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DESIGN AND DEVELOPMENT OF DELIVERY ROBOT

COLLEGE OF
ELECTRICAL AND MECHANICAL ENGINEERING
NATIONAL UNIVERSITY OF SCIENCES AND TECHNOLOGY RAWALPINDI
2024

COLLEGE OF ELECTRICAL AND MECHANICAL ENGINEERING

DE-42 MTS
PROJECT REPORT

DESIGN AND DEVELOPMENT OF DELIVERY ROBOT

Submitted to the Department of Mechatronics Engineering
in partial fulfillment of the requirements
for the degree of

Bachelor of Engineering
in
Mechatronics
2024

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ACKNOWLEDGMENTS

We would like to take this opportunity to express our heartfelt gratitude to the many individuals and organizations who have supported and guided us throughout the completion of this Final Year Project. First and foremost, we extend our deepest appreciation to our project supervisor, Dr Amir Hamza and co-supervisor, Col. Dr. Kunwar Faraz for their unwavering support, guidance, and invaluable insights. Their expertise, encouragement, and constructive feedback have been instrumental in shaping this project and enhancing my understanding of the subject matter.

We are also grateful to the faculty and staff of the NUST College of Electrical and Mechanical Engineering for providing a conducive learning environment and access to essential resources, without which this project would not have been possible. We would like to extend our thanks to our batchmates and friends who have been a source of inspiration and motivation. Their discussions, brainstorming sessions, and camaraderie have played a significant role in our personal and academic growth. We are indebted to our family for their unwavering support, encouragement, and patience throughout this academic journey. Their belief in our abilities and their sacrifices have been the driving force behind our accomplishments.

This project has been a tremendous learning experience for us, and it would not have been possible without the collective support and encouragement of these individuals and entities. We are truly grateful for their involvement in our academic journey. Lastly, we would like to express our gratitude to all those whose names may not appear in this acknowledgment but who have, in one way or another, contributed to the successful completion of this project.

ABSTRACT

This project focuses on designing and developing an autonomous ground vehicle for delivery purposes, with a particular emphasis on simplifying delivery processes with minimum human interactions. The main goal is to create an affordable and efficient solution for last-mile delivery in indoor environments. The drive architecture of the vehicle is equipped with various components, including LIDAR for localization, a camera for navigation, and an LCD display for assistance. These components are integrated into a microcontroller-based control system, which processes the data and navigates the vehicle autonomously to its destination. The design prioritizes simplicity and ease of maintenance, with modular components that can be easily replaced or upgraded. The chassis is constructed from strong and durable materials, making it suitable for various terrains. The fabrication process involved assembling off-the-shelf components, such as motors, wheels, battery and microcontrollers into a functional vehicle platform. The performance of the autonomous ground vehicle was evaluated through tests in real-world conditions, demonstrating its effectiveness in autonomously navigating indoor urban environments and delivering packages. Overall, this project contributes to the field of autonomous robotics by providing a practical and scalable solution for last-mile delivery challenge.

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LIST OF SYMBOLS

Latin Letters

m mass of complete robot with payload
I
moment
of
inertia w
angular
velocity
r
turning
radius
u coefficient of friction
g acceleration due
to gravity v
forward velocity

Greek Letters

α angular acceleration

Acronyms

UGV unmanned ground vehicle

CHAPTER 1: - INTRODUCTION

1.1 Project Background:

The rise of e-commerce and urban offices has led to a growing demand for effective last-mile delivery solutions. However, traditional delivery methods such as human couriers often face challenges in indoor environments like warehouses, hospitals, and office buildings due to limited budgets and recruitments. During the recent years in Corona Virus, a huge increase in demand was seen for contactless delivery services due to the spread of virus across the globe [1]. The world shifted to an online system that on one hand included online offices and education and on the other hand revolutionized the way at we think of our delivery services, we sought great potential in delivery robot systems in both indoor and outdoor environments [2]. It was seen that these autonomous delivery systems can not only provide with contactless delivery service but reduce human labor from offices to hospitals to warehouses, seeing this huge gap in market, we came up with a idea of designing a autonomous delivery robot [3]. This delivery robot will be first implemented in indoor environments with maximum payload of 5kgs. We aim to make a sustainable bot which can also be seen reliable in rather some rough conditions in addition to smooth indoor environments.

This project focuses on the design and development of an autonomous ground delivery robot tailored for indoor environments. The robot is intended to navigate autonomously using onboard sensors, eliminating the need for external control systems, and making it cost-effective and adaptable to various indoor settings. Key components of the robot include LIDAR for navigation, a durable chassis design for maneuverability, and a simplified control system for autonomous operation [4].

The project aims to demonstrate the feasibility and effectiveness of using autonomous ground delivery robots for indoor last-mile delivery [5]. By providing a cost-effective and efficient solution for indoor delivery, this project has the potential to revolutionize the way goods are transported and distributed in indoor environments. This project will be covered by 2 groups. We will be focusing on the design and fabrication of the bot, implementing the motor drive architecture, and performing all analysis to its goals. The other group will be focusing on the control part of the project. They will try to control and navigate it autonomously.

Overall, this project represents a significant step toward realizing the potential of autonomous ground delivery robots to improve last-mile delivery in indoor environments, making it more efficient, cost-effective, and sustainable.

1.2 Scope

Indoor ground delivery robots have a wide range of applications across industries such as warehousing, retail, healthcare, hospitality, office buildings, and manufacturing. These robots can automate tasks like moving goods within warehouses, restocking shelves, fulfilling online orders in retail, and transporting medications in healthcare facilities [6]. In hospitality, they enhance guest experience by delivering room service orders and amenities. Office buildings benefit from these robots for mail and package delivery and interdepartmental document transport [7]. In manufacturing, they optimize workflow by transporting components and materials [8]. Overall, indoor ground delivery robots improve operational efficiency, reduce labor costs, and enhance customer and employee experiences in various industries.

1.3 Deliverables

- Design and fabrication of a skid steer drive delivery vehicle having capability totransport payloads up to 5kgs in indoor environments.
- Performing complete kinematic, dynamic, and structural analysis of the vehiclefor the target payload.
- Development of a motor drive control architecture to achieve smooth drive during transportation of payloads.

CHAPTER 2: – LITERATURE REVIEW

2.1 Overview

The research on indoor ground delivery robots reveals a growing interest in their development and applications across various industries. These robots offer a promising solution to the challenges of last-mile delivery in indoor environments, such as warehouses, hospitals, and office buildings. Researchers and engineers have explored different aspects of indoor ground delivery robots, including design, navigation, control systems, and applications. One key research area is the design of indoor ground delivery robots. Studies have focused on creating robots that are compact, agile, and capable of carrying various payloads. Researchers have explored different chassis designs, sensor configurations, and locomotion mechanisms to optimize the robot's performance in indoor environments [9]. The applications of indoor ground delivery robots are vast and varied. In warehouses, these robots can automate tasks such as inventory management, picking, and packing, leading to increased efficiency and reduced labor costs [10]. In healthcare settings, they can be used to transport medications, medical supplies, and lab samples, improving the efficiency of healthcare operations [11]. In retail environments, they can automate the process of restocking shelves and fulfilling online orders, enhancing the customer experience. Overall, the research on indoor ground delivery robots highlights their potential to revolutionize the way goods are transported and distributed in indoor environments. Continued research and development in this field are expected to lead to further advancements in robot design, navigation, and control, ultimately leading to more efficient and cost-effective indoor delivery solutions.

2.2 History

The history of delivery robots' systems ranges back to early 2000s when the first ever delivery robot system was thought of. But the foundation of all these systems, the basis of design and idea ranges back to 1950s when Joseph Engelberger, who is also known as father of robotics, laid foundation for modern robotics and automation [12]. It was his concept which led to the idea of delivery robots. General Electric (GE), a pioneer company in renewable energy, shed some light on this idea and made the first ever mobile robot named “GeeWhiz” in 1960s.GeeWhiz was a mobile robot designed for material handling applications within industries. GE was interested in early research and development of robotic technology for mostly industrial applications. They thought that mobile robots hadthe potential to revolutionize the industry that we operate [13]. GeeWhiz was designed for autonomously transporting objects from one location to another.

Unluckily, this robot did not lead into a commercial product. Surely, this was a representation of the potential of ground robots as a replacement for human labor.

Sizing the potential set up by GE, Institute of Applied Artificial Intelligence(IAAI) in late 1980s and early 1990s introduced a delivery robot system named “Robotino” to the world [14]. This was aimed to assist in logistics and transportation. It helped refine the technology and algorithms needed for mobile robots to navigate autonomously in dynamic environments and interact safely with humans and other objects in their surroundings. Robotino was equipped with sensors, actuators and computer system that helped it navigate in indoor environments. All this led to the early concepts of autonomous delivery services in the early 2000s. Certain researchers and visionaries were inspired by the potential these robots brought to the table. In the meantime, certain advancements were madein sensor technology and computing power so that it was thought that the myths of autonomous delivery could be shaped into reality. Work on navigation and obstacleavoidance was also pushed forward by universities and research centers aimed at creating and conceptualizing this idea in controlled environments. In the late 2000s,prototyping of these robots began. These were not too reliable but early robots wereoften large, cumbersome, and limited to their range of capabilities.

In early 2010s, seeing the potential of this field many pioneering companieslike Starship technologies (2014), Savioke (2013) and Amazon Robotics stepped inwhich the research and development of these robots. Starship technologies was founded by Ahti Heinla and Janus Friis aimed on making small, wheeled delivery robots designed for not heavy duty rather focused on local deliveries [15]. Savioke was founded by Steve

Cousins aimed at making Relay robots which will originally be made for hotel deliveries [16]. Amazon, a company renowned for their innovations in logistics, came up with the idea of making six wheeled robots for delivery of packages to their customers to their homes in settled urban areas [17].

From 2010 to 2020, these companies grew up to launch their pilot projects like delivery of food and groceries over short distances. Starship technologies launched a similar project in London. Other companies also started their autonomous delivery robots in real world settings and environments.

