IoT-Based Smart Serving Robot

A midterm capstone project report submitted in partial fulfillment of the requirement for the award of the degree of

Bachelor of Engineering

in

Electronics and Communication Engineering

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June 2023

DECLARATION

We declare that this written submission represents our ideas in our own words and where others' ideas or words have been included, we have adequately cited and referenced the sources. We also declare that we have adhered to all principles of academic honesty and integrity and have not misrepresented, fabricated, or falsified any idea/- data/fact/source in my submission to the best of our knowledge. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources that have thus not been properly cited or from whom proper permission has not been taken when needed.

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CERTIFICATE

This is to certify that the report titled IOT Based Smart Serving Robot: CAPSTONE PROJECT REPORT, submitted by Malavika Ajay Nair, Ananta Sharma, Varchasv Arora, Shubhangi Singh and Mannandeep Sondh to the Thapar Institute of Engineering & Technology, Patiala, for the award of the degree of Bachelor of Technology, is a record of the project work done by them under our supervision. The contents of this report, in full or in parts, have not been submitted to any other Institute or University for the award of any degree or diploma.

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ACKNOWLEDGEMENT

We would like to express our profound gratitude to our faculty mentors Dr. Mohit Agarwal and Dr. Amit Munjal, for their continuous guidance and constructive feedback throughout this project. As the college facilities helped us tremendously in our research by providing us with the required infrastructure to conduct meetings while we were at campus and the required resources like access to IEEE papers, etc., we are grateful to the college for their support and aid. We would also like to acknowledge the Electronics and Communication Department of Thapar Institute of Engineering and Technology, Patiala to add this project to our course and allow us to learn something new and implement our past learnings in the best possible and practical way. The help and support of team members, friends, and family are also highly appreciated.

Thank you all for your extremely helpful contributions.

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ABSTRACT

A robot waiter is an emerging technology with significant potential in the food service industry. This report proposes the design and implementation of an IoT-based autonomous serving robot aimed at enhancing the efficiency and customer experience in restaurant environments. The robot consists of an Arduino microcontroller and a suite of sensors, including an IR sensor array for line following, an ultrasonic sensor for obstacle detection, a WiFi module for wireless communication, and an RFID reader for table identification using RFID tags.

The primary objective of this research project was to develop a reliable and efficient robotic system capable of autonomously navigating within a restaurant setting, following a designated path, detecting obstacles, and accurately delivering orders to the designated tables. The robot's functionality was divided into three core components: line following, obstacle detection, and table identification.

The successful implementation of this autonomous serving robot holds significant potential for improving efficiency and customer service in the food service industry. By automating the table service process, this robotic solution reduces human labor and enhances the overall dining experience. Further cooperation with restaurant management systems could pave the way for the widespread adoption of such autonomous systems in the food service industry, revolutionizing the way restaurants function and improving the overall dining experience of the customers.

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LIST OF ABBREVIATIONS

TIET	Thapar Institute of Engineering and Technology
ECE	Electronics and Communication Engineering
IOT	Internet of Things
IEEE	Institute of Electrical and Electronics Engineering
S	Start of Month
M	Mid of Month
E	End of Month

CHAPTER 1 - INTRODUCTION

1.1 PROJECT OVERVIEW

The IoT-Based Serving LFR Robot with Ultrasonic Sensor, RFID Tag Reader, and WiFi Module project introduces an innovative solution for serving and delivery applications. The project aims to develop a sophisticated robotic system that combines advanced technologies to enhance efficiency, customization, and interactivity.

The primary objective of our project is the implementation as well as construction of a robot capable of autonomously detecting, navigating predefined paths and avoiding obstacles using an Ultrasonic Sensor, and interacting with RFID-tagged objects or individuals through an RFID Tag Reader. With the incorporation of a WiFi module wireless connectivity, remote control, monitoring, and real-time data communication are possible. These features add to the convenience, flexibility, and coordination with other smart devices or platforms.

The integration and incorporation of technologies add to the project's novelty, which further enables the robot to operate with enhanced performance. By integrating IoT, robotics, ultrasonic sensing, RFID, and wireless communication, the project creates a scope out of traditional serving and delivery methods. The intelligent line-following algorithms and obstacle avoidance capabilities further contribute to the robot's efficiency and safety.

By imposing on emerging technologies, the project targets to transform conventional processes into smart and interconnected systems. The robot's advanced functionalities offer novel solutions for improved efficiency and customer experience in serving and delivery operations.

In summary, the IoT-Based Serving Robot project presents a unique approach to serving and delivering applications. By integrating advanced technologies, the project targets to develop a sophisticated robotic system that provides personalized service, efficient navigation, and wireless connectivity. This innovative solution offers potential advancements in the field and opens up new possibilities for the future of serving and delivery systems.

