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DESIGN & DEVELOPMENT OF ROBOT FOR STACKING IN WAREHOUSE (INSPIRED BY SQUID ROBOT)

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ABSTRACT:

The project aims to design and develop a warehouse management robot, an intelligent robotic system specifically designed to optimize warehouse operations. The robot's features are carefully selected to address the challenges of warehouse management, including autonomous navigation, versatile product handling, and seamless integration with existing systems. By leveraging robotics technology, the robot aims to enhance efficiency, accuracy, and safety in warehouse management, revolutionizing the industry.The robot is designed to climb a rack of cargo utilizing a rail attachment and a clamping mechanism. The robot should then travel horizontally across a level of cargo rack. The robot is designed to perform these tasks while lifting a cargo of weight 5 kg.

The project is inspired by a warehouse management robot, SqUID Bot, created by Bionic Hive Ltd. The robot and SqUID bot both utilize a mechanism of rails to climb vertically and share common design of cargo platform and chassis shape. However, mechanisms of both robots differ on the basis of vertical traversal where SqUID bot uses threaded wheels for traction, our design incorporates clamping wheels for the traction by using friction.The design of robot was made to include all the motors and electronics while supporting the on-board cargo load and weight of robot against gravity. The CAD analysis allowed for fine tuning of parameters like thickness of sheet used for fabrication to balance the weight of robot and its strength. Motors were selected after calculating the required torque for vertical motion. Also, linear actuators were designed to withstand the weight and provide stability through clamping wheels.The project contains a comprehensive computer-aided design (CAD) process, resulting in a detailed and precise model of the robot. Extensive analysis using tools like ANSYS has been conducted to evaluate the robot's structural integrity, operating efficiency, and overall performance. With the successful completion of the CAD design and analysis phase, the project is now ready to proceed with the fabrication of a proof of concept, setting the stage for further development and practical implementation.

Keywords: ***warehouse management robot, 3D modeling, ANSYS analysis, material selection, fabrication.***

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Chapter 1- INTRODUCTION

1.1.Motivation:

The requirement for more people to get orders out the door quickly and correctly is rising exponentially. Recruiting, training, and keeping people is becoming increasingly difficult for businesses as labor prices rise. When you include in the costs associated with ensuring the safety of employees, it's easy to see why robotic solutions would appeal to businesses.

In order to improve productivity, robots can be utilized for a variety of tasks in the fulfilment process, such as picking, physical pick and place, packing, and transporting merchandise between staging areas for put away or replenishing.

1.2.Definition of a Robot:

A robot is an automated system capable of performing predetermined tasks with high speed and precision, requiring minimal human intervention. Over the past 50 years, significant progress has been made in the field of robotics, encompassing the examination of their construction, programming, and application. [1].

1.3.Use case of Robots:

The following are areas in which robots excel above humans:

- Reduce the need for human intervention in routine business and manufacturing tasks by automating them.
- Perform inspections of potentially dangerous areas, such as those with a high potential for gas leaks.
- Handle and send out enterprise security reports.
- Prepare medication orders and set up intravenous lines.
- Bring in takeaway, room service and emergency ration packs ordered online.
- Be a surgical aid.

- Robots are useful in many other areas as well, including the arts, music, search and rescue operations, and even in the kitchen.

1.4.Warehouse Robots:

Robots in a warehouse can be fully or partially autonomous machines that help with material handling and other duties to improve warehouse efficiency [2].

There is a long history of using robots in warehouses. They've come a long way from their days as big robotic arms that were intended to do damage. Artificial intelligence (AI) and the Internet of Things (IoT) have enabled the development of more advanced robotic equipment employed in warehouses today. Warehouse robots have been instrumental in this progression towards greater automation in warehouse management.

1.5.Types:

Various jobs in a warehouse can be performed by robots to improve productivity, cut down on expenses, and safeguard employees. Examples of common warehouse robots include:

1.5.1.Robotic Arms

The robotic arm is the oldest type of industrial robot, having been used for making things since the dawn of factory automation in the automobile industry. Warehouses all around the world have come to rely on robotic arm technology to increase productivity in mundane, repetitive chores like product loading and sorting. These robotic arms are often installed at stationary workstations. [2].

Figure 1 Robotic arms used in Warehouse management robots.

1.5.2.Cobots

Cobots, or collaborative robots, are robots meant to collaborate with humans in the workplace [2].

Cobots typically fall into one of two categories:

1. Chatbots where you can introduce yourself. With this type of cobot, workers can save time and effort by reducing the distance they have to cover. Cobots move throughout a set area and stop where workers are to do a task. Common applications include picking and packing of actual goods.[3]

2. Robots that follow you around. In this scenario, the robot accompanies the human worker as they travel between workstations. After finishing its work, the robot will move on to the next area, and a replacement will be sent to the site. A follow-me bot might be used by a picker, for instance, to help with the packing process. When the follow-me robot has finished picking all of the items in a given location, it will move on to the packing area and be joined by a second robot to finish the job.[3]

Figure 2: Cobots working together in a warehouse.

1.5.3.Autonomous Mobile Robots (AMR)

Mobile robots that operate autonomously can transfer more inventory than a cobot can. They usually have fully stocked shelves that can be moved about the warehouse by themselves as different products are required in different regions. The use of robots like these has greatly influenced stock control [2].

Figure 3 AMRs working in a warehouse to transfer objects from one place to another.

1.5.4.Sorters

Fixed-position robot arms can sort products, but they have their limits. Robotic sorters that can move around the warehouse on their own are more efficient since they free up more floor space, are easier to maneuver, and weigh less than human workers. Automated material response (AMR) sorters can adapt placement and logistics to meet rising productivity demands.[2]

Chapter 2- BACKGROUND AND LITERATURE REVIEW

As we know, the world is advancing at rapid rate; the need for resources is also increasing. In order to cope with the increase of demand, robots are increasingly a desirable tool. One such robot is a warehouse-stacking robot (SqUID-bot). SqUID-bot is an autonomous robot that uses sensor technology to deliver inventory around the warehouse. It is a synchronized autonomous robot has three-dimensional movements allowing for a completely flexible operation. High-end control system and real time data analysis allow it to understand problems caused in a warehouse and rectify it.

2.1.Warehouse Management Robot:

Companies in the logistics, agriculture, and healthcare industries are constantly on the lookout for new ways to improve operational efficiency, accuracy, and security. Autonomous mobile robots (AMRs) are one promising new area of technology. AMRs have the distinguishing benefit over their forerunners, Autonomous Guided Vehicles (AGVs), in that they may function autonomously without the necessity for specified tracks or courses, therefore decreasing the need for constant human supervision [3].

Amazingly, AMRs can sense their environments and move through them without needing a wired connection to a power supply. Modern computing, efficient path planning using AI and machine learning, and state-of-the-art sensors make this a reality. AMRs, equipped with cameras and sensors, use complex navigation methods including collision avoidance to safely navigate around any objects they encounter. Whether it's a dropped box or a group of humans in their way, these smart robots can quickly adjust their routes to keep moving without incident.[4]

This cutting-edge technology has the potential to revolutionise many different markets. Automated movable racks (AMRs) are useful in the logistics industry because they can improve warehouse efficiency by picking, transferring, and organising inventory without human intervention. AMRs are able to efficiently navigate complex layouts thanks to their adaptability to changing conditions.[4]

AMRs aid in the agricultural sector's increasing productivity and long-term viability. These robots can optimise agricultural operations by planting, harvesting, and monitoring crops without human intervention. AMRs' high-tech sensors and AI prowess let them to identify crop health issues, administer precise remedies, and collect useful data for precision farming.[5]

Similarly, AMRs are reshaping the delivery of healthcare and the administration of healthcare facilities. By freeing up doctors and nurses to focus on providing quality care to patients, these robots can move medical supplies, administer drugs, and perform other mundane duties. In addition, AMRs with sanitization modules can help disinfect and maintain hygiene in healthcare facilities, which is beneficial for infection management and lessens the likelihood of cross-contamination.[5]

In general, AMRs are a huge step forward for the field of autonomous robots. The prospects for improving efficiency, precision, and safety in manufacturing are enormous thanks to their ability to function autonomously, understand their surroundings, and adapt to changing conditions. AMRs are set to revolutionise logistics, agriculture, healthcare, and other industries by leveraging sensors, AI, machine learning, and sophisticated computers, paving the way for more efficient and innovation in the future.[6]

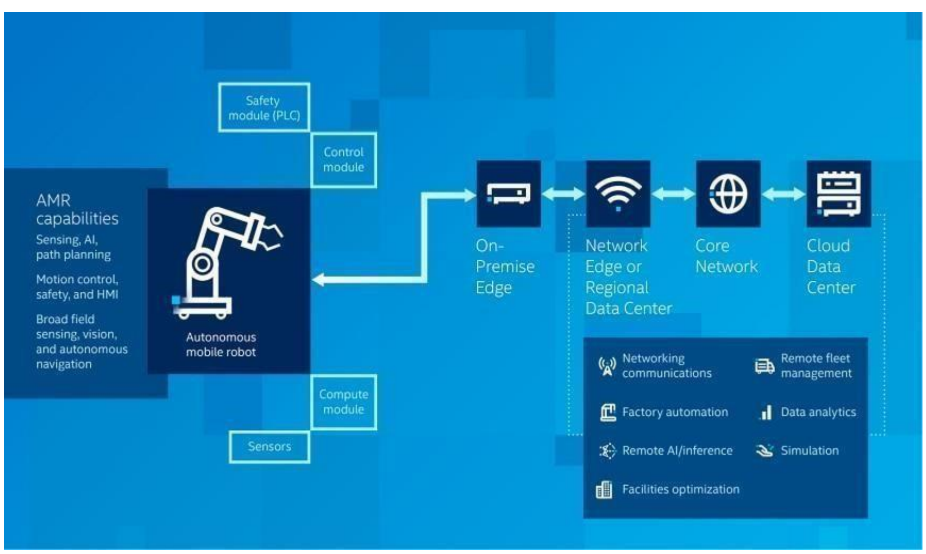

Figure 4 Working diagram of AMR with system components.

2.2.Benefits of Robotics in Warehouses and Manufacturing Autonomous Mobile Robots (AMR):

Companies that have successfully achieved IT/OT convergence can then take advantage of robotics to automate processes and reap other benefits.

1. More productiveness and efficiency. Robots are able to work nonstop for long periods of time, making them ideal for tasks that are both difficult and specialised, as well as those that are both extremely repetitious and very varied. To maximize output, this enables continuous production, safety inspections, and other duties [7].

2. Elevated standard of manufacture. Robotic arms provide inherent precision, consistency, and accuracy, which can be invaluable to organizations for activities requiring high levels of accuracy. By inspecting products in real time on production lines and cutting down on rework, AI-enabled robots significantly boost the quality of the product.[7]

3. Enhanced conditions for workers, including better ergonomics. Workers' safety is compromised when their jobs put them in potentially dangerous situations, force them to do physically demanding tasks repeatedly, or need them to handle potentially harmful chemicals or other substances. Robots can be used to replace humans in dangerous work environments, sparing employees' injury.[7]

4. More money was saved. The employment of robots for automation can lead to savings for enterprises thanks to boosted productivity and quality assurance, less waste, and minimized downtime.

5. Minimized trash. When correctly trained, robots can do delicate jobs with pinpoint accuracy. Defects, scrap parts, the need for rework, and waste can all be reduced when there is little room for variation in the production process.

6. Quicker iterations. Manufacturing cycle times can be shortened by using robots, which is why their adoption is so widespread. Robots are used because they can accomplish

tasks more quickly than humans, they don't need breaks, and they are precise in their operations, all of which contribute to the optimization of cycle times.[8]

2.3.Warehouse Management using AMRs:

The management of warehouses and supply chains involves a range of tasks and functions, including transportation, receipt, storage, sorting, packing, and dispatch of diverse goods. In contrast to fixed automation, an autonomous mobile robot (AMR) system frequently presents numerous significant benefits, including cost-effectiveness, rapid deployment, enhanced adaptability, and ease of scalability. Contemporary mobile robot solutions have been developed to enhance efficiency by enabling robots to selectively transport specific bags to pickers, thereby eliminating the need to transport entire racks.[9] Efficient transportation of objects, optimization of picking routes, and minimization of pickers' collection time are among the various operations associated with these centers that are enhanced by them. [9].

2.3.1.How AMRs operate:

To achieve self-directed operation, Autonomous Mobile Robots (AMRs) must possess the ability to perceive and comprehend their environment, make decisions based on that perception, communicate their decisions, and execute actions accordingly. AMRs possess cutting-edge camera systems, intricate sensors, artificial intelligence, machine learning, computing, and wireless communication functionalities. The aforementioned characteristics empower Autonomous Mobile Robots (AMRs) to comprehend and construe their environment, scrutinise the layout of the premises, arrive at informed judgements, and independently traverse to their desired endpoints without encountering hindrances such as shelves, industrial trucks, forklifts, and individuals. Motors are frequently utilised for the function of actuation. Several Autonomous Mobile Robots (AMRs) utilise infrared or ultrasound sensors to detect obstacles and navigate autonomously. In contrast, some AMRs rely on stereo vision and LIDAR (Light Detection and Ranging) to comprehend their surroundings. The concept of stereo vision pertains to the extraction of three-dimensional (3D) data from digital images, while LIDAR is a methodology that entails directing a laser at an object and gauging the duration it takes for the reflected light to reach the receiver, thereby ascertaining the distance. The avoidance of collisions is achieved through the implementation of deceleration, cessation, or redirection techniques for the trajectory of Autonomous Mobile Robots (AMRs). The integration of Autonomous Mobile Robots (AMRs) with control systems for warehouses and distribution centres is a feasible undertaking. It is feasible to programme them to meet the user's specifications. In case of battery depletion, individuals can proceed towards the nearest power source to recharge their batteries. The aforementioned traits enable Autonomous Mobile Robots (AMRs) to perform their designated tasks in a manner that is economically feasible, cognitively intelligent, and operationally proficient. The implementation of Autonomous Mobile Robots (AMRs) can yield substantial benefits to warehouses and analogous establishments [10].

Figure 5 AMRs using LIDAR for path planning and navigation.

2.3.2.Applications for AMRs:

The following are some more developing sectors where AMRs are finding uses:

1. Logistics hubs like distribution centers and warehouses are always bustling with activity. Workers are constantly coming and going from these facilities, transporting things by hand, using forklifts, and in other ways. Accidents and

injuries can happen at any time for a number of reasons, including being struck by a moving machine, tripping and falling, etc. AMRs are built to avoid colliding with humans; hence their use will reduce the number of warehouse personnel necessary.

2. Dull, tedious, and repetitive work includes things like transporting, loading, unloading, and sorting. When employees are overworked, their productivity and quality of work suffer. Such processes can be efficiently automated with the use of AMRs.
3. Inventory management is crucial in storage facilities and distribution centers; AMRs can help. They can be used to take inventory, and the data gleaned from that can be integrated with other company-wide IT solutions like WMSs and SCMs.
4. The rapid spread of eCommerce and the accompanying rise in customers' expectations for speedy delivery can be attributed, in part, to the prevalence of the pandemic. Complexities in delivery and inventory management are two areas where AMRs excel in providing solutions.[11]
5. People's shopping patterns have shifted, with internet purchases nearly replacing in-store ones as a result of COVID-19 and the subsequent lockdown situation. For the same reason, it's now preferable to keep people from having to constantly be in close quarters with one another at work.[11]

The future of the AMR industry is bright as more and more businesses adopt digital technology to raise their operational efficiencies, boost their productivity, increase their customer happiness, and acquire a competitive edge. In a similar vein, AMR users will reap the rewards of increased revenue, profits, shareholder value, and customer satisfaction as a result of the automation of processes. [12]

2.3.3.Difference between AGVs and AMRs:

The most common analogy for autonomous mobile robots is the well-established automated guided vehicle (AGV) in warehouses. The primary contrast between AGVs and mobile robots is the degree to which they are automated vs autonomous. While AGVs follow a set path that is detected by lasers or wires, autonomous robots are able to make constant course corrections with the help of AI. Pallets are typically employed with AGVs, while boxes or lightweight goods are more common with autonomous mobile robots [].

