEGA is responsible for executing the control logic and monitoring the various sensors integrated within the mechanism. The telescopic mechanism is equipped with position sensors, limit switches, and a weight sensor that are used to control the extension of the arms, the lateral motion of the gripping mechanism, and the motion of the platform on which the box is placed. Additionally, the mechanism features IR sensors that enable it to safely open the gripping arms without colliding with the surrounding environment and to identify the size of the package being picked up. By accurately detecting the position and motion of the arms, platform, and package, the control system is able to precisely maneuver the mechanism and ensure that the boxes are picked up and transported safely and efficiently. The sensor data is continuously fed back to the main control system of the autonomous mobile robot, which utilizes this information to optimize the operation of the telescopic mechanism within the warehouse environment.

3.1.3 Design of Scissor Lift

Scissor Lift Mechanism was chosen against other lifting mechanisms due to certain features it could provide that the others lacked or did not provide with good compatibility. The main benefits of the scissor lift are:

- Stability – It is very stable even when fully extended and especially when it is contracted.
- Versatility - It can be driven with a multitude of different sources in a variety of different environments

- When crumpled, it usually provides a lower center of gravity in comparison to other mechanisms such as chain drive
- Cost-effectiveness – Scissor lifts are often more affordable than other alternative mechanisms

Overall, the stability, versatility, height, cost-effectiveness, and safety features of scissor lifting mechanisms make them an excellent choice for a range of applications.

3.1.3.1 Geometric Parameters

The dimensions of the base are given to be 28 x 25 inch. This means the scissor assembly in contracted form must be confined within these base dimensions. For this purpose, simple geometrics have been used to find the optimal length for the links as well as the number of stages. The link length was chosen to be about 20 inches.

$$Length\ when\ crumpled = 20\cos(15) = \ 19.318\ inch$$

The scissor lift will be placed on the base such that this length comes along the 28-inch length of the base as it fits within the confinements of the base. Now we can check the height requirements which is 4 feet. The maximum angle for the scissor lift is 60 degrees. So, it will go from 15 to 60 degrees.

$$Height\ when\ extended = 20\sin(60) = 17.32\ \text{inch}$$

This means that one stage when fully extended gives us 17.32 inches of height. Our target is 4 feet, and we are using 3 stages for the scissor lift.

$$Total\ Height\ of\ Scissor\ Lift = 17.32(3) = 51.36\ inches = 4.28\ feet$$

When this value is multiplied by 3, it gives us a total height of 51.36 inches which equates to 4.28 feet. This means that the geometric parameters selected both fit in the base confinements and provide the maximum height as well.

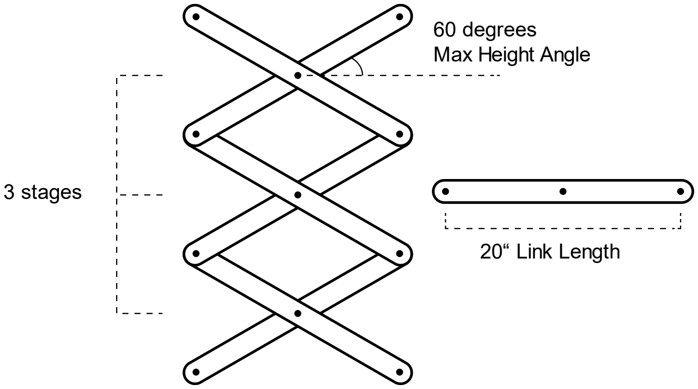


Figure 10 Schematic diagram of scissor lift

3.1.3.2 Analysis on ANSYS

Analysis was performed on analysis because the scissor assembly is by-nature statically indeterminate. Simulations were performed to tackle this. The modules of ANSYS used in our analysis are:

- Rigid Body Dynamics
- Transient Structural
- Static Structural

The values obtained from this analysis allowed us to select the Motor and Ball Screw which were used to drive the scissor lift. The key parameters studied from this analysis were the maximum axial load and the variation of axial load with time as the lifting process reached completion.

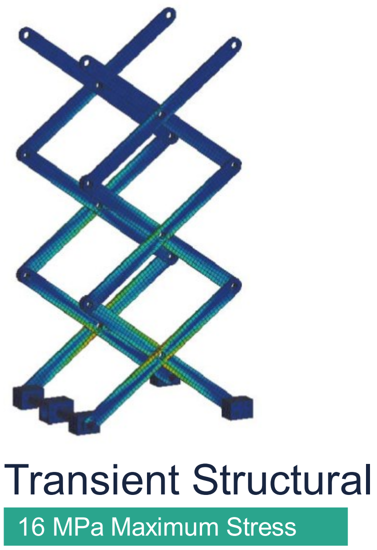


Figure 11 Transient structural analysis of scissor lift

3.1.3.3 Driving Mechanism

There are multiple driving mechanisms that can be chosen for a scissor lift. The most practical and suitable ones are:

- Pneumatic
- Hydraulic
- Electric

The mechanisms were analyzed, and a comparison was made. The Electric method was chosen because it was more appropriate for an AMV. The reason for this decision lies in the fact that both Pneumatic and Hydraulic require an additional mechanical component i.e a compressor or a pump. Both also require their complete flow circuits along with the requirement for a container. These add complications for an AMV that can easily be avoided by using actuators that are electrical especially in this application.