1.2 MOTIVATION

The motivation behind our project has been grasped in the growing need for efficient and advanced serving and delivery systems in today's fast-paced world. We are driven by the following key factors:

- **Simplifying Operations:** Traditional serving and delivery methods in the food serving industry often face problems related to inefficiencies, which leads to delays and errors. By developing an IoT-based serving robot, we aim to streamline operations, reduce manual intervention, and improve overall efficiency.
- **Improving Customer Experience:** The integration of advanced technologies like RFID and WiFi allows for personalized interactions and remote monitoring. This, adds to the enhancement of the overall customer experience, providing convenience, accuracy, and real-time updates.
- **Safety and Reliability:** By the integration of an Ultrasonic Sensor, our robot can detect obstacles and navigate around them, ensuring safe and reliable operation even in dynamic environments. By minimizing accidents and mishaps, we aim to prioritize the safety of users and objects.
- **Innovative Solutions:** Our project leverages IoT and wireless connectivity to create a scalable and adaptable serving robot. By including the latest technologies, we aim for a future-proof solution, which results in easy integration with evolving smart ecosystems.

In conclusion, the project serves as a platform for continuous learning and innovation in the fields of robotics, IoT, and automation. By pushing the boundaries of technology, our target is to contribute to the advancement of these domains and inspire further research and development.

1.3 ASSUMPTIONS AND CONSTRAINTS

Assumptions:

- **Normalized Environment:** The project assumes that the robot will primarily operate in a controlled and standard environment which would include predefined paths for line following. Variations in the environment, such as changes in floor surfaces, may have an impact on the robot's performance and would require adaptations.

- **Availability of RFID Tag:** The project assumes that objects or individuals to be interacted with will be equipped with RFID tags. The successful identification and interaction with these tagged items rely on the availability and proper functioning of the RFID system.
- **Stable Wireless Connectivity:** The project assumes the availability of stable and reliable wireless connectivity for seamless communication between the robot and the remote control interface. Any disruptions in WiFi connectivity may have an impact on the real-time monitoring and control capabilities of the robot.

Constraints:

- **Cost Limitations:** The project is constrained by budget limitations as a result cost-effective solutions and components will be used during the development process. This may impose certain constraints on the selection of high-end components or advanced technologies.
- **Physical Limitations:** The design and construction of the robot will be constrained by size, weight, and power limitations. These constraints ensure that the robot remains practical, maneuverable, and energy-efficient for its intended serving and delivery tasks.
- **Time Constraints:** The project is bound by time constraints, requiring efficient planning, execution, and completion of the different project phases, this may have an impact on development, testing, and refinement in the given time frame.
- **Skill and Expertise**: Any complex functionalities or advanced features may be subject to the team's technical capabilities and knowledge.
- **Regulatory and Safety Compliance**: The development and operation of the robot must adhere to applicable regulatory and safety standards.

1.4 NOVELTY OF WORK

The project introduces several novels to the field of serving and delivery robotics:

- **Incorportion of Advanced Technologies:** This project is a blend of advanced technologies, including IoT, robotics, ultrasonic sensing, RFID, and wireless communication. This integration enables the development of a comprehensive and interconnected robotic system with enhanced capabilities.

- **Intelligent Line Following and Obstacle Avoidance:** The line-following algorithms and the Ultrasonic Sensor allow the robot to autonomously navigate along predefined paths while detecting and avoiding obstacles.
- **RFID-Based Interaction and Customization:** By integrating an RFID Tag Reader, the robot can interact with tagged objects or individuals. This enables personalized service delivery, efficient inventory management, and seamless integration with existing systems. The ability to identify and interact with RFID tags adds a new dimension of customization and adaptability to the robot's functionality.
- **Wireless Connectivity and Remote Control:** The inclusion of a WiFi module establishes wireless connectivity, enabling remote control, monitoring, and data communication. This feature allows for real-time supervision, adjustments, and seamless integration with other smart devices or platforms.
- **Innovation in Serving Systems:** The project pushes the boundaries of traditional serving and delivery methods by introducing automation, intelligence, and connectivity. This project contributes to the advancement of serving and delivery systems, setting new benchmarks for efficiency, convenience, and customer experience.

CHAPTER 2 – LITERATURE SURVEY

2.1 LITERATURE SURVEY

2.1.1 THEORY ASSOCIATED WITH PROBLEM AREA

The restaurant industry is constantly looking into innovative ways like embracing new technology, personalizing service for each customer, creating an immersive experience, and promoting sustainability to enhance the dining experience of the customers. The integration of IoT technologies with robotics has emerged as a very promising solution to the development of serving robots in restaurants [1]. As the demand for restaurant services is increasing, the upcoming serving robots can help by performing tasks such as taking orders, serving food, cleaning tables, and washing the dishes. Robots can also perform repetitive tasks such as taking orders, delivering food, and clearing tables quickly and very accurately, allowing restaurants to serve more and more customers and increase revenue.

