Arab Academy for Science, Technology and Maritime Transport

College of Artificial Intelligence
Intelligent Systems

Bachelor of Artificial Intelligence Graduation Project
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Smart Delivery Robot
(AUCTUS)

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July – 2024

DECLARATION

We hereby certify that this material, which we now submit for assessment on the programme of study leading to the award of Bachelor of Science in Artificial Intelligence is entirely my own work, that we have exercised reasonable care to ensure that the work is original, and does not, to the best of my knowledge, breach any law of copyright, and has not been taken from the work of others and to the extent that such work has been cited and acknowledged within the text of our work.

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Arab Academy for Science, Technology and Maritime Transport

College of Artificial Intelligence
Intelligent Systems
Academic Year: 2024 Semester: 8
Graduation Project Summary Report

Project Title	Smart Delivery Robot (AUCTUS)	
Supervisor(s)	Omar Shalash	
Team members	**Registration Number**	**Name**
	20101169	Pavli Bahaa Tadros
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	20102961	Ahmed Mohamed El-Sayed
Project Deliverables	Fully functional autonomous delivery system	
Abstract	This project aims to revolutionize goods transportation through autonomous systems. It focuses on enhancing efficiency, reducing human intervention, and promoting	

<table>
<tr><td></td><td colspan="2">eco-friendly practices. The objectives center on developing a self-navigating robotic platform for secure, accurate, and convenient goods delivery, catering to modern logistical needs.</td></tr>
<tr><td>System Constraints</td><td colspan="2">Cost: The system must be affordable for both supermarkets and customers.
Size: The system must be compact enough to navigate through supermarket aisles.
Weight: The system must be light enough to be easily transported.
Power consumption: The system must be energy efficient.
Safety: The system must be safe for both customers and employees.</td></tr>
<tr><td>Project Impact</td><td colspan="2">Improving customer convenience
Improving environmental sustainability</td></tr>
<tr><td rowspan="7">Team Organization</td><td>Name</td><td>Tasks achieved</td></tr>
<tr><td>Pavli Bahaa Tadros</td><td>Hardware Tasks(Body fabrication) & Documentation</td></tr>
<tr><td>Ahmed Saad El-Menawy</td><td>Software Tasks(Navigation, Localization, Testing and handling errors) & Documentation</td></tr>
<tr><td>Amr Ashraf Fawzy</td><td>Software Tasks(Navigation, Localization) & Hardware Tasks(Body fabrication)</td></tr>
<tr><td>Youssef Ali Osman</td><td>Hardware Tasks(Electrical wiring, Handling hardware issues)</td></tr>
<tr><td>Abd El-Rahman Ahmed Magrash</td><td>Hardware Tasks(Electrical wiring, Handling hardware issues)</td></tr>
<tr><td>Ahmed Mohamed El-Sayed</td><td>Software Tasks(Web interface, Communication)</td></tr>
<tr><td>Ethics/Safety</td><td colspan="2">Privacy: The system will not collect any data that could be used to identify individuals.</td></tr>
</table>

	Accessibility: The system will be accessible to people with disabilities. Environmental impact: The system will be designed to be environmentally friendly.

Main Supervisor Signature

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ACKNOWLEDGMENT

Supervisor(s):

Dr. Omar Shalash, for his guidance, support, and encouragement throughout the project. His expertise and insights were instrumental in the successful completion of this work.

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Faculty members:

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Without the support of these individuals and organizations, this project would not have been possible. We are deeply grateful for their contributions and feel privileged to have had the opportunity to work with such talented and supportive people.

ABSTRACT

This report serves as an exploration and comprehensive analysis of the Smart Delivery Robot project, an innovative initiative aimed at revolutionizing goods transportation. Developed as a final-year project within the College of Artificial Intelligence, this document delineates the project's inception, design, functionality, technological underpinnings, and potential impact.

Commencing with an insightful introduction into the evolution of goods transportation, the report navigates through distinct sections, starting from the elucidation of the project's background and motivation. It outlines the challenges in traditional transportation methods and presents the objectives designed to address these inefficiencies. The report further delves into the intricate system design, elucidating the technology and algorithms employed, showcasing the Smart Delivery Robot's functionality and operational framework.

Highlighting the project's impact, the report meticulously delineates the anticipated benefits across various sectors, emphasizing enhanced efficiency, reduced errors, and a positive ecological footprint. It adeptly encapsulates the challenges encountered during the project's development phase, detailing the innovative solutions devised to surmount these obstacles.

The outline also extends to future prospects, scalability, and areas for improvement, illustrating the project's potential for revolutionizing logistics in diverse industries. Throughout, emphasis is placed on the Smart Delivery Robot's role in transforming traditional methods into autonomous, efficient, and environmentally conscious practices.

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LIST OF ACRONYMS/ABBREVIATIONS

AMR: Autonomous Mobile Robot

AI: Artificial Intelligence

ADR**:** Autonomous Delivery Robot

DOF: Degrees of Freedom

EKF: Extended Kalman Filter

GPS: Global Positioning System

GUI: Graphical User Interface

IMU: Inertial Measurement Unit

IIN : Internet-based Indoor Navigation

I2C: Inter-Integrated Circuit

LiDAR: Light Detection and Ranging

MCL: Monte Carlo Localization SLAM: ROS: Robot Operating System

ML: Machine Learning

RViz: Robot Visualization

Simultaneous Localization and Mapping

UI: User Interface

Chapter One

1. INTRODUCTION

1.1. OVERVIEW

The Smart Delivery Robot project represents an innovative stride in autonomous robotics, focusing on optimized goods transportation within confined spaces. This section offers a succinct yet comprehensive view of the project's significance in modern logistics and its potential implications for various industries.

Initially tailored for indoor applications, the Smart Delivery Robot prototype efficiently moves components from a centralized hub to designated areas. While initially optimized for indoor environments, this project envisions future adaptations for outdoor applications.

Equipped with cutting-edge technology like LiDAR and four motors with encoders, the Smart Delivery Robot ensures autonomous navigation and obstacle avoidance during transit. A user-friendly web interface is the cornerstone, enabling seamless control and monitoring.

- **Purpose and objectives:**

The primary goals encompass revolutionizing goods transportation, reducing reliance on manual labor, enhancing efficiency and accuracy, ensuring consumer convenience, and promoting sustainability.

- **Scope and significance:**

The project's aspirations to bridge the gap between traditional logistics methods and evolving transport needs underscore its significance. The integration of advanced technologies into the Smart Delivery Robot heralds' future innovations in autonomous transportation.

This overview sets the stage for subsequent sections by delineating the project's vision, immediate and future objectives, and broader implications within the logistics domain.

1.2. MOTIVATION AND APPLICATIONS

The genesis of the Smart Delivery Robot project lies in addressing the deficiencies inherent in conventional goods transportation systems. The motivation stems from the escalating demand for enhanced efficiency, accuracy, and sustainability in logistics operations.

1. Motivation

Traditional methods of goods transportation encounter persistent challenges, including prolonged processes, occasional inaccuracies, and inherent human errors. The reliance on manual handling not only induces delays but also amplifies operational costs. The pressing need to overhaul these inefficiencies propels the pursuit of autonomous and efficient delivery systems.

Enterprises increasingly seek innovative solutions like the Smart Delivery Robot to navigate these challenges effectively. These advanced systems promise to revolutionize goods transportation by offering augmented safety, swiftness, and precision, while mitigating the shortcomings of human intervention. This paradigm shift aligns seamlessly with the contemporary trend of embracing eco-friendly practices, thereby fostering a more sustainable and efficient future in logistics.

2. Applications

The Smart Delivery Robot's adaptability and versatility position it as a transformative solution across diverse industries. Primarily designed for streamlined indoor logistics, its potential applications transcend the confines of warehouses, extending to domains like retail, healthcare, manufacturing, and event management.

By envisaging adaptations for outdoor deployment, the Smart Delivery Robot expands its utility to accommodate various terrains and weather conditions. Its robust design fosters applications in outdoor logistics, catering to the evolving demands of a dynamic market landscape.

The envisaged spectrum of applications, from optimizing warehouse operations to facilitating outdoor event logistics, underscores the Smart Delivery Robot's potential impact across multifarious sectors. This adaptability signifies a pivotal shift towards harnessing autonomous technologies for a spectrum of logistical challenges, promising an era of efficiency, sustainability, and innovation.

1.3. CHALLENGES

Embarking on the development journey of the Smart Delivery Robot project unveiled a series of intricate challenges, necessitating innovative solutions to ensure the success of this autonomous goods transportation system. Several key hurdles were encountered and addressed throughout the project's evolution:

1. **Navigation in Indoor Dynamic Environments**

Challenge: Creating a navigation system enabling the Smart Delivery Robot to adapt to dynamic indoor environments, evade obstacles, and ensure secure transit.

Solution: Implemented LiDAR technology for real-time mapping and obstacle detection, empowering the Smart Delivery Robot to manoeuvre efficiently amid changing surroundings.

Challenge : Initial Exploration of GPIS: Initially, the project investigated the General Positioning and Information System (GPIS) for indoor navigation using WiFi access points. However, challenges such as inconsistent signal readings, noisy environments, and limitations of the path loss model presented significant hurdles.

Solution: Due to these challenges, the project shifted focus towards exploring alternative and more reliable indoor navigation solutions, ultimately implementing LiDAR technology as described above.

2. **User-Friendly Interface**

Challenge: Designing an intuitive and accessible web interface for seamless Smart Delivery Robot control and monitoring by users.

Solution: Conducted iterative user testing and feedback sessions to refine the app's interface, resulting in a user-centric control system.

Security of Luggage Compartment:

Challenge: Ensuring the safety of transported goods by preventing unauthorized access to the storage compartment.

Solution: Integrated a secure passcode system generated by the mobile app, granting exclusive access to the compartment to authorized users.

3. **Indoor to Outdoor Adaptation**

Challenge: Adapting the Smart Delivery Robot's capabilities from indoor to outdoor settings, considering diverse terrains and varying weather conditions.

Solution: Continual research and development to enhance the Smart Delivery Robot's design for outdoor applications, addressing factors like weather resistance and terrain adaptability.

4. **Integration of Hardware and Software**

Challenge: Ensuring seamless communication between the web interface and the Smart Delivery Robot's main board (powered by the Lattepanda Delta processor).

Solution: Rigorous testing and debugging to optimize integration, establishing a robust communication channel for efficient command execution and real-time monitoring.

5. **Power Management for Extended Operations**

Challenge: Managing power consumption to ensure prolonged operational periods without frequent recharging.

Solution: Implemented power-efficient components and continuously refined the power management system to strike a balance between performance and energy conservation.

Addressing these challenges has been pivotal to the project's development journey, underscoring the Smart Delivery Robot's commitment to overcoming obstacles and delivering a dependable, efficient, and user-friendly autonomous goods transportation solution.

1.4. PROBLEM STATEMENT

Traditional methods of goods transportation are laden with inherent challenges, encompassing sluggish processes, sporadic inaccuracies, and susceptibility to errors. Manual handling not only results in delays but also incurs higher operational costs. Acknowledging these drawbacks, there arises an escalating demand for autonomous and efficient delivery systems that streamline the transportation of goods.

Enterprises necessitate solutions akin to the Smart Delivery Robot to effectively counter these challenges. These advanced systems promise deliveries imbued with heightened safety, rapidity, and precision, thereby eradicating the drawbacks linked to manual intervention. The shift towards these innovative technologies resonates with the contemporary ethos of embracing eco-friendly transportation practices, paving the way towards a more sustainable and efficient future.

Our project aspires to bridge the chasm between traditional methods and the evolving requisites of modern logistics. By introducing a smart and autonomous solution, our aim is to not only elevate efficiency but also contribute to a more eco-conscious and technologically advanced approach to goods transportation.

1.5. OBJECTIVE

The Smart Delivery Robot project stands guided by a constellation of clear objectives, meticulously designed to confront the intrinsic challenges entrenched in traditional goods transportation methods and pave the path towards a more sophisticated and efficient future.

- Aims

Enhance Efficiency: Streamlining the goods transportation process by eliminating delays attributed to manual handling, thereby ensuring a more efficient and punctual delivery system.

Ensure Accuracy: Minimize errors and inaccuracies during transportation through the adept leveraging of autonomous technology, thereby establishing a reliable and precise delivery mechanism.

Reduce Costs: Mitigate the financial strain imposed by traditional transportation methods through the deployment of automated systems, fostering cost-effective and sustainable logistics.

- Goals

Autonomous Operation: Craft a Smart Delivery Robot endowed with autonomous navigation capabilities, thereby reducing reliance on human intervention, and mitigating the risks associated with errors and delays.

Seamless Integration: Devise a user-friendly web interface seamlessly intertwined with the Smart Delivery Robot, facilitating effortless control and real-time monitoring of the transportation process.

Enhanced Safety: Employ cutting-edge technologies, including LiDAR, to fortify obstacle avoidance and augment overall goods safety during transit.

Adaptability: Design the Smart Delivery Robot with the agility to modulate its capabilities, catering not only to indoor but also prospective outdoor applications, thus accommodating a diverse spectrum of logistical requisites.

Eco-Friendly Solutions: Contribute to the realm of environmentally sustainable transportation by optimizing energy efficiency and curbing the carbon footprint associated with goods delivery.

1.6. THESIS OUTLINE

This thesis is organized as follow:

1.1 Overview: Introducing the essence and scope of the Smart Delivery Robot project.

1.2 Motivation and Applications: The driving forces behind the project and its varied applications.

1.3 Challenges: An exploration of hurdles encountered and surmounted during project development.

1.4 Problem Statement: Articulating the quandaries within conventional transportation methods.

1.5 Objective: Aims and goals steering the Smart Delivery Robot's evolution.

1.6 Thesis Outline: A roadmap guiding the thesis progression.

Chapter Two

2. LITERATURE REVIEW AND RELATED WORK

2.1 Introduction

- **The Rise of Autonomous Delivery Robots**

The ever-expanding landscape of e-commerce has fundamentally altered consumer behaviour, leading to a surge in demand for fast and convenient delivery options. However, traditional delivery methods, reliant on gasoline-powered vehicles, are increasingly strained, facing challenges like:

Traffic congestion: Delivery trucks contribute significantly to traffic jams, especially in urban areas. This not only slows down deliveries but also increases emissions and fuel costs.

Rising fuel costs: Fluctuating fuel prices can significantly impact the operational costs of traditional delivery services.

Environmental concerns: Traditional delivery methods contribute to air and noise pollution, raising environmental concerns [1].

This has paved the way for a revolutionary new technology: autonomous delivery robots (ADRs).