In our selection for the driving mechanism was the about of time it will take to lift the scissor lift up to the required height. Furthermore, it was also useful to compare this time taken with the rpm of the motor. The formula that governs this is as follows.

$$V_{tr} = \frac{n \times P}{1000 \times 60}$$

V_{tr} = The speed at which nut moves (m/s)

P = The pitch of the ball screw (mm)

Using our values from the selected 1605 class ball screw. The pitch is 5 mm, and the rpm is dependent on how fast we desire the scissor to be lifted with some limitations. The safety limit for ball screws is 400 rpm. We shall use 200 rpm for the calculation.

$$V_{tr} = \frac{200 \ \times 5}{1000 \times 60}$$

$$V_{tr} = 0.01667 \ m/s$$

This is the speed of the ball screw nut. We are still concerned with the time taken to lift the scissor lift. We further our analysis by using geometric analysis on the scissor lift. The distance the ball screw is going to travel can be done by

$$Distance\ travelled = 20\cos(15) - 20\cos(60)$$

$$Distance\ travelled = 9.318\ inches = 0.2367\ meters$$

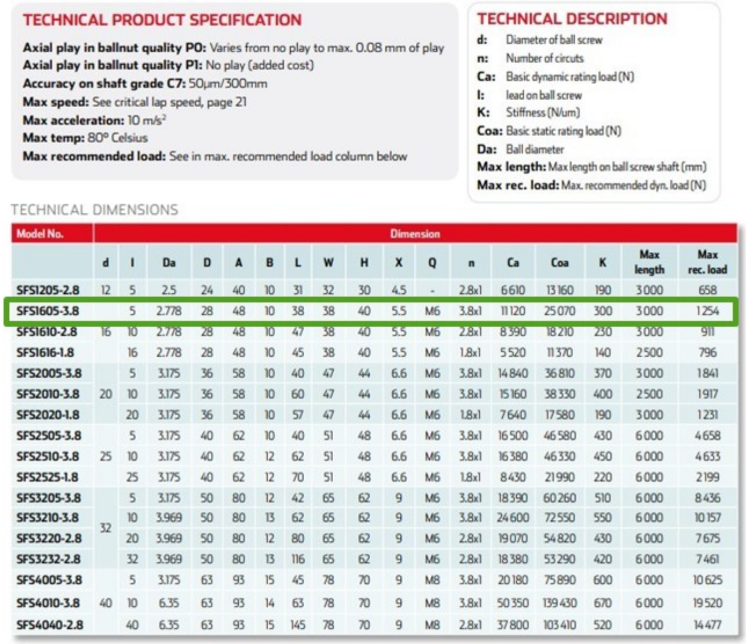
We have speed and velocity. To obtain the time we will use the basic equation of motion.

$$Time\ Taken = \frac{S}{V_{tr}}$$

$$Time\ Taken = \frac{0.2366}{0.01667} = 14.1\ seconds$$

This is clearly the time taken from the fully crumpled all the way to the maximum height of 50 inches. Using higher rpm, we can reduce the time taken for the scissor lift to achieve its maximum height.

The electric method that was chosen is a Ball Screw assembly that will drive two of the legs of the scissor lift from the base. The ball screw design analysis was performed, and various different considerations were taken into account. Ansys Static Structural analysis was performed on the scissor assembly that allowed us to obtain the axial load on the ball screw. The selected ball screw meets the requirements whereas it is within the load limit.



TECHNICAL PRODUCT SPECIFICATION

Axial play in ballnut quality P0: Varies from no play to max. 0.08 mm of play
Axial play in ballnut quality P1: No play (added cost)
Accuracy on shaft grade C7: 50µm/300mm
Max speed: See critical lap speed, page 21
Max acceleration: 10 m/s²
Max temp: 80° Celsius
Max recommended load: See in max. recommended load column below

TECHNICAL DESCRIPTION

d:	Diameter of ball screw
n:	Number of circuts
Ca:	Basic dynamic rating load (N)
l:	lead on ball screw
K:	Stiffness (N/um)
Coa:	Basic static rating load (N)
Da:	Ball diameter
Max length:	Max length on ball screw shaft (mm)
Max rec. load:	Max. recommended dyn. load (N)

TECHNICAL DIMENSIONS

Model No.	Dimension															
	d	l	Da	D	A	B	L	W	H	X	Q	n	Ca	Coa	K	Max length	Max rec. load
SFS1205-2.8	12	5	2.5	24	40	10	31	32	30	4.5	-	2.8x1	6610	13160	190	3000	658
SFS1605-3.8	16	5	2.778	28	48	10	38	38	40	5.5	M6	3.8x1	11120	25070	300	3000	1254
SFS1610-2.8		10	2.778	28	48	10	47	38	40	5.5	M6	2.8x1	8390	18210	230	3000	911
SFS1616-1.8		16	2.778	28	48	10	45	38	40	5.5	M6	1.8x1	5520	11370	140	2500	796
SFS2005-3.8	20	5	3.175	36	58	10	40	47	44	6.6	M6	3.8x1	14840	36810	370	3000	1841
SFS2010-3.8		10	3.175	36	58	10	60	47	44	6.6	M6	3.8x1	15160	38330	400	2500	1917
SFS2020-1.8		20	3.175	36	58	10	57	47	44	6.6	M6	1.8x1	7640	17580	190	3000	1231
SFS2505-3.8	25	5	3.175	40	62	10	40	51	48	6.6	M6	3.8x1	16500	46580	430	6000	4658
SFS2510-3.8		10	3.175	40	62	12	62	51	48	6.6	M6	3.8x1	16380	46330	450	6000	4633
SFS2525-1.8		25	3.175	40	62	12	70	51	48	6.6	M6	1.8x1	8430	21990	220	6000	2199
SFS3205-3.8	32	5	3.175	50	80	12	42	65	62	9	M6	3.8x1	18390	60260	510	6000	8436
SFS3210-3.8		10	3.969	50	80	13	62	65	62	9	M6	3.8x1	24600	72550	550	6000	10157
SFS3220-2.8		20	3.969	50	80	12	80	65	62	9	M6	2.8x1	19070	54820	430	6000	7675
SFS3232-2.8		32	3.969	50	80	13	116	65	62	9	M6	2.8x1	18380	53290	420	6000	7461
SFS4005-3.8	40	5	3.175	63	93	15	45	78	70	9	M8	3.8x1	20180	75890	600	6000	10625
SFS4010-3.8		10	6.35	63	93	14	63	78	70	9	M8	3.8x1	50350	139430	670	6000	19520
SFS4040-2.8		40	6.35	63	93	15	145	78	70	9	M8	2.8x1	37800	103410	520	6000	14477

Figure 12 Selection of Ball Screw (Selected Ball Screw shown in Red Rectangle)

3.1.3.4 Material Selection

The material selection process for the links of the scissor lift was performed in Ansys. The key parameter studied was the axial load on the ball screw due to the weight of the material. Moreover, the strength of the material was also studied such that the von-mises stresses produced in the links was less than the Yield Strength of the material. Transient Structural was also performed on this assembly alongside Rigid Body Dynamics.