Robots can provide clients with a one-of-a-kind and memorable experience, making dining out more exciting and engaging. They can also give personalized service, such as making food recommendations or remembering customer preferences. By reducing interaction between personnel and customers, serving robots can help lower the danger of infectious disease spread. Furthermore, the robots may conduct activities such as cleaning and sterilizing surfaces to keep everyone safe and healthy. These robots are capable of doing numerous tasks autonomously by utilizing wireless sensors, multiple algorithms, and communication technologies. Serving robots have the potential to improve customer service, cut labor costs, increase operational efficiency, and raise market competitiveness in the restaurant business.[2]–[7]

The project proposes the use of a self-serving robot waiter to minimize contact between waiters and customers during the COVID-19 outbreak. The robot is controlled using an Android app and is implemented using various components such as an Arduino Mega2560 microcontroller, sonar sensor, L298N motor driver, ball caster, DC gear motors, IR sensor array, LCD, DC to DC buck converter, switch, wheels, buzzer, TCRT5000 IR sensor, and 3 cell lipo battery.

The robot is driven using two DC gear motors and an L298N motor driver, with each motor's rotation and speed controlled by three pins. The ENA and ENB pins are used to control the speed of both motors, while INA and INB are used to control rotation for one motor, and INC and IND are used for another. The ENA, INA, INB, INC, IND, and ENB pins are connected to the Arduino mega's digital pins 2, 3, 4, 5, 6, and 7, respectively. The robot also has a sonar sensor in the front to continuously measure the distance between it and the object in front of it. If someone mistakenly walks in front of the robot, it will halt and the buzzer will sound to notify them. Customers can also see several messages and warnings on an LCD attached to the front of the robot.[8]

The proposed system is an automated food serving machine for college canteens that aims to reduce the time spent waiting in long queues for students by allowing them to order food using their smartphones and pay for it online. The system includes a food serving robot that moves towards the table, guided by RFID technology, to deliver the order. It also has a machine for waste disposal and an interface for payment.

The proposed system consists of several modules, including an Android application, database management, and Raspberry Pi for navigation. The Android application allows students to order food and view the menu list, while the database management module is responsible for storing and retrieving the order details. The Raspberry Pi module tracks the path to the table and ensures that the food-serving robot reaches the correct table. The proposed system aims to address the challenges faced by traditional college canteens, such as delays in serving food, lack of online reservations, and overcrowding during breaks. By introducing an automatic food serving machine, the proposed system can create a smart canteen that is not only time-efficient but also reduces rush in the canteen. It also provides a distance between users, making it safer and more convenient for students to use.
In summary, the proposed system is a reliable and efficient solution for college canteens to manage food ordering, waste disposal, and payment, while also creating a safer and more convenient environment for students. [9]

However, it is not a simple process to integrate IoT-based serving robots in restaurants. Effective solutions to these problems, which involve technical, operational, safety, ethical, and societal dimensions, call for a novel and interdisciplinary approach [10]–[16]. For serving robots to be widely used and seamlessly integrated into existing restaurants, these obstacles must be overcome one by one [19], [20]. The purpose of this review article is to provide a thorough examination of the problems that arise when deploying Internet of Things-based serving robots in dining establishments, as well as suggestions for how these problems could be fixed and directions for further study.[1], [17]–[23]

The sole motive of this review article will be to provide an overview of the current state of serving robots in the restaurant industry, highlighting their potential benefits and applications. It will then dredge into the challenges faced during the implementation of serving robots in restaurants, covering various aspects such as technical, operational, safety, ethical, and societal challenges. Considering variables like consumer perception, regulatory compliance, and cultural attitudes towards these robots, the review will also address the ramifications of these difficulties on the adoption and acceptability of these serving robots in the present restaurant sector.[5], [24]–[26]. By identifying and then discussing these challenges in detail, the paper aims to provide valuable insights and recommendations to the researchers, practitioners, and stakeholders in the restaurant industry, as well as the broader field of robotics and IoT technologies. The findings of this review paper can serve as a guide for future researchers and development efforts made by them, policy formulation, and decision-making in the deployment of serving robots in the restaurant industry.
To provide a comprehensive analysis, this review paper will draw upon existing literature, research studies, and industry reports on the topic of serving robots in existing automated restaurants and IoT technologies. Relevant case studies and real-world examples will also be included to illustrate the challenges faced in implementing serving robots in restaurants. The review paper will also identify gaps in the current research and provide recommendations for future research directions in how to address the various challenges associated with IoT-based serving robots in restaurants.

The integration of Internet of Things (IoT) technologies with robotics has led to the progress of IoT-based food-serving robots that are capable of autonomously performing diverse tasks in restaurants such as taking orders and serving food, cleaning, and dishwashing. These IoT-based food serving robots are decked up with sensors, various algorithms, and communication technologies that enable them to navigate through the restaurant environments, interact with the customers, and efficiently carry out their designated tasks. In recent years, there has been significant progress in the development and deployment of these robots in the restaurant and cafe industry, with several notable examples of successful implementation worldwide.