According to the Automated Guided Vehicle Market Analysis by Research and Markets, the AGV market expanded by 6.8 percent in 2019. However, according to a research by the consulting firm IDC, the growth rate of AMRs was over 20%. [7].

Ultimately, it's not that one system is superior to the other, but rather that they serve complementary purposes. For example, automated guided vehicles (AGVs) excel at moving big loads in stationary settings (like manufacturing logistics facilities), where operations tend to be consistent over time. According to the Europe Automated Guided Vehicle (AGV) Market Report published by Mordor Intelligence, this is why the system has been so effective in penetrating the automotive and food industries. [8]

2.3.4.AMR safety and maintenance:

The United States adheres to the ANSI/ITSDF B56.5-2012 Safety Standard for Driverless, Automatic Guided Industrial Vehicles and Automated Functions of Manned Industrial Vehicles and the ANSI/RIA R15.06-2012 Industrial Robots and Robot Systems – Safety Requirements as the guidelines for ensuring safe operation of mobile robots. [8]

The International Organisation for Standardisation (ISO) has recently developed the ISO 3691-4 standard, which is a dedicated international safety standard for this particular technology. This standard was published in 2020. Regarding maintenance, it is imperative to incorporate Autonomous Mobile Robots (AMRs) into the preventive maintenance strategies for warehouses, similar to other automated systems. particular instance, it can be observed that the subject matter at hand is being approached from a non-academic perspective. To enhance the academic rigour of the discourse, it is recommended that the language and structure of the text be modified to align with scholarly conventions.[13]

In numerous instances, it is the responsibility of AMR providers to address incidents that occur or impart specialised training to company technicians to enable them to do so. [13]

2.3.5.Cost of autonomous mobile robots:

With the emergence of novel technologies, the expenses associated with mobile robots are comparable to those of conventional automated systems. Despite this, it is noteworthy that the industrial robotics industry has observed a significant decline in prices in recent years, which can be attributed to advancements in technology and the realisation of economies of scale, as per data presented by ARK Investment Management [13].

In any case, given that this system does not necessitate significant modifications to the storage facility, there exist diverse contracting alternatives. The acquisition of autonomous robots can be facilitated through either direct purchase or the procurement of a licence, commonly referred to as Robotics as a Service (RaaS). The utilisation of autonomous mobile robots in project implementation presents a plethora of opportunities for businesses.[14]

2.4.Different models:

Different models of warehouse stacking robot have been developed over the years. Some of them are given below.

2.4.1.Bionic HIVE SqUID bot:

SqUID bot is a one-of-a-kind synchronised and autonomous robot with three-dimensional mobility and infinite operational flexibility. Using a sensor mounted on its underside, it scans the QR codes posted at the beginning of each aisle to determine its precise location in the warehouse. On the other side, it employs infrared (IR) sensors to track the lines and stay on its predetermined course. The SqUID bot has two pairs of Omni tyres under the payload area to allow it to freely rotate around its axis. The SqUID bot's main wheels are built in such a way that the distance between each wheel pair has been carefully thought out. There is a U-shaped steel structure in this area, with the bottom left open. The SqUID can easily scale the rails thanks to the gap between the primary tyres. This U-shaped support holds the rails in place to keep the robot from deviating from the track. The robot's motors allow it to travel in this vertical direction.[15] Below is a diagram depicting SqUID tyres:

Figure 6 A SqUID bot

To get to the rail, it counts the QR code tags put at the beginning of each aisle and then rotates its main wheels by 90 degrees when it reaches the required aisle. Since SqUID is equipped with sensors on the side facing the rails, it can realign its tyres so that the gap between them lines up with the track. This brings the robot into proper alignment with the rail. Motors are now powering the robot's ascent along the tracks. The SqUID is secured to the rail by a U-shaped framework. So, it travels up and down the tracks until it reaches a predetermined height or location, at which point it stops. Each rail junction is equipped with a motor that controls the small movable section of rail. Because of the motor, the part can be rotated by 90 degrees. Therefore, the robot will halt when it reaches this intersection. The signal has been sent to the motors at the intersection, and they are currently spinning clockwise. The SqUID's tyres can turn 90 degrees because they are also connected to the rail intersections.[15]

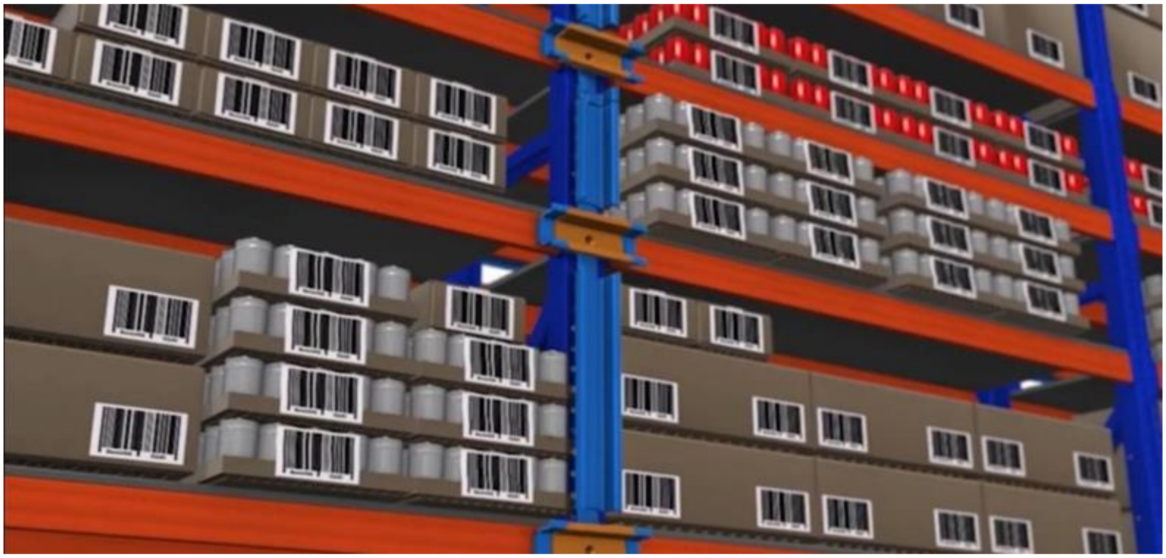

Figure 7 Moveable Rail Junctions

The robot now travels horizontally to the area where the package can be found. The robot will now use its scanner to read the bar code on the item of choice.

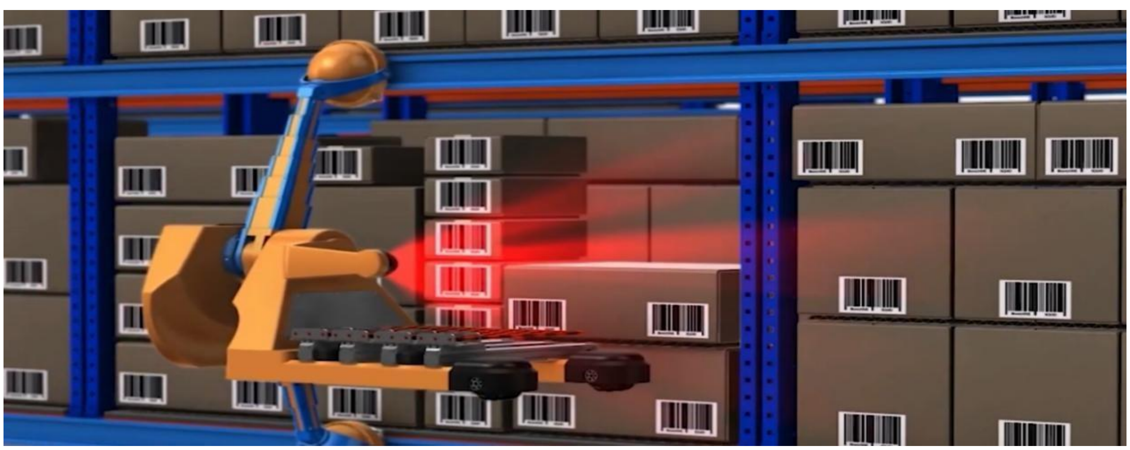

Figure 8 Scanning Package [15]

To secure the shipment, a movable suction pump-style actuator is fastened to the side of the cargo. The suction end needs to be able to reach the package, and the mechanism that moves it does just that. Once the package is fastened to it, the mechanism will draw it towards the bot until it is securely fastened to the payload area.

Figure 9 Suction Cups

After the necessary package has been loaded onto the SqUID bot's payload, it will descend the rail and deposit the package at the destination conveyor. These robots can now perform human labor significantly more effectively and reliably than ever before.

Figure 10 Delivery at Conveyor Belt [31]

A warehouse is more likely to have a fleet of robots than a single robot. With its sophisticated embedded control system and real-time data processing, Bionic Hive's algorithmic engine can dynamically comprehend problems generated in one warehouse and apply remedies to all warehouses in the network. Thanks to its high-tech hardware and complex algorithms, it can find its way about on its own and pick the quickest, most direct route. The robot is programmed to avoid stopping or delaying delivery of materials by rerouting itself when it encounters barriers. The SqUID's on-board sensors and machine learning enable it to navigate a warehouse without human intervention and deliver supplies where they are needed. The robot, which has a maximum load of 15.8 kilograms, can potentially reach higher shelves by attaching to vertical rails and runners in the warehouse.

Warehouses, like other industries, may have to make substantial financial investments and changes to their operational budgets when new technologies are adopted. All of the infrastructure needs to be upgraded so that it can support today's cutting-edge tools. Fortunately, this robot is not like that at all. [15].

Since it already makes use of the same facilities, boxes, and storage racks, its retrofitting capacity is easy to incorporate into the current working paradigm. The SqUID system will automate all package/case handling from receipt to delivery, and it may be easily installed on a standard pallet rack in any warehouse or distribution centre. In addition, it can pick from any location, be it on the ground or 20 metres (60 feet) in the air, which is very useful when the need for more SKUs and larger picking faces increases. From aisle to aisle or across the entire warehouse, SqUID deployment can be done concurrently with workflow with practically no downtime [16].

Warehouses and machinery are used for the bulk of freight. The control system, measurement and servo system, and mechanical system are the three mainstays of a stacking robot. The interface device that facilitates communication between the robot and its environs, the regulation of network connections, and the control of the servo system of the robot all commonly make use of a computer and associated memory, which are part of the control system. The measurement and servo system consists of a motion controller, servo amplifier driver, and AC servomotor providing position and speed feedback. The robot's mechanical system includes a stacking robot and a gearbox device for translating the servomotor's rotational motion into the desired motion. The stacker should reflect the best qualities of a fully mechanized storage facility. The stacker is the most important piece of machinery in the warehouse, so it must be operated quickly and reliably.

2.4.2.Aisle based compact storage system:

Crane-based compact storage systems have a restricted volume capacity. In a shuttle-based system, the use of lifts rather than cranes provides for more throughput flexibility. They are composed of numerous tiers of miniature storage planes, each holding a specific product type. Last in, first out is a method of controlling the load in a lane (LIFO).

Figure 11 multi-deep compact storage system [17]

Lifts transport loads vertically (pallets), whereas shuttles transport weights between levels. These move beneath them in each storage lane to store or retrieve the goods. Shuttles and cargoes may move horizontally in the system utilizing either a specialized shuttle and a transfer vehicle, or a standard shuttle that can move both vertically and horizontally without the need for a transfer vehicle. Tappia et al. (2016) use a multi-class semi-open queuing network and an open queue to duplicate each tier and vertical transfer method.

According to this company, generic shuttles may reduce overall distance for storage and retrieval activities because additional shuttle movements in the cross aisle without load are not required; however, a specialized shuttle may be more appealing economically because the generic shuttle is twice as expensive as the specialized shuttle. According to the manufacturer, a single layer system with a depth/width ratio of 1.25 reduces the projected throughput time. [17].

2.4.3.Development of Auto-stacking warehouse truck:

It is a prototype of a fully automated truck that can operate without the need for a skilled operator. The truck can convey the parcels to the warehouse on the programmed route and stack it in the suitable storage region, or deliver the package to the shipping zone, all with the use of an RFID card. It can greatly minimize the number of trained forklift technicians required and increase the safety of the warehouse environment.[18]

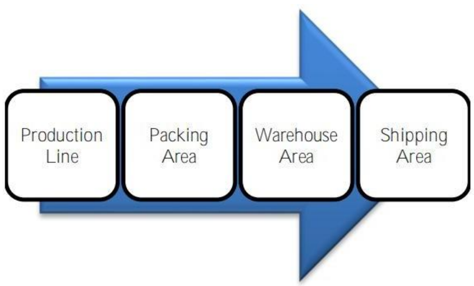

Figure 12 Flow of goods with RFID tag

The simulation's setting contains a shipping zone and two warehousing areas. The truck will be instructed to transport the goods from the factory to the relevant warehouse location, where they will be left in the correct storage counter, or to warehouse storage counter to the shipping area. In the designated warehouse, the products can be stacked. The warehouse truck follows the path of predefined curve on the floor for simplicity. A multicolored sticker is used on the truck to distinguish between different warehouses.[18]

The skeleton of the experimental truck is made of aluminum-extruded material. The kernel is a microchip 16-bit MCU, with an Arduino chip supplementing it to administer the truck. A trace sensor is utilized to identify the defined route, allowing the vehicle to follow it. To read distinct storage regions, a color sensor is used. A 12-volt DC deceleration motor is used to move the truck and fork up and down. A 5-volt DC stepper motor is used to lengthen the fork. [4] Figure below depicts the auto stacking warehouse truck in action. Initially the vehicle is parked at the packing area.[19]

Figure 13 Auto-stacking warehouse Truck

We direct the truck to pick up the merchandise and deliver it to the correct storage counter using an RFID card. On the truck, there are two function buttons and an emergency stop switch: one for picking up items from the warehouse to the shipping area and another for delivering goods to the warehouse area for stacking. Two RFID cards distinguish the several warehouses. There is a stacking restriction in each warehouse location. The vehicles move when a button is pressed, and an RFID message is read. The warning sign will glow when the destination warehouse is full of items and a goods stack is scheduled. By changing the command mode, you may silence the alarm. The items can be conveyed smoothly from the packing area to the storage area for stacking in the simulation, or they can be picked up from the storage area and transferred to the shipping area.[19]

2.4.4.Warehouse management system using microprocessor:

Robots can be used to manage warehouses. The robot performs the task of looking for an article, bringing it to the user, and then returning it to the same location where it was taken from it is no longer needed. For a wide range of sensor modalities, warehouse navigation uses monocular cameras mounted on the robot and a Teach and Repeat (T&R) operational strategy. Automation has taken the role of human touch. A warehouse management system is a software application designed to keep warehouse (distribution center) management and workers organized.[20]

They make administration's day-to-day planning (scheduling), organization (managing), staffing (employment), and controlling go smoothly. Transporting and stacking up of materials in and out of a warehouse will require deployment of the most available resources. By employing a revolutionary work procedure, robots and warehouse associate the task together, reducing travel time and increasing production. Material handling, welding and inspection are all done by industrial robots, which increases production. Robots that move on their legs, rails, or wheels are known as mobile robots. Domestic around the house. [21] The major parts of proposed method are microcontroller, sensor, supply, lifting motor, motor driver.