The maximum stress value for this load is ***16 MPa*** whereas the Yield Strength of the materials in question are:

- Aluminum – 241 MPa

- Steel – 295 MPa

Moreover, depending on the grade of the material, the Yield Strength varies significantly. The value of Maximum Von-Mises Stress is not high enough. This means that the amount of material used, such as the thickness, can also be modified.

The difference in the value of the axial load due to the difference in the weight of the materials can be found in the graph below:

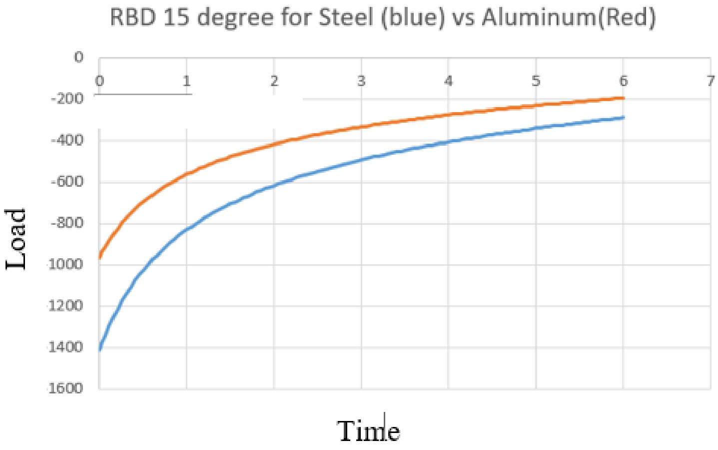


Figure 12 Comparison of the Axial loads of the different materials. The Graph is Load vs Time

According to this equation and the values given by the analysis. The torque rating for the ball screw was given to be 85 N-cm. This was then compared with the SFS standards for ball screws and a ball screw was selected that met the requirements.

According to the NEMA standards for motors, the motor that will meet the requirement for this torque will be ***NEMA 23 (2.5 A)***. This motor meets all the requirements in terms of torque as well as the voltage when it comes to battery life.

3.1.4 Design of Robot Base

The design of the base of AMR is completely dependent on the manufacturing and assembly of the scissor lift and telescoping mechanism. The dimensions of the base are 28-inch x 25-inch x 7 inch. The design of the base is divided into 2 parts: the upper and lower portion. The upper portion houses the lead screw and its motor, the slider assembly, and the scissor lift.

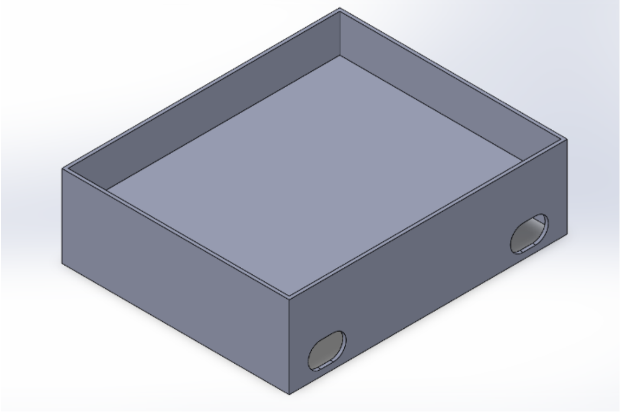


Figure 13: Upper portion of the base

The lower portion houses the motors that will drive the AMR. The battery will be mounted on top of the lead screw motor for easier accessibility since it will be often removed due to charging.

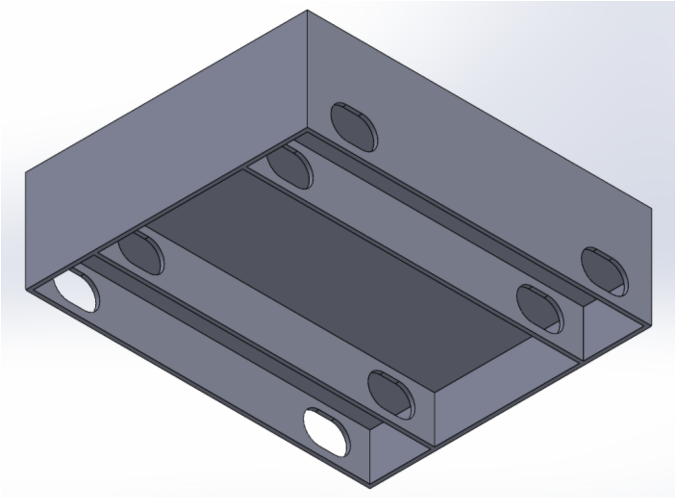


Figure 14: Lower portion of the base

3.1.5 Selection of Battery

3.1.5.1 Considered Parameters:

When selecting the battery for the robot, several parameters were considered to ensure optimal performance and efficiency. The right choice of battery is crucial to the success of the robot's operation as it is responsible for providing the necessary power to drive the motors, control systems, and sensors.

One of the most important factors to consider is the type of battery chemistry to be used. There are several battery chemistries available, each with its unique characteristics, advantages, and disadvantages. Lithium-ion batteries are popular in some robotics applications such as drones due to their high energy density and low self-discharge rate. Lead-acid batteries, on the other hand, are less expensive, but have lower energy density.