Figure 1: Amazon SCOUT

- **ADRs: Transforming Last-Mile Delivery**

ADRs are self-driving mobile robots designed to automate the last-mile delivery process, the final leg of a delivery journey from a distribution centre to the customer's doorstep. These intelligent machines navigate sidewalks and designated pathways, carrying packages directly to customers. The potential benefits of ADRs are vast, promising to:

Streamline deliveries: ADRs can navigate congested urban areas and designated pathways more efficiently than traditional delivery vehicles, potentially reducing delivery times.

Reduce costs: Electrically powered ADRs minimize fuel consumption and eliminate the need for human drivers, leading to significant cost savings.

Minimize environmental impact: By reducing reliance on traditional delivery vehicles, ADRs contribute to lower emissions and a cleaner environment [1].

- **Leading the Charge: Pioneering Companies and Their Technologies**

Several companies are at the forefront of ADR development, each with its own unique approach and technological advancements:

Starship Technologies [2]: These well-known delivery robots utilize a suite of sensors for comprehensive environmental awareness, including: Six cameras: Providing real-time visual data of the surroundings.

Radar: Detecting objects in low-light conditions or situations where camera vision might be impaired. Ultrasonic sensors: Identifying nearby obstacles at short distances. Additionally, they employ GPS for overall positioning and advanced computer vision algorithms to interpret visual data and navigate complex environments.

Amazon Scout: While specific details are limited, Amazon's Scout delivery robots are known to utilize a combination of:

Cameras: Capturing visual data of the surroundings.

LIDAR (Light Detection and Ranging): Creating a detailed 3D map of the environment for precise navigation and obstacle avoidance.

Sensors: Detecting obstacles and enabling safe operation.

Postmates X [3](Theta Robotics): Theta Robotics' delivery drones, currently in pilot testing with Postmates, rely on a combination of technologies for autonomous navigation:

LIDAR: Creating a 3D map of the environment and enabling precise navigation.

Cameras: Providing real-time visual data.

Radar: Enhancing obstacle detection, particularly in challenging weather conditions. Additionally, they are equipped with redundant flight control systems for enhanced safety in case of malfunctions.

This review delves deeper into the specific applications and potential of these technologies throughout the following sections.

2.2 Benefits and Applications of ADRs

- **Reduced Cost and Improved Efficiency**

Traditional delivery methods involve significant operational costs:

Fuel expenses: Delivery trucks rely on gasoline or diesel, leading to high fuel consumption costs that fluctuate with market prices.

Vehicle maintenance: Maintaining a fleet of delivery vehicles can be expensive, with ongoing service and repair needs.

Driver salaries: Driver wages and benefits are a major cost factor in traditional delivery operations.

ADRs offer a more cost-effective solution:

Electrically powered: ADRs typically utilize electric motors, significantly reducing reliance on fossil fuels and minimizing fuel costs.

Lower maintenance: Electric motors generally require less maintenance compared to gasoline or diesel engines.

Labor cost savings: ADRs operate autonomously, eliminating the need for human drivers. Furthermore, some ADRs, like those by Starship Technologies, employ advanced route planning algorithms to optimize delivery routes. This reduces travel time and associated costs, while also contributing to:

Reduced distance traveled: Optimized routes minimize the total distance traveled [4] by ADRs, further lowering operational costs.

- **Reduced Traffic Congestion and Emissions**

The surge in e-commerce deliveries has led to a rise in traffic congestion, particularly in urban areas. Traditional delivery vehicles contribute heavily to this problem, adding to traffic volume and exhaust emissions [5].

ADRs offer a sustainable alternative:

Smaller size: ADRs are compact and maneuverable, allowing them to navigate congested areas more efficiently than traditional delivery trucks. This reduces overall traffic congestion [6].

Electric motors: Electric motors in ADRs produce zero tailpipe emissions, unlike gasoline or diesel engines. This contributes to cleaner air and reduced greenhouse gas emissions [1]. Additionally, the quieter operation of electric motors reduces noise pollution in urban environments.

- **Increased Delivery Flexibility and Convenience**

ADRs offer greater flexibility and convenience compared to traditional delivery methods [7]:

Navigation capabilities: Some ADRs, like those developed by Starship Technologies [2] with their six cameras, can navigate sidewalks and designated pathways. This allows them to reach customers in locations previously inaccessible to traditional delivery vehicles.

24/7 operation: Many ADRs are equipped with features like redundant battery systems [8], enabling them to operate 24/7. This allows for more convenient delivery options, catering to customer preferences for flexible delivery times.

Ideal for smaller deliveries: ADRs are well-suited for handling smaller packages, such as online grocery orders or restaurant meals delivered by services like Postmates X [9].

- **Successful Real-World Application**

ADRs are transitioning from concept to reality, with several companies actively implementing them in real-world settings:

College Campuses and Corporate Parks: Universities and office complexes often have large, pedestrian-friendly areas, making them ideal environments for ADRs. These robots can efficiently deliver packages, food orders, or office supplies directly to buildings or designated pick-up locations. Starship Technologies [2] robots, with their advanced obstacle avoidance capabilities, are well-suited for these environments.

Gated Communities and Restricted Areas: ADRs offer a secure and convenient solution for deliveries within gated communities or restricted areas where access for traditional delivery vehicles might be limited. Theta Robotics' delivery drones, utilizing LIDAR technology [10] for precise navigation, can efficiently deliver packages within these areas.

Integration with Existing Delivery Infrastructure: ADRs can be integrated with existing delivery infrastructure, acting as the last-mile leg of the journey. Packages can be transported from warehouses or distribution centres to designated drop-off points using traditional methods, where ADRs pick them up for final delivery. This hybrid approach leverages the strengths of both traditional and autonomous delivery systems.

These real-world applications demonstrate the potential of ADRs to transform the way we receive our goods, offering greater efficiency, convenience, and environmental benefits.

Figure 2: Posmates X

2.3 Technology and Design of ADRs

- **The Navigation Backbone: Sensor Fusion and Machine Learning**

The success of ADRs hinges on their ability to navigate autonomously and safely within their environment. This is achieved through a complex interplay of technologies [11], often referred to as sensor fusion, where data from various sensors is combined and interpreted to create a comprehensive picture of the surroundings. Here is a breakdown of some key technologies:

LiDAR [10] (Light Detection and Ranging): This sensor emits pulses of light and measures the reflected time to create a highly detailed 3D map of the environment. Companies like Amazon Scout leverage LIDAR technology for precise route planning and obstacle detection, allowing their robots to navigate complex urban areas.

Cameras and Computer Vision [12]: Cameras provide real-time visual data of the surroundings. Advanced computer vision algorithms process these images, enabling the ADR to recognize traffic signs, pedestrians, and potential obstacles. Starship

Technologies utilizes six cameras for comprehensive obstacle detection, allowing their robots to navigate busy sidewalks and pathways.

Ultrasonic Sensors [13]: These sensors emit and detect high-frequency sound waves, allowing the ADR to detect nearby objects at short distances. This is particularly useful for identifying low-hanging obstacles or objects directly in front of the robot, such as curbs or uneven pavement.

Radar [14]: While not universally used, radar technology can be employed for additional obstacle detection, especially in low-light conditions (e.g., nighttime) or situations where camera vision might be impaired (e.g., heavy fog).

GPS and Localization Techniques [15]: Global Positioning System (GPS) provides the ADR with its general location. However, for precise navigation within urban environments, additional localization techniques are often employed. These might include real-time mapping and positioning systems that utilize landmarks or pre-defined digital maps.

Machine learning [16] plays a crucial role in processing and interpreting the data collected by these sensors. By continuously learning from real-world data, ADRs can improve their ability to:

Recognize objects and patterns [17]: Machine learning algorithms can help ADRs accurately identify pedestrians, cyclists, traffic signs, and other objects in their environment.

Predict movement and behaviour: By analysing past data, ADRs can learn to anticipate the movement of pedestrians and vehicles, allowing for safer navigation in dynamic environments.

Adapt to changing conditions: Machine learning enables ADRs to adapt their behaviour based on weather conditions, lighting variations, or unexpected obstacles.

- **Beyond Navigation: Design Considerations for Effective ADRs**

The design [18] of ADRs goes beyond just the sensor suite. Here are some additional key considerations:

Payload and Carrying Capacity: The carrying capacity of ADRs varies depending on the specific design and application. Generally, they can handle payloads ranging from a few kilograms to around 50 kilograms. This allows them to deliver a wide variety of items, including groceries, packages, restaurant meals, or even laundry.

Battery Life and Power Management: Efficient battery systems are crucial for ADRs to ensure they can complete their delivery routes. Companies like Starship Technologies utilize redundant battery systems, allowing their robots to operate 24/7 with minimal downtime for charging. Additionally, features like route optimization algorithms can help conserve battery life by minimizing travel distances.

Durability and Weatherproofing: Since ADRs operate outdoors, they need to be designed to withstand various weather conditions. This includes features like weatherproofing to protect sensitive electronics from rain, snow, or extreme temperatures. Additionally, temperature control systems might be necessary for deliveries involving perishable goods, and robust construction is essential to handle bumps and uneven terrain.

Security Measures for Packages: The security of packages during delivery is a major concern. ADRs may incorporate features like secure locking mechanisms, tamper-evident seals, or even GPS tracking to ensure the safe delivery of goods.

These design considerations, along with the continuous advancement of sensor technology and machine learning algorithms, are paving the way for the development of ever more sophisticated and capable ADRs.

Figure 3:Starship by Starship Technologies

2.4 Social and Regulatory Issues

While ADRs offer numerous potential benefits, their implementation also raises several social and regulatory concerns:

- **Societal Impacts**

Job Displacement in the Delivery Sector: The widespread adoption of ADRs could potentially lead to job losses in the traditional delivery sector. Delivery drivers, mail carriers, and similar occupations might be impacted as autonomous robots take over delivery tasks. This raises concerns about the need for retraining programs and support for workers who might be displaced.

Public Perception and Concerns about Safety and Privacy: The introduction of autonomous robots into public spaces raises public concerns about safety and privacy. Some individuals might be apprehensive about sharing sidewalks with self-driving machines, fearing accidents or malfunctions. Additionally, concerns regarding data privacy might arise, as ADRs equipped with cameras and sensors like those used by Starship Technologies could collect information about their surroundings and delivery routes. Companies will need to ensure transparent data collection practices and robust security measures to address these concerns.

Accessibility Considerations for People with Disabilities: The design and operation of ADRs need to consider the needs of people with disabilities. Navigation challenges for users with visual impairments or limited mobility must be addressed to ensure equitable access to deliveries. This might involve features like audible alerts, integration with assistive technologies, and clear pathways for safe interaction [19] with ADRs.

- **Regulations and Legal Considerations**

The operation of ADRs in public spaces necessitates a robust regulatory framework. Here are some key areas that require attention:

Safety Standards and Testing Procedures [19]: Standardized safety protocols are crucial to ensure the safe operation of ADRs. These standards should address aspects like collision avoidance, speed limits, and emergency response procedures. Additionally, rigorous testing procedures need to be established to evaluate the safety and reliability of ADRs before deployment. Companies like Amazon Scout, which are still under development, will need to undergo thorough testing to ensure their robots meet safety regulations.

Insurance Requirements and Liability: Clear guidelines regarding insurance coverage for ADRs are essential. In case of accidents or malfunctions, it needs to be established who is liable – the manufacturer, the operator, or the programming code itself. Determining liability will be crucial for holding companies accountable and ensuring proper insurance coverage for potential damages.

Zoning and Permitting Regulations: Regulations regarding the operation of ADRs within specific zones, such as sidewalks or pedestrian walkways, need to be established. Permitting processes might be required to ensure responsible deployment and adherence to safety standards. Local authorities will need to develop clear guidelines for where and how ADRs can operate to minimize disruption and ensure the safety of pedestrians.

Addressing these social and regulatory issues proactively will be crucial for fostering public trust and ensuring the smooth integration of ADRs into our communities. Responsible development, transparent data practices, and a commitment to safety will be essential for this technology to reach its full potential.

2.5 Future Outlook and Conclusion

- **The Evolving Landscape of Autonomous Delivery**

The future of ADRs is brimming with exciting possibilities. As technology continues to advance, we can expect to see significant developments in several key areas:

Increased Autonomy and Intelligence: ADRs will likely become increasingly autonomous, capable of making real-time decisions and adapting to dynamic environments. This could involve advanced obstacle avoidance capabilities using more sophisticated sensor fusion techniques, route optimization based on real-time traffic data and weather conditions, and even the ability to handle unexpected situations like road closures or detours.

Integration with Artificial Intelligence and Machine Learning: Machine learning algorithms will play a critical role in enhancing the capabilities of ADRs [20]. Through continuous learning and data analysis, these robots will become more adept at navigating complex environments, understanding human behaviour [21] (e.g., recognizing hand signals from pedestrians), and optimizing their delivery routes based on factors like traffic congestion and weather patterns.

Expansion into New Delivery Applications: The potential applications of ADRs extend beyond traditional package delivery. They could be integrated into food delivery services, allowing restaurants to deliver meals directly to customers' doorsteps. Additionally, they could be utilized for grocery delivery, offering convenient solutions for online grocery purchases, or even for tasks like medicine delivery for pharmacies.

- **Conclusion**

This literature review has explored the current state of ADR technology, its potential benefits and applications, and the challenges associated with its implementation. We have seen how ADRs offer a promising solution to the growing demand for efficient and sustainable last-mile delivery. Their ability to reduce costs, minimize environmental impact, and offer greater delivery flexibility holds immense potential to transform the logistics landscape.

However, it is crucial to acknowledge the social and regulatory concerns surrounding the use of ADRs. Addressing issues like job displacement, public perception, accessibility considerations, and data privacy will be critical for ensuring their successful integration into our communities. Furthermore, establishing robust safety standards, clear legal frameworks, and responsible deployment practices will be essential for fostering public trust.

- **Project Contribution: A Focus on Indoor Navigation and SLAM**

In conclusion, the future of autonomous delivery robots (ADRs) is bright. Through ongoing innovation, responsible implementation, and a focus on both technological advancement and social considerations, ADRs have the potential to revolutionize the way we receive goods, creating a more efficient, sustainable, and convenient delivery ecosystem.

The Smart Delivery Robot takes a significant step forward in the field of ADR development by focusing on optimized goods transportation within confined spaces, particularly warehouses. While initially designed for indoor environments, the project's core technologies and problem-solving approach hold promise for future adaptations to outdoor applications.