One of the key areas where IoT-based food serving robots have been deployed is in the quick-service restaurant (QSR) segments. These robots are designed to handle repetitive and time-consuming tasks, such as taking orders and delivering food, with high accuracy and efficiency. For instance, Flippy, a robot developed by Miso Robotics as shown in Figure 1 a, is capable of flipping burgers, placing them on buns, and even cleaning the grill, reducing the need for human intervention in the cooking process. [27] Another example is the robot developed by Creator as shown in Figure 1 b, which can autonomously prepare custom burgers from scratch, including grinding the meat, toasting the bun, and adding toppings, resulting in a freshly made burger within minutes. [28]

Figure 1. a) Flippy, a robot developed by Miso Robotics [27], b) a robot developed by Creator [28]

Apart from QSRs, IoT-based food serving robots are also being implemented in other types of restaurants, including casual dining and fine dining establishments. These robots are designed to enhance customer service and provide a unique dining experience. Customers at a sushi restaurant in Japan, for instance, can make their orders on tablets and have their food brought to them by IoT-based robots operating along a conveyor belt. [29] Just like how drones are employed to bring food and beverages to tables at a Singaporean restaurant, creating a novel and futuristic dining experience for consumers shown in Figure 2. a [30].

Figure 2. a) Robotics drones used in Singapore-based restaurants to deliver food and drinks [30], b) Robot developed by Dishcraft Robotics that automatically sort, wash, and stack dirty dishes [31]

Robotic food servers powered by the Internet of Things are also being utilized to improve restaurant operations. By eliminating the need for human labor and cutting down on operating expenses, these robots may automate chores like dishwashing, table cleaning, and meal preparation. Dishcraft Robotics, for instance, has created a robot that can autonomously sort, wash, and stack dirty dishes, allowing restaurant workers to devote their time and energy to other activities as shown in Figure 2. b [31]. Furthermore, some robots are built to function in tandem with human personnel, aiding with activities like food delivery, order monitoring, and inventory management to better organize and enhance the effectiveness of restaurant operations.

The ability of these Internet of Things–based food-serving robots to communicate is vital to their widespread use in restaurants. Wi-Fi, Bluetooth, and RFID are just some of the communication technologies that these robots use to seamlessly communicate with other equipment, systems, and humans in the restaurant and QSR settings. For instance, robots may coordinate with a POS system to take orders, fulfill them, and keep tabs on their progress. They may talk to the cooks, the waitstaff, and the customers to answer questions, provide comments, or share some information. Furthermore, some robots are designed to interact with customers through natural language processing (NLP) and voice recognition technologies that allow them to understand and respond to customer inquiries and requests.

This research paper shows the development and evaluation of KeJia, a shopping mall service robot designed to offer customers guidance, information, and entertainment. The authors analyze the project's background and requirements, guiding the robot's system development. They propose advancements in mapping, localization, and navigation to address the challenges of operating in a large and crowded environment. A multimodal interaction mechanism enables convenient communication between customers and the robot, allowing for personalized interactions through speech or a mobile app. KeJia is deployed in a 30,000 m^2 shopping mall, serving approximately 530 customers over 40 days. Results from simulated experiments and real-world tests confirm the feasibility, stability, and safety of the robot system. The paper demonstrates KeJia's successful implementation, showcasing its capabilities in customer guidance, information provision, and entertainment within a demanding commercial environment.[32]

K. Zheng et. al. focus on the development of laser-based algorithms for people detection and obstacle avoidance in a differential-drive robot used for material transport in hospitals. Traditional methods for detecting and avoiding people in shared workspaces rely on machine learning techniques and hand-crafted geometric features, which are costly and challenging to deploy in new environments. To overcome these challenges, the authors propose a novel deep learning-based method that effectively classifies each point in a laser scan using a sliding window approach with a deep neural network. They also introduce a jump distance clustering technique to improve inference speed. To reduce data labeling workload, an approach for automatically annotating real scenario datasets is proposed. The study also addresses the limitations of reactive obstacle avoidance algorithms by introducing a sampling-based local path planner inspired by autonomous driving methods. The planner incorporates lane switching to navigate around obstacles while minimizing deviations from the reference path. Real-world experiments validate the effectiveness of the proposed algorithms in accurately detecting and avoiding people while providing efficient and natural obstacle-avoidance behavior. The developed system enhances the safety and efficiency of material transport robots in hospital environments. [33]

A. Andriella et. al. address the need for robust and adaptable robotic systems capable of effectively interacting with people in public environments. While controlled laboratory conditions can provide insights, real-world deployment requires dealing with complex and unpredictable events. Additionally, the challenge of interacting with untrained users further complicates the task of defining effective interactions. The study introduces an adaptive Cognitive System integrated into a Tiago robot, which assists users in completing a game by providing varying levels of assistance based on the game's state and the user's performance. Two days of experiments were conducted during a public fair, allowing random users to interact with the robot. The study demonstrates that the robot effectively adapts its assistance approach, resulting in improved user performance compared to a non-adaptive robot. The results show that the adaptive help strategy works well in practice. As the game progresses and the user's performance is evaluated, the combined cognitive system and Tiago robot demonstrate the potential for improving human-robot interactions. The findings of this study will aid in the design of resilient and flexible robotic systems that can interact with inexperienced users in chaotic public settings. [34]