The energy density determines the amount of energy that can be stored in each battery volume or weight.

The voltage and capacity of the battery are also important parameters to consider. The battery to be chosen is of 12 volts since the motors that will be directly driven by the battery only operate at 12 volts. The servo motors operating at smaller voltages will be powered by the Arduino.

The charging time of the battery is also an important parameter to consider, especially for applications where the robot needs to operate continuously. Since dark warehouses are in constant operation, it is preferred that the battery can power the robot for as long as possible and has quick recharging capabilities. The charging time should be short enough to ensure that the robot spends the maximum amount of time in operation rather than charging. The battery should also be able to operate a larger number of charge cycles without degrading.

3.1.5.2 Comparison of battery types

	Lithium Ion (LiPo) battery	**Lead Acid Battery**
Weight	Lighter	Heavier
Cost	Expensive	Cheaper
Longevity	Fewer charge cycles	More charge cycles

Energy Density	Higher	Lower

3.1.5.3 Battery Selection

It should also be considered that the battery is also playing an important role other than powering the robot. It is also balancing the center of gravity of the robot and preventing the robot from toppling over. When the package is retrieved from the shelf unto the robot, the center of gravity of the robot is raised and there is a risk of being toppled. Thus, by strategically placing the battery opposite to the scissor lift, the battery's weight will be balancing the robot's COG. Hence there is no preference of energy density for a battery and cost takes precedence which is why we are choosing lead acid battery.

Figure 15: 12Ah Lead-Acid Battery

The chosen capacity of the battery is **12 Ah**. The robot has an estimated current draw of 11.5 Amperes if the telescoping mechanism, lead screw and drive mechanisms are operating simultaneously. According to the discharge curve, this translates into an operating time of roughly 40 minutes.

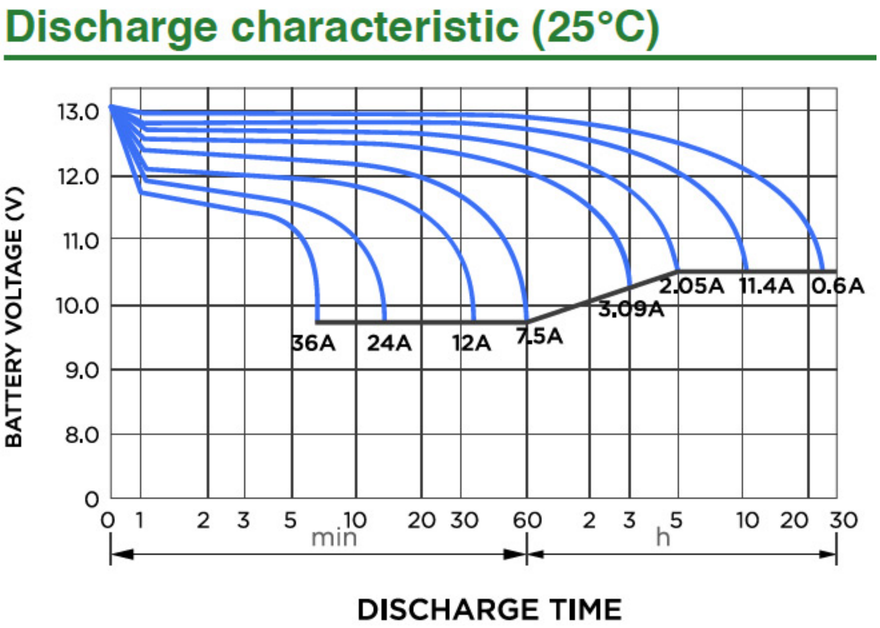


Figure 16: Voltage vs. discharge time curve for 12 Ah battery

It should be noted that all the stepper motors will never be running simultaneously, hence the estimated running time of the battery is 1.5 hrs.

3.1.6 Sensors:

The use of sensors in our robot involves the need to avoid and detect obstacles. Proximity sensors are used for this purpose. Our robot comprises of the following sensors:

3.1.6.1 Wheel encoders:

The wheel encoders measure the rotary speed and direction or speed of the shaft. There will be four-wheel encoders on each wheel to ensure the proper movement of robots' wheels.

Figure 17: Wheel encoder

3.1.6.2 Ultrasonic sensor:

The ultrasonic sensor will be utilized to detect and avoid obstacles. The ultrasonic sensors will be used at the front, sides and back of the robot base. Moreover, these will also be used at the top platform to detect an object in the rack.

Specifications:

- The sensing range lies between 40 cm to 300 cm.
- The response time is between 50 milliseconds to 200 milliseconds.
- The Beam angle is around 50.
- It operates within the voltage range of 20 VDC to 30 VDC

- Preciseness is ±5%
- The frequency of the ultrasound wave is 120 kHz.
- Resolution is 1mm.
- The voltage of sensor output is between 0 VDC – 10 VDC

Figure 18 Ultrasonic Sensor

3.1.6.3 Infrared Sensors:

Alongside ultrasonic sensors, infrared sensors will be used for object detection to increase accuracy.

Figure 19 Infrared Sensor

3.1.6.4 Arduino Mega:

Arduino Mega is a microcontroller board based on the ATmega2560 microcontroller. The Arduino Mega has 54 digital input/output pins, 16 analog inputs, and 4 UARTs (hardware serial ports). It also has a larger flash memory and RAM compared to other

Arduino boards, allowing it to handle more complex code and perform more complex operations. In our project, the Arduino is used to receive sensor data from the different sensors and send it to ROS for necessary operation to be performed with the given data.