The project's contribution lies in its focus on Simultaneous Localization and Mapping (SLAM) for indoor navigation. SLAM [22] allows the Smart Delivery Robot to build a real-time map of its surroundings while simultaneously pinpointing its location within that map. This is crucial for enabling autonomous navigation in dynamic environments like warehouses, where obstacles can shift or people might be moving around.

The Challenge: Choosing the Right SLAM Algorithm

Several SLAM algorithms exist, each with its strengths and weaknesses. The project's decision to utilize LiDAR technology for obstacle detection and navigation opens the door for two prominent SLAM algorithms:

GMapping [23] (Grid-based Mapping): This popular algorithm builds a map of the environment by representing it as a grid of cells. Each cell holds the probability of being occupied by an obstacle. GMapping works well in static environments and is computationally efficient. However, it can struggle in highly dynamic environments where obstacles move frequently.

Hector SLAM [24]: This algorithm utilizes a different approach, employing a particle filter (MCL - Monte Carlo Localization [25]) to maintain a set of possible robot poses (positions and orientations) and their corresponding map representations. Hector SLAM is more robust in dynamic environments as it can adapt its map and pose estimates more readily in response to changes. However, it can be computationally more expensive than GMapping.

In the project's the choice of LiDAR and its focus on dynamic environments suggest that Hector SLAM might be a more suitable algorithm compared to GMapping. The ability of Hector SLAM to adapt its map and pose estimates in real-time would be beneficial for navigating warehouses where obstacles like forklifts or pallet jacks might be present.

Beyond Navigation: The Smart Delivery Robot's Broader Impact

The success of the project demonstrates the potential for similar autonomous systems to revolutionize indoor logistics. The Smart Delivery Robot's focus on efficiency, reduced reliance on manual labor, and user-friendliness aligns perfectly with the broader goals of ADR development. By addressing challenges like navigation in dynamic environments, user-friendly interfaces, and security measures, the project paves the way for the development of more sophisticated autonomous indoor goods transportation systems.

This focus on indoor SLAM serves as a valuable steppingstone for the development of future outdoor ADRs. The learnings and technological advancements from the project can be adapted and expanded upon to create robust navigation systems for outdoor delivery robots, ultimately contributing to a more efficient and automated future for the logistics industry.

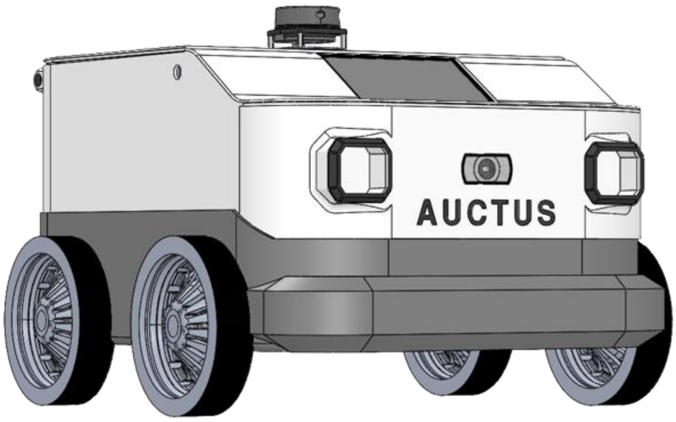

Figure 4: AUCRUS Design

Chapter Three

3. PROPOSED MODEL

3.1.SYSTEM ARCHITECTURE DIAGRAM

- Smart Delivery Robot System Architecture Overview as shown in figure 5
- This diagram outlines the fundamental components driving the Smart Delivery Robot's functionality:
- Key Components:
- Lattepanda Delta (Main Board): Decision-making, data processing, and communication hub.
- Arduino (Motor Control): Governs movement and offers feedback.
- Sensors: Lidar (mapping), IR sensors (obstacle detection), and a camera (enhanced vision).
- User Interaction:
- Mobile App: Provides location data and generates passcodes.
- Touch Screen: Enables user commands and passcode input.
- Security Measures:
- Component Relationships:
- Motor Control: Lattepanda Delta commands movement through the Arduino.
- Sensor Interaction: Lidar, IR sensors, and camera data employed for navigation and perception.
- User Interface: Control inputs managed via the mobile app and touch screen.
- Secure Access: Lattepanda Delta oversees latch control, ensuring secure compartment handling.

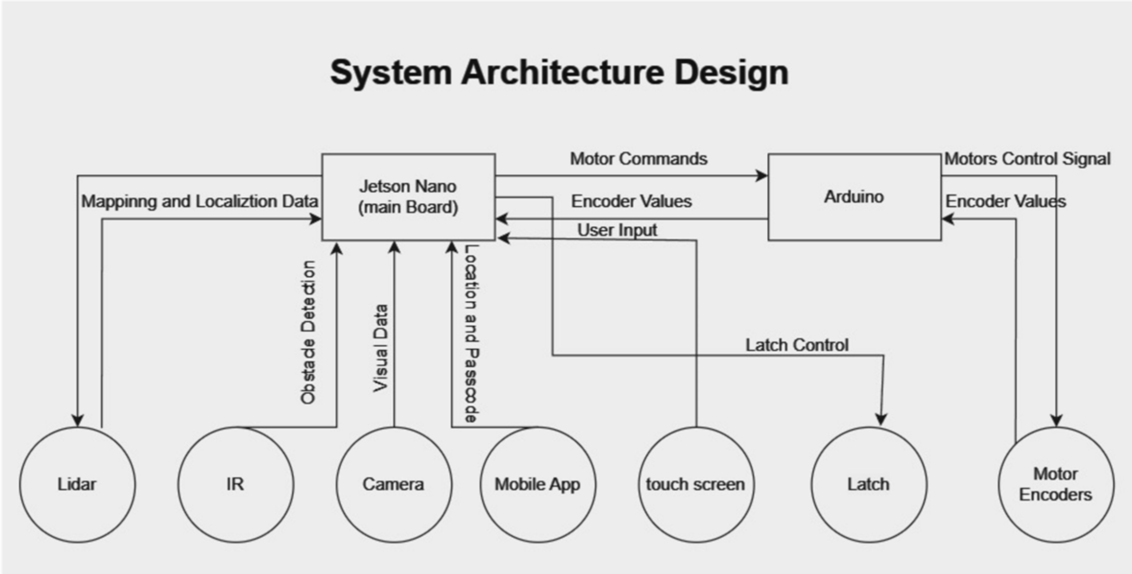

Figure 5: System Architecture Diagram

3.2. DESIGN BLUEPRINT

As shown in figure 6: Blueprint of the AUCTUS Project

This figure serves as a comprehensive representation of the AUCTUS project, offering diverse perspectives vital for grasping its design and structure. It includes:

Top View: An aerial representation highlighting the project's upper dimensions.

Elevation View: A depiction focusing on the project's vertical dimensions.

Bottom View: Providing insights into the lower aspects of the project.

Side View: Offering lateral perspectives crucial for understanding its shape and structure.

These views collectively provide essential insights into the AUCTUS project's comprehensive blueprint, aiding in a thorough comprehension of its design complexities.

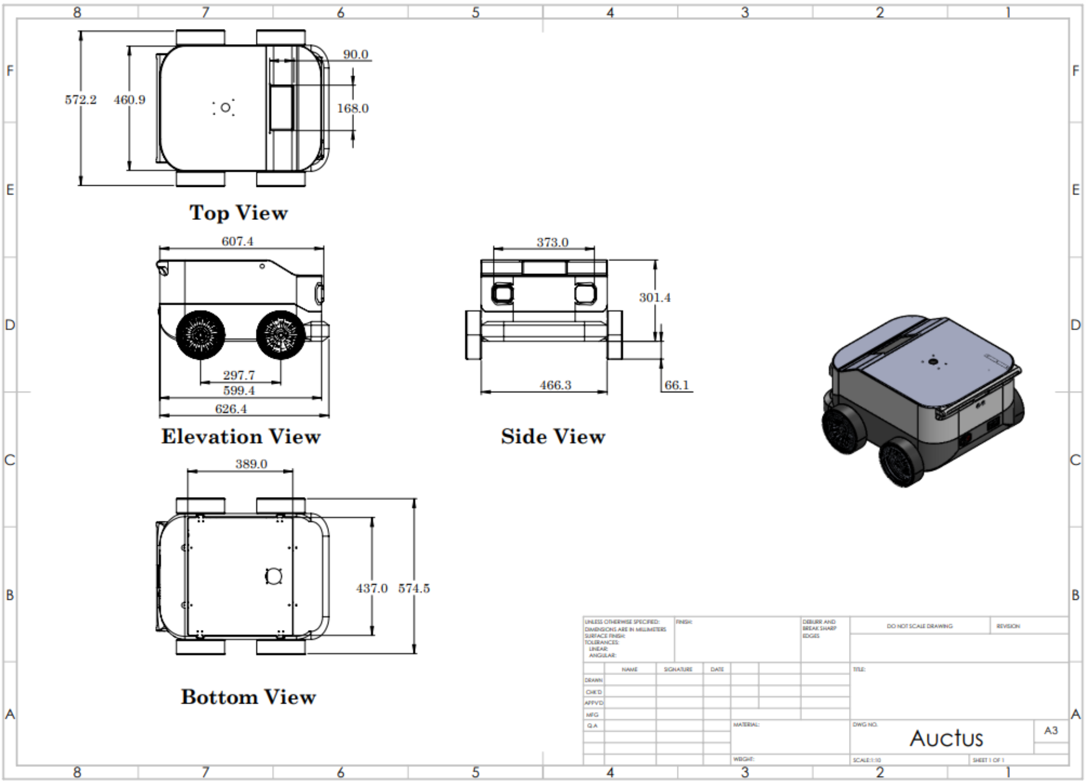

Figure 6:Design Blueprint

3.3.SEQUENCE DIAGRAM

As shown in figure 7: This sequence diagram offers a holistic depiction of interactions among users, a web interface, and the innovative Smart Delivery Robot system engineered for efficient goods transportation. It visually outlines the stepwise process initiated by users via the mobile app, covering order placement, real-time tracking of the Smart Delivery Robot's movement, and secure item retrieval. It details the complex authentication protocols, including user verification and access code validation, ensuring a secure user-Smart Delivery Robot interaction. The diagram illustrates a seamless flow of actions involving user notifications, access control, and successful transaction completion. It underscores the system's reliability, convenience, and robustness in enabling hassle-free goods transportation while upholding user security and satisfaction as primary objectives.

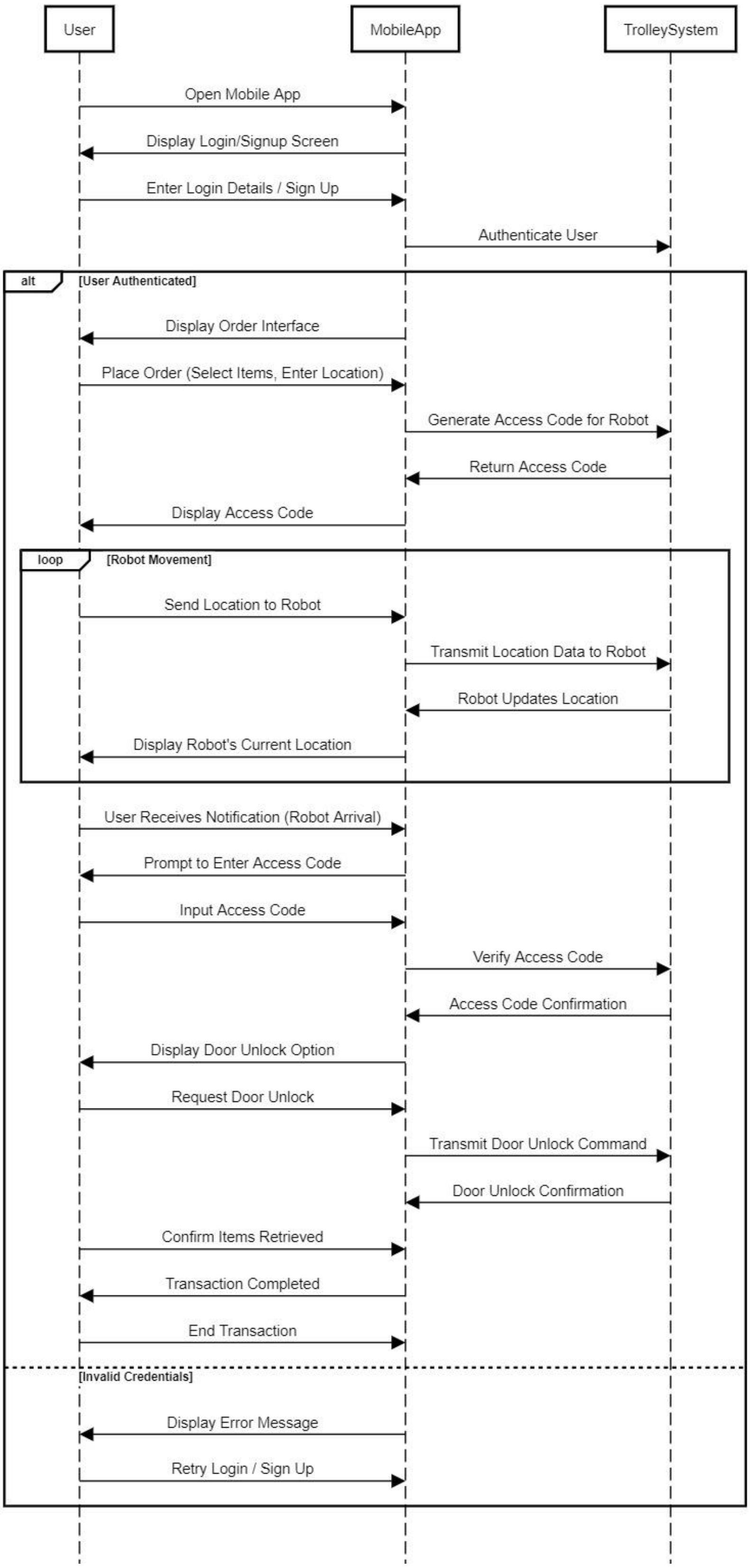

Figure 7:Sequence Diagram

3.4. Block Diagram

As shown in figure 8: Smart Delivery Robot (AUCTUS) System Architecture
This block diagram offers a comprehensive view of the interconnected components that constitute the innovative Smart Delivery Robot system, designed to streamline goods transportation, and revolutionize material handling.