2.5.Mechanism Selection

In the process of designing the SqUID bot, a comparative analysis was conducted between the aforementioned model and an in-pipe inch worm robot, a chair lift machine utilised in skiing, and various self-locking mechanisms. The decision was made to equip the robot with a self-locking mechanism in order to facilitate its ascent of the rack. In order to ascend the rack, various models were taken into consideration. [22]

2.5.1.Self-Locking Mechanism, Unidirectional:

The robotic system is comprised of a pair of unidirectional self-locking mechanisms and a telescoping mechanism. The primary purpose of the unidirectional self-locking mechanism is to restrict movement in one direction while allowing free motion in the opposite direction, as stated in reference [23].

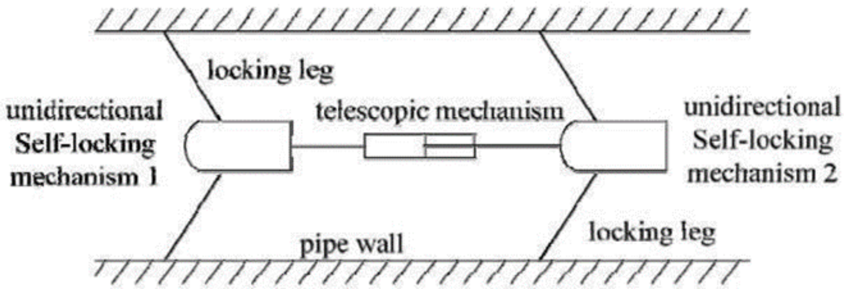

Figure 14 Unidirectional self-locking system for in-pipe robot propulsion

2.5.1.1.Drawbacks:

This particular mechanism exhibits two limitations, which are outlined below:

I. One issue is that the supporting legs consistently pre-press into the pipe wall, leading to significant friction against the robot's motion. This friction results in energy loss and substantial wear of the supporting legs, ultimately reducing the robot's lifespan. [24]

II. The second observation pertains to the unidirectional motion of the robot utilizing the aforementioned locking mechanism, as depicted in Figure 14. [24]

2.5.2.Inclined Plane locking:

The utilisation of inclined planes for locking mechanisms can be classified into two distinct types [10, 11], as illustrated in Figure 4. The mechanism primarily employs the concept of self-locking of an inclined plane to achieve unidirectional locking. As illustrated in Figure 4 (a), when a lateral force is applied to the supporting shaft in the leftward direction, the system exhibits a corresponding leftward displacement. This displacement results in the wheels rolling up the inclined plane of the conical body, thereby augmenting the normal pressure exerted by the locking wheels on the inner wall.

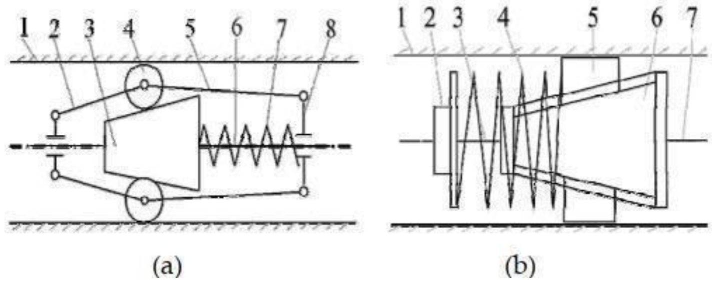

Figure 15 The use of an inclined plane to illustrate a locking procedure. Pipe wall (1), connecting bar (2), conical body (3), locking wheel (4), connecting bar (5), supporting shaft (6), spring (7), carriage (8) makes up (a) the first locking technique

The mechanism is currently fixed in a leftward position. In the event that a force is applied to the supporting shaft in the rightward direction, the conical body will undergo a corresponding rightward displacement. As a result, the locking wheels will disengage from the pipe wall, thereby enabling the mechanism to move towards the right. The theory of locking, as depicted in Figure 4 (b), bears resemblance to that of Figure 16 (a). The utilisation of springs in Figures 16 (a) and (b) serves the purpose of maintaining contact between the locking wheels or wedges and the inner wall of the pipe. [25]

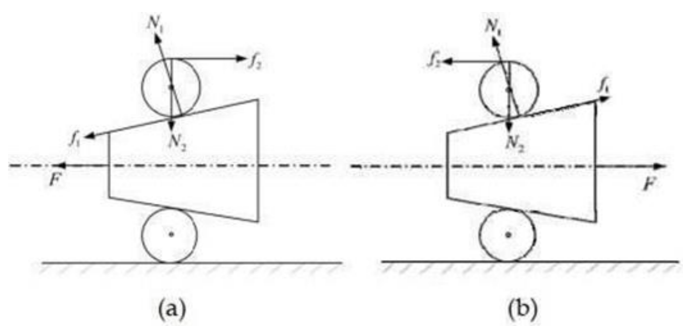

Figure 16 The mechanical basis behind the inclined plane locking method: two directions: (a) reverse and b) reverse

2.5.2.1.Drawbacks:

This approach also has a limited number of disadvantages.

I. One limitation of the locking mechanism is its ability to achieve self-locking in a single direction.

II. The second limitation pertains to the adapted pipe diameter, which is constrained by the conical body's length and taper. large or it will not fit through the pipes. long, and thus the adapted diameter range is usually not large. [26]

2.5.3.Locking Method Using Cams:

The methodology employed is founded upon the self-locking mechanism inherent in a cam, as visually depicted in Figure 6. The motor drives the lead screw to rotate, so the moving nut moves along the axis of the lead screw. Simultaneously, the nut actuates the pushing bar, thereby inducing the parallel quadrilateral bars to undergo a transformation. The cams affixed to the horizontal bars exert pressure on or disengage from the interior pipe surface, thereby achieving the state of being secured or unsecured [27].

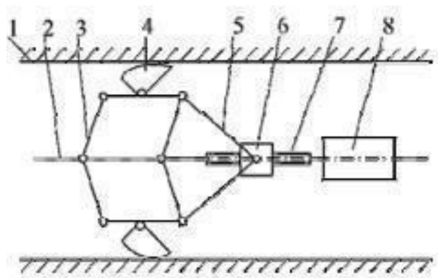

Figure 17 This diagram depicts a locking system that makes use of cams. From top to bottom, we have: (1) a pipe wall; (2) a carriage; (3) a set of parallel four bars; (4) a cam; (5) a pushing bar; (6) a nut that moves.

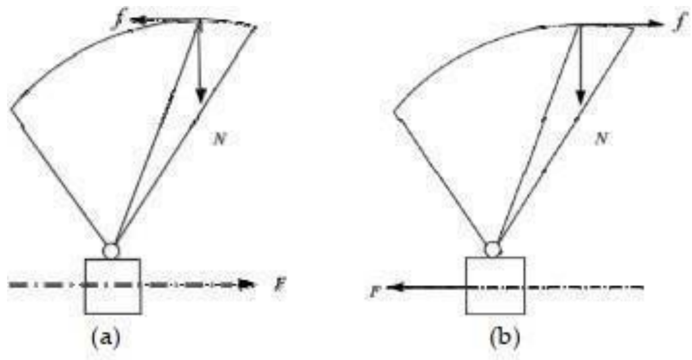

Figure 18 As an example of the mechanical principle behind a cam's locking ability: two directions: (a) reverse and (b) advance[28]

As shown in Figure 18 (a), the friction force f causes the cam to rotate anticlockwise when the mechanism is subjected to a forward tractive force. So, the friction force f and the acceleration N are both raised. Self- locking will occur when the friction force F becomes greater than F. As can be seen in Figure 18 (b), when the mechanism experiences a tractive force in reverse, the cam spins clockwise and N decreases, resulting in a lower friction force f. This means that the mechanism can be operated in reverse without being locked. [29]

2.5.3.1.DRAWBACKS:

The following are some of the mechanism's flaws:

1. The robot can only move in one direction, and the four bars are under considerable stress. If the bar is small and thin, it can only withstand a minimal amount of force before breaking. [30]

2. Second, it's more difficult to set up the cams if the bar's dimensions are on the tiny side. [16][31]

2.6.Warehouses using mobile robots are more productive, especially for low-weight items:

When is it best to deploy mobile robots at your facility? When dealing with a large volume of small, diverse items with strict delivery deadlines, AMRs have proven to be very effective. Productivity needed per robot can be calculated using KPIs from warehouse management, such as the number of picking orders per hour per operator or internal order cycle time (obtained through an LMS). This guarantees that the company will save money as a result of their deployment. [32]

Rising costs of materials and shrinking business margins have made mobile robots a practical choice for logistics automation in many settings. Still, it's a good idea to analyse current processes and the feasibility of incorporating these devices into existing workflows in order to gain a quick return on investment with this form of automation. [33]

2.7.Chair lift self-locking mechanism:

A "grip" that squeezes the cable is built into each chair. When the lift is in use, the motor at the station pulls on the cable, which in turn moves the seats. Traditional chair lifts had the seats permanently fastened to the cable; these were called "fixed" chair lifts. The velocity of the chairs was thus determined by the velocity of the cable [34].

Figure 19 Chair lift self-locking mechanism

2.8. Final Design:

Inspired by this design, we settled on a rack configuration in which the main wheel is large and two smaller wheels, one on each side of the robot, "insert" into the rack on either end. The bot's small wheels have no purpose when it's on the ground, but they provide a supporting force when it's preparing to climb the rack by pressing against the top side of the railing while the weight of the robot acts on the bottom side of the railing via the main wheel.

Chapter 3- METHODOLOGY

3.1.Modeling:

The incorporation of 3D modelling and ANSYS analysis in the creation of a robot for warehouse management is of utmost importance due to various reasons. To begin with, the utilisation of 3D modelling facilitates the creation of a comprehensive digital depiction of the robot's blueprint, which empowers engineers to envision and enhance its mechanical configuration, sensor amalgamation, and control mechanism prior to its actual production. This facilitates the identification of possible design deficiencies, guarantees optimal utilisation of space, enables effective navigation, and ensures smooth handling of diverse commodities within the warehouse. The utilisation of ANSYS analysis is crucial in the assessment of the structural soundness and operational efficacy of the robot across various scenarios. Through the implementation of stress testing and simulations, engineers have the ability to detect potential vulnerabilities, enhance the durability of components, and augment the overall resilience of the robot.[35]

Here are some important key points to keep in mind before starting 3D modeling and ANSYS analysis of a warehouse management robot:

- **The robot's environment**: The robot's environment must be considered when designing the robot. The robot must be able to navigate safely and efficiently in the warehouse environment.

- **The robot's tasks**: The robot's tasks must be considered when designing the robot. The robot must be able to perform the tasks required of it in the warehouse environment.

- **The robot's budget:** The robot's budget must be considered when designing the robot. The robot must be designed to meet the requirements of the warehouse environment within the budget constraints.[36]

3.2.CAD Models:

Prototypes featuring varying robot and rail configurations were extensively built and tested to find the best one that matched the needs of the warehouse management robot development project. In order to accomplish this, high-quality computer-aided design (CAD) software called SolidWorks was used to develop precise and detailed blueprints for the prototypes. After that, we used ANSYS, a popular engineering simulation software, to run extensive studies on the prototypes and check out how well they worked.[37]

It can help to reduce the time and cost of development.It can help to improve the quality of the robot.It can help to ensure that the robot meets the requirements of the warehouse environment. Overall, 3D modeling and ANSYS analysis are essential tools for the design and development of warehouse management robots. By using these tools, engineers can create robots that are safe, efficient, and effective.[37]

3.3.Vertical Traversal Mechanism:

A robot needs the traction supplied by the weight of the robot on horizontal surfaces move. To climb vertical surfaces a variety of techniques can be used to produce traction, such as:

1. **Magnetic Attachments:** The robot can be outfitted with strong magnets if the fence is built of a ferrous substance (like iron or steel). The robot can be secured to the railing using the magnets and then pulled higher using the resulting traction.

2. **Adhesive Materials:** Strong adherence to the wall and railing can be created with the help of materials like specialized tapes or synthetic adhesives inspired by gecko feet.

3. **Gripping Mechanism:** Make sure the robot has some way of grabbing onto the railing, such claws or specialized suction cups. The robot's ability to maintain traction and avoid falling while climbing should depend on the effectiveness of these processes.

4. **Clamping Mechanism:** Design some kind clamping mechanism to keep the robot firmly pressed up against the railing. This could be accomplished with the help of

adjustable clamps or braces that can secure themselves to rails of varying sizes.

5. **Treaded Wheels and Tracks:** Specialized wheels or tracks with treads can be installed on the robot in place of the gripping devices. The railing can be gripped with these treads, or frictional contact can be made to avoid slipping.

3.4.Clamping Mechanism

The approach followed by this project is clamping mechanism. The clamping mechanism provides numerous benefits for a rail-based wall-climbing robot. The benefits include:

1. The main benefit of a clamping mechanism is the secure grasp it gives on the railing. The force applied by the clamps is adequate to keep the robot from slipping or detaching while it is ascending. This safeguards the robot's integrity and reduces the potential for mishaps.

2. It is possible to construct a clamping mechanism to fit a wide range of rail widths and forms. The robot's adaptable clamps allow it to securely attach to railings of differing sizes, increasing the robot's usefulness and adaptability.

3. Traction Improvements Gripping surfaces are commonly integrated into the clamps of the mechanism. The clamps' contact area with the railing can be increased by using materials with strong friction qualities on these surfaces. The robot is able to apply more force to the wall thanks to the increased traction.

4. Clamping mechanisms can provide a high level of reliability if they are well-designed and implemented. The locking mechanisms and clamps used to keep the robot linked to the railing are designed to resist the stresses and vibrations it will experience while climbing.

5. The robot can be quickly and easily attached and detached from the railing. This function allows the robot to move freely, either between fixed points on the wall or to an entirely new position.

3.5.Working of Clamping Wheels:

For a robot to successfully use a railing to scale a vertical surface, it needs a bracing or clamping mechanism that will firmly hold it against the railing. This mechanism is designed to give the robot a firm hold on the surface it is climbing and stop it from slipping or losing traction.

This is an abstract description of mechanism for clamping:

3.5.1.Adjustable Clamps:

Adjustable clamps with wheels that act as clamping tools are a unique and flexible way to hold and secure things. Unlike traditional clamps, which have jaws or arms that don't move, these new clamps have wheels that make them active and flexible. With this design, the wheels are both the surface for gripping and the way to change, so they can be used for a wide range of tasks.

A benefit of using wheels as clamps is that they make the clamps easier to move. Since the wheels can turn, they make it easy for robots to move to different places. This is especially helpful in situations where items need to be moved or changed a lot.

3.5.2.Actuation System:

There are several benefits to using a power screw as the clamping mechanism instead of another actuation method. The considerable mechanical advantage offered by the screw thread is a notable benefit. Clamping force is increased noticeably when compared to alternative actuation methods thanks to the power screw's excellent transfer of rotational motion into linear motion. Because of this, it can be used in situations that call for a firm hold.

Power screws also provide for fine-tuned regulation and control. The amount of linear displacement per revolution can be adjusted by changing the pitch and lead of the screw thread. When working with items of diverse sizes or materials, the ability to precisely regulate the amount of pressure applied is invaluable.

The self-locking features of power screws allow them to remain in place even after the power is turned off. This improves the clamping mechanism's steadiness and dependability by lowering the possibility of accidental loosening or slipping. It's especially useful where constant clamping pressure must be maintained for long periods of time.