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2.3 Present Technology and Future

Today many companies have registered in research and development of autonomous delivery services namely kiwi Bot, Nuro and Yandex Rover. These have invested heavily in automation and robotics. Starship Technologies have started testing their robots in countries like the US and UK for food delivery services. Amazon Scout and Uber Eats has also invested in delivery robots in selected neighborhoods [18].

Companies aim to increase the efficiency as well as cost effectiveness in delivery robots' systems. Autonomous robots are seen as a convenient and accessible delivery service. By offering on-demand delivery options that are fast, reliable and easy to easy companies hope to attract more customers. Companies hope to contribute to environmental sustainability by reducing their carbon footprint. By using electric powered delivery robots instead of traditional delivery options companies can contribute to a cleaner and greener environment. The hope to achieve an environment in which all sorts of delivery services are fully optimized through automation and technology [19].

2.4 Current Situation of Indoor Delivery

Currently in developing countries like Pakistan, autonomous indoor delivery services are still not documented. People in these countries are still livingin the era in which human labor is used for delivery of packages, components or even small things like medicines or files. This is due to the sole reason of cheap human labor. As the countries are progressing and literacy rates are going up, the modern industry is shifting towards the use of only technical labor. Technical labor is human labor with technical knowledge to benefit the industry or a company. All the tasks like loading, moving and storing are now being shifted to machines for better accuracy and time management.

Study from Merchant, M.E., “The Inexorable Push for Automated Production,” Production

Engineering, January 1977, pp. 45–46 [20], we see that 95% of the time spent in material handling in a factory or industry is in moving and waiting for processing in industry and 5% of the time is spent on machine.

A greater statistic is that out of this 5% time spent on machine, 70% is spent on loading, positioning, and gauging and about 30% is spent on processing such as cutting etc. This tells us that to increase efficiency of a production plant is of utmost necessity to increase automation in material handling rather than only spending capital on processing [21]. If the process of material handling is smoothened using delivery robots and automated vehicles, the efficiency of the industry will increase way much. [22]

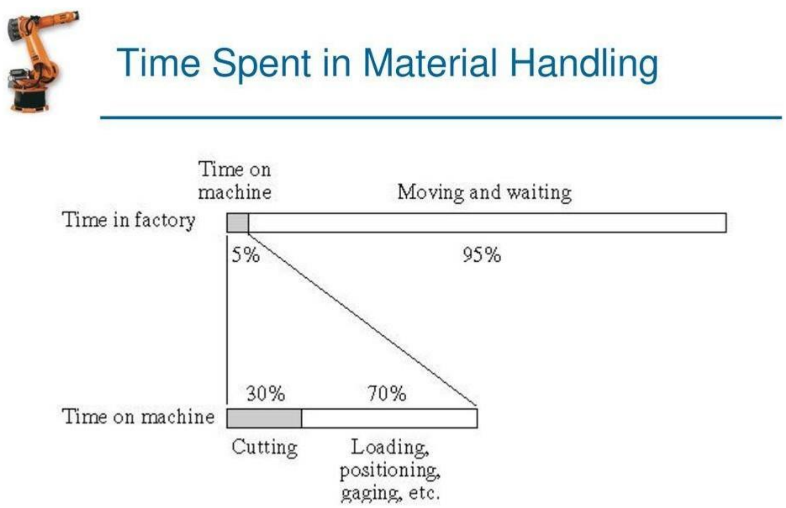


Figure 1 Time spent in material handling [22]

2.5 Current and Predicted Market

The current market for autonomous delivery robots is around 500 million dollars worldwide but this market is continuously booming. We have seen that demand of delivery robots has surged in developed countries and regions like North America and Europe [23]. The continent of Asia is also booming in this industry as it has good potential for autonomous driven robots.

Many researchers and businessmen around the globe have determined a huge increase in the market of delivery robots from 2022 onwards to 2025. It is expected that the market will surge 400% and will reach 2000 to 2500 million dollars from 500 million dollars in 2022. It was found that this market will be in center of the attention of all the investors as it will find its application in all fields from medicine to food restaurants to warehouses and work [24]shops in military bases and cargo storage houses. This contactless delivery service will help eradicate the spread of diseases in far flung areas that pose threat to people transporting essentials to the infected people in the area.

Another survey has declared that the market will expand near to 4000 million dollars till 2032 year. This survey has declared that the greatest market increase will be in North America. Europe will come in the second place with Pacific-Asia in the end. [24]

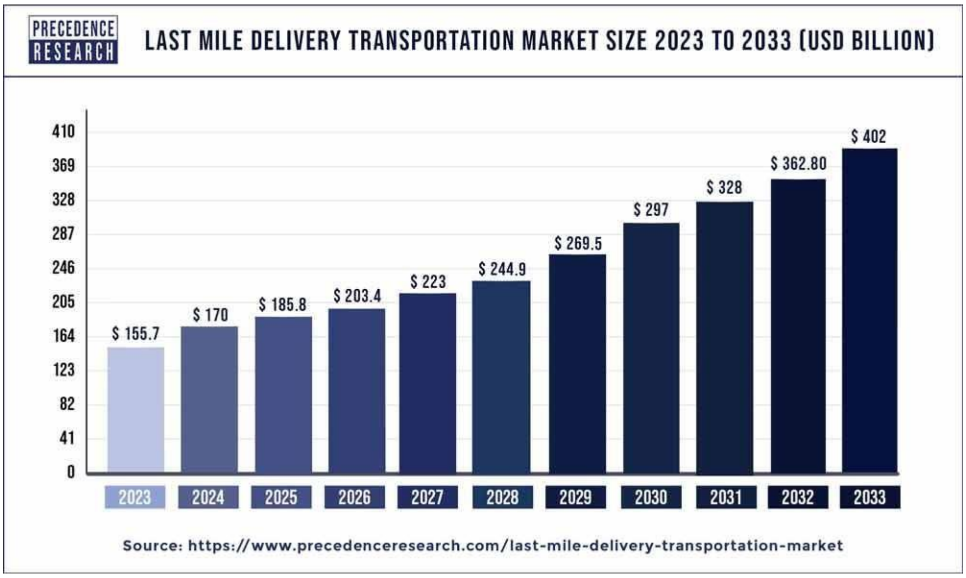


Figure 2 Market Overview of delivery Robots [24]

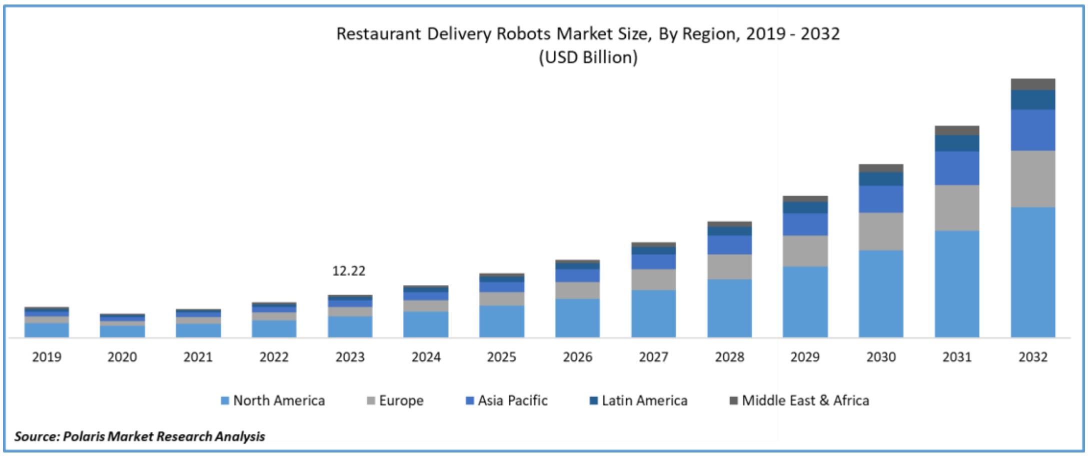


Figure 3 Market Size of delivery robot in different regions [25]

2.6 Types of Delivery Robots

There are many types of delivery robots that the world has seen till this date today. All of them are designed for different purposes and specific environments.
Following are some of the types of these autonomous delivery robots:

2.6.1 Ground Delivery Robots

These delivery robots are designed to operate by travelling and transporting payloads through the ground [26]. These robots usually operate in indoor environments but are now being expanded to last mile delivery services for carrying packages and payloads from one point to another. [27]

Figure 4 Ground Delivery Robot [27]

2.6.2 Aerial Delivery Drones

These are unmanned aerial drones aimed at carrying small payloads from one place to another through the air. These UAVs are used for delivering goods over medium or short distances [28]. The concept is to introduce such drones in places where there is an issue of terrain or limited road infrastructure. [29]

Figure 5 Aerial Delivery Drone [29]

2.6.3 Warehouse Robots

Many delivery robots are used in warehouses for material handling of goods before they are being transported for sales or as packages to customers. Huge manpower is required for the handling of these warehouses [30] . These robots were introduced to reduce human labor and automate the process of picking, packing, and shipping goods. These robots can move shelves, pallets, and individual items within a warehouse. [31]

Figure 6 Warehouse Delivery Robots [31]

2.6.4 Food Delivery Robots

Food delivery is also seen as a potential market for delivery systems to be engaged [32]. Modern restaurants are leading to contactless delivery of food in restaurants by introducing automated robots as waiters which will take orders as well as deliver food to the table autonomously. [33]

Figure 7 Food Delivery Robot [33]

CHAPTER 3: – HARDWARE

3.1 Main Components

In this section, we delve into comprehensive details about the components constituting the autonomous delivery robot (ground vehicle), revolutionizing the payload delivery process. The underlying principle of mechanical mobility involves making light weighted and durable chassis, mounting wheels and motors (notably having enough torque), sensors for object detection and navigation, power system and a payload handling mechanism. This chapter aims to provide an in-depth analysis of the core components targeted in this project.

3.1.1 The Motor Controller

Any system's brain is its processing unit, which controls input from a variety of sensors and sends commands to output devices when necessary. We have decided to utilize the Arduino 2560 as the onboard controller for our Unmanned Ground Vehicle (UGV). This is illustrated in the figure that goes with it. The ATMEGA 2560 microcontroller, which runs at 16MHz and has a built-in USB/ISP interface for programming, is the basis of the Arduino 2560 [34]. The MEGA board can be expanded with a variety of add-ons, such as Ethernet, GSM, motor driver, and GPS shields [35].