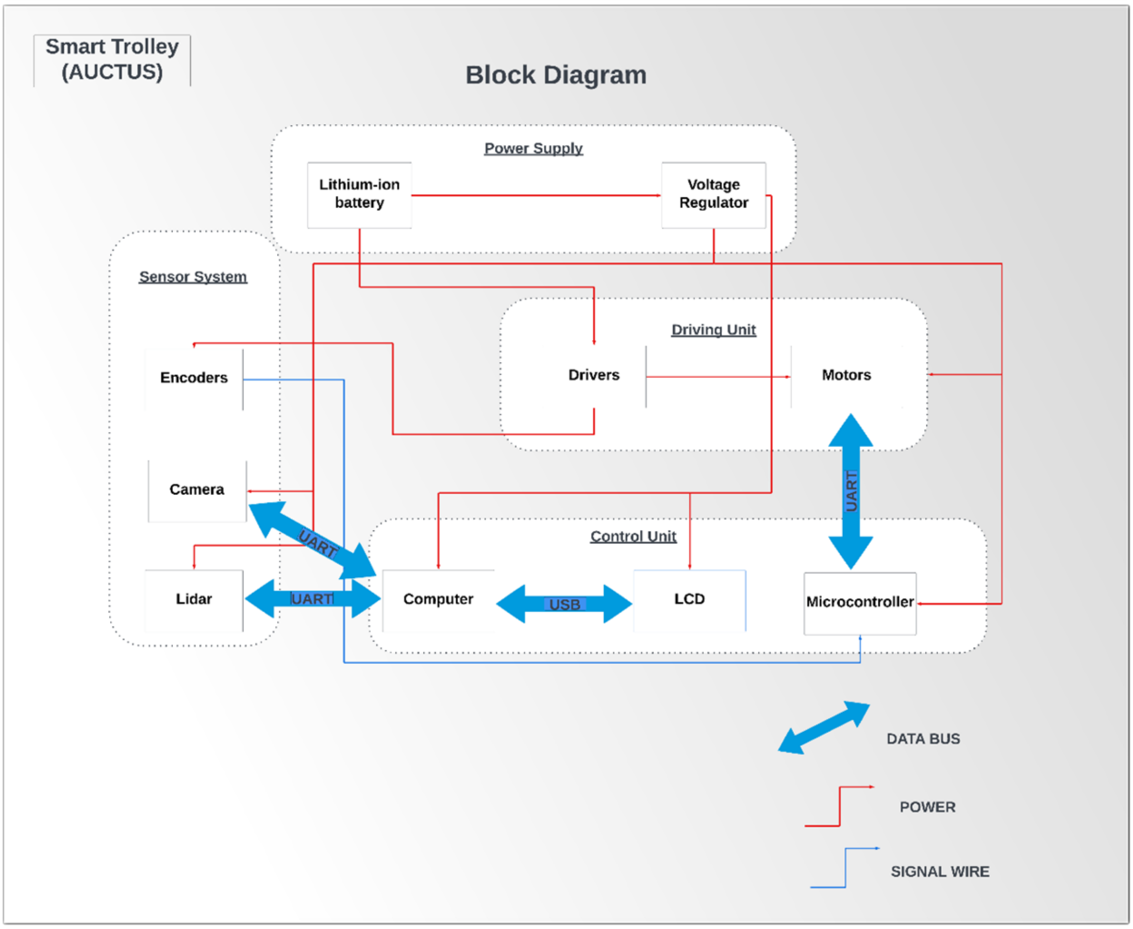

Figure 8:Block Diagram

3.5. Project Components

The figure 9 below showcases the custom-made body of the Smart Delivery Robot, constructed entirely from scratch. The chassis, made from rigid material, provides a sturdy base for the robot. Four drive wheels at the base of the Smart Delivery Robot. The platform on top serves as the designated area for carrying goods within the environment. Pre-drilled holes or brackets is designated as mounting points for sensors used for navigation and obstacle detection. The overall design prioritizes functionality and provides a solid foundation for the Smart Delivery Robot's operation.

Figure 9: Fabricated body

In the figure 10 depicts the robot base of the Smart Delivery Robot, housing several crucial hardware components that enable its movement and control. Here's a breakdown of the visible elements:

Batteries (2x): Two batteries are present, likely providing redundancy and extending the operational runtime of the Smart Delivery Robot between charges.

Lattepanda Delta: The Lattepanda Delta is a single-board computer (SBC) that serves as the brain of the robot. It likely houses the processing power and electronics required to run the control algorithms, sensor data processing, and decision-making for autonomous navigation.

Four Motors: Four motors are visible, presumably connecting to the wheels of the Smart Delivery Robot. These DC motors provide the driving force that propels the robot around its environment.

IMU (Inertial Measurement Unit): An IMU sensor is likely present to measure the robot's orientation and movement in real-time. This data is critical for maintaining stability and accurate navigation, especially during turns or uneven terrain.

Motor Drivers (2x): Two motor drivers are required to control the four motors. These drivers receive commands from the Lattepanda Delta and regulate the power delivered to each motor, enabling forward, backward, and precise directional movement of the Smart Delivery Robot.

Arduino Mega: The description mentions an Arduino Mega, which might be used for interfacing with lower-level sensors or components. It could also provide additional processing power or input/output capabilities to complement the Lattepanda Delta.

Overall, the robot base integrates these hardware components to form the core of the Smart Delivery Robot's mobility system. The combination of power source, processing unit, motors, sensors, and drivers enables controlled movement and navigation within the warehouse environment.

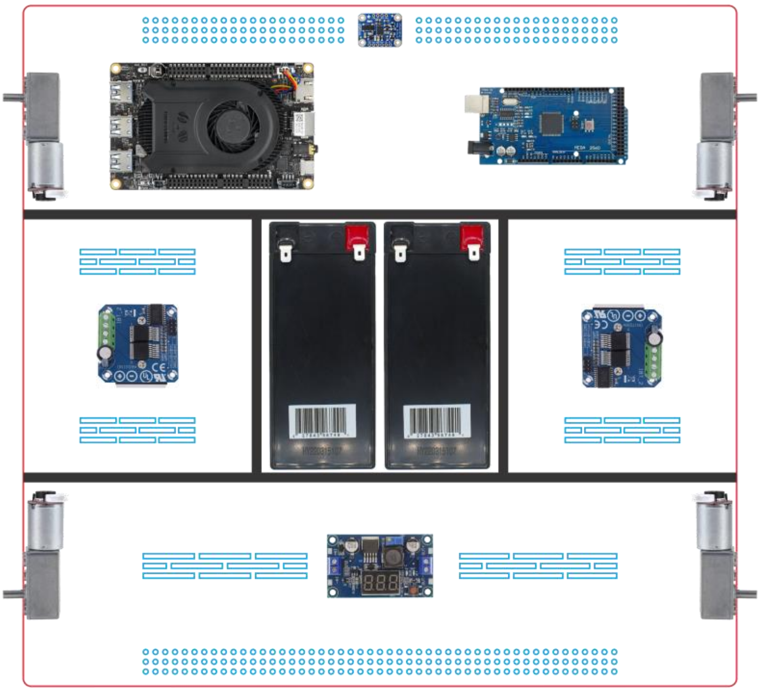

Figure 10: Robot Base

In the figure 11 depicts the LiDAR A1M8 sensor, a crucial component for the Smart Delivery Robot's navigation system. LiDAR stands for Light Detection and Ranging. It's a sensor that emits laser beams and measures the reflected light to create a 3D map of the surrounding environment. Here's how the LiDAR A1M8 contributes to the Smart Delivery Robot's functionality:

Environment Mapping: The LiDAR A1M8 continuously scans its surroundings, generating a real-time point cloud of obstacles and features within the warehouse. This data is essential for the robot to understand its environment and navigate safely.

Obstacle Detection: By analyzing the LiDAR data, the Smart Delivery Robot can identify and avoid obstacles like walls, shelves, or misplaced objects in its path.

Localization and Mapping: The LiDAR data can be used to localize the Smart Delivery Robot's position within the warehouse and potentially build a map of the environment over time. This information is crucial for planning efficient routes and ensuring safe navigation.

Benefits of LiDAR A1M8:

High Accuracy: LiDAR sensors offer precise 3D mapping compared to other sensors like cameras, which can be susceptible to lighting variations.

Long Range: The A1M8 model likely offers a decent range for obstacle detection within a typical warehouse environment.

Solid-State Design: LiDAR sensors are generally robust and reliable compared to mechanical sensors with moving parts.

Overall, the LiDAR A1M8 sensor plays a vital role in the Smart Delivery Robot's perception system, providing crucial data for obstacle detection, localization, and safe autonomous navigation within the environment.

Figure 11: LIDAR A1M8

"The robot's power system utilizes a DC-DC Buck Converter **(Figure 12)**. This component efficiently reduces the voltage from the main battery pack (12v) to a lower voltage level (7v) required by specific components within the system, ensuring optimal power delivery and efficient operation."

Figure 12: DC-DC Buck Converter

"The robot's motor control system utilizes a BTS7960 Motor Driver **(Figure 13)**. This integrated circuit functions as a high-current driver, enabling the control and direction of the robot's motors with high efficiency. The microcontroller board sends control signals to the BTS7960, which in turn regulates the power delivered to the motors, allowing for precise movement and control of the robot."

Figure 13:BTS7960 Motor Driver

"The robot's compartment door utilizes a digital servo motor **(Figure 14)**. Unlike traditional servo motors, digital servos provide precise positioning control through digital pulses sent by the microcontroller board. This allows for accurate and repeatable movements of the compartment door(box)."

Figure 14:digital servo motor

In the **figure 15** below the robot is powered by a rechargeable battery pack (12v 9A) .The battery pack supplies the electrical energy required by the robot's various components, enabling its operation. The capacity of the battery pack determines the robot's operational runtime between charges.

Figure 15: Battery pack 12V 9A

This **figure 16** depicts the Logitech C920 HD Pro Webcam, a crucial component for the Smart Delivery Robot's security monitoring and surveillance system. The webcam captures a live video feed of the warehouse environment, providing valuable benefits:

Real-Time Monitoring: The webcam stream allows remote human supervisors to monitor the Smart Delivery Robot's operation and the surrounding warehouse environment in real-time. This enables quick response to potential issues or unexpected situations.

Security Surveillance: The webcam footage can be recorded and stored for security purposes. This can help deter unauthorized activity and provide evidence in case of incidents within the warehouse.

Future Integration Potential:

The description mentions the possibility of using the webcam for "Simulated Environment Visualization." While not currently implemented, this could be an interesting future exploration:

First-Person View in Simulation: The webcam feed could be integrated into the simulation software, offering a first-person perspective for visualizing the virtual warehouse environment from the robot's viewpoint. This could aid in testing and debugging navigation algorithms.

Overall, the Logitech C920 HD Pro Webcam plays a significant role in enhancing the security and monitoring capabilities of the Smart Delivery Robot project.

Figure 16:Logitech C920 HD Pro Webcam

The **figure 17** showcases the Lattepanda Delta, a vital piece of hardware serving as the brain of the Smart Delivery Robot. It's a single-board computer (SBC) that integrates various functionalities essential for autonomous operation:

Processing Power: The Lattepanda Delta houses a powerful processor capable of running the complex algorithms required for tasks like sensor data processing, navigation planning, and real-time decision-making.

Memory and Storage: The Lattepanda Delta comes equipped with memory (RAM) to handle active processes and storage (eMMC) to store essential data like operating systems, navigation maps, and control programs.

Connectivity: The Lattepanda Delta likely offers various connectivity options like Wi-Fi, Bluetooth, and Ethernet ports. These allow the Smart Delivery Robot to connect to external networks, potentially receive updates or communicate with a central control system.

Input/Output (I/O): The Lattepanda Delta provides I/O capabilities through ports like USB or HDMI. These ports enable connection to other hardware components like sensors, motors, and the webcam .

Overall, the Lattepanda Delta serves as the central processing unit for the Smart Delivery Robot. Its combination of processing power, memory, storage, connectivity, and I/O capabilities makes it a powerful platform for running the algorithms and programs that enable autonomous navigation within the warehouse environment.

Figure 17: Lattepanda Delta (Main Computer)

This **figure 18** show cases the Arduino Mega, a microcontroller board that might play a supporting role in the Smart Delivery Robot's hardware system. Here's a breakdown of its potential functionalities:

Lower-Level Control: The Arduino Mega is a versatile microcontroller commonly used for interfacing with sensors and actuators. While the Lattepanda Delta serves as the main computer, it's possible the Arduino Mega is used to handle lower-level control tasks. For example, it could directly read sensor data from specific components and send this information to the Lattepanda Delta for higher-level processing and decision-making.

Communication Bridge: The Arduino Mega might also be used as a communication bridge between the Lattepanda Delta and other sensors or components that operate on different communication protocols. This could help facilitate data exchange between various hardware elements within the Smart Delivery Robot.

Standalone Functionality: In some scenarios, an Arduino Mega might be programmed to handle specific tasks independently. However, considering the presence of the more powerful Lattepanda Delta, it's less likely the Arduino Mega has standalone control responsibilities in this project.

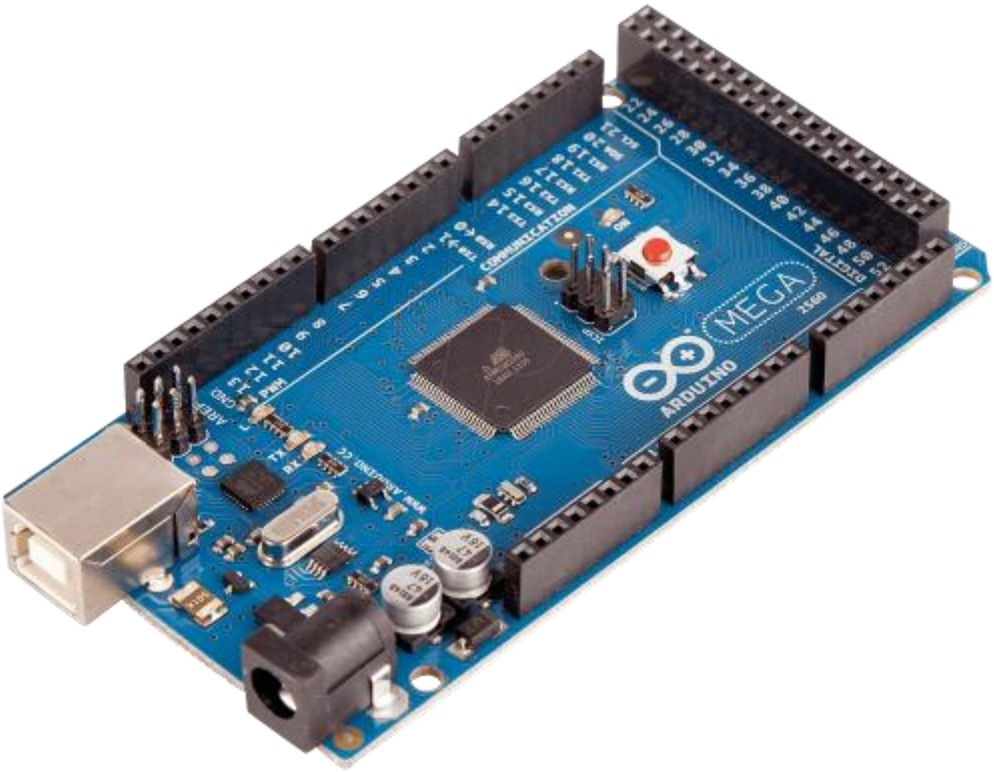

Figure 18:Arduino Mega

The **figure 19** show cases one of the DC motors used to drive the wheels of the Smart Delivery Robot. Here's a breakdown of its key features and their significance:

12V DC Motor: The motor operates on a 12-volt DC power supply, likely sourced from the batteries mentioned in Figure 10. This DC power provides the rotational energy required to propel the Smart Delivery Robot wheels.