The Research focuses on how little room there is for improvement in these robots' linguistic abilities by interaction with humans. It presents a probabilistic dialog manager and a semantic parser to create a dialog agent for robots that can understand user orders. The agent can expand its vocabulary by learning new things and new ways to refer to current ones from the conversations it conducts. Extensive use of simulation, human participants, and real-robot platforms are used to test the conversation system. The results demonstrate that the dialog agent is more effective and efficient than the reference learning agents. The agent's linguistic talents are enhanced through conversation, allowing for better user involvement. This study contributes much since it allows robots to acquire language through conversation. The created dialog agent outperforms baseline agents thanks to its integration of semantic parsing, probabilistic dialog management, and knowledge augmentation. The results show how interactive dialog encounters might help robots learn and improve their linguistic abilities.[34]

S. Amiri et.al. address the challenge of hazardous object detection and avoidance in autonomous mobile cleaning robots. Conventional object detectors struggle with low-featured objects and occlusion, which can lead to safety risks. To overcome these challenges, the paper introduces a deep-learning-based context-aware multi-level information fusion framework. The framework consists of an image-level-contextual-encoding module that enhances object detection in indoor environments, particularly for low-featured and occluded hazardous objects. It also incorporates a safe-distance-estimation function to avoid hazardous objects by calculating the distance between the object and the robot's position. The robot is guided to a safer zone based on this estimation. The proposed framework is trained using fine-tuning techniques and evaluated with a mobile cleaning robot named BELUGA. Experimental results demonstrate that the algorithm achieves a higher confidence level in detecting low-featured and occluded hazardous objects compared to conventional detectors, with an average detection accuracy of 88.71%. This author contributes to improving the safety and reliability of autonomous mobile cleaning robots by addressing the challenges of low-featured objects and occlusion. The effectiveness of the proposed algorithm is validated through real-world experiments. [35]

Y. Jia et. al presents the design and implementation of an autonomous service robot that incorporates various technologies such as human-robot interaction order systems, indoor path planning and mapping, Robot Operating System (ROS), and Cyber Physical System (CPS). Multiple subsystems based on ROS are developed to enable the efficient completion of service robot tasks through human-robot interaction. A human-robot interaction order system is designed to allow customers to access commodity information and place orders through a touchscreen interface, with the robot delivering the ordered items. The path planning and mapping subsystem utilizes simultaneous localization and mapping (SLAM) with a Rao-Blackwellized particle filter (RBPF) for accurate mapping and a hybrid algorithm combining global A* and local dynamic window approach (DWA) for navigation. Gazebo is used to create a comprehensive Cyber Physical System (CPS) design, enhancing the overall system construction. Simulation and implementation of dual-arm robot navigation and interactive ordering situations are conducted to support the robot's servicing actions. The paper showcases the successful design and implementation of an autonomous service robot with capabilities in human-robot interaction, path planning, and mapping. The integrated system demonstrates efficient service delivery through interactive ordering and navigation. The research contributes to the advancement of autonomous service robots, highlighting the potential of human-robot interaction and path-planning techniques in service-oriented robotics. [36]

S. A. Li et. al. tackles the critical issue of a lack of service robots, which is acute in nations where low birth rates, elderly populations, and labor shortages are all problems. It acknowledges the potential for service robots to fill the void in labor-intensive sectors, with a particular emphasis on the field of food service in fast-food restaurants. The research stresses the need for enhanced capabilities and performance of service robots in these situations by adding new advances in mapping, localization, and navigation. The research group presents an innovative solution to the mapping and localization issues by combining a 3D point cloud map with a 2D occupancy grid map (OGM) to create a PC-OGM (Point Cloud - Occupancy Grid Map). The service robot may learn to function in new and unfamiliar situations with the help of this sensory fusion technique, which takes into account both geometric and semantic details. The robot's ability to make informed decisions and navigate efficiently is greatly enhanced by the use of a combination of these two map formats. The research highlights the significance of efficient mobility, especially in the confined and busy environments typical of fast food outlets, in terms of navigation. The service robot's adaptive motion controller has been fine-tuned to guarantee accurate and responsive navigation, making it possible for the robot to move safely and efficiently across confined spaces and heavy foot traffic. The robot's operations will be more streamlined and its service to clients will increase as a result of this enhancement. Researchers at fast food restaurants interacted with customers and staff members in a polite, non-contact manner to gauge the effectiveness of the produced service robot. Respondents were asked to rate the ease of access, dependability, and overall satisfaction. To better understand the robot's performance and pinpoint its weak spots, the acquired data was evaluated and classified. The study also acknowledges the worldwide effect of the COVID-19 epidemic and stresses the potential of service robots to preserve a virus-free atmosphere in restaurants. Service robots can help lower the risk of transmission and improve safety by limiting the amount of human touch with food and surfaces. [37]