Figure 8 Arduino Atmega [35]

Specification	Explanation
Microcontroller	Atmega2560
Operating Voltage	5V
Input Voltage	7-12V
Digital I/O pins	54
Analog Input pins	16
Flash Memory	256KB
SRAM	8KB
EEPROM	4KB
Clock Speed	16MHz

Table 1: Specifications of Arduino Atmega

3.1.2 The Chassis

The chassis is the foundation of the delivery robot system. It is the frame of the robot that supports all the components inside it. Chassis handles the payload handling mechanism along with battery, motor controllers, sensors etc. The weight of chassis is of great importance which in turn highlights the significance of the material used in fabricating chassis. The material used in making chassis are hollow steel rods. Hollow steel rods have high strength and durability which makes them ideal for chassis of delivery robots. They have the capability to withstand heavy loads without breaking.

An added advantage lies in weight management, these steel rods are very cheap, and light weighted so they can hold maximum payload while producing minimum load on motors. The dimensions of the chassis are 20 x 40 inch. The height of the robot will be 12inch. The ground clearance is set to be 2inch for the chassis.

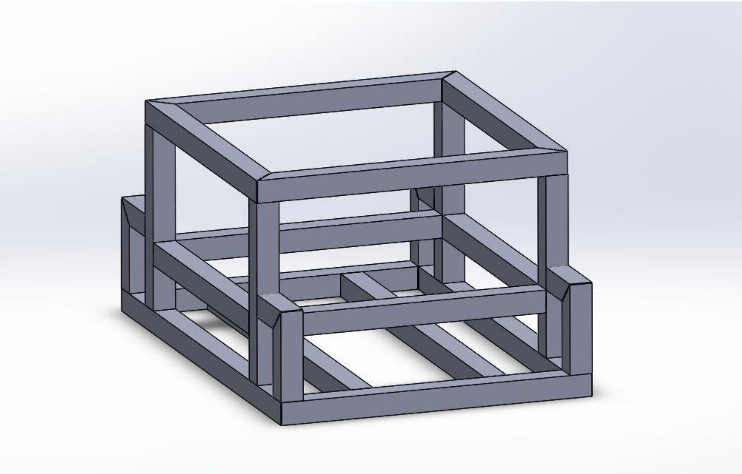


Figure 9 Chassis

Property	Typical Value
Tensile Strength	400 – 700 MPa
Yield Strength	250 – 450 MPa
Modulus of Elasticity	190 – 210 GPa
Poisson's Ratio	0.27 - 0.30
Density	7.85 g/cm^3
Thermal Conductivity	40 – 60 W/(m.K)

Table 2: properties of hollow steel rods

3.1.3 Wheels

Wheels are a crucial part for mobility of robots. The wheels used in this robot are light rubber wheels with diameter of 6.5in. They produce ground clearance of 2inch and wheels with 2 DOF are used instead of mecanum wheels (4 DOF) for cost effectiveness. These wheels are durable and due to their large diameter, they also cater the issue of slippage in indoor environments specifically. The wheels have ground clearance of 2inch to cater for any rough unforeseen environment too.

3.1.4 The Battery Pack

At the heart of the delivery robot lies the battery pack, a crucial component providing power to the Geared DC motor. A 7000MAH battery is used as per our requirement responsible for giving constant voltage to our system.

Figure 10 Battery Pack

3.1.5 The Motor

Aligned with our project objective of developing an efficient and cost-effective ground delivery robot system meticulous consideration is given to the selection of reliable motors. The electric motor stands as the central powerhouse in any delivery robot, dictating the overall efficiency, torque, and reliability of the system. We are using a simple Geared Brushed DC motor with hall encoders. We will use 4 of these24V DC motors. Hall encoders are used to provide feedback back to the system. Addressing the importance of high torque in this domain, we have preferred a DC geared motor instead of a simple DC motor. Following are some properties of the motor used:

- 6mm Shaft Diameter
- 27.5mm Body diameter
- 24V DC motor
- 37mm head diameter

Figure 11 Geared Brushed DC Motor

3.1.6 Payload Handling Mechanism

For delivery robots, a payload handling mechanism is required to transport packages or items. 8mm PVC sheets are used to make a bin of PVC to handle all sorts of packages as payloads. This bin is attached to the main frame of the robot by means of nuts with drill bits. The bin has a covering lid on top of the bin so that payload can be safely contained inside the bin. Acrylic is used to cover the front and back ends of the robot.

3.1.7 Motor Driver

A motor driver is an essential part of driving the bot. The motor driver used here is a simple L298N motor driver IC. It is used to regulate the current and voltage coming from motor controllers (Arduino / raspberry pi) and reaching to DC motor. This is necessary for the safety of motors as it protects motors from damage to overheating and overcurrent. It ensures that the power supplied to the motors is regulated. They are also responsible for controlling the direction of rotation of motor which in turn allows the robot to move forwards and backwards.

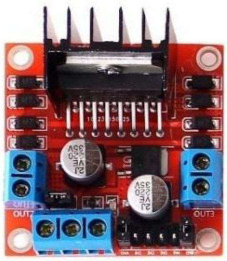


Figure 12 Motor Driver L298N

3.1.8 Other Sensors and Integration

Other sensors and components relating to controls are also integrated with this system. For example, LIDAR, Raspberry pi 4, etc. These sensors are used for obstacle detection and navigation which helps the robot move autonomously with indoor environments. The use of such sensors will be discussed in the controls part. Each of these components plays a crucial role in the operation of an indoor ground delivery robot, enabling it to navigate, perceive its environment, and perform delivery tasks autonomously and efficiently.

3.2 Motor Drive Architecture

Several components mentioned above constitute motor drive architecture, it refers to the integration of those electronic components which work to make the delivery robot move. The essential components are Motor Controllers (Arduino, Raspberry pi 4), Motor driver ICs, Voltage regulator and battery pack all interconnected though wires. A False switch is also added after the battery so that power can be cut off if there is any issue with power used.

The battery pack is connected to a false switch and then to a voltage regulator. The voltage regulator is responsible for converting the 12Vs from battery to 5V which is essential for motor controllers. If voltage regulator is not used and 12V is directly fed into motor controllers, it will cause the motor controllers to burn out and fail. This proves the essence of voltage regulator.

Motor Controllers are brains of the system that provide details like target speed for the wheels. These controllers send signals to motors which then set their speed and direction of rotation. The signals are then fed into the motor driver IC. Motor drivers are used to regulate the PWMs received from motor controllers. It reads the signal of controllers and changes the voltage and current to optimum settings so that the DC motor moves as the commands of motor controller are set.

DC Motors carry out the instructions as given by motor drivers. Encoders are attached to DC motor which shows a closed loop system. A closed loop system is a system in which feedback of the motor is again fed into motor controllers for further optimization if required. This feedback system changes the speed and direction of motors as per necessity.

Hall encoders are used in this system for simplicity, cost effectiveness and accuracy. A Hall effect sensor is placed near a rotating shaft, and a magnet is attached to the shaft. As the shaft rotates, the magnet passes by the Hall effect sensor, creating a magnetic field that the sensor can detect. A voltage pulse is generated each time the shaft rotates. Variation in this voltage pulse indicates a specific position of the rotating shaft.

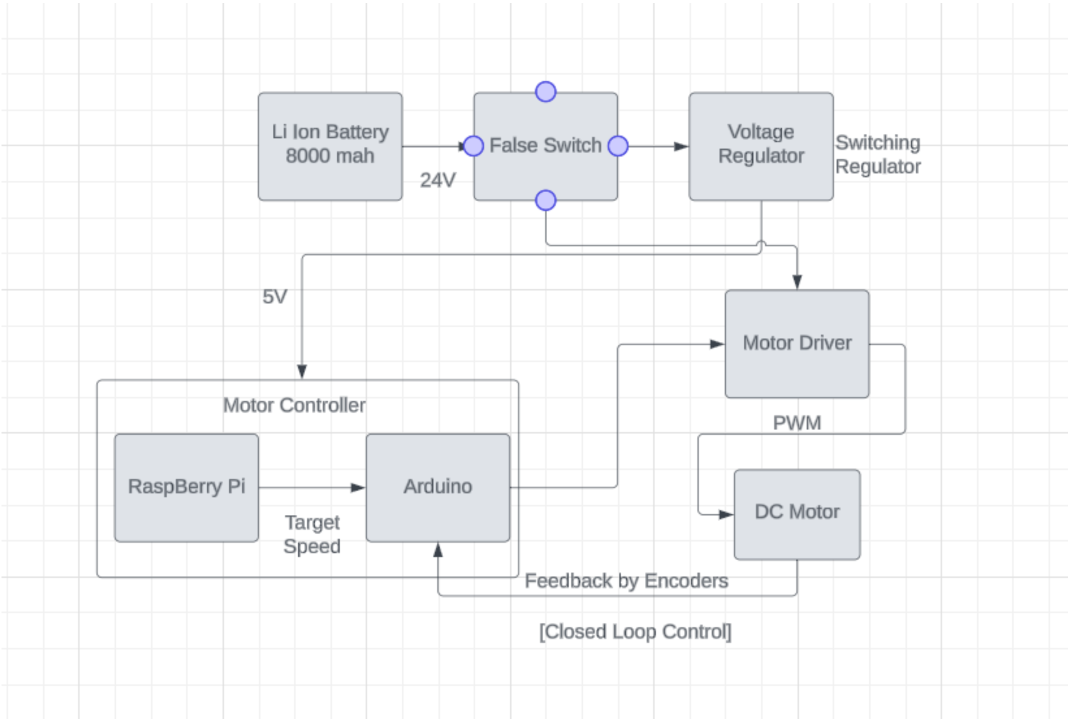


Figure 13 An illustration of Motor Drive Architecture

3.3 Calculations and Requirements

Certain calculations are necessary before the integration of electronic components. It is compulsory to find out about which battery is required and what is the torque requirement from the motors. All these calculations help us to decide and determine the specifications of motors and batteries etc.