32RPM Free-Run Speed: This refers to the motor's rotational speed without any load. In ideal conditions (no weight on the wheels), the motor can spin at 32 revolutions per minute. However, this speed will decrease under load conditions as the motors need to overcome friction and the weight of the Smart Delivery Robot and payload.

40Kg.cm Torque: Torque represents the motor's rotational force. A higher torque value indicates the motor's ability to generate more force to overcome resistance. In this case, 40Kg.cm translates to roughly 4 Newton meters (Nm) of torque. This torque capability is sufficient to propel the Smart Delivery Robot within a warehouse environment even with a moderate payload.

Encoder: The presence of an encoder is a crucial aspect of this motor. An encoder is a sensor that measures the motor's rotational position and speed. This information is fed back to the control system (likely the Lattepanda Delta mentioned earlier). The control system utilizes this encoder data for several purposes:

Precise Speed Control: By knowing the exact rotational speed of each motor, the control system can precisely regulate the power delivered to the motors. This enables smooth and controlled movement of the Smart Delivery Robot.

Odometry: Encoder data can be used for odometry, a technique to estimate the robot's position based on the distance traveled by its wheels. This information is essential for navigation and ensuring the Smart Delivery Robot follows the intended path.

Stall Detection: The encoder can also help detect if a motor stalls (stops rotating) due to excessive load or obstacles. This information allows the control system to take corrective actions like reversing the motor or alerting the human supervisor.

Overall, the 12V 32RPM 40Kg.cm motor with encoder is a crucial component of the Smart Delivery Robot's drive system. The combination of motor power, torque, and encoder feedback enables controlled movement, precise navigation, and obstacle detection for efficient and safe operation within the warehouse.

Figure 19: Motor 12V 32RPM 40Kg.cm with Encoder

In following **figure 20** the custom-made wheels of the Smart Delivery Robot, constructed using a combination of materials for optimal functionality and cost-effectiveness. The description mentions the challenges of finding suitable pre-made wheels and the decision to fabricate them due to regional limitations and budget constraints. Here's a breakdown of the material choices and their potential benefits:

Metal Outer and Inner Covers: Using metal for the outer and inner wheel covers provides significant advantages. Metal is known for its durability and strength, making the wheels resistant to damage from bumps, impacts, or carrying heavy loads within the environment.

Metal Couplers: Metal couplers likely connect the inner and outer wheel covers, providing a solid structure for the wheels. The strength of the couplers ensures proper load distribution and prevents deformation during operation.

Rubber-like Material Exterior: The exterior of the wheels likely features a rubber-like material to provide several benefits:

Traction: Rubber offers good traction on various surfaces, including environment floors. This traction is crucial for ensuring smooth movement and preventing the wheels from slipping, especially during turns or changes in speed.

Shock Absorption: Rubber has shock-absorbing properties, which can help cushion the impact of bumps or uneven surfaces during operation. This reduces vibration transmitted to the Smart Delivery Robot and potentially improves the lifespan of other components.

Cost-Effectiveness: While fabricating the wheels might involve labor costs, the choice of materials like metal and rubber strikes a balance between affordability and performance, especially considering the unavailability of suitable commercial options in available region.

Figure 20: Fabricated Wheels

3.6. DESCRIPTION OF EACH PHASE

Planning Phase:

Objective: Defining project goals, scope, and objectives.

Tasks: Creating a project plan, setting timelines, resource allocation, and risk assessment.

Deliverables: Project charter, scope statement, and initial feasibility reports.

Design and Architecture Phase:

Objective: Developing the blueprint and structure for the Smart Delivery Robot.

Tasks: Designing the hardware, software architecture, and user interface.

Deliverables: Technical specifications, system design documents, and prototype plans.

Development Phase:

Objective: Building the Smart Delivery Robot based on the design and architecture.

Tasks: Coding, hardware assembly, software implementation, and integration.

Deliverables: Prototype or initial version of the Smart Delivery Robot.

Testing and Quality Assurance Phase:

Objective: Verifying functionality and ensuring quality standards are met.

Tasks: Conducting tests, debugging, and user acceptance testing (UAT).

Deliverables: Test reports, bug-fixes, and validated prototype.

Deployment Phase:

Objective: Rolling out the Smart Delivery Robot for real-world use.

Tasks: Installing the system, training users, and addressing initial issues.

Deliverables: Operational Smart Delivery Robot system.

Monitoring and Optimization Phase:

Objective: Monitoring performance and fine-tuning the Smart Delivery Robot.

Tasks: Collecting performance data, analysing feedback, and implementing improvements.

Deliverables: Performance reports, system updates, and optimized functionalities.

Scaling and Expansion Phase:

Objective: Expanding the Smart Delivery Robot's capabilities or adapting it for broader use.

Tasks: Iterative improvements, adding new features, and scalability assessments.

Deliverables: Updated versions, extended functionalities, and adaptability for outdoor use.

Maintenance and Support Phase:

Objective: Sustaining the Smart Delivery Robot's operational efficiency.

Tasks: Regular maintenance, user support, and addressing system issues.
Deliverables: Maintenance reports, user manuals, and continuous support services.

3.7. DESIGN ISSUES

Payload Capacity: Optimizing the Smart Delivery Robot's storage to accommodate various sizes or weights of goods effectively.
Environmental Adaptability: Ensuring the Smart Delivery Robot can navigate diverse terrains, handle different weather conditions, and operate in low-light environments efficiently.
Integration with Existing Infrastructure: Seamless integration into established logistics systems or processes to ensure compatibility and efficient communication.
Cost-Effectiveness: Balancing the integration of high-tech components with cost efficiency without compromising functionality.
User Experience: Enhancing the user interface of the mobile app or the Smart Delivery Robot's interaction with users for a more user-friendly and intuitive experience.
Power Management: Efficiently managing the Smart Delivery Robot's power consumption for extended operations without frequent recharging, optimizing energy use.

3.8. WEB INTERFACE FUNCTIONALITY

Introduction

The Auctus smart delivery robot leverages a web-based interface system for seamless user interaction and remote operation within indoor environments. This system comprises two distinct websites: a Main Website accessible from any device and a Robot Control Website displayed on the robot's onboard screen.

(Figure 21: Login) illustrates the login page of the Main Website, where users can enter existing credentials or create new accounts to access functionalities for placing orders and tracking deliveries. Administrators can also log in here to access their exclusive features.

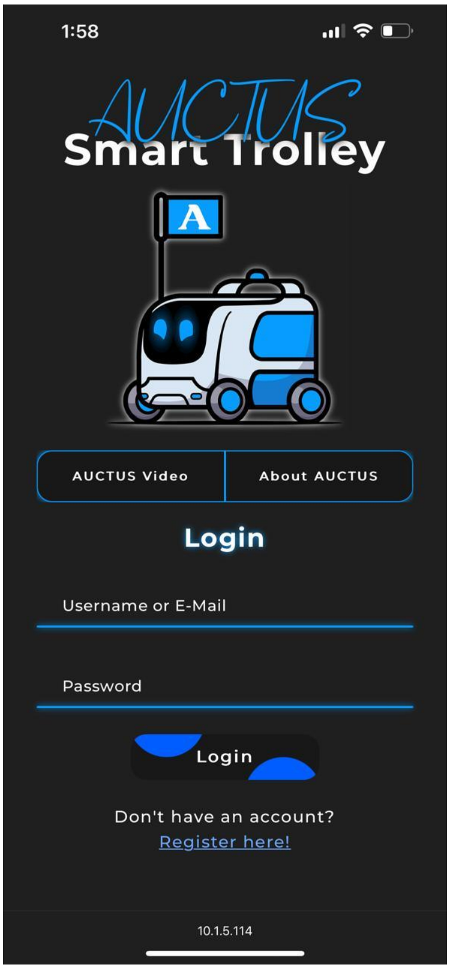

Figure 21: Login/Register page

(Figure 22: Register Page) is displayed if users choose to create a new account on the Main Website. This figure can be placed alongside Figure 17 if you want to showcase both login and registration options.

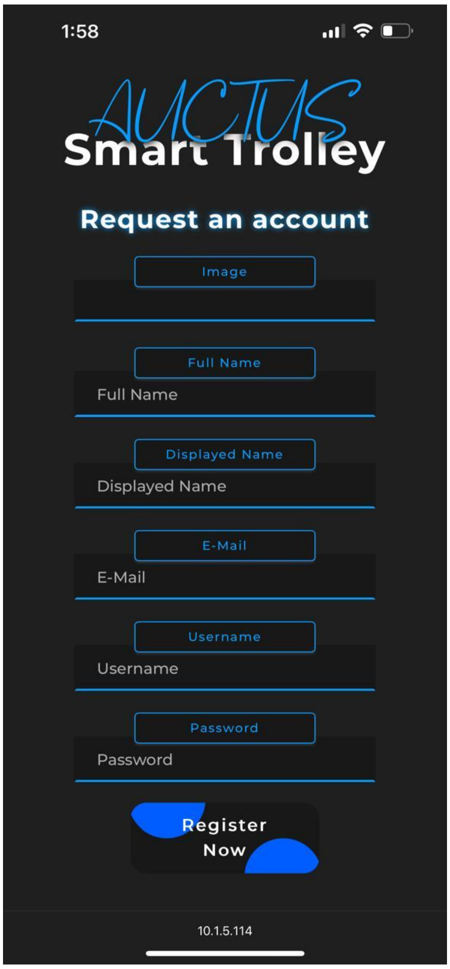

Figure 22: : Register Page

Main Website Functionalities

The Main Website serves as a central hub for both users and administrators, offering an intuitive interface for:

- **User Ordering:** Users can conveniently place orders for components, specifying pickup and delivery locations through user-friendly controls. **The (Figure 23: Home Page)** showcases a list of available components that users can browse through to initiate the ordering process. **(Figure 24: Cart - specifying pickup and delivery locations)**

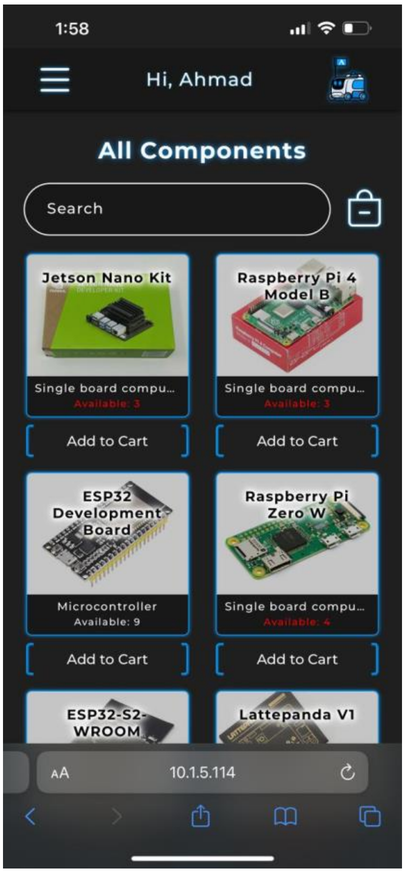

Figure 23: Home page

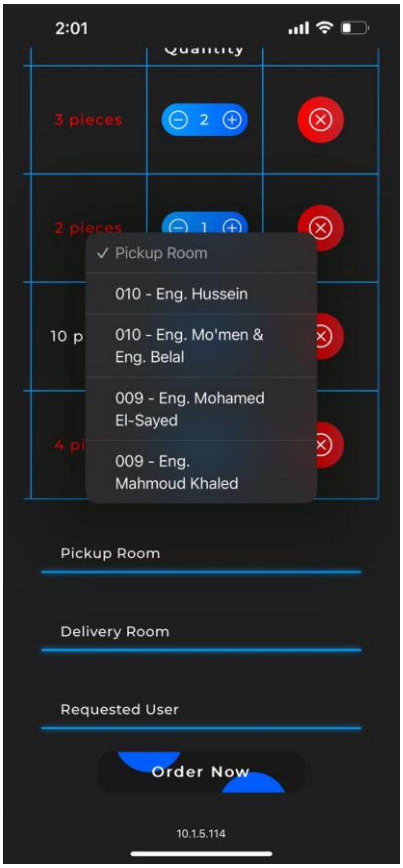

Figure 24:Cart - specifying pickup and delivery locations

- **Order Management:** The platform facilitates order tracking and management for users.
- **Live Monitoring (Admin only):** Administrators have exclusive access to a live video feed from the robot's front-facing camera, enabling real-time monitoring of its journey and activities. **(Figure 25: Camera Stream – Admin Options - Live Location & Scan QR Code)** showcases these options available on the user's mobile device during the delivery process.