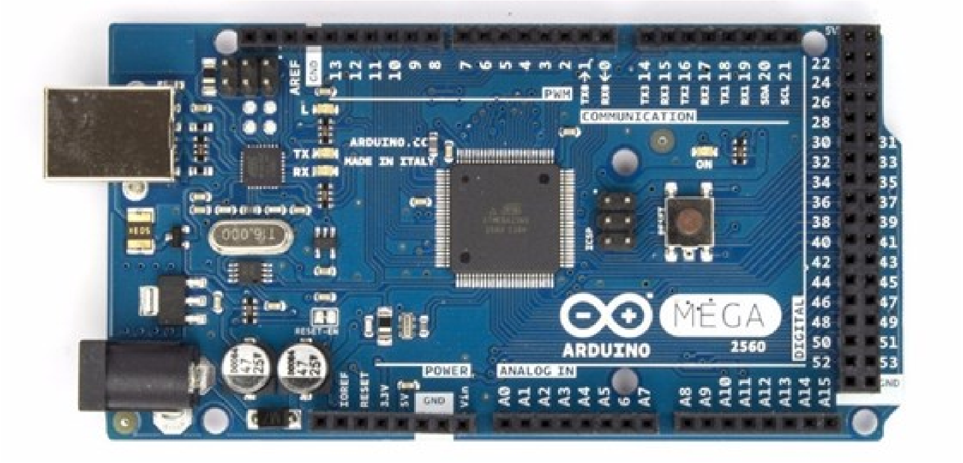


Figure 20 Arduino Mega

3.1.7 Robot Operating System (ROS)

The Robot Operating System is used to create the robot and its operating environment. The Robot was created utilizing python language in visual studio. Presently the robot is in the essential structure to work for way arranging and impediment evasion.

Setting up a ROS work area, which, first and foremost, filled in as the focal catalog. Several packages were created within the workspace to house the robot's various features. The modular design of these packages made it possible to efficiently develop and integrate various components.

Path planning, which is necessary to enable autonomous navigation, was one of the project's most important components. To handle this test, we chose to use the A* calculation, a famous and powerful technique for tracking down the briefest way between two focuses on a diagram. Using a heuristic function, the algorithm intelligently explores the graph by considering both the cost of getting to a particular node and the estimated cost of getting from that node to the goal position.

A methodical approach was used to seamlessly incorporate the A* algorithm into my ROS project. We, first and foremost, centered around precisely demonstrating the climate wherein the robot would work. Using data structures like occupancy grids or point clouds, a suitable representation of the surroundings could be created for this purpose. This climate model filled in as the establishment for building the chart essential for way arranging.

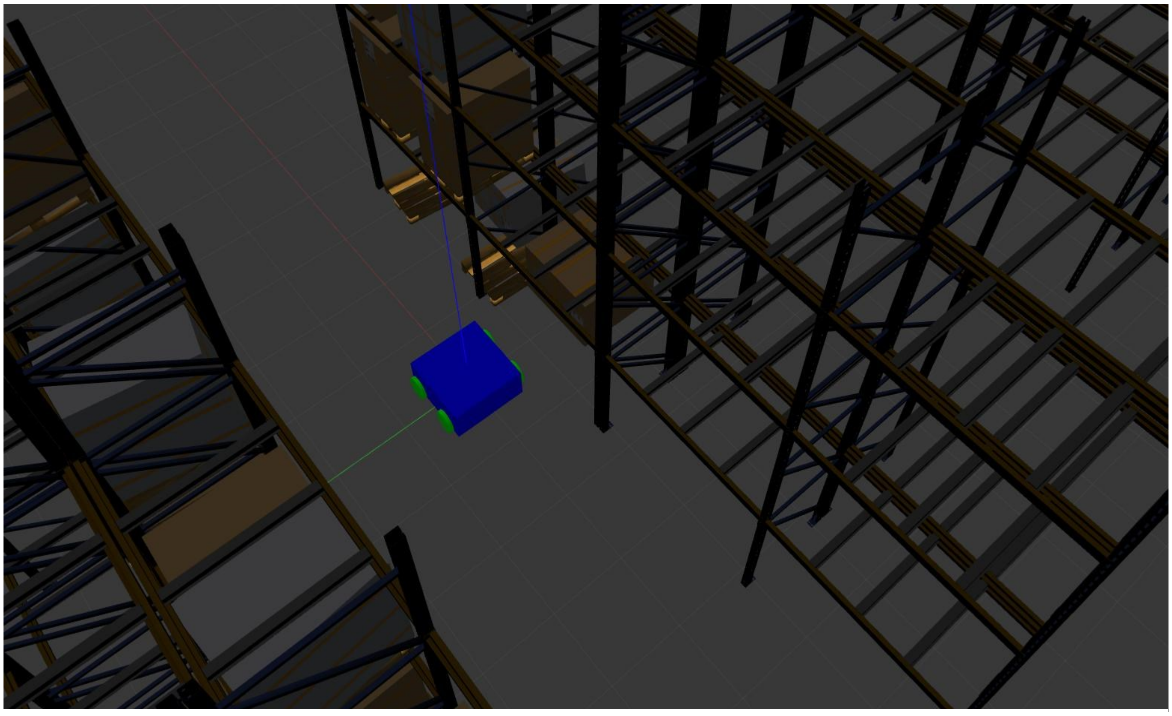


Figure 21: Robot in a virtual environment

A graph that represented the connections between various nodes was created after the environment model was created. Every hub in the diagram addressed a discrete area inside the robot's current circumstance, and the edges of the chart meant the associations between nearby hubs. This diagram shaped the reason for the A* calculation to explore and look for the ideal way.

A heuristic function was created to provide the A* algorithm with effective direction. The cost from any given node to the goal position is estimated by this function. During exploration, the most promising routes were given priority by incorporating this heuristic into the algorithm. The heuristic capability assumed a fundamental part in directing the A* calculation towards the objective productively.

By extending hubs, monitoring the way, and continuously moving towards the objective position, the A* calculation had the option to successfully track down the most limited way through the climate.

Sensor Selection and Integration:

Ultrasonic sensors that are viable with ROS were chosen cautiously. In the wake of guaranteeing similarity with ROS, sensors were associated with the equipment of the robot. Either using an interface board or wiring the sensors to the appropriate microcontroller pins was required for this.