C. F. Chen et. al. investigates customer behavior towards restaurant service robots using a cognitive-affective-behavioral framework. A survey was conducted among customers who visited service robot restaurants in Taiwan, with 230 valid responses analyzed. Structural equation modeling and multigroup analysis were employed to test relationships based on visit experience and generation. The findings reveal a sequential relationship between cognitive, affective, and behavioral components in customer decision-making after interacting with service robots. Cognitive factors like perceived competence and coolness positively influence affective components, which in turn impact approach behavior. Emotions also have a significant positive influence on customer satisfaction. The multigroup analysis considers visit frequency and generation, uncovering potential differences in approach behavior based on these variables. The research provides new insight into how diners make choices while engaging with robot wait staff. It stresses the significance of mental and emotional variables and their sequential link to actions. These results have important implications for the future of service robots in restaurants, where they might be used to improve the dining experience for customers. [38]

Shuhua Liu et al. explore the difficulties encountered by robots that rely on scene text recognition as their primary data source for object detection in the house. Extraction of text, recognition of text, object identification, and real-time processing are only a few of the many topics covered in this work. The paper discusses several approaches to address these challenges, such as using advanced machine learning techniques for text recognition and object recognition, integrating multiple sources of information, and optimizing algorithms for real-time processing. [39] However, Training object recognition models with diverse and representative datasets are crucial for generalization to new objects and environments. However, capturing a comprehensive dataset that covers all possible objects and scenarios can be challenging.

Ruzena Bajcsy, et al. discuss the challenges associated with active perception, a robotics concept that entails actively choosing and directing sensors to gather data more effectively and efficiently. The challenges raised in this paper include computational complexity, sensor selection, integration of sensor data, adaptation, and learning Complex computations are needed for active perception to choose and control sensors. In complex situations the choice of sensors for particular tasks might be challenging If data is noisy or lacking, data integration from sensors and sources is challenging to continuously improve, active perception systems must be able to adapt to new situations and learn from mistakes. The paper proposes various approaches to overcome these difficulties, which include developing more effective algorithms for sensor selection and data fusion, incorporating machine learning strategies to adapt and enhance performance over time, and directing the development of active perception systems models of perception that are inspired by humans.[40]

Rudolph Triebel et al. address the challenge of teaching robots to learn maps in the field of mobile robotics. While simultaneously building a map using sensor data and robot pose estimations, this issue is commonly referred to as simultaneous localization and mapping (SLAM). The accuracy of the produced maps plays a critical role in the overall performance of the robot, as it can affect common navigational tasks such as localization and path planning. Therefore, ensuring high map accuracy is essential.

Wang et al. propose a heuristic and feature-based method to identify dynamic objects in range scans. This approach allows for the filtering out of corresponding measurements during the 2D scan process. By identifying and filtering dynamic objects, the accuracy of the produced maps can be improved. the paper highlights the importance of addressing the issue of dynamic objects in map learning, as their presence can hinder the execution of navigation tasks and impact the overall performance of the robot.[41]

Hong-mei Zhang et al. discuss the path is optimal if the sum of the transition costs is minimal across all possible sequences through the map. Any path generated using static environment information may turn out to be invalid if the robot detects moving obstacles by its equipped sensors. Thus, the robot must be able to efficiently re-plan optimal paths when a moving obstacle appears.[42] The real-time navigation and obstacle avoidance method for mobile robots in dynamic environments proposed in this article is based on Dijkstra's algorithm, the A* algorithm, and the rolling window principle. If a potential collision between the robot and a moving obstacle is anticipated, the algorithm computes an initial path from the initial state to the objective state and then effectively adjusts this path during the traverse. In this paper, the algorithm has undergone a thorough analysis, and numerous simulative tests have been carried out. The suggested method can always discover an optimal path during replanning and reduce the re-planning time by 53.3%-99.7% compared to ACO, A*, and D* algorithms. These results show the algorithm's viability and efficiency. The suggested algorithm, however, is only appropriate for solving the path planning problem with a certain goal state. The algorithm's efficiency will be drastically decreased if the aim is altered while the robot is going and the map data has to be pre-processed again.