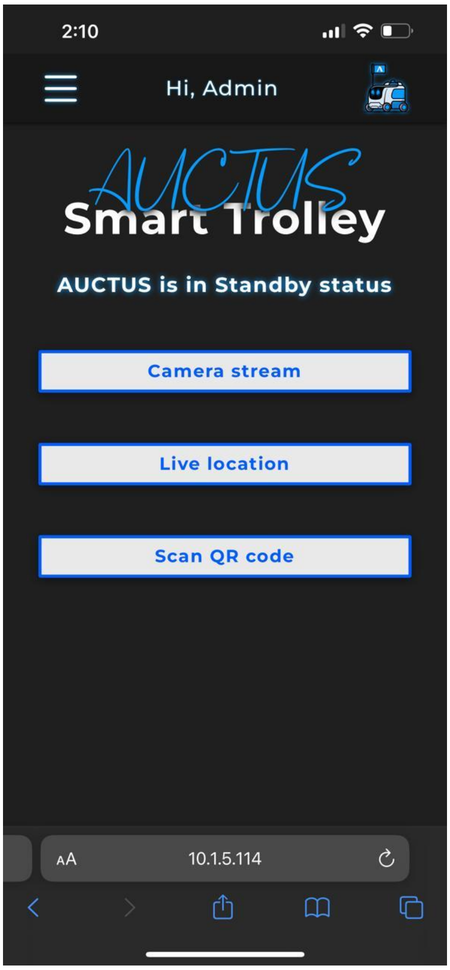

Figure 25: Admin Options

- **Live Location Tracking:** Utilizing data from RViz, the Main Website dynamically updates and displays the robot's real-time coordinates (x, y), providing users with continuous visual feedback of its location during operation. **(Figure 26: User Options - Live Location & Scan QR Code)** showcases these options available on the user's mobile device during the delivery process.

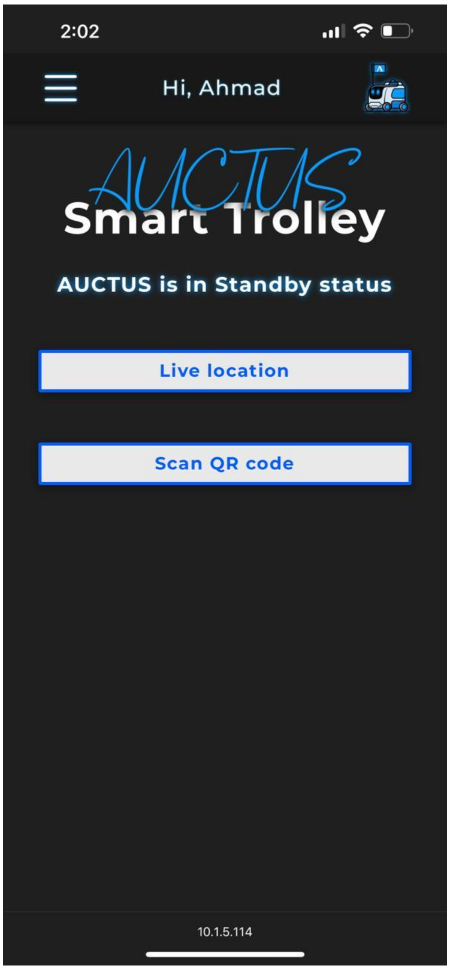

Figure 26: User Options

Robot Control Website Functionalities

Running on the robot's onboard screen, the Robot Control Website is designed for real-time monitoring and control of the robot's operational state. Here's how it facilitates user interaction:

- **Data Acquisition:** The Robot Control Website dynamically fetches data received from the Main Website via Google Firebase, a real-time database service. This data translates user instructions into executable commands for autonomous navigation.
- **Secure User Authentication:** As the robot reaches the designated pickup location, a secure QR code is displayed on its screen. Users must scan this code with their mobile device for verification before interacting with the robot. This ensures only authorized users can initiate component retrieval.

- **User Confirmation:** Throughout the pickup and delivery processes, the Robot Control Website prompts users via the onboard interface to confirm critical actions, such as loading or unloading components, using a designated button. This step ensures user engagement and verifies that the correct procedures are followed before proceeding with the next operational phase.

Operational Sequence

The web interface system facilitates a well-defined operational sequence for component delivery:

1. **User Order Placement and Confirmation:** Users place an order for a component through the Main Website, specifying pickup and delivery locations. Additionally, the system allows users to create custom packages **(Figure 27)**. This feature enables users to define the package name, description, dimensions, weight, and then add it to their cart for delivery.

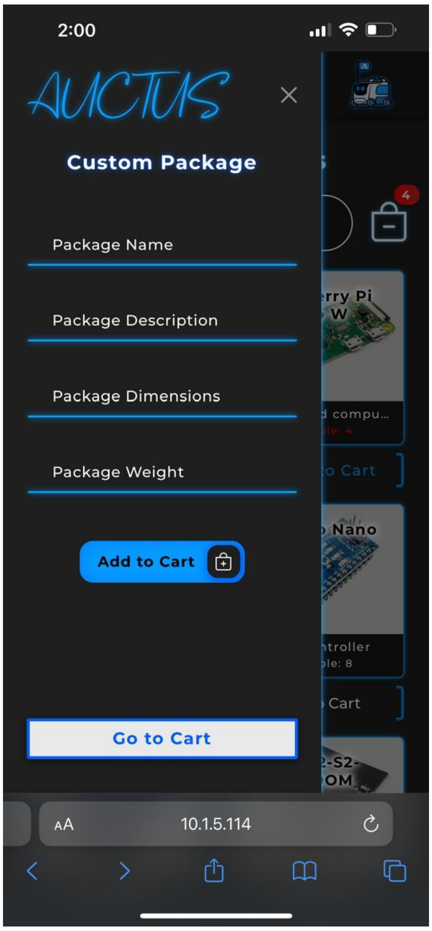

Figure 27: Custom package

2. **Robot Navigation:** Upon confirmation, the robot autonomously navigates to the designated pickup location.
3. **User Authentication (Pickup):** At the pickup location, the robot displays a QR code on its screen. Users must scan this code with their mobile device to authenticate and initiate component retrieval.
4. **Component Retrieval and Confirmation:** Following successful authentication, servos within the robot's system open the cargo compartment. **(Figure 28: Cart with Edit Options)** can be included here to illustrate how users might have edited their cart on the Main Website before initiating the delivery process. The Robot Control Website prompts the user to confirm loading the component with a button press.

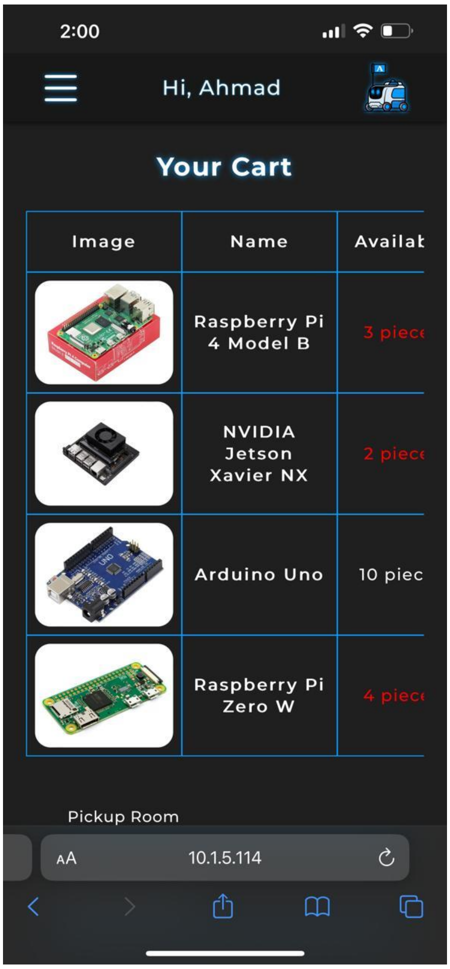

Figure 28: Cart

5. **Autonomous Delivery:** Once the component is loaded and confirmed, the robot navigates to the designated delivery room.

6. **User Authentication (Delivery):** Similar to the pickup process, the robot displays a QR code upon arrival at the delivery location. The recipient must scan this code to confirm receipt of the component.
7. **Component Delivery and Confirmation:** The Robot Control Website prompts the recipient to confirm unloading the component with a button press, finalizing the delivery process.
8. **Return to Home Position:** After successful delivery, the robot autonomously returns to its designated home position, completing the delivery cycle.

Robot Control Website Status Display

The Robot Control Website features a dynamic interface that displays eight primary operational statuses on the robot's screen, providing real-time feedback and enhancing user interaction:

- Standby: Indicates the robot is powered on and awaiting instructions. **(Figure 29: Standby Screen)**

Figure 29: Standby screen

- Going to Pickup Location: Shows the robot is en route to retrieve a component. **(Figure 30: Pickup Location Screen)**

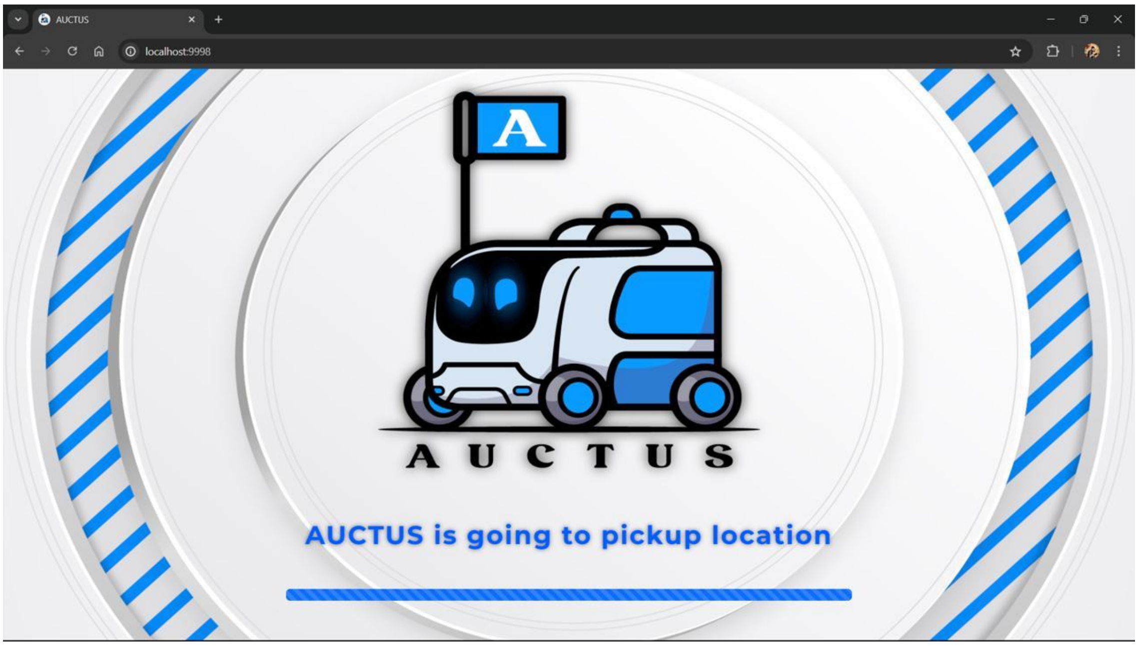

Figure 30: Pickup Location Screen

- Waiting to Scan QR-Code (Pickup): Awaits user interaction to scan the QR code for validation. **(Figure 31: QR-Code (Pickup) Screen)**

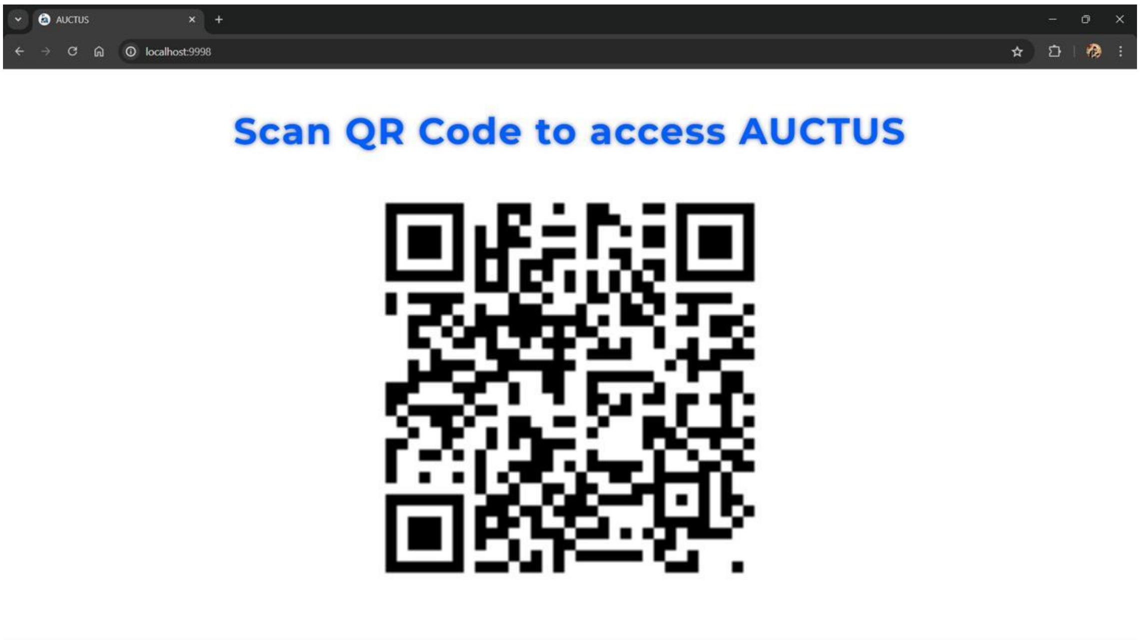

Figure 31: QR-Code (pickup) Screen

- Waiting to Finish Loading Package (Pickup): Ready for the user to load the component and confirm with a button press. **(Figure 32: Waiting to Finish Loading Package)**

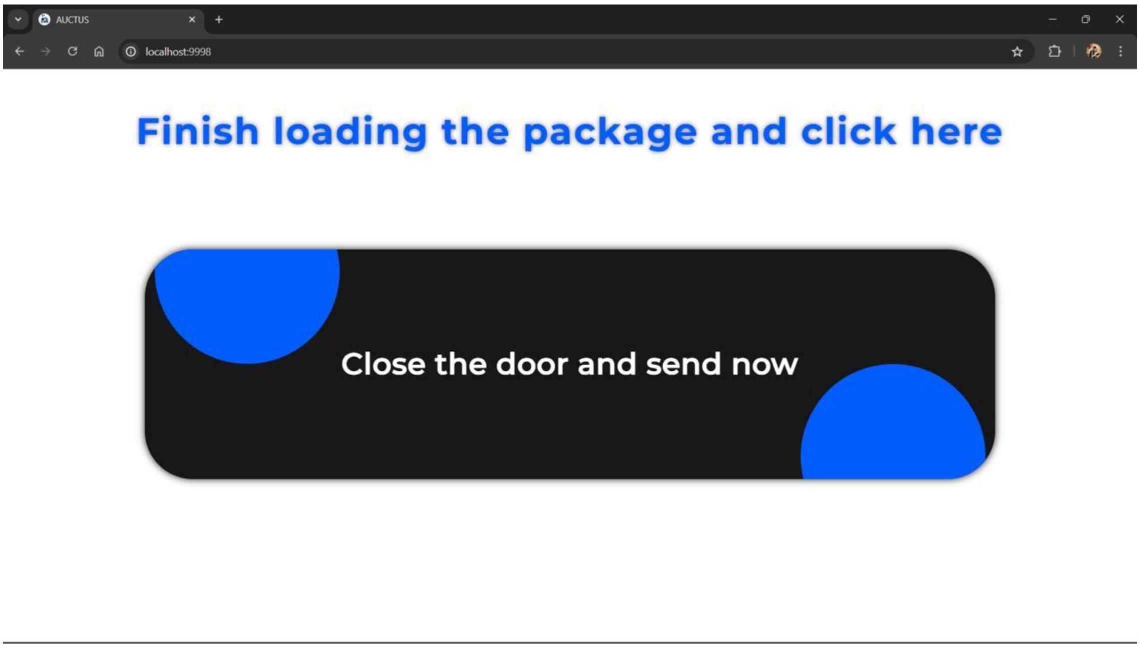

Figure 32: Waiting to Finish Loading Package

- Going to Delivery Location: Indicates the robot is navigating to the designated delivery room. **(Figure 33: Going to Delivery Location Screen)**