ROS Package Installation:

As the sensors we utilized in the robot were HC-SR04 hence the ROS package of **hc_sr04** was selected. This package included drivers and libraries required for sensor communication.

Creating the Sensor Node:

A custom ROS node was built to handle communication between the sensor and the ROS ecosystem. The subscription to the sensor data, its processing, and the publication of pertinent information for obstacle avoidance were all the responsibility of this node. In addition, appropriate libraries and packages were utilized for seamless integration.

ROS Message Definition:

to represent the ultrasonic sensors' data output. A custom ROS message was characterized to indicate to the sensor information. Distance, angle, and a timestamp were all fields in this message. The required conditions were used to specify the values. The message's format was specified in a.msg file, and the rosmsg command was used to compile it so that it could be used in the ROS ecosystem.

Sensor Data Publishing:

The data read from the sensors was then formatted within the sensor node in accordance with the previously defined message format. The sensor data was devoted to a ROS topic via the ROS Publisher API. Other ROS nodes that needed to subscribe to the sensor data were able to access it as a result of this.

Obstacle Avoidance Node:

A ROS node for avoiding obstacles was then created. The sensor data topic that was published by this node was subscribed to by this node. It processed the information from the sensors that came in to find obstacles, figure out how far away they were, and make a good path for the robot to follow while avoiding collisions.

Algorithm Implementation:

Path planning and obstacle avoidance were put into practice within the obstacle avoidance node. This program used the ultrasonic sensors' sensor data to generate intelligent judgements. It produced orders to safely drive the robot around obstacles after analyzing the distances and angles supplied by the sensors to establish their presence and location.

Actuator Control:

The robot's actuators, or the motors for the wheels, were supplied with the produced commands after the obstacle avoidance algorithm had identified the safe path.

Testing and Refinement:

To ensure precise sensor readings, trustworthy obstacle recognition, and efficient obstacle avoidance, the integrated system underwent testing. Based on input from testing, the algorithm's parameters and the sensor arrangement were adjusted. The obstacle avoidance system's performance might be optimized thanks to this iterative procedure.

The robot was able to comprehend its environment and safely maneuver around obstacles by creating bespoke ROS nodes for sensor integration and obstacle avoidance.

3.2 Manufacturing Methods and Procedures

This section will provide an overview of the manufacturing procedures employed for the design and development of the telescopic mechanism, scissor lift, mobile base, and the other components of the robot. The section will also highlight the key considerations taken into account during the manufacturing process, such as cost-effectiveness, scalability, and quality control. Ultimately, this section will provide insight into the practical aspects of bringing the autonomous mobile robot from design to reality.

3.2.2 Fabrication of Telescopic Gripper

The fabrication of the telescopic gripper is a crucial component of the autonomous mobile robot. Most of the work involved in the fabrication process is assembly, including the attachment of plates and the integration of 3D printed components. The manufacturing process involves several steps that must be performed with precision to ensure that the gripper operates smoothly and efficiently. In this section, we will discuss the fabrication methods and procedures used to create the telescopic gripper, including the materials used, tools required, and assembly techniques.

3.2.2.1 Manufacturing of gripper arms

To ensure that the telescopic gripper is lightweight and rigid, the arms of the mechanism are constructed from aluminum. The individual plates used for the arms have a thickness of 3mm and are bent to the specific configuration as shown in the provided picture. These plates are shaped to accommodate other components and keep the mechanism as compact as possible. The use of aluminum also ensures that the mechanism is resistant to corrosion and can withstand the harsh conditions of the warehouse environment. The plates are bent using precision equipment to ensure that the final product meets the necessary specifications.

In addition to bending, the arms of the telescopic gripper are also drilled with holes and slotted at various locations to fit the necessary components. This ensures that the components are securely fastened to the arms and can operate effectively. The holes and slots are precisely located to ensure that the components are aligned correctly, and that the mechanism operates smoothly.

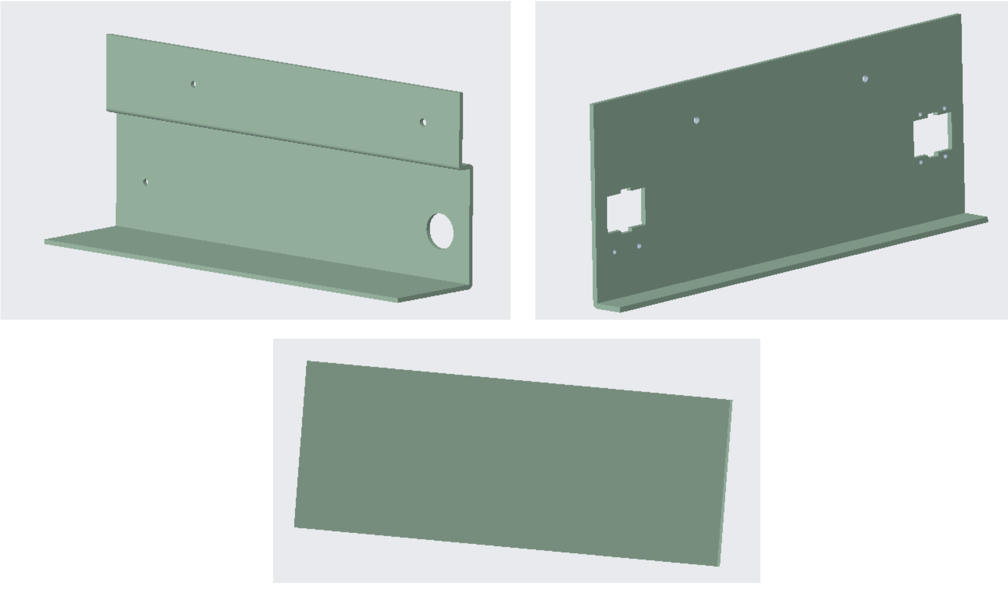


Figure 19 22 Aluminium plates for ground, first and second stage respectively

3.2.2.2 Assembly of Linear slides

In the telescopic mechanism, drawer slides have been chosen to facilitate sliding motion between the two stages of arms. The use of drawer slides instead of linear guideways helps reduce costs while maintaining satisfactory performance. The lateral motion and motion of the package platform are achieved using linear motion shafts, which are mounted on the ground plate using shaft supports. The linear motion shafts are also more cost-effective compared to linear guideways. To ensure secure mounting and stability, the drawer slides have been mounted directly to the plates using bolts.