Power screws also have a straightforward and sturdy construction, meaning they're low-maintenance and built to last. When compared to alternative actuation systems, they tend to be more durable and require less repairs and replacements over time. Because of its small size and light weight, power screws can easily be incorporated into a wide range of robotic systems and applications. In addition to their adaptability and convenience, they are also simple to install and work with a variety of mounting arrangements.

3.5.3.Locking and Release Mechanism:

The power screw's great mechanical advantage guarantees that the screw will remain securely fastened and prevents the clamp from being accidentally released. The release mechanism, meantime, oversees releasing the clamp in such a way that neither the clamp nor any nearby objects are damaged. The power screw gradually releases its hold by spinning the motor in the opposite direction. Thus, both objectives are solved by power screw mechanism.

3.6.Prototype Designs:

The prototypes were developed with the unique requirements of warehouse management in mind. Modern mechanical layouts, sensor integration, and effective control mechanisms were all part of the robot designs. SolidWorks enabled engineers to create detailed digital representations of robot blueprints, allowing for a pre-production stage of visualizing and optimising the designs in a virtual environment. By doing so, we were able to spot any flaws in the warehouse's layout and fix them, leading to better space utilisation, easier navigation, and more streamlined product handling. After the prototypes were built in SolidWorks, they were put through an ANSYS analysis to check for structural integrity and operating efficiency in various settings. Engineers used stress testing and simulations to thoroughly evaluate the prototypes, finding flaws and weaknesses in the design. In-depth analysis of the prototypes' performance was made possible using ANSYS software, allowing engineers to boost the longevity of individual components and the robots' overall robustness. The creation of the warehouse management robot relied heavily on iterative design, construction, and analysis of prototypes, all of which were aided by software packages like SolidWorks and ANSYS. Reduced development time and cost, higher quality final design, and compliance with warehouse environment standards are just a few of the many benefits of combining 3D modelling with simulation analysis. To summarize, the employment of SolidWorks software for 3D modelling and ANSYS software for analysis and simulation played a significant role in the successful development of optimized prototypes for the warehouse management robot. The utilization of these tools has enabled engineers to make well-informed decisions, enhance designs, and attain the intended performance, leading to the creation of secure, productive, and proficient robots that are customized to address the demands of warehouse management operations. Following are some of the models we considered or tested to find the best fit.

3.6.1.Design 01(continuation of Previous Contributions):

This design presents our previous degree’s final design selection which focuses on a rail-mounted robot equipped with swivel ball caster wheels. The design represents the culmination of our efforts in developing a robust and efficient robot capable of traversing along a rail system while accommodating a payload. This section provides a detailed explanation of the design and its important features.

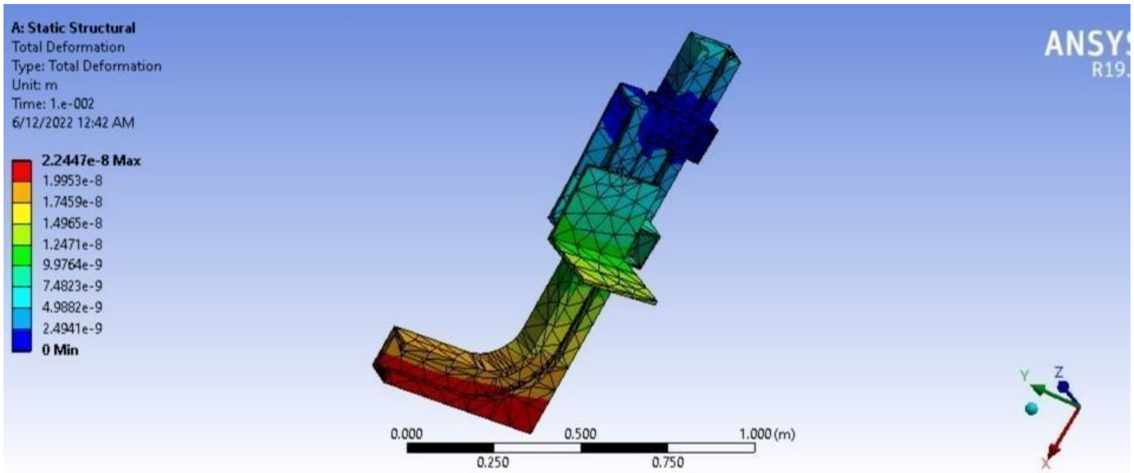

Figure 20 Final Design of previous degree - Rail-Mounted Robot with Swivel Ball Caster Wheels ANSYS Analysis

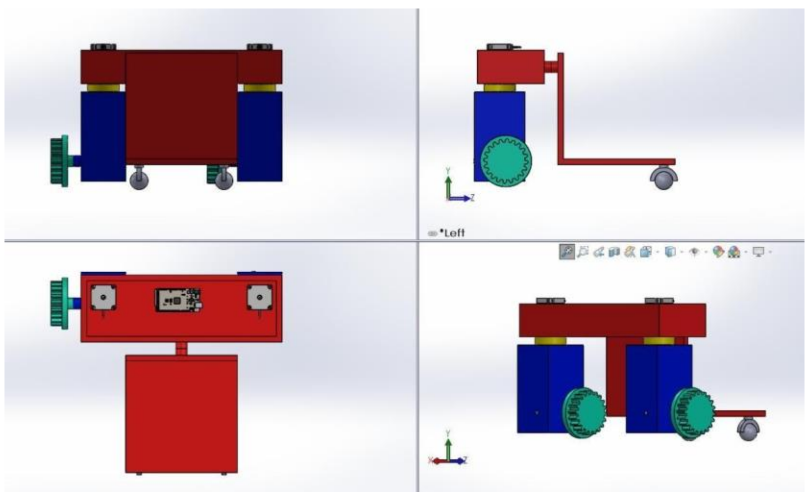

Figure 21 Final Design of previous degree - Rail-Mounted Robot with Swivel Ball Caster Wheels

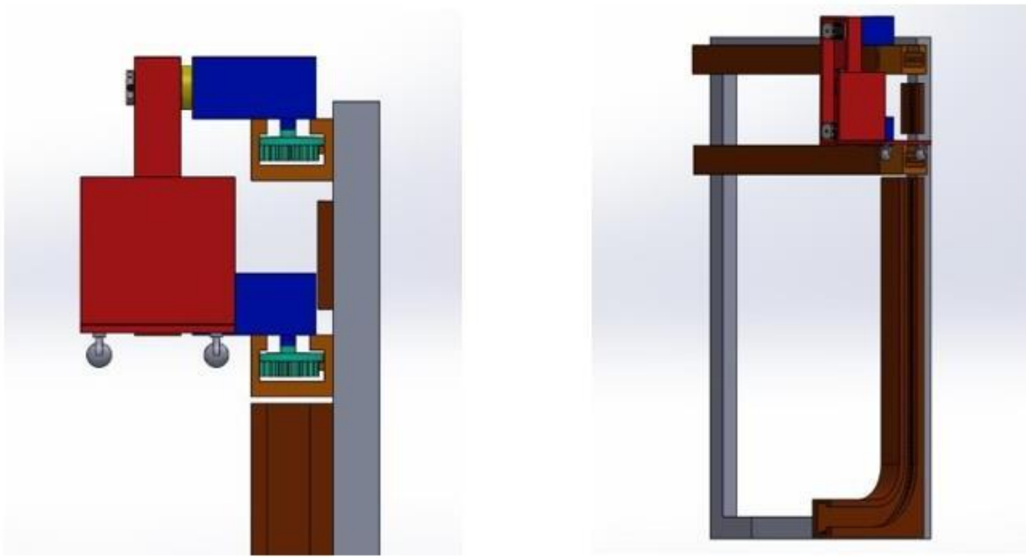

Figure 22 Final design of DE 40 (Graduation batch 2022) - Rail -Mounted Robot with Swivel Ball Caster Wheels

1. **Rail and Rack System:**

   The robotic system utilizes a rail and rack mechanism to enable directed linear movement along the rail. The rail has been engineered with contoured external edges to effectively retain the robot and avert lateral displacement. The robot's rack, which is incorporated within its body, interacts with the pinion to facilitate seamless and regulated motion along the rail.

2. **Swivel Ball Caster Wheels:**

   The swivel ball caster wheels have been implemented as a replacement for the previous design's Omni wheels. The aforementioned alteration confers upon the robot the ability to move omnidirectionally, without necessitating the incorporation of supplementary motors. The implementation of swivel ball caster wheels contributes to the robot's increased maneuverability.

3. **Movable Pivot:**

   In order to mitigate the challenge of the robot's rear end coming into contact with the rail during transitions, a mechanism featuring a movable pivot has been implemented. The pivot mechanism facilitates a seamless transition of the rail from a vertical to a horizontal position, thereby preventing any hindrances that may arise due to the robot's interaction with the rail.

4. **Load Distribution:**

The appropriate distribution of load is of utmost importance in ensuring stability and achieving optimal performance. The design integrates forces of 30N individually exerted on the boxes to replicate the weight distribution of the robot's constituents. Furthermore, an additional force of 50 Newtons denotes the maximum payload capacity that the robot can support. This guarantees that the mechanical stability of the robot is preserved during practical operational circumstances.

5. **Structural Analysis:**

The feasibility and strength of the design have been assessed through the utilisation of static structural analysis. The critical junctures within the robot's framework have been analysed to determine the highest levels of deformations, equivalent elastic strains, and equivalent von Mises stresses. The findings of the analysis have demonstrated enhanced efficacy and viability in contrast to prior iterations, instilling assurance in the mechanical soundness of the robot.

6. **Comprehensive documentation:**

The documentation of the design is thorough, encompassing detailed engineering drawings, computer-aided design models, and reports of analysis. The present documentation constitutes a significant asset for comprehending the complexities of the design, enabling its reproduction and subsequent advancement by upcoming scholars and professionals in the field.

3.6.2.Key take aways of this design

The design of the rail-mounted robot with swivel ball caster wheels was the culmination of the final year project in our previous academic programme. Through the identification and mitigation of constraints and the integration of enhancements, we have devised a resilient and viable resolution for rail-oriented robotic systems. The design incorporates crucial components such as the rail and rack system, swivel ball caster wheels, movable pivot, and load distribution considerations to ensure optimal functionality. This design provides comprehensive documentation that can serve as a fundamental basis for future developments and utilisation of rail-mounted robots.

3.6.3.Shortcomings of this Design:

The deficiencies of the former degree's ultimate year project design of the rail-mounted robot with swivel ball caster wheels are presented in bullet points below:

1. **Instability of Swivel Ball Caster Wheels:** The utilisation of swivel ball caster wheels, despite their advantageous maneuverability, may instigate instability in instances of rapid or sudden directional alterations, thereby jeopardizing the robot's equilibrium and accuracy.

2. **Complexity of Movable Pivot Mechanism:** The implementation of a movable pivot mechanism for rail transitions introduces mechanical intricacy and elevates the likelihood of potential failure points. Achieving dependable functionality necessitates meticulous calibration and upkeep.

3. **Limited Load Distribution Consideration:** The design methodology takes into account the distribution of loads, but it may not comprehensively address the actual variations in weight or distribution of payload in real-world scenarios. These circumstances may lead to asymmetries, undue stress on particular constituents, or diminished efficacy while functioning with diverse loads.

4. **Potential Performance Limitations:** The performance of the design could be constrained by the intrinsic features of swivel ball caster wheels, which include restricted load-bearing capacity and limitations in navigating uneven terrains or obstacles.

5. **Maintenance and Calibration Requirements**: The intricate design components and mobile pivot mechanism of the device may necessitate periodic maintenance and calibration in order to achieve peak efficiency, thereby increasing the overall maintenance burden and possible periods of inactivity.

6. **Safety Concerns:** The utilisation of swivel ball caster wheels and the movable pivot mechanism may give rise to safety apprehensions if not appropriately designed and upheld, which could result in mishaps or unsteadiness while in operation.

3.6.4.Design 02 (First draft of our Implementation):

In order to tackle the shortcomings of design one we introduced a new mechanism and new approach which is show in figure. By taking into account the identified shortcomings of the previous design and improving on it by iterating a simplified, small scale and more grounded approach. Here are some of the key features and improvements in our first design:

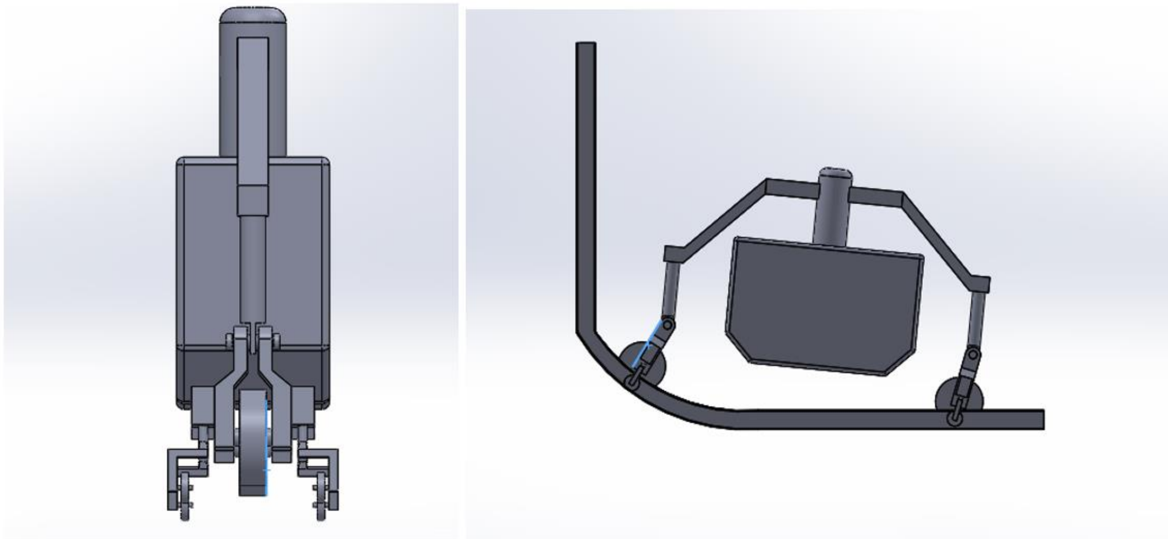

Figure 23 Front and Side View of the Design 2

1. **Compact and Streamlined Structure:**

   The new layout is more compact and streamlined because of its reduced dimensions. Because of the decrease in bulk, the robot is better able to round corners and go around obstacles.

2. **Lightweight Aluminum Construction:**

   The aluminum used to make up the robot's body and frame makes it both lightweight and strong. Aluminum’s 7high strength-to-weight ratio makes it a good choice for the robot's frame because it allows us to use less materials without sacrificing durability. This helps with both saving power and enhancing maneuverability.

3. **Utilization of Normal Tires:**

   The new design eliminates the problems caused by the constant wearing of gear by using standard tyres instead. When compared to low-profile tyres, normal ones offer superior traction, durability, and terrain versatility. This solves the gear issues that plagued the earlier design.

4. **Integration of Magna Wheels:**

   Magna Wheels are incorporated into the design; these are specialised wheels that make use of magnetism. These wheels have superior grip and traction, allowing for smooth and steady travel around the tracks. The Magna wheels' magnetic affinity to the rail keeps the train steady and keeps it from derailing.

5. **Simplified and Reliable Mechanism:**

   The new design reduces the number of moving parts and potential failure areas, making the system simpler and more reliable. The robot's dependability, maintainability, and resistance to mechanical failure are all improved by reducing its level of complexity.