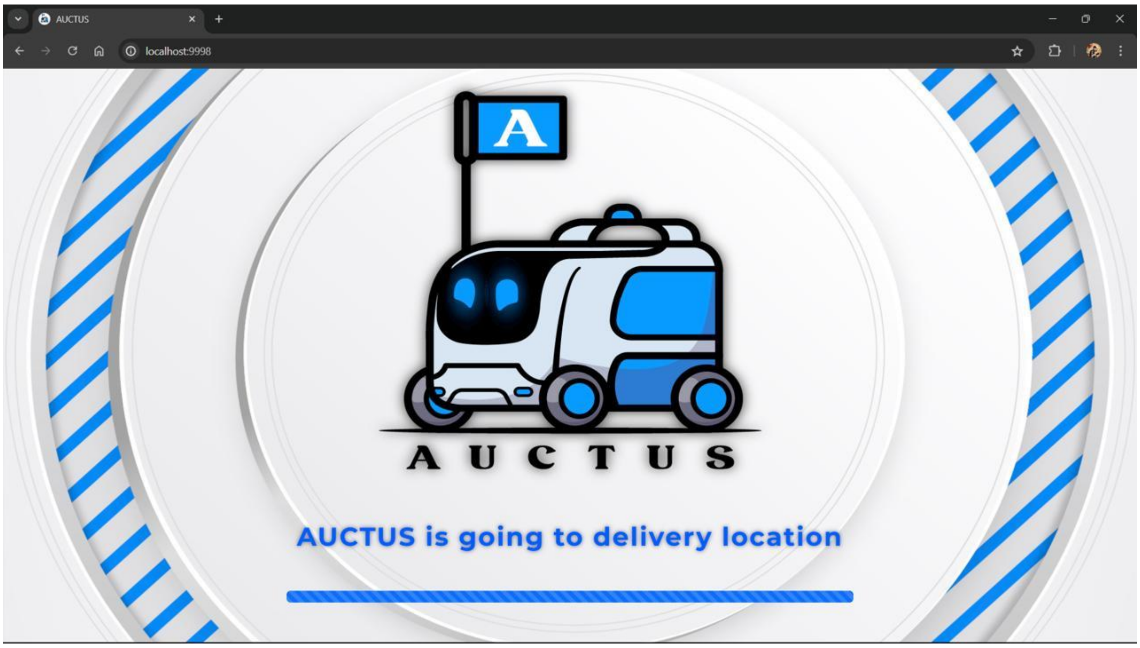

Figure 33: Going to Delivery Location Screen

- Waiting to Scan QR-Code (Delivery): Awaits user interaction to scan the QR code for delivery validation. **(Figure 34: Scan QR-Code (Delivery) Screen)**

Figure 34: Scan QR-Code (Delivery) Screen

- Waiting to Finish Loading Package (Delivery): Ready for the recipient to unload the component and confirm with a button press. **(Figure 35: Waiting to Finish Loading Package (Delivery Screen)**

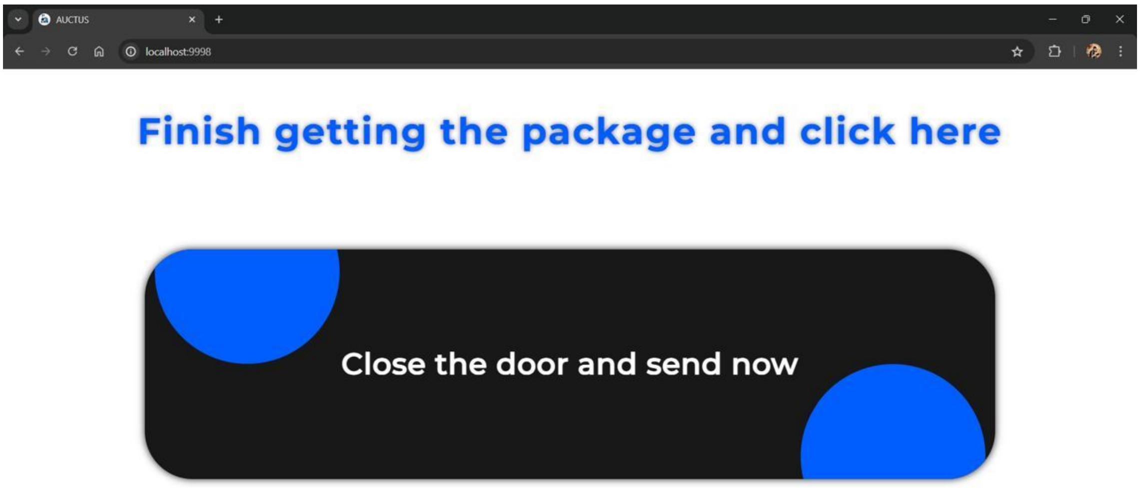

Figure 35:Waiting to Finish Loading Package (Delivery Screen

- Going to Home Location: Shows the robot is returning to its designated home position after completing the delivery. **(Figure 36: Going to Home Location Screen)**

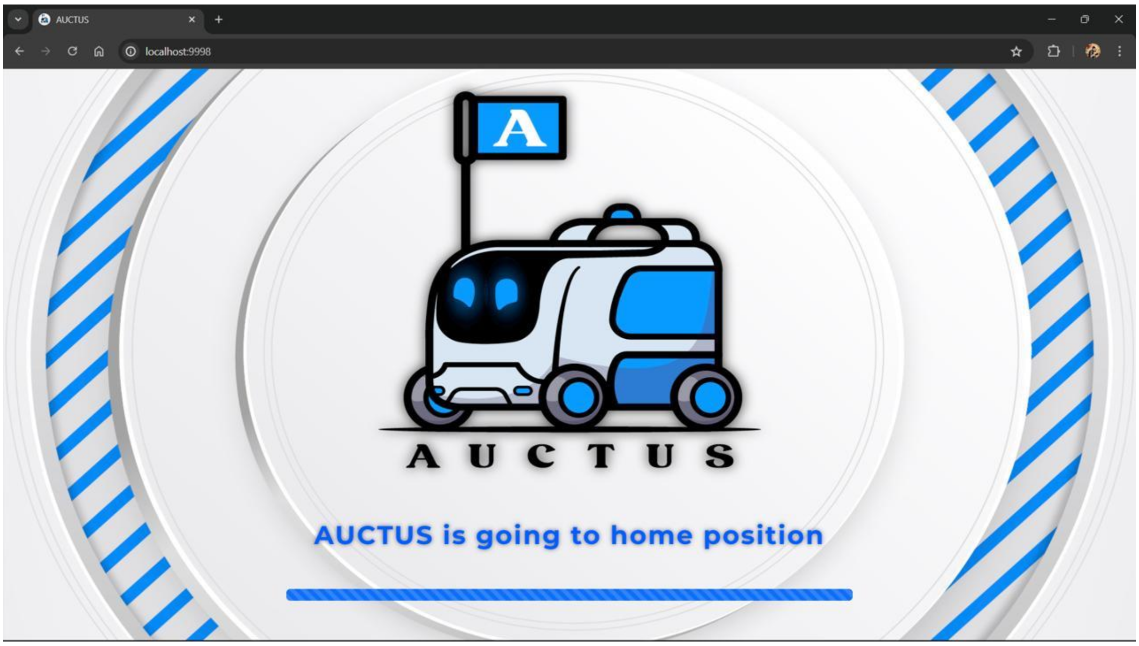

Figure 36: Going to Home Location Screen

Conclusion

The web interface integration plays a crucial role in the Auctus smart delivery robot's functionality. It facilitates seamless user interaction, secure user authentication

Chapter Four

4. PROJECT SIMULATION AND PERFORMANCE EVALUATION

4.1. PROJECT SIMULATION AND PERFORMANCE EVALUATION

This section delves into the simulation and performance evaluation aspects of the Smart Delivery Robot project. Here, we explore how the robot's navigation capabilities were tested in a controlled virtual environment using Robot Operating System (ROS) and the RViz visualization tool. Additionally, we'll discuss how the learnings from simulation inform potential real-world deployments.

4.2. SIMULATED ENVIRONMENT AND PERFORMANCE METRICS

The simulated environment serves as a critical testing ground for the Smart Delivery Robot's navigation algorithms and sensor fusion techniques. Here's a breakdown of the key elements:

Virtual Environment Design: The simulation environment replicates a environment layout, including walls, obstacles (shelves, boxes), designated pick-up and drop-off points, and pathways for the robot to navigate. The complexity of this layout can be varied to test the robot's adaptability in different scenarios.

Sensor Suite Integration: The simulated Smart Delivery Robot is equipped with a sensor suite similar to the one envisioned for real-world deployment. This typically includes:

Inertial Measurement Unit (IMU): Provides data on the robot's acceleration, orientation, and angular velocities.

Wheel Encoders: Measure the rotational speed of the wheels, enabling the estimation of travelled distance.

LiDAR (Light Detection and Ranging): Creates a 3D map of the environment by emitting laser beams and measuring their reflections. This allows for real-time obstacle detection, localization and avoidance.

Sensor Fusion with Extended Kalman Filter (EKF): The sensor data from IMU, encoders, and LiDAR is fused using an Extended Kalman Filter (EKF). This technique combines data from multiple sensors to create a more robust and accurate estimate of the robot's position, orientation, and movement within the simulated environment.

4.3. PERFORMANCE EVALUATION IN SIMULATION

The simulation environment allows us to evaluate the Smart Delivery Robot's performance using various metrics:
Delivery Time: The time taken by the Smart Delivery Robot to complete a simulated delivery task, measured from start to finish.
Path Efficiency: The directness of the path taken by the robot compared to the ideal route, calculated using distance metrics. This assesses the effectiveness of the robot's path planning algorithms.
Obstacle Avoidance Success Rate: The percentage of times the robot successfully navigates around obstacles without collisions. This evaluates the accuracy and efficiency of the sensor fusion and obstacle detection techniques.
Sensor Data Analysis: If the simulation logs sensor data, we can analyze how the different sensors (IMU, encoders, LiDAR) contribute to the overall navigation and obstacle avoidance performance.

4.4. TRANSITIONING FROM SIMULATION TO REAL-WORLD PERFORMANCE

The insights gained from the simulation environment provide a valuable foundation for real-world deployments of the Smart Delivery Robot. While the simulation offers a controlled setting, real-world environments are more complex and unpredictable. Here are some additional considerations:
Sensor Calibration and Noise Reduction: Real-world sensor readings can be affected by factors like lighting variations and sensor noise. Calibration techniques and noise reduction algorithms become crucial for ensuring accurate sensor data in real-world operation.
Localization and Mapping Challenges: Real-world environments may have dynamic obstacles or unexpected changes in layout. The robot's localization and mapping algorithms need to be robust and adaptable to handle these variations.

Integration with External Systems: In a real-world environment, the Smart Delivery Robot might need to interact with other systems like traffic management or inventory control. The simulation can be a starting point for testing these communication protocols and ensuring smooth integration.

In the **figure 37** below depicts the starting position of the Smart Delivery Robot within the environment, visualized using the Robot Operating System (ROS) tool RViz. The background grid represents a map of the environment, likely including walls, obstacles, and designated pathways for the robot to navigate. The square with a triangle on top signifies the Smart Delivery Robot, positioned at the bottom left corner, indicating its designated starting point for the simulated delivery task. The text "2D Pose Estimate" in the bottom right corner suggests that RViz is displaying the robot's estimated location and orientation within the 2D map.

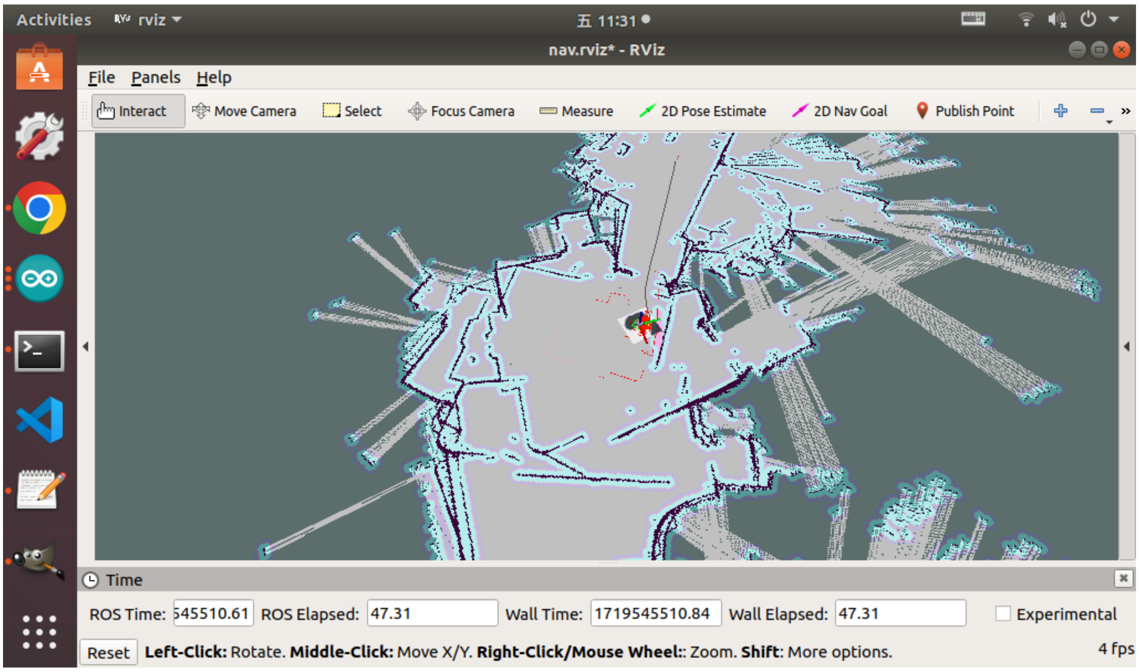

Figure 37:Starting Position of the Smart Delivery Robot in the Environment (RViz)

This image serves as a starting point for understanding the performance evaluation of the Smart Delivery Robot in a controlled virtual environment. The simulation environment, created using RViz, allows for testing the robot's navigation capabilities, obstacle avoidance, and path planning algorithms without the risks associated with real-world deployments.