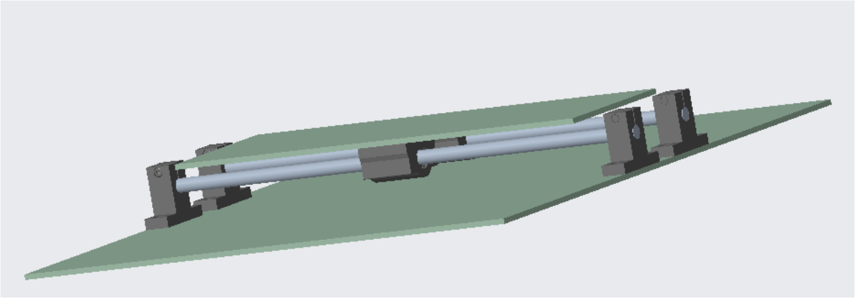


Figure 23 Base platform with linear slides

3.2.2.3 Pulley Mounts and Flap Assembly

For the assembly of the telescopic gripper, 3D printed mounts are utilized for stage 1, which are directly bolted to the stage 1 plates. The flaps are made of aluminum and the assembly is designed with a servo motor that is mounted to the 2nd stage grippers. The use of 3D printing technology enables the creation of customized and precise mounts that can easily be integrated with other components. Additionally, aluminum flaps provide durability and reliability in the operation of the telescopic gripper.

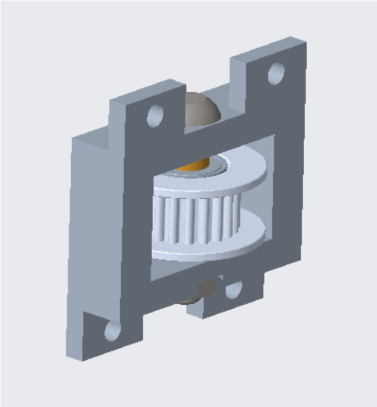


Figure 25 3D printed mount of gt2 pulley

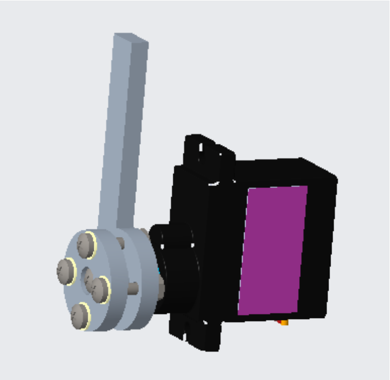


Figure 25 Flap assembly with servo motor

3.2.3 Manufacturing of Scissor Lift

The manufacturing of scissor lift involves many different processes such as drilling, welding, cutting and finishing.

3.2.3.1 Procurement of Links

Due to the market constraints, we were not able to procure the links per the exact size. We procured the links via wholesale sellers of Aluminum and Mild Steel. The wholesale standard for hollow and plate type aluminum or steel is a singular 20 feet long piece. The material then had to be cut using our own working.

3.2.3.2 Drilling

Holes had to be drilled in the links according to the undermentioned diagram. The holes were required in order to the make the revolute joints for the working of the scissor lift.

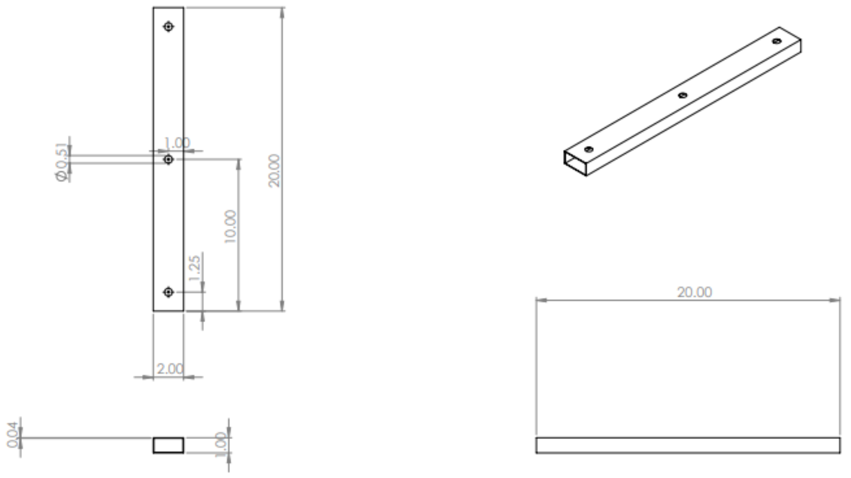


Figure 26 Engineering Drawing of hollow links

3.2.3.3 Cutting

The links were cut with metal saw cutters to fit the size of 20 inches. Moreover, piping required for the revolute joints were cut with a hacksaw. This cutting allowed us to size the material according to our requirements.

3.2.3.4 Welding

Welding was required where pipes were to be welded with the links in order to bring stability to the joint. The welding was performed in the Manufacturing Resource Center.

Moreover, there are several components which may have to be welded with the base for stability of the lift.

3.2.3.5 Finishing

After the cutting, it is necessary to the perform the finishing processes on the material in order to use it in the assembly. The material was finished using files of different shapes as well as metal grinders.

CHAPTER 4: RESULTS AND DISCUSSIONS

4.1 Design Phase

The results from the design phase are related to the analysis performed.