6. **Improved Load Distribution:**

   A more even distribution of weight is maintained throughout the structure thanks to careful planning. The payload carrier's adjustable suspension system and modular design make it suitable for transporting a wide variety of loads while maintaining a high degree of operational stability.

   The new design is an easier-to-operate, more streamlined, and more trustworthy rail-mounted robot. It fixes the problems of its predecessor while also improving performance, maneuverability, security, and flexibility.

3.6.5.Shortcomings of this Design:

The redesigned robot model, while aimed at improving certain aspects, still has several shortcomings that need to be addressed:

Stability Issues: There is still a chance that the redesigned design will be unstable, especially when riding the rails. If the robot's stability isn't sufficiently improved, it may be more prone to tipping or swaying, putting its safe operation and efficiency at risk.

1. **Balance Control Challenges:**

The design may still have trouble staying stable when in motion, even with the alterations. The robot's ability to move over the rail system smoothly will be hindered if it does not have a robust and effective balance control mechanism.

2. **Unrealistic Functionality:**

It's possible that the updated design is unrealistic and impractical for its intended use. The load capacity, durability, and operational efficiency needs of the project may not be met if regular tires are used and scaled-down aluminum construction is implemented.

3. **Uncertain Reeling Travel Mechanism:**

There might not be a clear and dependable mechanism for the reeling movement along the rail system in the design. The lack of a robust system to ensure appropriate engagement and movement along the rail raises concerns about the dependability and effectiveness of the robot's travel mechanism.

4. **Manufacturing Complexity:**

The addition of new parts such as magna wheels and balancing control devices could make mass production more difficult for the updated design. The additional complexity might cause problems during production, assembly, and maintenance, which can drive up prices and lengthen turnaround times.

To overcome these shortcomings, it is crucial to reassess and refine the design, focusing on improving stability, balance control, and practicality. Addressing the uncertainties in the reeling travel mechanism and simplifying the manufacturing process will contribute to a more reliable and feasible final design for the project.

3.6.6.Design 03 (Second Iteration of our Implementation):

The third iteration of the design has undergone substantial enhancements to rectify the limitations observed in the preceding versions. The primary objective is to augment the stability, balance, and certainty in the process of reeling travel, while simultaneously minimizing the manufacturing complexity and enhancing the overall functionality. The design exhibits notable characteristics and enhancements that are essential to its functionality. These are:

1. **Clamping Wheels for Certain Reeling Travel:**

Clamping wheels are incorporated into the design for secure and precise rail travel. These wheels' firm hold on the rail makes for a steady and manageable mode of transportation. Clamping wheels improve the safety of reeling travel by preventing slippage and ensuring steady progress.

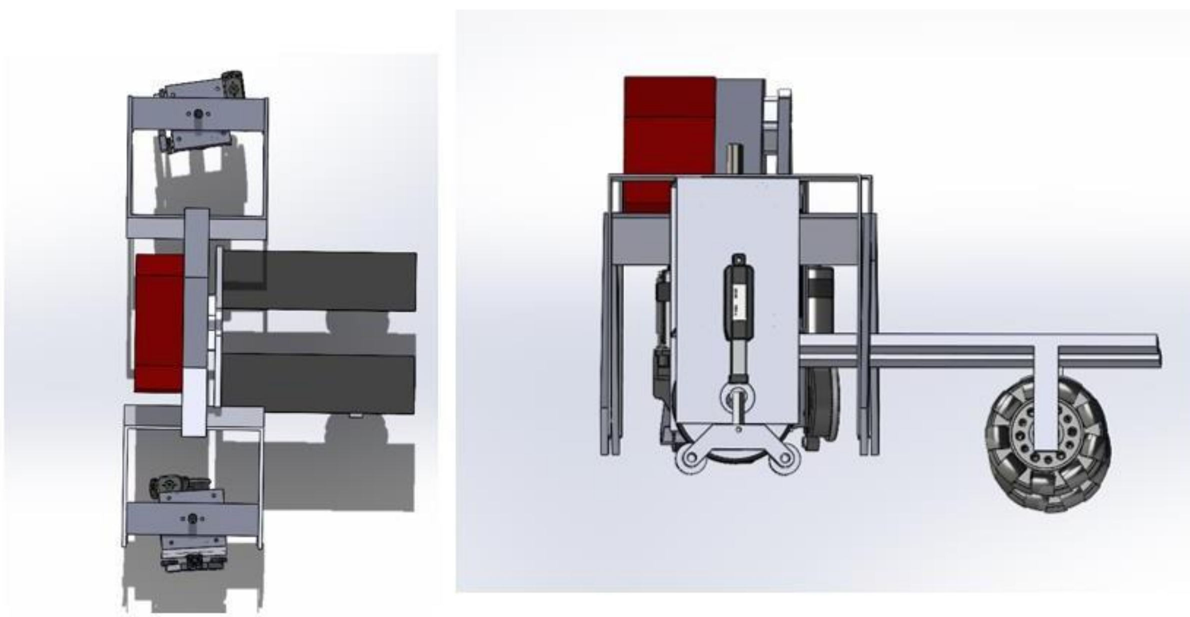

Figure 24 Top and side view of Final design

2. **Improved Stability and Balance:**

Steeper angles on several portions of the robot address concerns stability and balance. By shifting the centre of gravity lower, these angles enhance the structure's overall stability. A broader wheelbase is also adopted to improve stability in motion and lessen the possibility of tipping or swaying.

3. **Streamlined Manufacturing with Thin Aluminum Sheet:**

The robot's build makes use of lightweight aluminum sheets to streamline production. The use of this material keeps the structure strong while simplifying production. Aluminum's lightweight rigidity increases its longevity and makes it simple to put together.

4. **Rigid Components for Enhanced Functionality:**

Rigid components were incorporated into the design to increase utility. Robot dependability and robustness can be improved by using metal or reinforced plastic. This makes it so the robot can more reliably and efficiently carry out its intended tasks while also withstanding the external forces that might be applied to it.

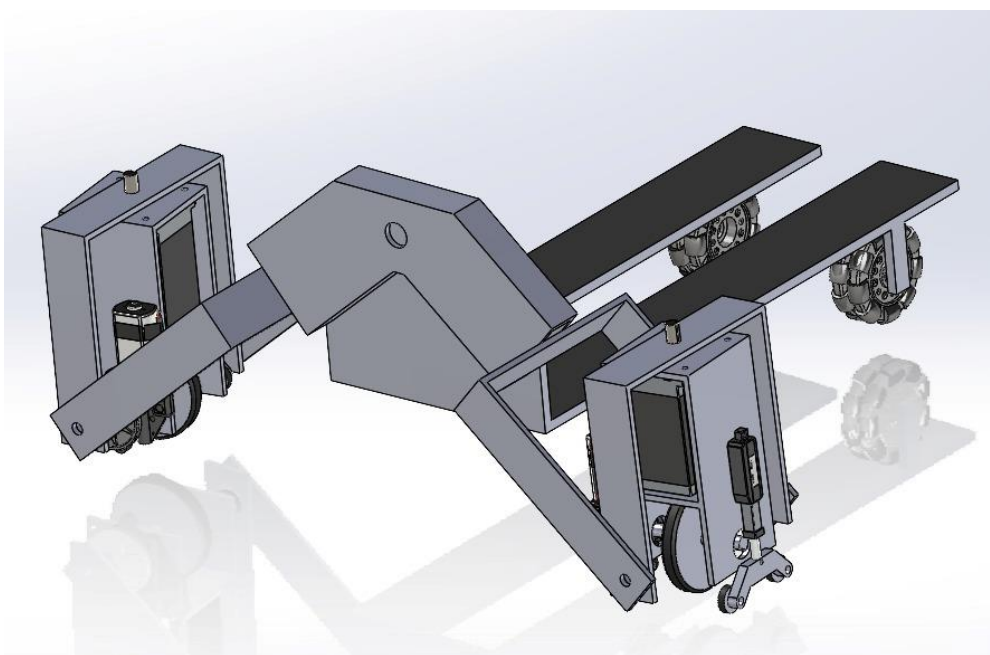

Figure 25 Front View of Final Design

These enhancements fix the problems with the limitations of the preceding prototypes and enhance the overall quality of the robotic model. The incorporation of clamping wheels guarantees consistent and dependable reeling movement, whereas the adoption of more acute angles, broader wheelbase, and utilisation of slender aluminum sheets amplifies steadiness, equilibrium, and production ease. Furthermore, the incorporation of inflexible elements enhances the functionality of the robot, enabling it to execute its duties with accuracy and efficiency.

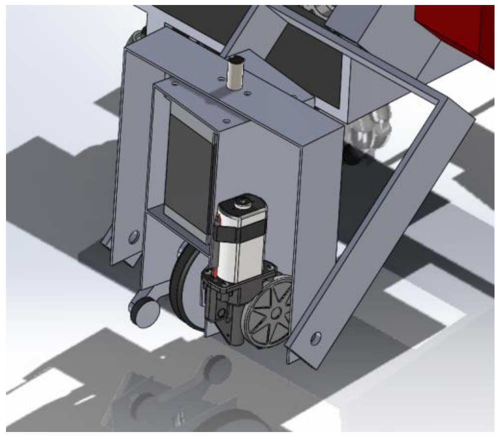

Figure 26 Wheelbase and Motor Alignment of the axle

3.7.Simulation:

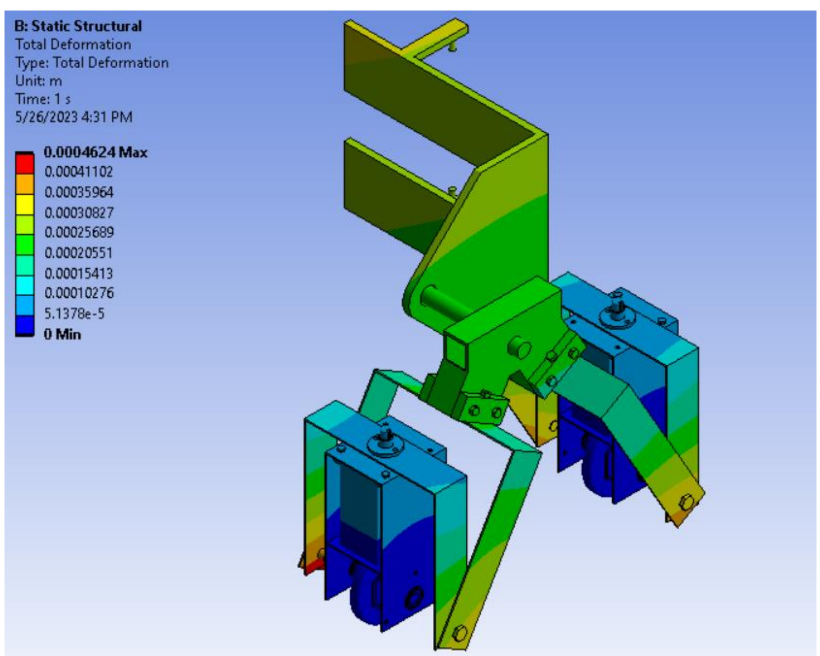

Figure 27 Ansys Results under static Analysis for 50N

Design 3 can have its structural integrity, performance, and practicality assessed through analysis with the advanced engineering simulation software ANSYS. By simulating the design's performance in a variety of scenarios, ANSYS analysis helps engineers make educated decisions and achieve optimal results.

Materials and component selection are two areas where ANSYS analysis has proven useful. Engineers can evaluate the performance of different materials and components by modelling different scenarios and applying different loads and stresses to determine the best options for the design. Engineers may simulate the effects of varying mechanical qualities, such strength, stiffness, and elasticity, on a design's performance and longevity with the help of ANSYS.

Engineers are able to model and analyse the design's structural behavior, such as stress distribution, deformation, and failure spots, using ANSYS analysis. This data is useful for pinpointing potential points of failure and refining the design for maximum durability and dependability. Static structural analysis allows engineers to evaluate how a design will react to given loads, checking for compliance with all necessary safety aspects and design standards.

In addition, problems and constraints in the design can be found with the help of ANSYS analysis. It allows engineers to test the design under realistic conditions to see if it holds up to things like vibration, heat, and stability. Engineers can make better decisions on how to modify, update, or tweak components and materials to address design flaws and boost the design's performance and usefulness after running it using ANSYS.

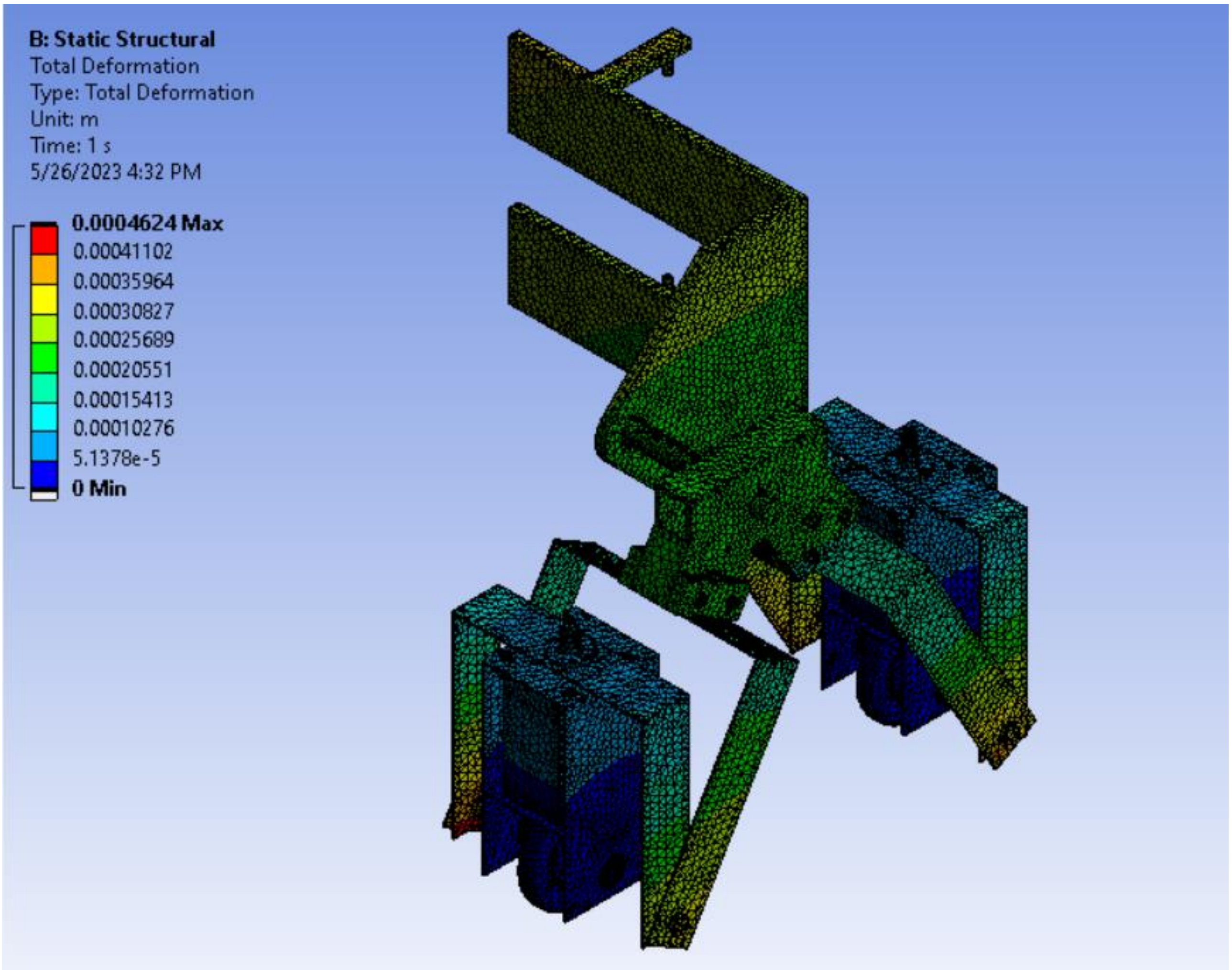

Figure 28 ANSYS Analysis of the proposed design

The model is comprised of a total of 54 distinct components. The components encompassed in this assembly comprise of the robot's wheels, primary body, screws, bearings, and loading platform. The objective of this simulation is to determine the static loading state of the robot under the condition where a 5 kg payload is present on the platform and the robot is stationary on the rack, with the motor being self- locked.