In the **figure 38** below provides a glimpse into the Smart Delivery Robot's mid-navigation stage. While a single image does not capture the entire path, it showcases the robot actively navigating within the simulated environment. The specific details visible might include:

Partial Map View: We might see a portion of the environment map, potentially including obstacles or pathways the robot has already navigated or is currently approaching.

Robot Mid-Journey: The Smart Delivery Robot's position in the middle of the map suggests it's actively moving towards the goal location from its starting point (Figure 17).

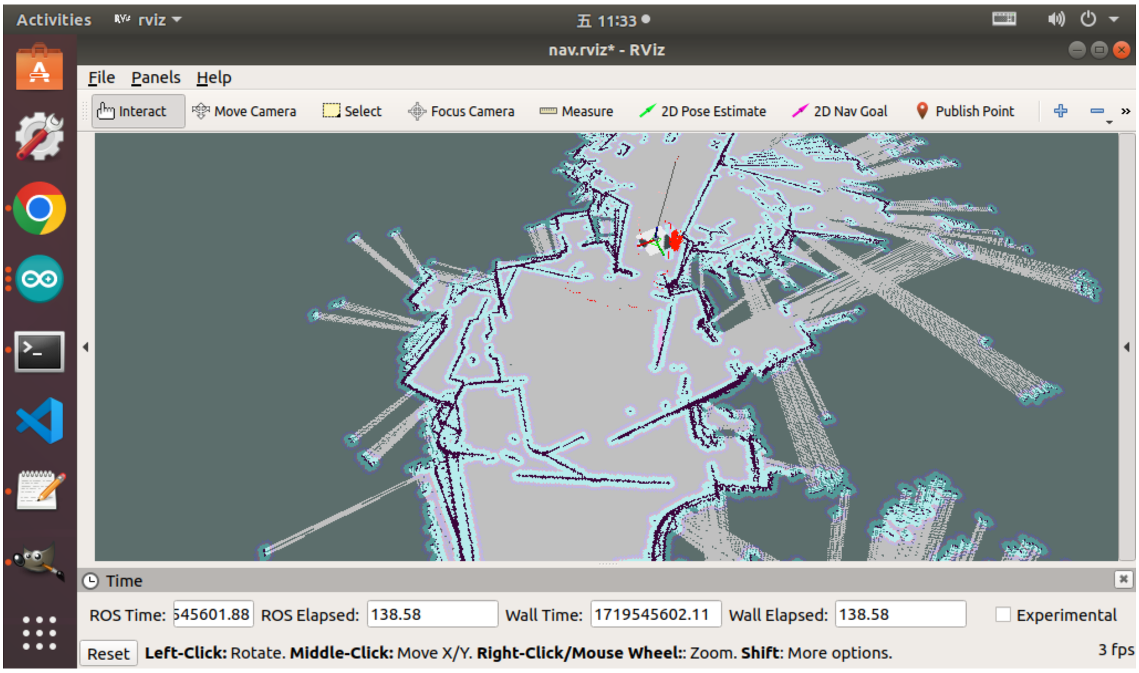

Figure 38:Mid-Navigation Position of the Smart Delivery Robot in the Environment (RViz)

In the **figure 39** below illustrates the Smart Delivery Robot successfully reaching its designated goal location within the simulated environment, as visualized using RViz. The background grid represents the map of the environment, and the square with a triangle on top signifies the Smart Delivery Robot positioned near the center, indicating its arrival at the goal. The text "2D Pose Estimate" in the bottom right corner suggests that RViz is displaying the robot's estimated location and orientation within the 2D map.

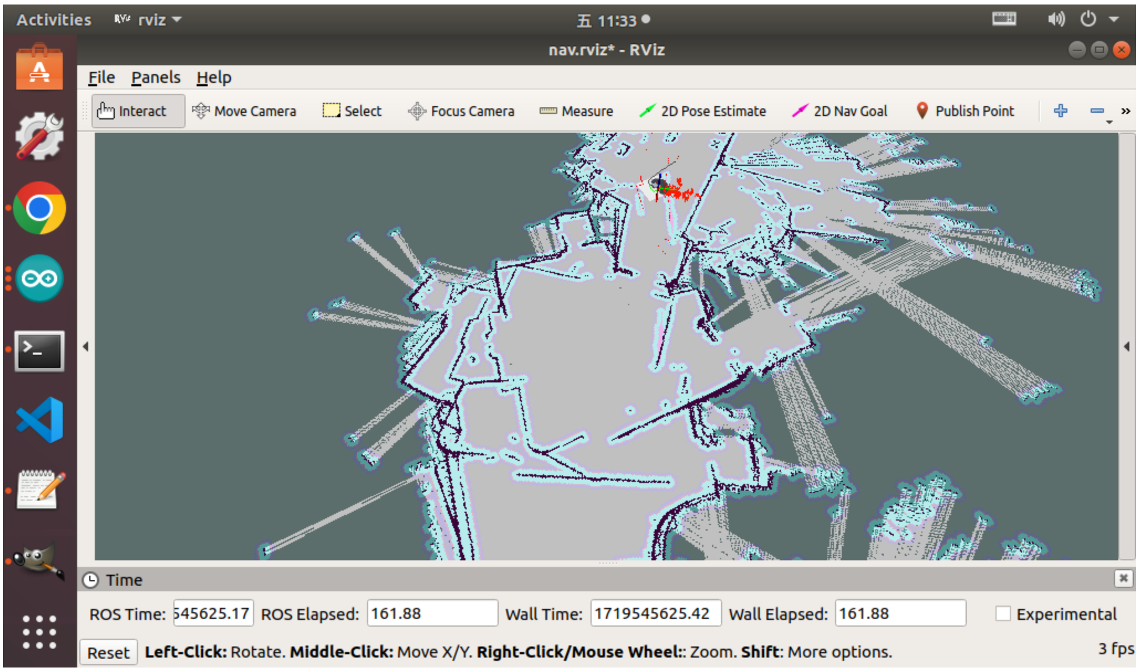

Figure 39:Smart Delivery Robot Reaching the Goal Position (RViz)

The key elements typically include:

Map: The background grid represents a top-down view of the simulated layout. It might include walls, shelves, designated pick-up and drop-off points, and potentially other obstacles the Smart Delivery Robot needs to navigate around.

Robot Icon: The square with a triangle on top represents the Smart Delivery Robot robot. Its position at the starting point establishes the initial location from which the robot will begin its simulated delivery tasks.

2D Pose Estimate: The text "2D Pose Estimate" indicates that RViz is displaying the robot's real-time estimated position and orientation within the 2D map. This information is crucial for evaluating the accuracy and effectiveness of the robot's navigation algorithms.

While this figure provides a snapshot of the starting point, subsequent sections of this chapter will delve deeper into the details of the simulated environment, including its complexity, obstacle configurations, and different scenarios tested. We will analyze the Smart Delivery Robot's performance metrics, such as delivery time, path efficiency, and obstacle avoidance success rate, to gain insights into its effectiveness and potential for real-world applications.

Chapter Five

5. BUSINESS MODEL

5.1. Business Model Canvas

As shown in figure 19 it illustrates the business model for the Smart Delivery Robot, detailing the production steps, revenue generation, and cost structure.

Key Partnerships:

The figure highlights the motivation for forming key partnerships essential to the development and success of the Smart Delivery Robot.

Key Activities:

It outlines the activities necessary to build the Smart Delivery Robot and addresses potential problems that may arise during production.

Value Proposition:

The value proposition section compares the Smart Delivery Robot to similar products, emphasizing its unique benefits and the value it offers to customers.

Customer Segments:

Identifies the target customers for the Smart Delivery Robot, including educational organizations, companies, hotels, hospitals, residential compounds, and other private zones (closed areas).

Customer Relationships:

Describes the types of customer relationships, such as personal assistance or self-service, and the communication channels available, including the website, email, app, and social media.

Channels:

Explains the supply channels through which customers can learn about the Smart Delivery Robot, such as online advertisements, blog posts, and information provided on the website or app.

Cost Structure:

Details the costs involved in creating and delivering the Smart Delivery Robot, including expenses for hardware, body materials, marketing, and manufacturing.

Revenue Streams:

Describes how revenue is generated from the Smart Delivery Robot, including sales to target customers and sponsorships.

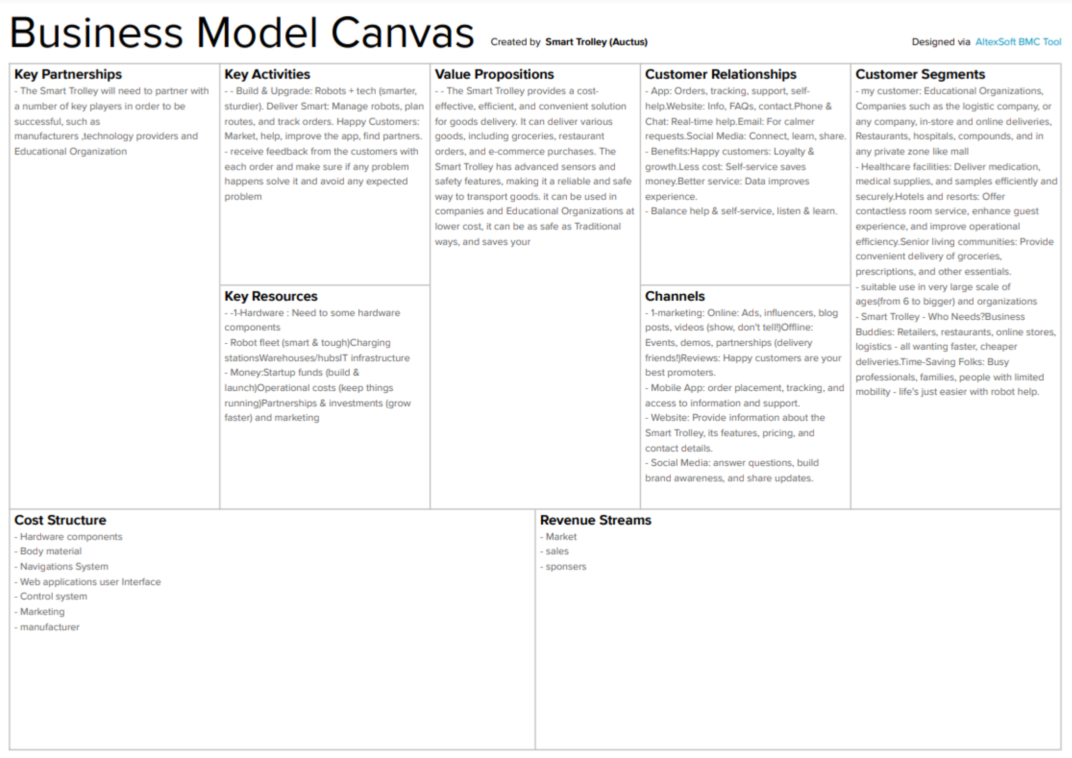

Figure 40:Business Model Canvas

5.2.COMPONENTS OF THE BUSINESS MODEL

1. Key Partnerships:

- Manufacturers
- Technology providers
- Educational organizations

2. Key Activities:

- Building & upgrading robots and technology
- Managing robots, planning routes, and tracking orders
- Market engagement, app improvement, finding partners
- Customer feedback and issue resolution

3. Key Resources:

- Hardware components (robotic parts, charging stations, warehouses/hubs, IT infrastructure)
- Financial resources (start-up funds, operational costs, partnerships & investments, marketing)

4. Value Propositions:

- Cost-effective, efficient, and convenient goods delivery
- Ability to deliver various goods including groceries, restaurant orders, and e-commerce purchases
- Advanced sensors and safety features for reliability and safety

5. Customer Relationships:

- App-based orders, tracking, and support
- Website information and FAQs
- Real-time help via phone, chat, and email
- Social media engagement for connection, learning, and sharing

6. Channels:

- Online and offline marketing (ads, influencers, events, partnerships)
- Mobile app for order placement and tracking
- Website for information about the Smart Delivery Robot
- Social media for customer engagement and updates

7. Customer Segments:

- Educational organizations
- Companies (logistics, stores, restaurants)
- Healthcare facilities
- Hotels, resorts, senior living communities
- Broad age range and diverse organizational use cases

8. Cost Structure:

- Hardware components
- Body material
- Navigation system
- Web application user interface
- Control system
- Marketing
- Manufacturing costs

10. Revenue Streams:

- Market sales

Chapter Six

6. CONCLUSION AND FUTURE WORK

6.1 Conclusion:

The Smart Delivery Robot project marks a significant stride in revolutionizing autonomous goods transportation. Throughout this endeavour, several key achievements have been realized:

Achievements: Highlight the milestones achieved, such as successful autonomous navigation, efficient goods delivery, or any significant technological breakthroughs.

Benefits Recap: Summarize the benefits offered by the Smart Delivery Robot, emphasizing improved efficiency, reduced costs, and enhanced user convenience.

Impact on Logistics: Discuss the potential impact on logistics, including operational efficiency, scalability, and the adoption of eco-friendly practices.

6.2 Future Work:

To further advance the Smart Delivery Robot project and enhance its capabilities, several avenues for future development stand prominent:

6.3 Enhanced Features:

Discuss potential upgrades like increased payload capacity, improved adaptability to various environments, or advanced user-interface enhancements.

6.4 Industry Integration:

Explore possibilities for integrating the Smart Delivery Robot into diverse industries beyond initial applications, broadening its scope and impact.

6.5 Technological Refinements:

Address areas such as refining power management for longer operation, implementing more advanced navigation algorithms, or exploring emerging technologies.

6.6 Significance:

Lastly, reiterate the significance of the project in transforming goods transportation, embracing technological innovation, and contributing to a more sustainable and efficient future.

By encapsulating the achievements, indicating potential growth areas, and reaffirming the project's importance, this conclusion sets the stage for the Smart Delivery Robot's ongoing evolution and impact.

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