4.1.1 Scissor Lift

The results from the scissor lift are compiled in the table below:

Parameter	Result
Recommended RPM	250-300
Total Weight	8 kg
Max. Load on the ball screw	950 N
Recommended Torque	85 N-cm
Number of Stages	3
Link Length	20 inches
Total Height	51.32 inches

We have observed that these results deduced from the design phase are the ones that are expected to be manufactured. However, when the manufacturing takes place, there are bound to be changes made to the design in order to accommodate the market availability of items.

4.1.2 Base

The design of the base was finalized and the dimensions to be selected were 18 x 22 inches. However, this is the amount of space needed to accommodate the scissor lift mechanism. The actual base might have to be bigger to cater for the motor and other driving mechanisms. The base was to be made from L bars.

4.2 Results after manufacturing

4.2.1 Scissor Lift

The scissor lift has been developed to meet the height target of 4 feet and exhibits a load capacity exceeding 2 kg. Meticulous load calculations and the inclusion of a safety factor have led to a slight over-designing approach, ensuring reliability. The lift consistently achieves the desired height and demonstrates robust load-handling capabilities, providing a dependable solution for various applications.

4.2.2 Base Manufacturing

During the construction of the base, it was realized that the base had been over-designed, resulting in a weight that exceeded the recommended limits. This realization serves as valuable feedback for future attempts, highlighting the importance of considering weight as a critical factor. The excess weight prevented the use of flexible couplings for the wheels at the base, necessitating the implementation of a more rigid coupling mechanism for proper mounting of the shaft. These findings emphasize the need for careful consideration of weight distribution and appropriate coupling methods in future scissor lift designs.

4.2.3 Ball Screw

The ball screw was indeed the correct choice for the scissor lifting mechanism as it was to both bear the load of the scissor lift as well as lift the scissor lift with ease. The ball screw selected was the 1605 class ball screw that allowed us to couple it with a NEMA 23 using a 6 to 10 flexible coupling.

4.2.4 Motor

The motor that was selected to lift the scissor lift was also appropriate and performed the tasks required by it. It was able to bear the load of the scissor lift and hold it in place. Moreover, it was also able to lift the scissor lift at a reasonable pace.

The motor was first run with a 1.5 A adapter plugged into the wall. The motor was able to lift the scissor lift but was not able to hold the scissor lift in its place. When it was connected to the battery, it was running with its full 2.5 A and was able to hold the scissor lift in its place. The scissor lift was able to lift up to height of 4ft in 16 sec while the calculated time was estimated to be 14 sec, thus loss in the lifting time can be attributed to the friction losses in sliding components.

4.2.5 Payload Capacity

The robot was initially designed to lift the package weighing up to 2kg but in order to fulfill the requirements of model rigidity the links were overdesigned. The scissor lift was tested to the load capacity of 6kg, however the estimated maximum load capacity for design is around 8-10 kg.

4.3 Drawbacks

4.3.1 Robot Base

The base was fabricated way above its maximum weight limit, which caused extra load on the wheel suspension (flexible couplings used in this case). The overall increase in weight forced the design to include heavy drive motors and couplers were unable to withstand the load of base.

4.3.2 Scissor Lift

The platform for mounting telescopic arms was fabricated from mild steel which increased the overall weight of system by 5-6 kg. The selected motor was unable to drive ball screw at such a heavy load and forced us drive the mechanism without upper platform.

4.3.3 Telescopic

The overall design approach was to design telescopic mechanism compact as possible to fulfill the warehousing shelves space requirements. However, this included unnecessary design complications in manufacturing of telescopic arms. The design was completed and materials were sourced but due to time and resources limitation we were unable to completely implement functional prototype of telescopic arms.

4.4 Summary

The design phase of the scissor lift established specifications such as a 4-foot height target, 8 kg total weight, and 2 kg load capacity. The scissor lift successfully met these requirements during manufacturing, but over-designing the base caused issues with weight and the use of flexible couplings. The ball screw and motor performed well, and the scissor lift demonstrated a potential load capacity of 8-10 kg. Drawbacks included excess weight on the base, limitations with the motor and platform plat, and incomplete implementation of telescopic arms. Future designs should consider weight distribution and coupling mechanisms for optimal performance.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

The development of an autonomous warehouse robot using ROS represents a major step in the automation of the logistics industry, as well as providing a promising platform for further research and development in this area in the future.

There can be no doubt that the development of an autonomous warehouse robot using ROS represents a significant step in the automation of the logistics industry and provides a promising platform for further research and development in this field as a whole.

It is fair to say that the development of an autonomous warehouse robot based on ROS represents a significant step forward in automating the logistics industry, as well as providing a promising platform for further study and development.

A developing an autonomous warehouse robot using ROS represents an important step towards achieving automation in the logistics industry, and it provides a promising platform for advancing further research and development in this field in the future.

This is a great step forward towards automation in the warehouse industry and presents an opportunity for further research and development in this field as the development of an autonomous warehouse robot using ROS presents an important step towards the automation of the logistics industry.

In summary, the development of a warehouse robot that can be autonomously controlled using ROS represents a fascinating step towards automating the logistics industry, and it offers a promising basis for further research and development in this discipline.

Considering the potential of ROS as an autonomous warehouse robot, in addition to being an important step toward the automation of the logistics industry, this research and development activity provides an important platform for future research and development in this area.

The development of an autonomous warehouse robot using ROS is regarded as a significant step forward towards the automation of the logistics industry in general and provides a great platform for further research and development in this field in general, and in this particular area specifically.

It can be concluded that the development of an autonomous warehouse robot using ROS represents an important step in the automation of the logistics industry and provides a promising platform for further research and development in this field to move ahead.

It can be said that the development of an autonomous warehouse robot using ROS represents a significant step towards automated logistics for the logistics industry, and also a viable platform to conduct further research and development in this field in the future.

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