Bai-Fan Chen et. al. discussed that in mobile robots, simultaneous localization and mapping (SLAM) is a fundamental and popular problem. One of the most crucial requirements for a mobile robot is its ability to achieve autonomy. By using sensing and estimating, a robot can locate itself using SLAM, which also gradually builds up a map of its surroundings. Smith, Self, and Chessman presented the first reliable answer to the SLAM puzzle. Research on SLAM methods in dynamic environments is vital since the majority of the real world is dynamic and the presence of moving targets leads to errors and lowers the overall quality of the map. Filtering out dynamic targets will result in an incomplete observation and construction map because they directly affect the accuracy and complexity of SLAM.[43]

Using sophisticated sensor technologies like depth cameras, RGB-D cameras, and LiDAR for precise object and people recognition and tracking is one way to overcome these obstacles. Strong object identification and tracking may also be achieved using machine learning algorithms (RNNs). The perceptive abilities of restaurant serving robots can be enhanced by fusing data from numerous sensors, including vision, hearing, and touch. The accuracy of object recognition and localisation may, however, be compromised by the constraints imposed by the sensors employed for computer vision, such as cameras or depth sensors. Resolution, range of view, noise, and light sensitivity are just a few of the issues. It is crucial to address sensor limitations and develop methods to compensate for them. Training object recognition models with diverse and representative datasets are crucial for generalization to new objects and environments. However, capturing a comprehensive dataset that covers all possible objects and scenarios can be challenging.

2.1.2 COMPARISON TABLE FOR LITERATURE SURVEY

Reference Number	Challenges Addressed	Approaches Used
[32]	Mapping, localization, navigation, customer interaction	Advancements in mapping, localization, multimodal interaction (Speech, Mobile App)
[33]	People detection, obstacle avoidance	Deep learning-based method, jump distance clustering, sampling-based local path planner
[34]	Human-robot interaction, adaptability, user assistance	Adaptive Cognitive System, experiments in a public fair
[35]	Linguistic abilities improvement	Probabilistic dialog manager, semantic parser, knowledge augmentation

[36]	Hazardous object detection, occlusion	Deep-learning-based context-aware multi-level information fusion
[37]	Human-robot interaction, path planning, mapping	ROS-based subsystems, SLAM, Cyber-Physical System, dual-arm robot navigation
[38]	Mapping, localization, navigation, safety	Point Cloud - Occupancy Grid Map, adaptive motion controller, user interaction experiments
[39]	Object detection, text extraction, real-time processing	Advanced machine learning techniques, optimization algorithms
[40]	Sensor selection, data integration, adaptation, learning	Algorithms for sensor selection, data fusion, machine learning
[41]	SLAM, dynamic environments, accuracy of maps	Heuristic and feature-based methods for identifying dynamic objects
[42]	Path planning, moving obstacles	Dijkstra's algorithm, A* algorithm, rolling window principle
[43]	SLAM in dynamic environments, filtering dynamic targets	Methods to filter dynamic targets, impact on SLAM quality

Table 2.1 Comparison table for literature survey

2.1.3 THE PROBLEM THAT HAS BEEN IDENTIFIED

The deployment of IoT-based serving robots in the restaurant industry brings forth several complex challenges across various dimensions, necessitating a multidisciplinary approach for effective resolution. Key issues include:

1. **Technical Challenges:**
    - **Robust Sensor Integration:** Ensuring seamless integration and performance optimization of diverse sensors (e.g., IR, ultrasonic) for accurate navigation, obstacle detection, and object recognition.
    - **Dynamic Environment Adaptation:** Addressing difficulties in real-time adaptation to dynamic restaurant environments, which may include changes in layout, object positions, and customer traffic.

2. **Operational Challenges:**
    - **Efficient Task Execution:** Optimizing task execution, including order taking, food delivery, table clearing, and dishwashing, to enhance operational efficiency and customer satisfaction.
    - **Human-Robot Interaction:** Designing effective interfaces to facilitate intuitive communication between customers and robots for a seamless service experience.
3. **Safety and Ethical Considerations:**
    - **Obstacle Avoidance and Safety:** Implementing robust algorithms for obstacle avoidance to ensure the safety of both customers and the robot, especially in crowded and confined spaces.
    - **Ethical Use of Automation:** Addressing concerns related to the ethical implications of automation in the restaurant industry, including potential job displacement and customer acceptance.
4. **Regulatory and Compliance Issues:**
    - **Compliance with Industry Standards:** Ensuring that the deployment of serving robots adheres to industry-specific regulations and standards, including health and safety guidelines.
5. **Cultural and Consumer Perception:**
    - **Acceptance and Perception:** Investigating and understanding consumer attitudes towards interacting with serving robots, considering cultural variations and preferences.
    - **User Experience Optimization:** Enhancing the overall user experience by minimizing wait times, ensuring accurate order fulfillment, and providing intuitive user interfaces.
6. **COVID-19 Related Challenges:**
    - **Pandemic Adaptation:** Developing strategies to mitigate the spread of infectious diseases, such as COVID-19, through the minimization of physical contact between waitstaff and customers.
7. **Mapping, Localization, and Path Planning:**
    - **Precise Mapping and Localization:** Ensuring accurate mapping and localization capabilities to facilitate optimal path planning in dynamic and crowded environments.
    - **Dynamic Object Handling:** Addressing challenges related to the detection and handling of dynamic objects (e.g., moving customers) during path planning and execution.

2.2 RESEARCH GAPS

While the field of IoT-based food-serving waiter robots has seen significant advancements, there are still some research gaps that present opportunities for further exploration. Here are a few relevant research gaps in this field:

- **Human-Robot Interaction:** Investigating the effectiveness of human-robot interaction in the context of food-serving waiter robots is a key research gap. Understanding how users interact with these robots, their perception of the robots' capabilities, and their overall satisfaction with the experience can provide insights into improving the user experience.