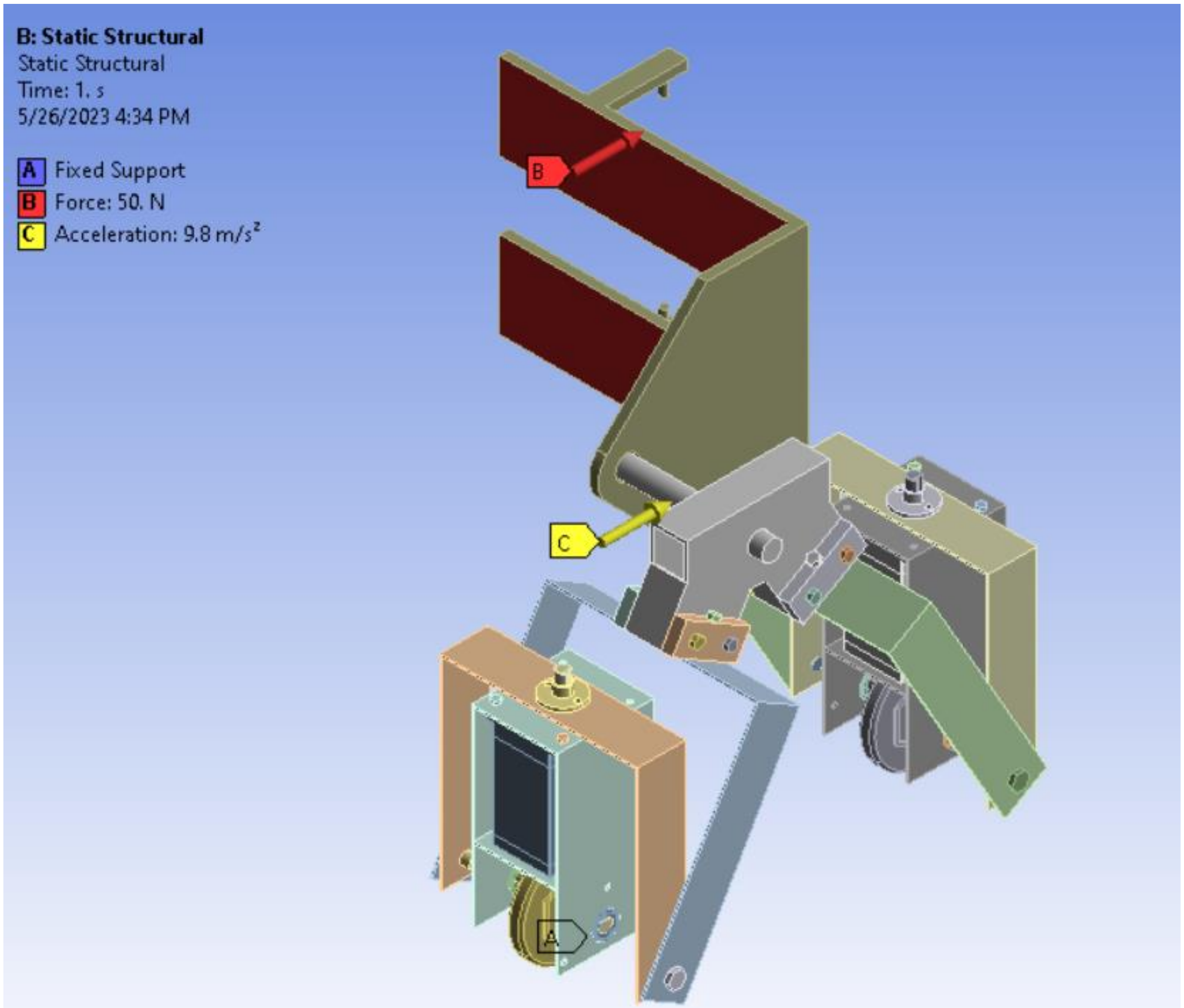

Figure 29 Parameters for the Calculation of deformation.

In ANSYS static analysis, nodes and mesh are very important for describing a structure's physical geometry and breaking it down into smaller parts that can be analyzed separately. Nodes are basically points in space that determine where the structure is and how it moves. In the finite element model, they are the points where different parts join. Each node has a unique number that identifies it and is linked to certain degrees of freedom, such as moving and turning.

On the other hand, the mesh is how the structure is broken up into small pieces. Depending on how hard the math is, these parts can be triangles, quadrilaterals, tetrahedrons, or hexahedrons. In the meshing process, the structure is broken up into these parts by joining the nodes in the right way. In this way, a discrete model comes close to the continuous shape.

The mesh density and type of element have a big effect on how accurate and efficient the research is. A coarse mesh could miss important features and give wrong results, while a fine mesh could take longer to calculate. The choice of element type should also match the type of study and the behavior of the structure being looked at.

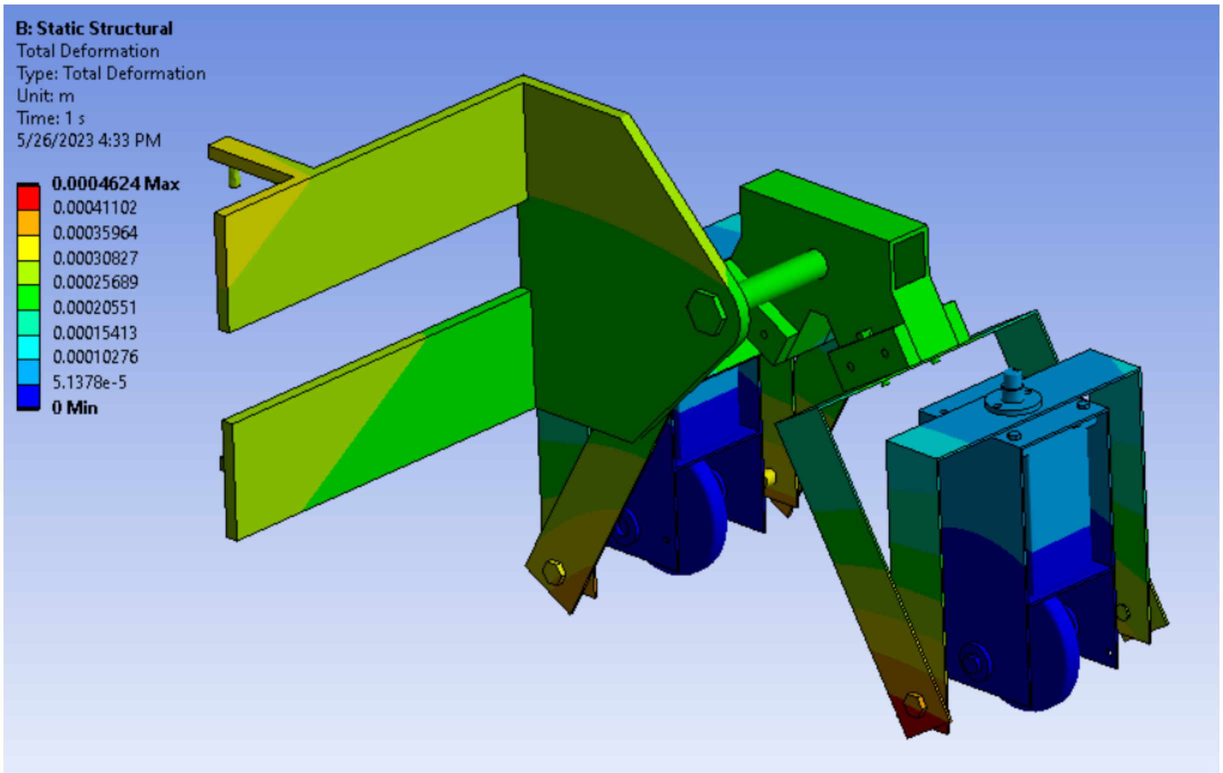

Figure 30 Robot whole chassis under full load.

ANSYS has different meshing ways to meet the needs of different types of analysis. Here are some of the meshing ways that ANSYS has to offer:

1. **Patch Independent Meshing (PIM):**

   PIM is an irregular meshing method in ANSYS that is completely automatic. It makes a high-quality mesh without any feedback from the user. PIM works well with both 2D and 3D models and is good for complex shapes.

2. **Multizone Meshing:**

   This method lets you make a mesh with different types of elements and settings in different places, or zones. It gives you options for how to mesh different parts of a model that have different needs, such as finer mesh in important areas and rougher mesh in less important areas.

3. **Hybrid Mesh:**

   A hybrid mesh is made by mixing different meshing methods in ANSYS. With this method, you can use the best parts of different meshing methods in different parts of the model. For example, combining structured and unstructured meshing methods to record both complex and simple geometries.

For our analysis we used a hybrid meshing method to incorporate the best of both methods. We used meshing element order to be program controlled which sets linear ordering for surface bodies and quadratic ordering for solid bodies. The sizing of elements was selected to be adaptive which allows different size of elements depending on the geometric properties, like a large element size for plane and large body and smaller size for complex parts in geometry.

Based on the results of the static analysis conducted by Ansys, we have made modifications to the dimensions of the aluminum sheets utilized in the construction of the robot, reducing their width from the initially assumed 6 mm to 2 mm. This alteration has led to a total reduction in weight of 16 kg, thereby decreasing the necessary torque required by the drive wheel motors (Power Window Motor) to climb the vertical rail. In addition to the necessary clamping force exerted by the linear actuator, this results in a reduction of the necessary torque for the power screw system motor. The utilization of lighter motors leads to reduced dimensions and increased portability, while simultaneously decreasing the power demand of the motors.

In conclusion, the evaluation and optimization of Design 3 rely heavily on the results of the ANSYS study. The best materials and parts may be chosen for a design thanks to the ability to simulate their use in the process. Finding instabilities, enhancing stability, and fixing prospective problems are all aided by ANSYS analysis. Engineers can make design iterations and improvements with the help of ANSYS, resulting in a more robust and efficient final product.

3.8.Calculations:

For the calculations of force required by linear actuator for clamping action we have:

Force applied by linear actuator: F_l

Total weight of the robot and cargo: W

Total height of robot from center of wheels to center of gravity: h

Total wheelbase of the robot: b

Reaction force by wheel A in x direction: F_{ax}

Reaction force by wheel A in y direction: F_{ay}

Reaction force by wheel B in x direction: F_{bx}

Reaction force by wheel B in y direction: F_{by}

Assume that the robot is climbing the rail and it stops midway. Now in this position the upper wheel is labeled as wheel A and lower wheel is labeled as wheel B as follow:

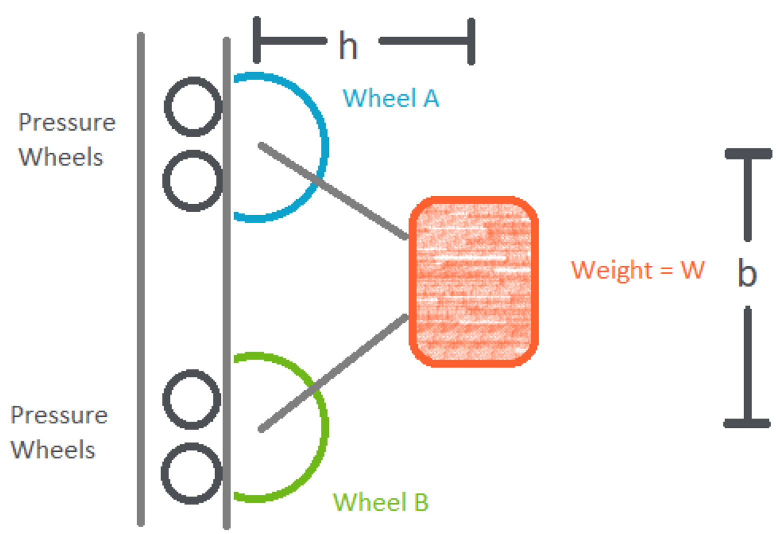

Figure 31 Calculations of the wheel Assembly on the railing mid traversal.

In the above figure we have a sideview of the robot which shows the pressure wheels being attached to the side rails while drive wheels gripping the main rail for traction.

Suppose we are using self-locking motors and both wheels are locked in place, then both wheels will behave as fixed points if enough static friction is provided to overcome the weight of robot. The free body diagram of the robot in this state would be as:

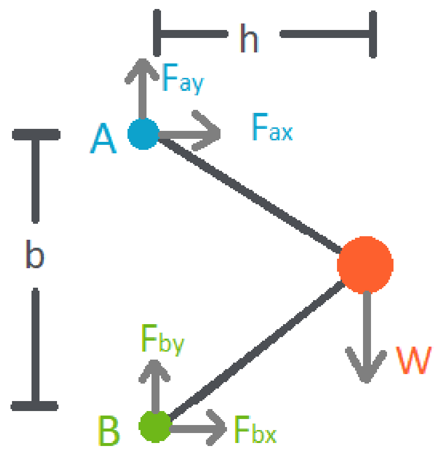

Figure 32 Free body diagram of the wheel Assembly on the railing mid traversal.

Now to calculate the amount of grip forced required by the linear actuator first, we apply equilibrium of moment at point B:

$$W \times h = F_a \times b \qquad (1)$$

$$F_{ax} = \frac{W \times h}{b} \qquad (2)$$

This force is in the assumed direction and by convention it will act on the pressure wheels instead of drive wheels.

Now, we apply equilibrium of moment at point A:

$$W \times h = -F_{bx} \times b \qquad (3)$$

The negative sign is because of both moments being equal and having opposite directions. Then:

$$F_{bx} = -\frac{W \times h}{b} \quad (4)$$

Here the negative signs show a change in direction compared to originally assumed direction, thus this force will act on the main drive wheels.

Then apply equilibrium of forces in y direction to get:

$$F_{ay} + F_{by} = -W \quad (5)$$

The negative sign is due to the opposite directions of forces. Suppose the y-component of forces on the points A and B are equal then we get:

$$F_{ay} = F_{by} = -\frac{W}{2} \quad (6)$$

Now the formula for static frictional force is:

$$F_s = F_{normal} \times \mu \quad (7)$$

Where μ is the coefficient of static friction.