3.3.1 Motor Selection

Motors are selected based on the requirements of torque and rpms for the delivery system. We need to have the knowledge of the diameter of wheels with the maximum weight of the bot (both payload and the mass of the bot added). This will help us set a range of torque requirements so we can procure motors near to range subjected to availability. Below are shown certain calculations for the torque:

Torque = Force x radius

We need to have the force per wheel and the radius of the wheels used.

Force per wheel = maximum weight / number of wheels = (15kg x 9.8) / 4 = 37N (approx.)

Diameter of wheel = 6.5in = 0.165m Radius of the wheel = 0.165m / 2 = 0.08m

Required torque = 37N x 0.08m = 2.96Nm or 29.6kgfcm per motor

3.3.2 Battery Selection

Selecting the battery with the required power is necessary for the safe functioning of the components. Optimum MAH battery must be used. Calculations are follows:

We need to find the total requirement of current that was drawn from the circuit and the operating time of the battery.

Total current drawn = 5A

Operating time requirement = 1- 1.5hrs

Maximum Stall Current through one motor = 1.7A For 4 motors = 1.7 x 4 = 6.8A = 7A (approx.)

For 1hr operating time, the power requirement of battery will be:

= 7AH = 7000MAH

So, a battery of at least 7000MAH is required for this system.

3.3.3 Current Regulation

We intend to find the total drawn from the circuit. We will be using maximum stall current so that we set a upper limit to current so we know the feasible and optimum operating current range.

First, we will find the current passed through each of the components. Most of these readings are available with the specifications from the manufacturers.

Raspberry pi 4= 1.5A LIDAR = 1A

Arduino = 0.1A Motor Driver = 0.1A

LCD Display Screen = 1A

Total = 1.5 + 1 + 0.1 + 0.1 + 1 = 3.7A = 4A (approx.)

Required Voltage for Motor Controllers = 5V Power = Voltage x Current

= 5V x 4A

= 20W

Assuming that all this regulation is processed with 100% efficiency. Voltage of battery used = 12V

So, the current drawn by the regulator from the power supply is.

= 20W / 12V = 1.67A

To be on the safer side, we assume the current to be 1.7A. Current drawn by all motorsis:

= Stall current x number of motors

= 1.7A x 4

= 6.8A

Total current drawn will be:

= 6.8A + 1.7A

= 8.5A

So, the maximum stall current will be 8.5A.

3.4 Fabrication and Assembly

After the selection of the required components, all these components are assembled. A chassis is designed for the foundation of the base using hollow steel rods. All components are installed on the base of the robot. Battery is in the center with motors at all 4 corners near to the wheels. There will be 2 motor driver ICs for 4 motors. The steel rods are welded together to provide strength and support to the robot). A PVC bin with a lid on top will be used for carrying packages while transporting them. All the electronic components are integrated through a Veroboard.

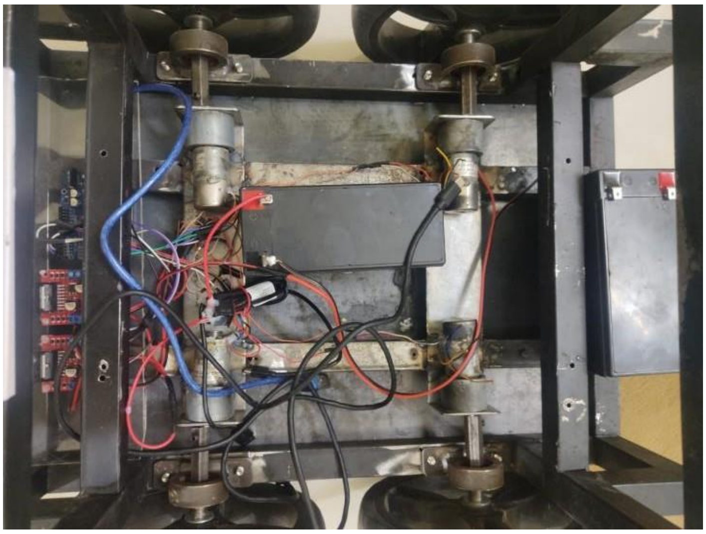


Figure 14 Assembled Components in Base of Robot

Figure 15 Final assembled product

CHAPTER 4: – DESIGN

4.1 Design Selection

There are many body design options available. For our product, we needed to select a somewhat related design that will give a basic idea of what we will be going to make. For taking a decision, a decision matrix is the best method.

4.1.1 Decision Matrix

A decision matrix is a tool that helps in analyzing all available options according to various requirements. All options are ranked according to the most important factors already defined. It makes it easy to select the most suitable option. It reduces decision fatigue and subjectivity of decision-making.

In our case, we first visited all the sites of different companies such as Starship technology, Nuro and Turtle bot etc. We needed to produce a design that is on the one hand simple, easily manufacturable and cost effective and on the other hand strong enough to be durable and reliable. Even if our objective is to make a robot for indoor environments, we wanted to ensure that the robot could handle some rough environment or terrain too if put to a test. We surfed all the markets of Islamabad and Rawalpindi to look for delivery robots. After a market survey, we realized that none of the delivery robots are sold in Islamabad and Rawalpindi.

Then after studying research papers, patents and searching online market available designs, we made a decision matrix.

4.1.2 Decision Factors

The important decision factors in our case are:

Price of the product.

Working Performance (Reliability and Strength)

Level of simplicity in making the product.

All initially selected design options are given points according to their importance in product manufacturing.

4.1.3 Available Options

- Option 1

Figure 16 Design Option: 1 [36]

- Option 2

Figure 17 Design Option: 2 [37]

- Option 3

Figure 18 Design Option: 3

4.1.3.1 Decision Matrix

	Price	Performance	Diversity	Ease to fabricate	Strength		
			Importance				
	5	5	5	5	5		
Options	Rating	Rating2	Rating3	Rating4	Rating5	Raw Score	Final Score
Option 1	4	5	3	4	3	19	95
Option 2	4	5	5	5	5	24	120
Option 3	4	4	5	4	4	21	105

Figure 19 Decision Matrix

- Price is based on the estimated sale price.
- Working performance is based on the life of the product.
- Diversity is based on working in diverse environments (indoor andoutdoor).
- Strength is based on product’s durability and reliability.
- Ease to fabricate is based on the design complexity, material availability,and cost of fabrication

4.1.4 Decision Making

- Option 1

Option 1 had a good performance and had a good sale price too but was rejected because of very low strength to endure any sort of rough environment and with near to zero ground clearance. This structure is very sensitive and can resort to failure if its environment was changed [36].

- Option 2

Option 2 had a good sale price and performed well in all domains that we had set previously. It had good ground clearance and is easy to fabricate too. This is the main reason it was selected [37].

- Option 3

Option 3 was easy to fabricate and diverse too, but it lacked in the domain of strength and price. The robot has small compartments where only small payloads like medicines can be stored which limits the use of robot to only medical use. Thiswas the reason it was rejected.

4.2 Design of Delivery Robot

Software was required to model and design the delivery robot and to analyze it. A structure can is not manufactured until it is completely modelled and analyzed. Here we have used SolidWorks 2022 for modelling and designing the CAD model and ANSYS for all structural, dynamic, and kinematic analysis.

4.2.1 CAD Modelling

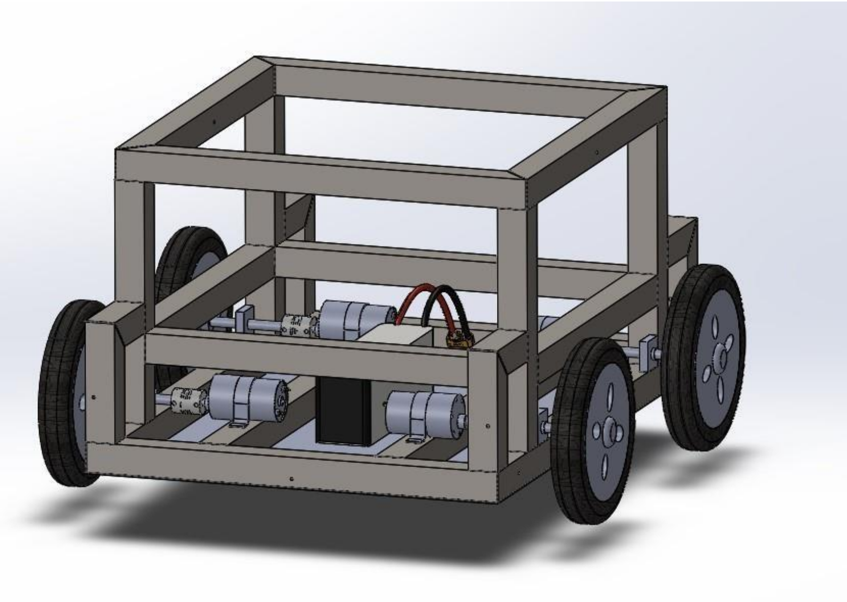


Figure 20 Chassis of Delivery Robot

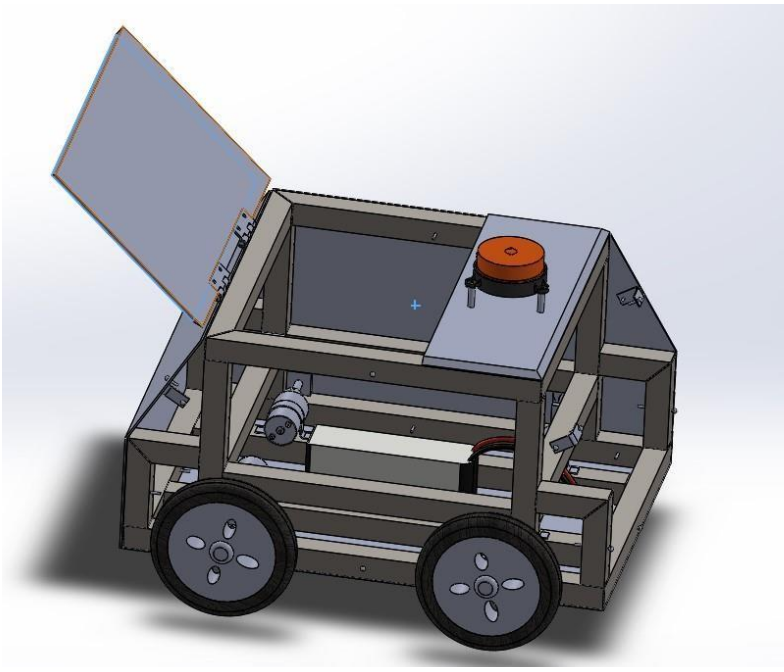


Figure 21 Battery and Motors placed in base of Robot.