Since we want to support the entire weight of robot and cargo, we need to equate the total static frictional force to the total weight.

$$(Force\ on\ top\ wheel) \times \mu + (Force\ on\ bottom\ wheel) \times \mu = (Total\ Weight) \quad (8)$$

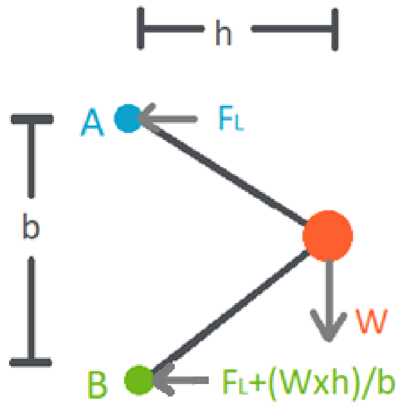

Figure 33 Force diagrams of the Clamping wheels

The amount of force acting on top wheel is equal to the force generated by the linear actuator only. That is:

$$Force\ on\ top\ wheel = F_l \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .\ \mathrm{i}$$

And the amount of force acting on the bottom wheel is summation of both the force generated by the linear actuator and the force applied by weight of the robot being F_{ax} which is as follow:

$$Force\ on\ bottom\ wheel = F_l + F_{ax} \qquad (9)$$

Thus, the equation becomes as follow:

$$F_l \times \mu + (F_l + F_{ax}) \times \mu = W \qquad (10)$$

According to previous equations $F_{ax} = {}^{W \times h}/_{b}$, thus we get:

$$F_l \times \mu + \left(F_l + \frac{W \times h}{b}\right) \times \mu = W \qquad (11)$$

Rearranging the equation gives:

$$F_l = \frac{W \times b - W \times h \times \mu}{2 \times b \times \mu} \tag{12}$$

$$F_l = \frac{(b - h \times \mu) \times W}{2 \times b \times \mu} \tag{13}$$

This equation gives the required amount of force to be applied by linear actuator to keep the robot in placed and thus supporting its weight.

Now we put the height of robot $b = 1.3 \times h$, $W = 120\ N$ (7 kg for the robot and 5 kg for the cargo) and an approximate $\mu = 0.3$ for our robot.

$$F_l = 200\ N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \text{ii}$$

For linear actuator we are using a lead screw mechanism with a geared motor. The amount of torque required by motor is then calculated by the following formula:

$$T_R = \frac{F \times d_m \times (\pi \mu_f d_m + L)}{2 \times (\pi d_m - \mu_f L)} \tag{14}$$

Where, F is the force to be lifted or applied.

d_m is the mean diameter and it is equal to sum of diameter and half of pitch.

L is the amount traveled per revolution, for single pitched it is equal to pitch of screw.

μ_f is coefficient of thread friction.

Put

$$F = F_l = 200\ N \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \text{iiii}$$

$$d_m = 7\ mm \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \text{ivv}$$

$$L = 2\ mm \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{v}$$

and

$$\mu_f = 1.5. \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{vi}$$

We get the required torque to be around:

$$T_R = 0.219\ N.m \tag{15}$$

For the calculations of the torque required by power window motors to lift the robot along with the cargo we have:

The torque of motor:

$$T = 5\ Nm \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{vii}$$

Diameter of wheel:

$$D = 4\ in = 10\ cm \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{viii}$$

Radius of wheel:

$$R = 2\ in = 5\ cm \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{ix}$$

Mass of robot and cargo:

$$m = 12\ kg \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{x}$$

Weight of robot:

$$W = m \times g = 12 \times 9.8 \tag{16}$$

$$W = 117.6\ N$$

Required Torque to lift this weight is:

$$T = F \times R \tag{17}$$

$$T = 117.6 \times 0.05$$

$$T = 5.88\ Nm \quad (18)$$

Torque required by single wheel is:

$$T = \frac{5.88}{2} = 2.94\ Nm \quad (19)$$

3.9.Hardware Section:

The robot's components were chosen after extensive calculations while considering their accessibility, cost, and performance.

3.9.1.Motors:

There are two types of motors being used, one for the main drive wheel and one for pressure wheels.

3.9.1.1.Power Window Motor:

Power window motors are a special kind of motor that is mostly used in car doors so that the window glass can be moved up and down. The locking device is the part of a power window motor that makes it stand out. When the power goes out, this motor stays in the same place by itself. It has a 20-degree pressure slope. On the shaft's end, there are seven teeth. This motor can turn both clockwise and anticlockwise, so it can go in either way.[38]

We use a power window motor to drive the main wheel because it has a small body and gives us the torque we need. It also includes a self-locking mechanism that provides automatic brakes whenever the robot must stop midway through the climb.[39]

Figure 34 DC gear motor used for the drive wheel.

Voltage	12V
Unload Current	3A
Rated Current	10A
Load Current	4.5A
Unload Speed	90 rpm
Rated Speed	60+/-10 rpm
Rated Torque	5Nm

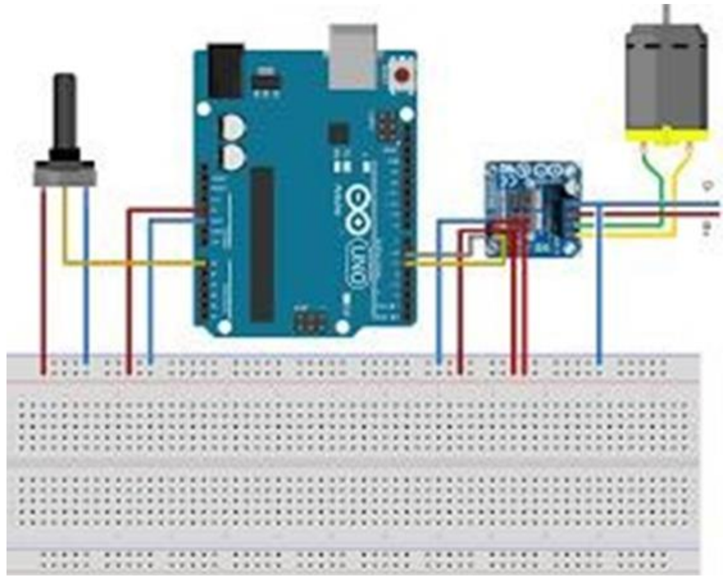

Figure 35 Circuit for the motor

3.9.1.2.Geared Motor:

DC gear motors combine a DC motor and a gearbox into a single, space-saving device. They allow for higher torque at a regulated and exact rotation. Wherever dependable and efficient power transmission is necessary, such as in robotics, automation, and a wide range of industrial applications, gear motors are often utilized. They are well suited for applications that require strong torque at low speed. Because of their compact size and integrated gear system, they provide good torque multiplication. DC gear motors are a versatile tool that may be used for controlled motion and power transfer in a variety of settings, from hobby projects to industrial applications.[40]

To reduce size and weight without sacrificing torque, we are employing a DC geared motor in the linear actuator which has torque higher than $0.219\ N$ as per the calculations. [41]

Figure 36 gear motor for linear actuator

Voltage	5V
Unload Current	0.15A
Rated Current	1A
Load Current	0.5A
Unload Speed	40 rpm
Rated Speed	30+/-5 rpm
Rated Torque	0.5Nm

3.9.1.3.Stepper Motor:

It is possible to transform electrical pulses into discrete mechanical revolutions or steps with the help of a stepper motor, which is a specific kind of electric motor. In situations where precise position control and synchronization are essential, stepper motors shine in comparison to traditional motors that rotate constantly.[42]

A stepper motor has a rotor, a stator, and a set of electromagnets that make up its basic structure. The motor's rotor spins, whereas the stator is always in one place. The electromagnets, or stator windings, are uniformly distributed over the stator's circumference. These electromagnets generate a magnetic field that interacts with the rotor by being energized sequentially.[43]

The principle of electromagnetic induction is at the heart of how stepper motor's function. The rotor's teeth or poles are attracted to the magnetic field created when the stator windings are energized in a specific order. The rotor progresses through the alignment process and into the next phase as the stator windings are energized. The stator windings respond to a series of electrical pulses that control the rotation's direction and speed.[44]

There are a number of benefits to using stepper motors. First, they allow for pinpoint management of location and motion. Accurate positioning and repeatability are made possible by the steps' correlating to fixed angular displacements. Second, the magnetic attraction between the stator and rotor allows them to stay put even when the power is off. When the motor needs to stay in one place or when there's a chance of a power outage, this holding torque comes in handy.[44]

Robotics, 3D printers, CNC machines, and industrial automation are just a few of the many uses for stepper motors. Their streamlined control interfaces, tremendous torque at low speeds, and pinpoint precision make them a popular choice. Specialised control circuits or microcontrollers commonly power stepper motors by generating the necessary pulse sequences to regulate rotation and speed.[45]

All things considered; a stepper motor is an electric motor that rotates in distinct increments. It accomplishes precise position control via the interplay of electromagnets in the stator and the rotor. Numerous fields that depend on precise, coordinated motion make use of stepper motors. Here are some of the advantages of stepper motors:

- High precision and repeatability
- No need for feedback devices
- Simple control
- Rugged and reliable

Here are some of the disadvantages of stepper motors:

- Can be noisy.
- Can be slow.
- Can be expensive.

We use stepper motors for our robot because the benefits by far exceed the drawbacks. For the application of rotating the wheels we are using NEMA 17 which is only about $1.7 \times 1.7\ in$ while providing ample amount of torque.[46]

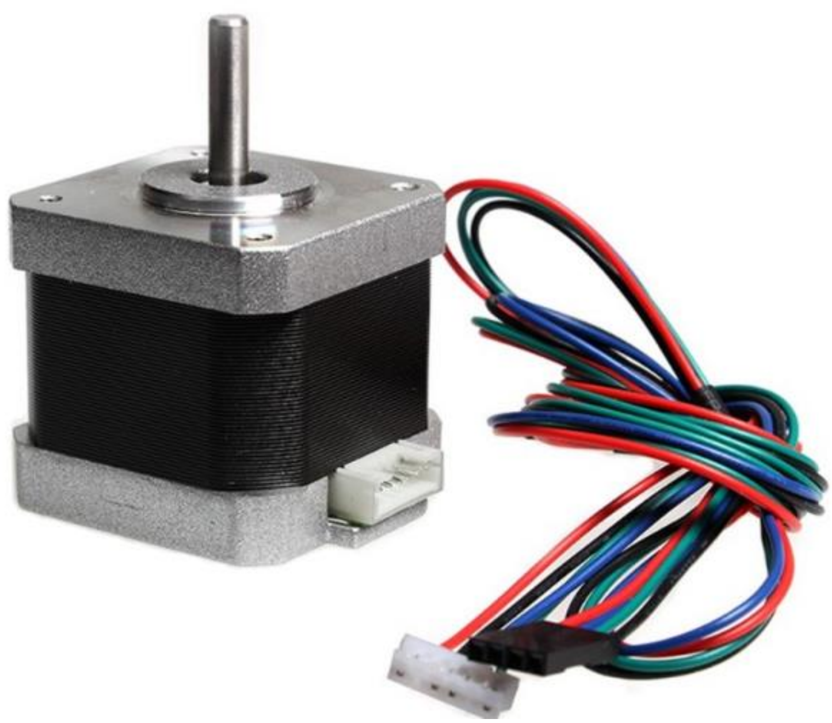

Figure 37 Stepper Motor for Platform rotation

3.9.2.Power Screw:

Mechanical power screws change the direction of rotation into linear motion. They feature a screw with a threaded shaft and a matching nut. When precise and regulated linear motion is required, power screws play a vital role. They have widespread applications in fields as diverse as manufacturing and transportation.[47]

Power may be transmitted effectively thanks to the mechanical advantage provided by the threads on the screw shaft and nut. When you turn a screw, the nut travels a linear distance down the length of the screw. This mechanism enables controlled movement and exact placement of loads or parts.[48]

Ball screws, acme screws, and lead screws are just a few examples of the many varieties of power screws on the market. Pitch, lead, and thread profile all have an effect on the power screw system's speed, precision, and load-carrying capacity.[49]

When a precise and regulated linear motion is required, lead screws are the recommended choice. They are easy to use, inexpensive, and can support a lot of weight. Lead screws are great for vertical or stationary uses due to their self-locking characteristic, which prevents them from moving in the absence of electricity.

Figure 38 Linear actuator mechanism with coupler and Screw

3.9.3.Microcontroller:

A microcontroller is a small, integrated circuit that combines the functions of a microprocessor, memory, and input/output peripherals into a single chip. It is designed to execute specific tasks and control electronic devices with high precision and efficiency. Microcontrollers are widely used in various applications, ranging from consumer electronics and automotive systems to industrial automation and medical devices. They provide a cost-effective solution for embedded systems, offering real-time control, low power consumption, and compact size. With their ability to interface with sensors, actuators, and other components, microcontrollers play a crucial role in powering the Internet of Things (IoT) revolution. Their versatility, flexibility, and programmability make them an essential component in today's technologically advanced world.[50]

3.9.3.1.Arduino Uno:

The ATMEGA328P forms the basis of the Arduino Uno microcontroller. It includes a USB port, a power jack, an ICSP header, a reset button, and 14 digital I/O pins in addition to 6 analogue inputs and a 16 MHz ceramic resonator. It has everything you need to get started with the microcontroller; all you need to do is plug it into a computer through USB or supply power via AC-to-DC converter or battery. We should not be too concerned when dealing with Arduino Uno, since the chip can be readily replaced, and it can begin functioning again.[51]

Figure 39 Arduino Uno

3.9.3.2.Arduino Mega:

The ATmega2560 forms the basis for the sophisticated microcontroller board known as the Arduino Mega. With its 54 digital I/O pins, it may be easily connected to other devices and expanded upon. Furthermore, it has 16 analogue inputs, allowing for extensive sensor integration and granular analogue readings. The Arduino Mega has a large amount of storage space for code and data, with 256KB of flash memory, 8KB of SRAM, and 4KB of EEPROM. The board can be powered by either an external USB cable or an external power supply. Multiple UART serial ports, USB support, I2C and SPI interfaces, and other communication options allow for simple integration with a wide variety of peripherals. The Arduino Mega, when programmed with the Arduino Software

(IDE), is a powerful platform for complex tasks needing a lot of input/output (I/O), storage space, and processing speed. Due to its low cost, wide availability, and sufficient capabilities, we have chosen Arduino Mega as the robot's central processing unit.[52]

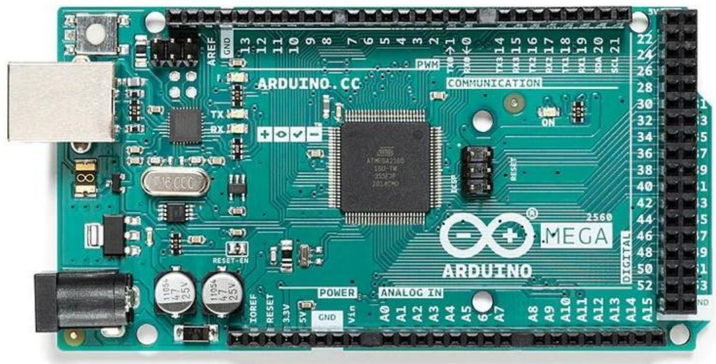

Figure 40 Arduino Mega

3.9.4.Power Supply:

A charger for a laptop computer can be used to power DC motors. Taking advantage of the laptop charger's output voltage and current capabilities, it can be used as a quick and easy power source for DC motors. A laptop charger, with the right wiring and voltage regulation, may provide reliable power for DC motors in a wide range of applications, including robotics, do-it-yourself projects, and even some small-scale automation. This low-cost option makes efficient use of preexisting resources and offers a realistic way to power DC motors without investing in costly external converters. We are using a Dell Laptop charger providing power up to 90W which is more than enough to power both power window motors.[52]

3.9.5.Bearing:

Bearings are essential mechanical parts because they prevent unwanted movement and allow for easy rotation. Rolling elements, like balls or rollers, are sandwiched between an inner and an outer ring. The automotive, manufacturing, and machinery sectors are just a few examples of the many uses for bearings. They provide for the smooth transfer of rotational motion while bearing substantial loads with little to no detriment to their service life. Bearings play a crucial role in maintaining the smooth and reliable operation of machinery and equipment due to their capacity to reduce friction and boost overall performance.[53]

We are using bearings of inner diameter of 8mm for supporting the axle of main drive wheel. Also, we are using another bearing of inner diameter of 12mm for ease of rotation of the drive boxes.