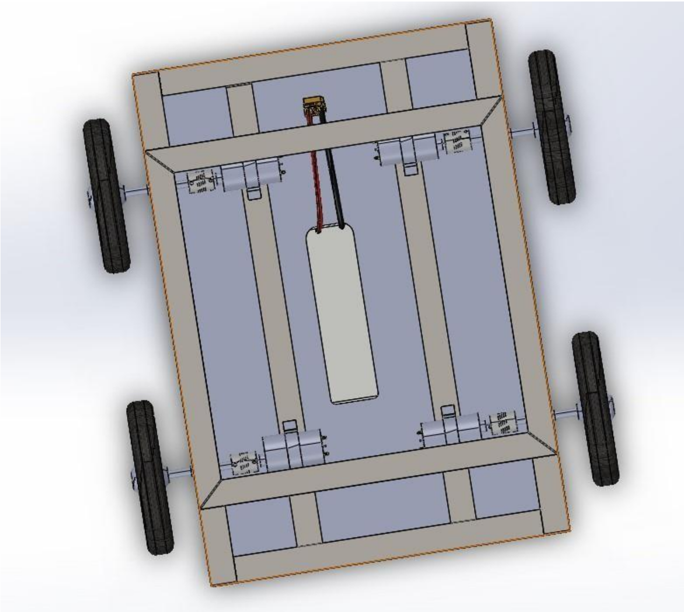


Figure 22 Top View of delivery robot

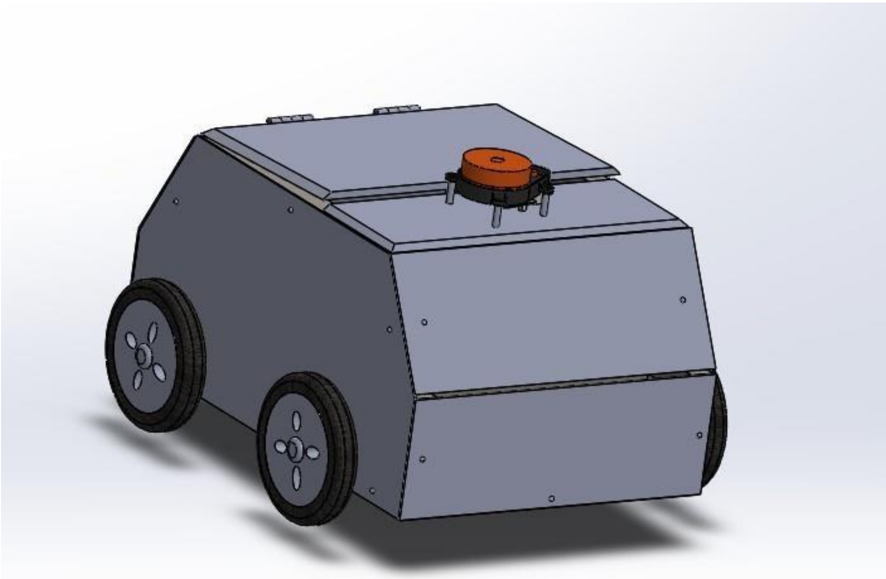


Figure 23 Final Design of delivery robot

4.3 Analysis of Delivery Robot

Next, it was necessary to calculate the maximum stress and deformations that would occur if the manipulator was loaded to the maximum. This delivery robot system's study was done with ANSYS 2023. To find the locations of higheststress, the SolidWorks design was imported into the ANSYS interface. The mesh produced by **ANSYS,** and the application of a 5 kilogram**s** payload are shown in the attached figure. There will be a thorough structural and dynamic study done.

4.3.1 Static Structural

Different analysis such as deformation, equivalent elastic strain, damage, and safety factor etc are done in the category of static structural in ANYSIS 2022. Following describe the verification from ANSYS software:

4.3.1.1 Total Deformation

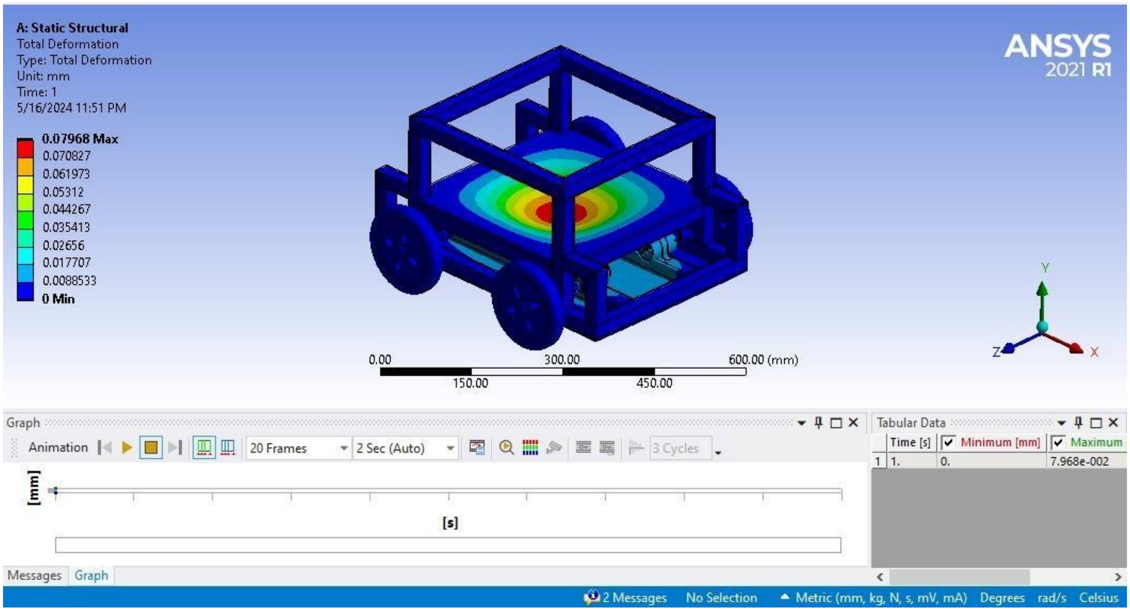


Figure 24 Total Deformation

4.3.1.2 Equivalent Elastic Strain

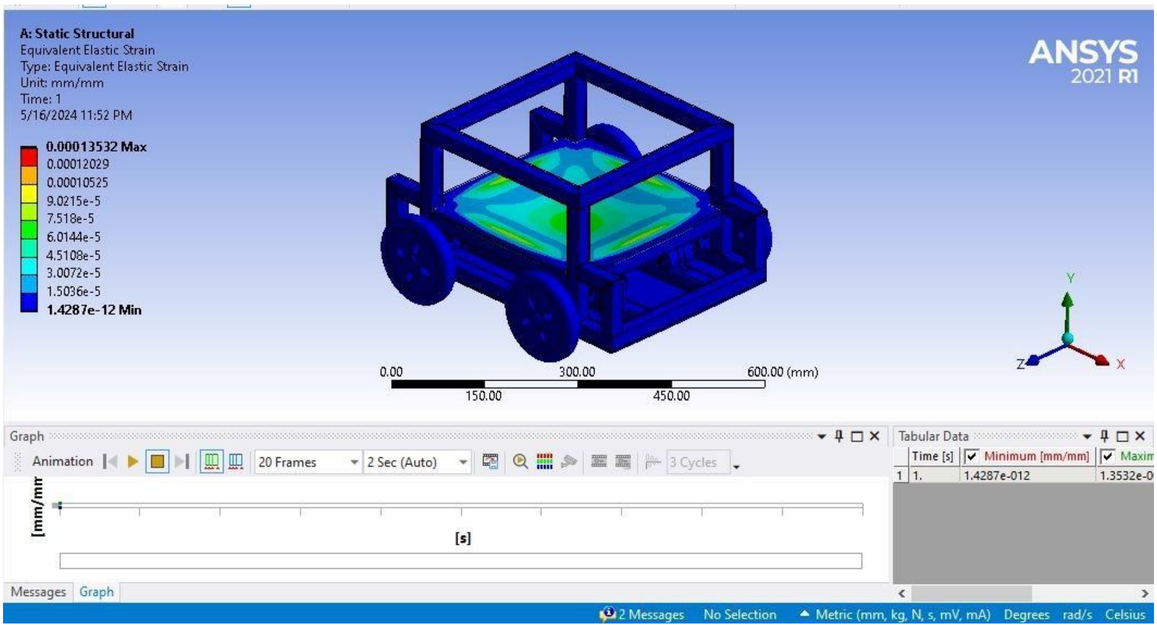


Figure 25 Equivalent Elastic Strain

4.3.1.3 Equivalent Elastic Stress

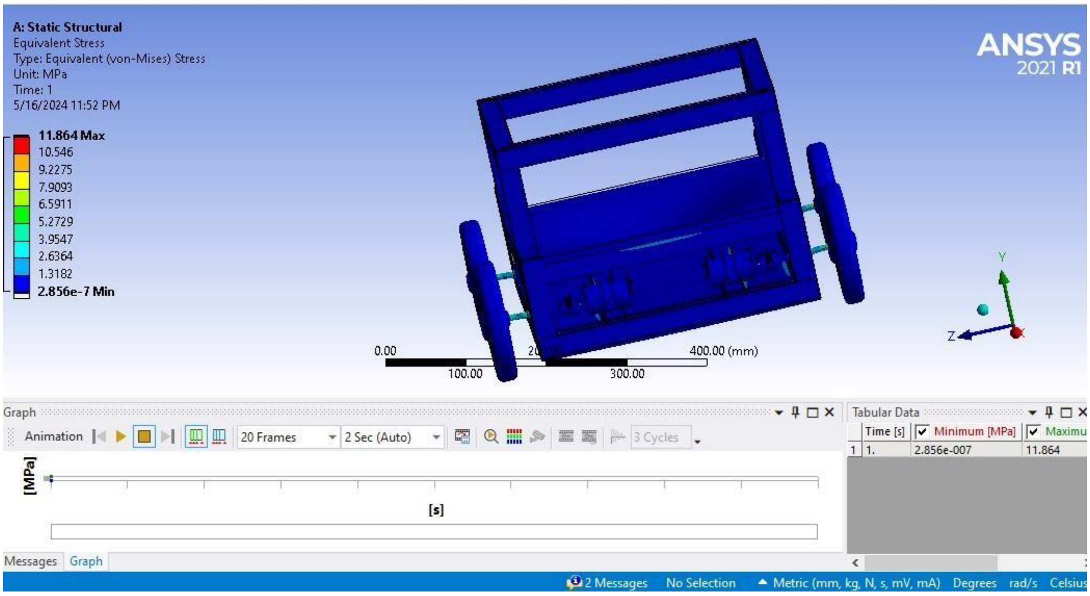
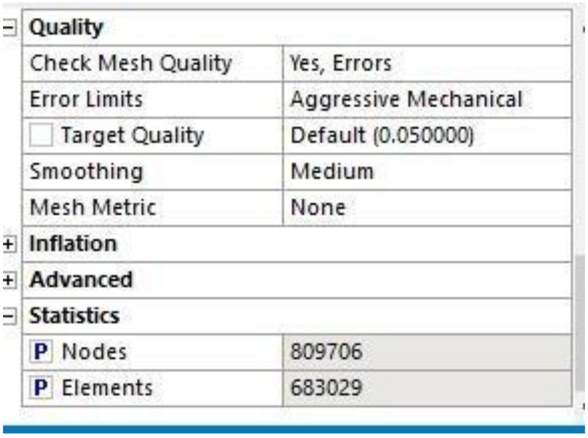


Figure 26 Equivalent Elastic Stress

4.3.1.4 Meshing



Quality	
Check Mesh Quality	Yes, Errors
Error Limits	Aggressive Mechanical
Target Quality	Default (0.050000)
Smoothing	Medium
Mesh Metric	None
Inflation	
Advanced	
Statistics	
Nodes	809706
Elements	683029

Figure 27 Meshing characteristics.

4.3.1.5 Damage

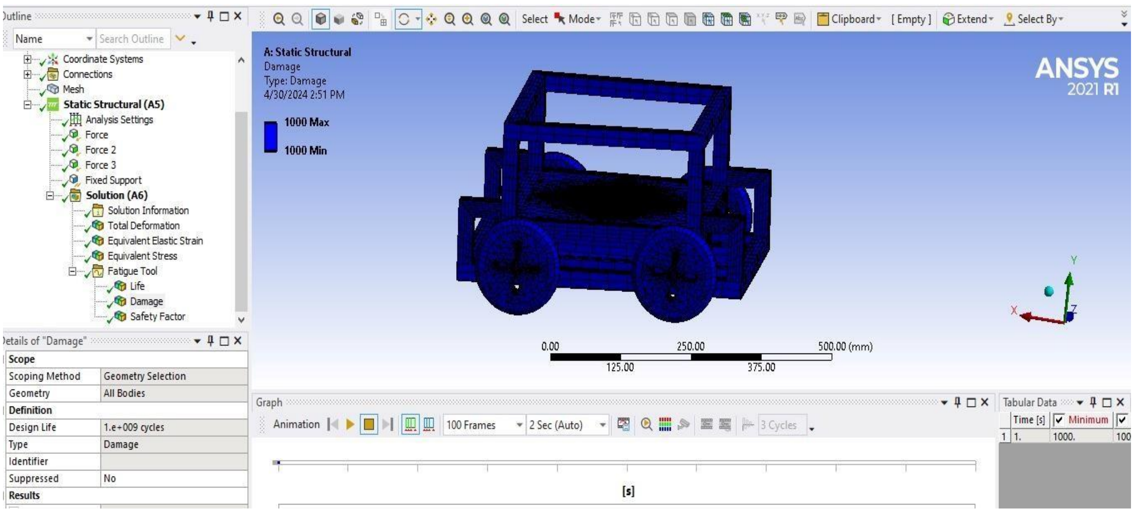


Figure 28 Damage

4.3.1.6 Safety Factor

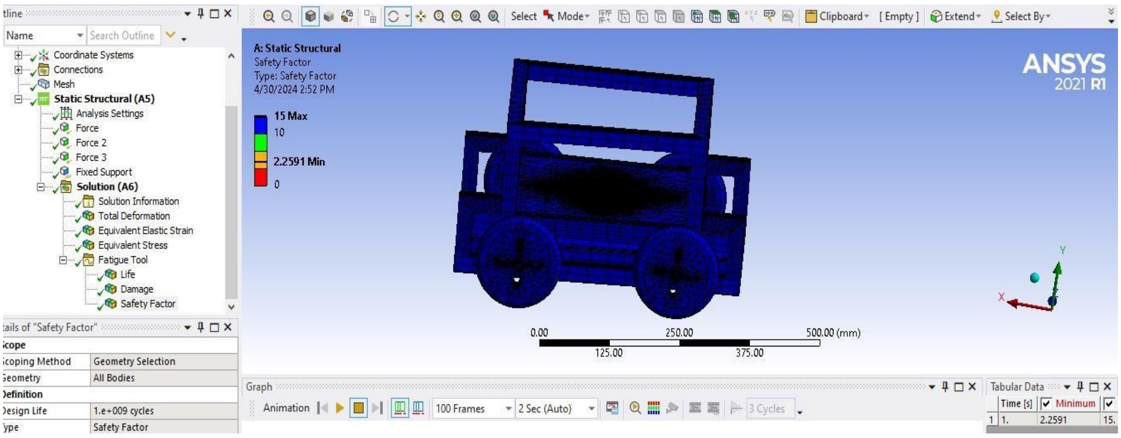


Figure 29 Safety Factor

4.3.1.7 Modal

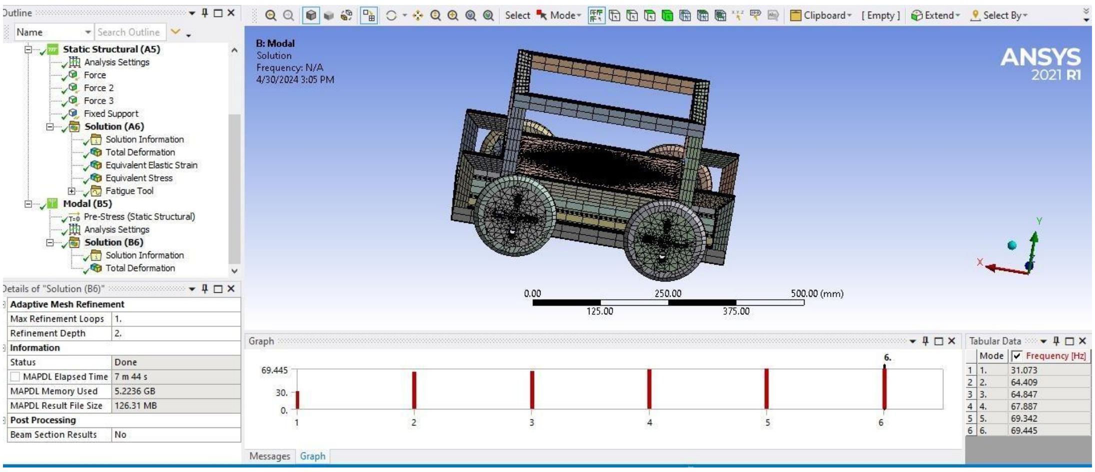


Figure 30 Modal

4.4 RC Control

In advance to complete fabrication and designing, another added task that was carried out was the RC control of the complete ground vehicle. RC refers to remote control of any system. The system in our case in a UGV is called delivery robot. There are two basic operations included in RC control.

4.4.1 Transmitter

A transmitter called RF 330 is used in this project. This is an inexpensive controller used to transmit radio frequency (RF) signals such that they control the movement of the delivery robot. There are 4 buttons shown on the hardware interface. All of these indicate different operations, for example throttle, steering, etc.

4.4.2 Receiver

A receiver of 433 MHz is used in this project. This is an inexpensive IC used to receive the radio frequency (RF) signals from the transmitter and convert them into electrical signals as instructions to be carried out. It contains VCC, ground and data pins to receive and carry out instructions. It is directly connected to Arduino. The VCC and ground pins are short with the Arduino. There are 4 channel pins of 433 MHz receiver. All these pins are used for different operations. To give an example, Channel 1 maybe used for throttle control, channel 2 for steering etc.

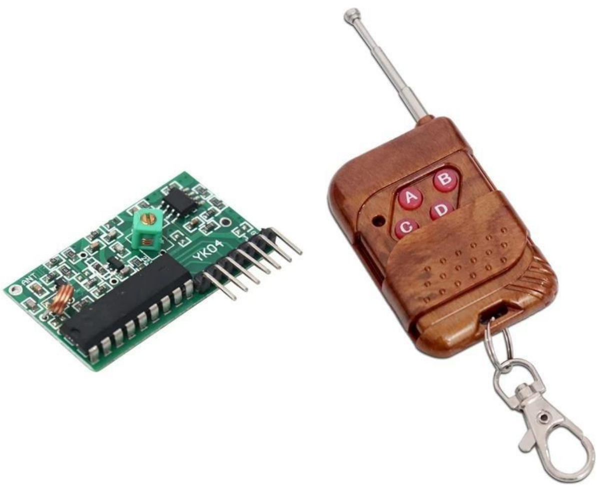


Figure 31 RF330 controller and receiver

CHAPTER 5: – RESULTS AND CALCULATIONS

5.1 Kinematics

A subfield of mechanics called kinematics studies how objects move without considering the forces causing them to move. Kinematics, sometimes known as the geometry of motion, is the study of body trajectories, velocities, and accelerations.

We first must select the motion drive of the delivery robot to analyze its kinematic model [38]. Here we have chosen skid steer drive as our choice of motion drive. Skid steer drive is a way for vehicle to turn by rotating or moving its wheel at different or opposite speeds or directions respectively. In this type of drive, we control the speed of each wheel independently. In this way, the vehicle will turn by causing one side of wheels to move faster or slower than other side.

This helps to change or switch directions of movement of robot.

5.1.1 Generalized Wheel Model

Here we first must discuss the generalized model of delivery robot beforehand [39]. Generalized model is shown in both vehicle and wheel frame of reference in the form of Bi and Ci respectively.

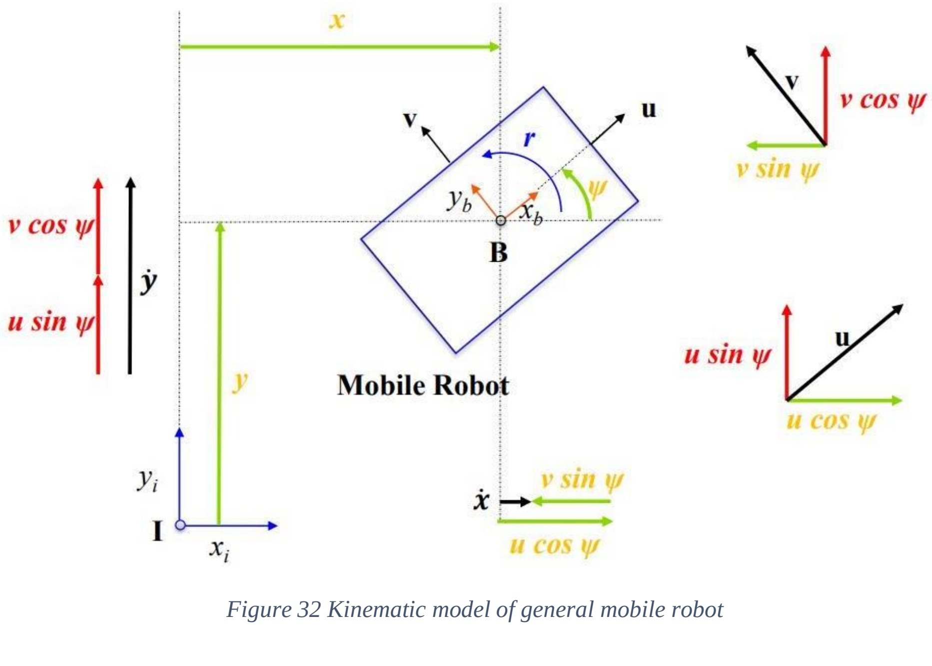


Figure 32 Kinematic model of general mobile robot

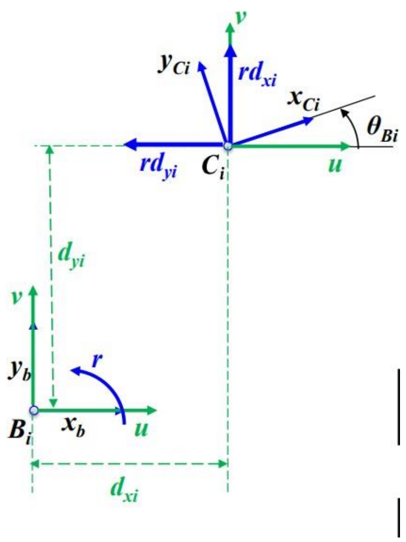


Figure 33 Description of components of B (vehicle) and C (wheel) frame of reference

Evaluating the formula of the complete generalized model of ground delivery robot drive, we can find the angular velocities of all the different wheels of the robot. We have used a 4 wheeled delivery robot so there will be 4 different angular velocities of all different wheels. The generalized model is shown.

$$\boldsymbol{\omega_i} = \begin{bmatrix} \frac{1}{a_i} & \frac{1}{a_i} tan\phi_i \end{bmatrix} \begin{bmatrix} cos\theta_{Bi} & sin\theta_{Bi} \\ -sin\theta_{Bi} & cos\theta_{Bi} \end{bmatrix} \begin{bmatrix} 1 & 0 & -d_{yi} \\ 0 & 1 & d_{xi} \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix}$$

- ω_i: Angular velocity of the ith wheel
- a_i : Radius of the ith wheel
- θ_{Bi} : Angle between the vehicle frame B and the wheel frame (C_i)
- d_{xi} and d_{yi}: position coordinates of C_i w.r.t. B
- ϕ_i : Angle between the roller axis and the x_{Ci} axis
- u: Forward velocity of the mobile robot w.r.t. **I**
- v: Lateral velocity of the mobile robot w.r.t. **I**
- r: Angular velocity of the mobile robot w.r.t. **I**

Figure 34 General form of Angular Velocity of wheel of ground

5.1.2 Skid Steer Drive

Skid steer drive lets a vehicle turn by speeding up or slowing down its wheels on each side independently. By doing this, one side can move faster or slower than the other, helping the vehicle to turn or change direction smoothly [40].

5.1.2.1 Working

Skid steer vehicles generally have 4 wheels with 2 sets of wheels on both sides of the ground vehicle. One of the main features of skid steer driven robots is the ability to independently control each side wheel of the vehicle. It means that the left side wheels can be moved in different directions and speeds as compared to the right-side wheels and vice versa. During turning, one side of the wheels will be driven faster or slower as compared to the other side wheels. This differential created in speed or direction will cause the vehicle to skid around a pivot point between the set of both sided wheels. If we talk about the maneuverability of the ground vehicle, skid steer drive will offer a high maneuverability and allow the vehicle to turn within its own footprint. This is ideal under the condition in which a vehicle has to operate in tight spaces and navigate around the obstacle.

5.1.2.2 Advantages

Skid steer driven robots have high maneuverability which means they can turn in small and congested places. It has a simple mechanical design and are very cost effective. Skid steer driven robots are efficient and produce a very easy of control.

5.1.2.3 Mathematical Model

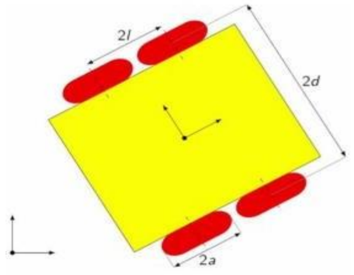


Figure 35 4 wheeled Skid steer ground vehicle

First, we will find all the parameters required for extraction of angular velocity of each wheel of these 4 wheeled robots. This includes position coordinates (d), Angle between vehicle frame and wheel frame (Theta), angle between roller axis and xci axis (phi) and radius of every wheel (a), etc.

$$d_{x1} = l \quad d_{x2} = -l \quad d_{x3} = -l \quad d_{x4} = l \quad d_{y1} = d \quad d_{y2} = d \quad d_{y3} = -d \quad d_{y4} = -d$$

$$a_1 = a_2 = a_3 = a_4 = a \qquad \theta_{B1} = \theta_{B2} = \theta_{B3} = \theta_{B4} = 0 \qquad \phi_1 = \phi_2 = \phi_3 = \phi_4 = 0$$

Figure 36 Parameters required to find angular velocity of ith wheels.

Substituting all these parameters in the original equation of angular velocity of wheels i.e. we will find general form of each wheel separately.

$$\omega_1 = \begin{bmatrix} \frac{1}{a} & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & -d \\ 0 & 1 & l \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix} = \frac{1}{a}(u - rd)$$

$$\omega_2 = \begin{bmatrix} \frac{1}{a} & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & -d \\ 0 & 1 & -l \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix} = \frac{1}{a}(u - rd)$$

$$\omega_3 = \begin{bmatrix} \frac{1}{a} & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & d \\ 0 & 1 & -l \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix} = \frac{1}{a}(u + rd)$$

$$\omega_4 = \begin{bmatrix} \frac{1}{a} & 0 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & d \\ 0 & 1 & l \end{bmatrix} \begin{bmatrix} u \\ v \\ r \end{bmatrix} = \frac{1}{a}(u + rd)$$

Figure 37 Substitution of parameters in general equation

We need to find the value of a (radius of wheel), u (forward velocity of robot), r (angular velocity of ground vehicle) and d (position coordinates) in real time.

5.1.2.4 Calculations

We must find the values of radius of wheel, forward velocity and angular velocity of the complete delivery robot and position coordinates. The radius of the wheel and forward velocity are calculated in real time, but we will use mathematical formulation approach for angular velocity of complete robot.

Angular acceleration is given by:

Angular acceleration = torque / Moment of inertia (1)

Also, angular acceleration can be calculated by:

Angular acceleration = w^2 / r (2)

Where w is given as angular velocity and r as turning radius Comparing both equations (1) and (2)
Torque / moment of inertia = (angular velocity) ^2 / turning radius

Isolating angular velocity to one side:

Angular velocity = square root ((torque x turning radius) / I) (3)

So, we have to find torque, turning radius and moment of inertia.

- Moment of Inertia

  Considering bot as a rectangular prism and taking moment of inertia of it

  I = m / 12 (a^2 + b^2)

  Where a is taken as length of robot, b as width of robot and m as mass of robot(including payload)

  a= 20 inch = 0.508m

  b= 14inch = 0.3556m

  I = 15 / 12 (0.508^2 + 0.3556^2)I = 3.23

  So, moment of inertia of the robot is

- Turning Radius

  The turning radius is approximately half of the distance from left wheel to the rightwheel.

  R = L /2

  L = 16inch = 0.4064m

  = 0.4064/ 2

  = 0.2032m

  So, turning radius of the robot is

- Torque

  The torque of the complete ground vehicle is required. It can be found by thesimple formula of torque given as:

  Torque = r x F

  Where r is the distance from center of mass to the wheel and F is the total forcewhich includes all the forces acting on the vehicle.

There are at least three forces acting on the ground vehicle. One is the normal force acting perpendicularly on the robot. The second force is the frictional forces acting on the robot as the robot moves on the terrain. The last force is the centripetal force on the ground vehicle as it moves in a circular motion. All these forces can be written in an equation as follows:

Total Force = Normal Force + Centripetal Force – Friction Force (4)

As the formula of forces is given as:

Normal force = m x g

= 15 x 9.8

= 147N

Where m is mass of vehicle (including payload) and g is acceleration due to gravity

Centripetal force = (m x v^2)/r

v = 0.381m/s = 0.4 m/s (approx.)