Figure 41 Bearings used for clamping mechanism.

3.9.6.Mecanum Wheels:

Mecanum wheels are a subset of omnidirectional wheels that provide robots unprecedented freedom of movement. These unusual wheels have several little rollers set at an angle to one another, giving them the ability to roll in both directions. The robot's accurate translations and rotations are made possible by individual control of each wheel's rotation. Robotics, automation, and the material handling industries are just a few of the many places where Mecanum wheels are put to use. Because of their high degree of mobility, they can easily do activities including navigating in any direction, pinpointing their exact location, and navigating tight spaces. Mecanum wheels have several benefits, but they also have some drawbacks. The benefits they offer are outweighed by the fact that they have a worse grip than regular wheels and need an additional motor to be controlled.

Figure 42 Wheel Module for the platform wheels

3.9.7.Steel Ball Omni wheels:

Unique among wheel designs, steel ball omni wheels enable robots and vehicles to move in any direction. These wheels can roll in any direction since they are equipped with a ring of tiny steel balls. Smooth motion and rotation may be achieved even in tight quarters thanks to the balls' ability to function as individual wheels. Omni wheels with steel balls provide for greater maneuverability, finer control, and less drag. Robotics, automation, and portable platforms all benefit from their utilization because of the importance of fast, precise motion. Their only real drawback is that they don't grip well on some surfaces and wear out quickly. However, they are a practical choice due to their simplicity, low price, and availability.

Figure 43 Alternative to Mecanum wheels

Chapter 4- :

4.1.Fabrication

The term "fabrication" is used to describe the process of building and assembling a robot from its constituent parts and subsystems. Putting together materials, electronic components, mechanical elements, and software programming to realize design concepts and standards.

The production of robots plays a crucial role in maximizing the effectiveness and productivity of warehouse management. Material handling, inventory control, order fulfilment, and transportation are just some of the warehouse-specific duties that can be performed by these robots.

The first step in the fabrication process is to develop a comprehensive manufacturing strategy that considers every aspect of the robot's design and functional requirements. The materials, parts, and production methods needed to assemble the robot are spelt out in detail in this design. The robot's longevity, reliability, and performance in a warehouse context all hinge on the materials you choose for it.

After all the necessary materials are gathered, skilled craftspeople next shape, cut, and assemble them into the final product. Welding, milling, 3D printing, and wiring are all examples of such procedures. Precision and accuracy are given extra care to guarantee the robot's correct positioning and optimal performance.

During the manufacturing process, quality control checks are carried out to ensure that the robot's parts are complete and fully operational. Individual components may need to be tested, as well as overall performance and adherence to safety regulations.

After construction is finished, the robot is put through extensive testing and validation to make sure it lives up to its promised capabilities. The capabilities and dependability of the robot in a warehouse setting are tested by performing functional tests, stress testing, and simulations of actual warehouse scenarios.

The production of robots for use in warehouse management contributes to a number of ways. Automation of routine processes, reduction of human effort, and enhanced precision in inventory management all contribute to greater warehouse productivity. These robots can work without stopping, consistently, reducing human mistakes and speeding up the distribution process. Robots can be tailored during manufacture to do tasks unique to warehouses, such as moving between different product categories or navigating intricate floor plans.

4.1.1.Components of the SqUID bot

The SqUID bot is a warehouse stacking robot that is designed to climb and navigate vertical rails. The robot is made of three main components: the railing system, the main body, and the platform.

4.1.1.1.Railing System:

The railing system plays a pivotal role in the robot's functionality, offering essential structural support and ensuring stability during vertical climbing maneuvers. To fabricate this crucial component, meticulous attention was given to every detail. A standard railing was carefully chosen as the foundation, serving as the base structure for the system. To achieve the desired L shape required for secure clamping of the wheels, a Plane Mild Steel thin sheet was skillfully welded to the railing. The welding process was executed with precision, guaranteeing a robust and durable connection that could withstand the rigorous demands of the robot's operations. This meticulous fabrication process yielded an optimal shape, enabling efficient wheel clamping and ensuring the railing system's ability to withstand the forces involved in vertical climbing.

4.1.1.2.Main Body

The main body of the robot is the central axle that houses all the essential elements required for movement and climbing along the railing system. The main body is made of a 4mm thick aluminum sheet. The use of aluminum offers several advantages, such as its lightweight nature and excellent strength-to-weight ratio.

In the fabrication process, small U-shaped rectangular components were strategically incorporated in layers within the main body structure. These components served multiple purposes, providing mounting points for motors, wheels, and clamping mechanisms. By carefully positioning these components, the robot's weight distribution was optimized, ensuring efficient movement and stability during operation.

To further enhance the stability and maneuverability of the robot, the main axle was designed in a reverse boat shape. This unique shape provided a wider wheelbase, distributing the load evenly across the wheels and increasing the overall stability of the structure. With a stable and well-designed main body, the robot could navigate the vertical rails with precision and control.

4.1.1.3.Platform

The platform of the robot plays a vital role in supporting additional components and carrying loads. The platform is made of two sheets of 4mm thick aluminum that have been layered together. This construction method increases the integrity and strength of the platform, enabling it to handle substantial loads without compromising stability. The choice of aluminum for the platform also offered additional benefits. Apart from its inherent strength, aluminum is resistant to corrosion, ensuring the longevity of the robot. Furthermore, aluminum's excellent thermal conductivity facilitated efficient heat dissipation, making it ideal for applications requiring prolonged operation.

Moreover, the use of aluminum for the platform facilitated the integration of Magna wheels. These specialized wheels possess unique features such as enhanced traction and maneuverability, which greatly contributed to the overall performance of the robot. With the Magna wheels integrated into the platform, the robot could navigate through various terrains and overcome obstacles with greater ease and precision.

4.1.2.Fabrication Process

The fabrication process of the SqUID bot's components involved careful selection of materials and precise assembly techniques. The railing system was constructed by welding a Plane Mild Steel thin sheet to a standard railing, providing the necessary L shape for clamping wheels. The main body, fabricated using a 4mm thick aluminum sheet and incorporating U-shaped rectangular components, offered stability and efficient weight distribution. The platform, crafted from layered aluminum sheets, ensured strength, load-carrying capacity, and integrated Magna wheels for enhanced maneuverability. The combination of these well-fabricated components resulted in a robust and agile robot capable of climbing and navigating rails effectively.

4.1.3.Railing:

4.1.3.1.Design Considerations:

The process of making the SqUID bot railing begins with careful design considerations. The main objective is to construct a solid structure that can support the robot's movement along a preset path. The channel on one side of the robot, which the clamping wheels would travel through, was employed in the railing design that we selected.

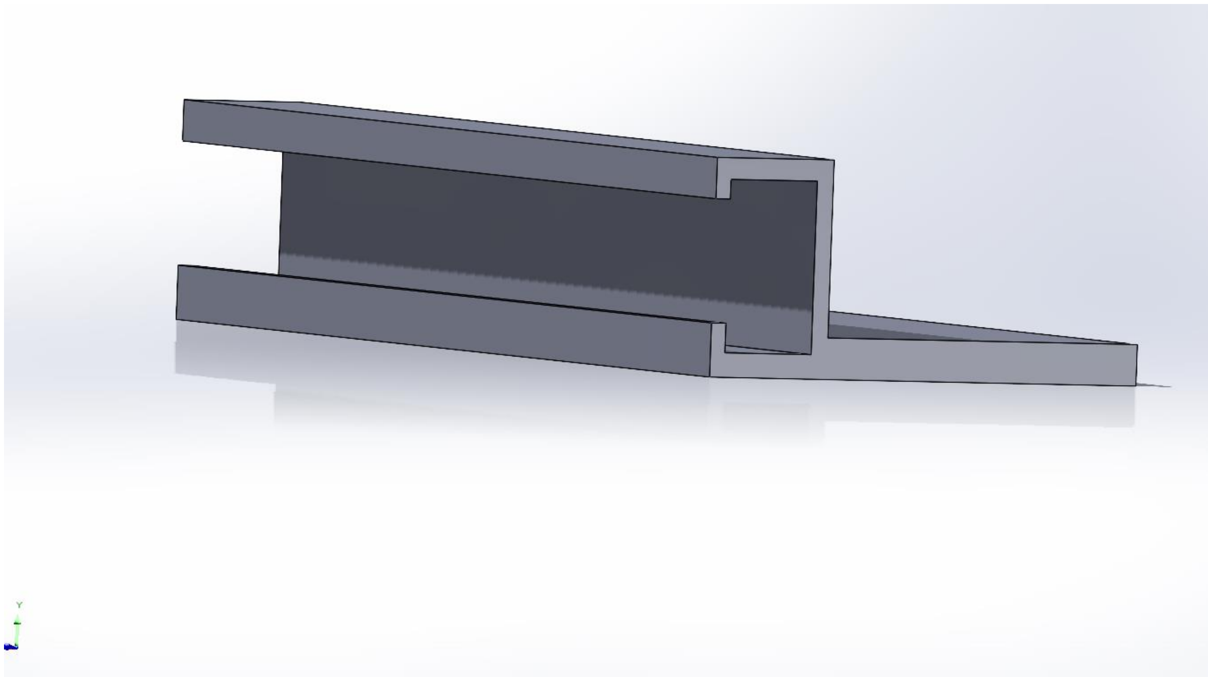

Figure 44 intended Design for the railing.

4.1.3.2.Material Selection:

The main driving wheel path is made out of steel, while the channel is made out of aluminum. These two materials are utilised to make the railing. Aluminum is utilised for the channel because it is strong, lightweight, and corrosion resistant. Steel is utilised for the main drive wheel path because it is durable and robust enough to handle the weight and wear caused by robot movement.

The channel dimensions were 3x1.5 cm. This channel was selected as the clamping wheels are of 1.4 cm. The main drive wheel plate width was kept being 4 cm (1.57 in) as we are using wheels of 1 inch.

4.1.3.3.Production Process:

The main driving wheel's route was created using a steel plate, while the support wheels were created using an aluminum channel. Steel sheet and channel were first cut to the necessary lengths before production began. In accordance with the specifications of the design, the strips are created and bent. The channel was forcefully bent after being cut at evenly spaced intervals to create the bent in effect. The channel and aluminum strip were then joined via welding.

The aluminum railing is treated on the surface after welding to boost its tensile strength. Rough edges are rounded off, and the surface is cleaned of any welding slag. Grinding was employed to produce a surface that was uniformly smooth.

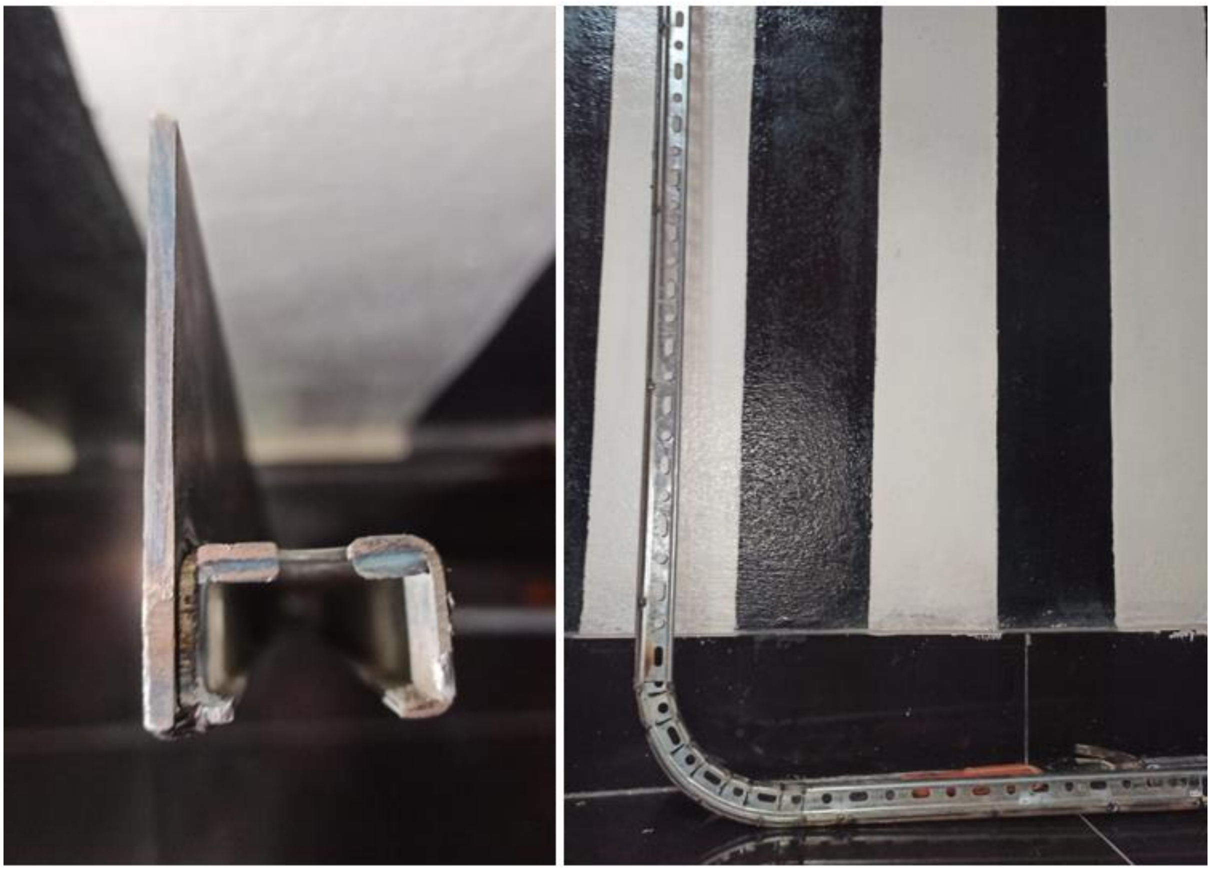

Figure 45 Front(left) and side(right) view of the fabricated railing

Chapter 5- CONCLUSION AND FUTURE WORK

5.1.Conclusion:

The SqUID bot is a strong and adaptable robot that has several potential applications in a manufacturing or storage facility. The robot may be used to move goods around the warehouse, stack pallets, and retrieve items from high shelves. The SqUID bot's ability to go around obstacles and over rough terrain makes it a good fit for use in complicated warehouses.

The SqUID bot represents a major technical leap with game-changing potential for the warehousing sector. Workers will have more time for customer service and inventory management because of the robot's ability to do activities currently performed by humans. The SqUID bot will also contribute to a more secure warehouse by decreasing the likelihood of injuries from laborious manual handling.

The SqUID bot is a compelling symbol of the promise of robotics to better human life. The robot's potential to revolutionise numerous industries lies in its capacity to do complicated tasks with pinpoint accuracy and high efficiency. We can look forward to ever more impressive robots that will make our lives easier and more productive as robotics technology advances.

5.2.Future work:

This project was made with the aim for the stacking in a warehouse, but as this is, the first prototype of its kind so there can be many improvements made to the SqUID bot as given below:

a) Can introduce AI to become self-operating.
b) GPS can be added to give the live location of the robot.
c) Bluetooth mechanism can be added to operate the robot wirelessly.
d) Color counting mechanism can be added to reach the exact position on aisle.
e) A suction pump mechanism can be added to fetch the package on the payload of bot.
f) Climbing speed of robot can be increased.
g) Cooling mechanism can be added for motors to operate for a much longer time.

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