= (15 x 0.38^2) / 0.2032

= 10.65N

Where m is mass of vehicle (including payload), v is forward velocity of vehicleand r is turning radius (as calculated above)

Frictional Force = u x m x g

= 0.9 x 15 x 9.8

= 132.3N

Where u is coefficient of friction, m is mass of vehicle (including payload) and g isacceleration due to gravity.

Substitute all these formulas in equation (4);

Total force = mg + mv^2/r – u x mg

= 147 + 10.65 – 132.3

= 25.35N

So, the total torque calculated is:

Torque = r x F

= 0.1524 x 25.35

= 3.4N

Substitute the values of torque, turning radius and moment of inertia in the main equation (3) of angular velocity of complete vehicle.

Angular velocity = sq ((3.4 x 0.2082) / 3.23)

= 0.439 x 60

= 25 rpms of complete vehicle

So angular velocity of the ground vehicle will be 25rpms.

Substitute this value in the kinematic model shown above to find out the angular velocities of all the wheels individually can be found by substituting instantaneous forward velocities of the specified wheel.

CHAPTER 6: – CONLUSIONS AND FUTURE WORK

6.1 Conclusion

In this project, design and fabrication of a delivery robot (ground vehicle) was complete with main areas of concern of adaptability, safety, and efficiency. It is a low cost, multipurpose delivery robot that can be used in multi environments such as both indoor and outdoor environments. It can used for both indoor applications like carrying payloads such as medicines in hospitals to small packages in warehouses. For outdoor applications it can has a steel structure with high endurance and ground clearance to work outdoors such as carrying parts and payloads in a workshop to carrying payloads like files to other offices in a rough terrain. It was initially designed to carry payloads of 5kgs but adding to its multitasking its steel frame can hold up to 15kgs.

The robot has a steel frame with acrylic sheets covering its sides. Sensors like Lidar, etc are placed and mounted to their respective positions. The payload carrying mechanism has a box with hinges on top for safety of while carrying the payload. This project has various critical aspects to ensure its successful design and fabrication.

The initial phase was the conceptualization of the complete robot with regards to its objectives, requirements, and market. We did extensive research on all the available options of design that we had, we set a parameter to each design consideration and selected the best and feasible design using decision matrix formula. A complete CAD model was made with every minute detail that the project or design had to offer. Before fabrication, every requirement was checked by complete analysis on the robot with proper material considerations that could endure its payload followed by its fabrication. The last part of its analysis holds the kinematic model of the complete ground vehicle with some calculations required for operation.

To conclude, every aspect of the design and fabrication of the robot held key importance and attention to detail. Our goal was to make a delivery robot for indoor environments but for an added incentive we generalized the function, took some considerations in design like steel structure rods etc and diversified it for outdoor environment. Much more additions can be made for future work.

6.2 Future Work

With the advancements in technology, there is always room for improvement in future. There are certain issues that can be overcome in a ground vehicle for the better and extensive use of the vehicle. This UGV can be deployed in large environments so an improved battery life would increase the working hours of the UGV. Batteries are usually imported in Pakistan, a better and expensive battery with high MAH rating can be used for this large and outdoor environment application.

This UGV has a basic payload carrying mechanism. This can be advanced with respect to adding different payload carrying mechanism. To start with, a conveyer belt can be attached on the top of the robot which can help transport payload of the surface to a different place [41]. Same work can be optimized by a manipulator which can work like a robotic arm to transport payloads in addition to the robot just carrying it from one place to another [42]. UGV can have a chain type mechanism so that it can move up and down the large storage shelves in a military or private warehouse.

Figure 38 Delivery robot with manipulator [42]

Figure 39 Delivery robot with conveyor belt [41]

The movement can be optimized by using a mecanum drive robot instead of skid steer. Simple wheels can be replaced by mecanum wheels which will optimize its movement especially in indoor environments where the area for movement is not too much. These four-dimensional movement wheels can optimize his load bearing vehicle for indoor warehouses and narrow areas like hospitals or offices [43].

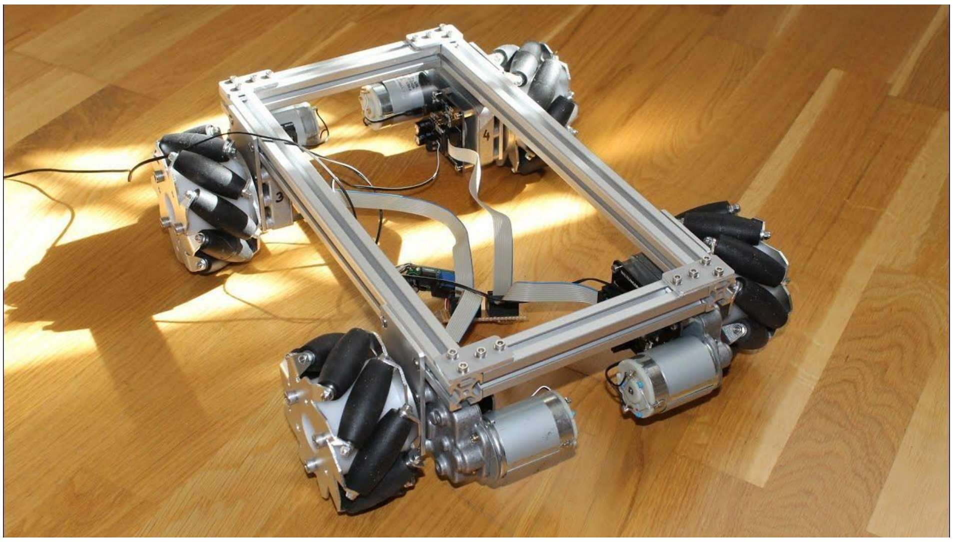


Figure 40 Mecanum wheeled vehicle [43]

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ANNEXURES

ANX-A

LIST OF VENDORS

Component	Vendor	Address	Contact
4 motors and encoders RF Remote	Electronics World	Shop No. 7, Ground Floor, Raza Plaza, College Road	03425095058
Arduino At mega L298 Vero Board Buck Converter 32 GB SD card USB TTL LCD Display	Allied Electronics	Shop No. 653, D.A.V College Road, Electronics Market	03335730914
Tyres PVC Sheet	Khawaja Brothers	Shop No.7, Umer Plaza DAV, College Road	03162482022
Battery	China Electronics	TM Plaza, Electronics market, DAV College Road	03165192716
Power Bank	Master Tech	Shop No. 3, DAV College Road Chowk	03215534135

ANX-B

Code

```
void setup()
{
// put your setup code here, to run once:
Serial.begin(9600);
pinMode(6,OUTPUT);
pinMode(7,OUTPUT);
pinMode(8,OUTPUT);
pinMode(9,OUTPUT);
pinMode(10,OUTPUT);
pinMode(11,OUTPUT);
pinMode(12,OUTPUT);
pinMode(13,OUTPUT);

digitalWrite(6,LOW); // far, lft bck
digitalWrite(7,LOW); // rev, lft bck
digitalWrite(8,LOW); // far, lft frnt
digitalWrite(9,LOW); // rev, lft frnt
digitalWrite(10,LOW); // rev, rit bck
digitalWrite(11,LOW); // far, rit bck
digitalWrite(12,LOW); // rev, rit frnt
digitalWrite(13,LOW); // far, rit frnt
}

void loop() {
// put your main code here, to run
repeatedly:int a = analogRead(A0);
```

```
int b =
analogRead(A1);int c =
analogRead(A2);int d =
analogRead(A3);
 // Serial.print(a);
 // Serial.print(b);
 // Serial.print(c);
 // Serial.println(d);


   if(a>512)
   {
    far();
    }
   else if(b>512)
   {
    rev();
    }
   else if(c>512)
   {
    rit();
    }
   else if(d>512)
   {
    lft();
    }
    else
```

```
{
 stp();
 }


}


void far()
{
digitalWrite(6,HIGH); // far, lft bck
digitalWrite(7,LOW); // rev, lft bck

digitalWrite(8,HIGH); // far, lft frnt
digitalWrite(9,LOW); // rev, lft frnt
digitalWrite(10,LOW); // rev, rit bck
digitalWrite(11,HIGH); // far, rit bck
digitalWrite(12,LOW); // rev, rit frnt
digitalWrite(13,HIGH); // far, rit frnt
delay(500);
 }

void rev()
{
digitalWrite(6,LOW); // far, lft bck
digitalWrite(7,HIGH); // rev, lft bck
digitalWrite(8,LOW); // far, lft frnt
digitalWrite(9,HIGH); // rev, lft frnt
digitalWrite(10,HIGH); // rev, rit bck
digitalWrite(11,LOW); // far, rit bck
digitalWrite(12,HIGH); // rev, rit frnt
digitalWrite(13,LOW); // far, rit frnt
```

```
delay(500);
 }


void rit()
{
digitalWrite(6,HIGH); // far, lft bck
digitalWrite(7,LOW); // rev, lft bck
digitalWrite(8,HIGH); // far, lft frnt
digitalWrite(9,LOW); // rev, lft frnt
digitalWrite(10,HIGH); // rev, rit bck
digitalWrite(11,LOW); // far, rit bck
digitalWrite(12,HIGH); // rev, rit frnt
digitalWrite(13,LOW); // far, rit frnt


delay(500);
 }

void lft()
{
digitalWrite(6,LOW); // far, lft
bck digitalWrite(7,HIGH); // rev,
lft bckdigitalWrite(8,LOW); // far,
lft frnt digitalWrite(9,HIGH); //
rev, lft frntdigitalWrite(10,LOW);
// rev, rit bck
digitalWrite(11,HIGH); // far, rit
bck digitalWrite(12,LOW); // rev,
rit frnt digitalWrite(13,HIGH); //
far, rit frntdelay(500);
 }
```

```
void stp()
{
digitalWrite(6,LOW);    // far, lft bck
digitalWrite(7,LOW); // rev, lft bck
digitalWrite(8,LOW); // far, lft frnt
digitalWrite(9,LOW); // rev, lft frnt
digitalWrite(10,LOW);   // rev, rit bck
digitalWrite(11,LOW);   // far, rit bck
digitalWrite(12,LOW);   // rev, rit frnt
digitalWrite(13,LOW);   // far, rit frntdelay(500);
}
```