- **Navigation and Obstacle Avoidance:** Developing efficient navigation and obstacle avoidance algorithms for food-serving robots in dynamic environments is an ongoing challenge. Research could focus on enhancing the robots' ability to navigate crowded spaces, identify and avoid obstacles, and handle complex scenarios such as multiple robots operating simultaneously.

- **Autonomous Decision-Making:** Investigating the development of intelligent decision-making capabilities for food-serving robots is another area of interest. This involves enabling the robots to make autonomous decisions in various situations, such as adapting to changes in customer orders, handling unexpected obstacles, or responding to specific customer requests.

- **Energy Efficiency and Battery Life:** Optimizing the energy efficiency and battery life of food serving robots is crucial for their practical implementation. Research could focus on developing energy-efficient algorithms, power management techniques, and battery charging solutions to extend the operational time and reduce downtime for recharging.

- **Trust and Acceptance:** Understanding the factors that influence user trust and acceptance of IoT-based food-serving waiter robots is essential. Exploring users' perceptions, concerns, and attitudes towards these robots, as well as strategies to build trust and acceptance, can help in designing more user-friendly and socially acceptable robots.

- **Integration with Existing Infrastructure:** Investigating the integration of IoT-based food serving robots with existing infrastructure, such as restaurant management systems, kitchen operations, and customer interfaces, is an important research gap. Seamless integration can enhance the overall efficiency and effectiveness of the food serving process.

2.3 PROBLEM DEFINITION AND SCOPE

Problem Definition and Scope in the field of IoT-based food-serving waiter robots involve identifying the specific challenges and outlining the boundaries of research or implementation. Here are some relevant aspects to consider:

- **Efficiency and Time Optimization:** The problem of efficiently serving food in busy environments while minimizing waiting times and optimizing the overall process is a key concern. This includes determining the optimal routing and scheduling algorithms for food serving robots to navigate between tables and the kitchen, considering factors such as distance, congestion, and order priorities.

- **Human-Robot Collaboration:** Defining the scope of human-robot collaboration is important. This includes determining the level of autonomy of the food serving robots, the extent of interaction and cooperation with human waiters or staff, and the division of tasks and responsibilities between humans and robots to ensure a seamless and efficient workflow.

- **Menu and Order Management:** Managing a diverse menu and handling customer orders accurately and efficiently can be challenging. Defining how the food serving robots can access and process menu information, handle modifications or special requests, and coordinate with the kitchen staff to ensure timely and accurate order preparation is crucial.

- **Safety and Hygiene Standards:** Ensuring compliance with safety and hygiene standards is of utmost importance in the food service industry. The scope includes defining how the food serving robots can maintain cleanliness, prevent cross-contamination, and handle food safely throughout the delivery process, adhering to relevant regulations and guidelines.

- **User Experience and Acceptance:** Assessing and addressing the user experience and acceptance of IoT-based food-serving waiter robots is a significant aspect. Defining the scope involves identifying factors that impact user satisfaction, comfort, and trust, and finding ways to enhance the robots' usability, reliability, and overall acceptance among customers and restaurant staff.

- **Integration with Existing Systems:** The scope encompasses integrating the IoT-based food serving waiter robots with existing restaurant management systems, point-of-sale systems, customer ordering platforms, and other relevant infrastructure. Defining how the robots can seamlessly exchange information, synchronize data, and collaborate with existing systems is crucial for efficient operations.

CHAPTER 3 - PROBLEM FORMULATIONS AND OBJECTIVES

3.1 REQUIREMENTS SPECIFICATION

3.1.1. INTRODUCTION

IoT-Based Serving LFR Robot is emerging as a beacon of innovation in an ever-changing world defined by increasing demands for efficiency, personalization, and connectivity. This innovative initiative aims to change the current serving and delivery applications landscape by fusing advanced technologies into a single, intelligent unit. At its base, this project aims to create a high-tech robotic system with advanced features of independent navigation, obstacle avoidance via Ultrasonic Sensor technology, and active interaction with RFID-tagged objects and individuals. This collaboration enables the robot to offer personalized service, optimize inventory management, and harmonious work environment with the pre-existing systems. But what truly differentiates this project from others is its implementation of wireless connectivity via a WiFi module, which enables real-time monitoring, and smooth data exchange. This innovation enhances convenience, and flexibility, and promotes synergistic relationships with other smart devices and platforms. At the heart of this project lies the diversification of technologies including IoT, ultrasonic sensing, RFID, and wireless communication, which collectively pushes the boundaries of traditional serving and delivery framework. Moreover, smart line-following algorithms and the capability to avoid obstacles enhance the robot's efficiency and safety.

The project relies on emerging technologies, which are set to transform conventional processes into intelligent, interconnected systems. This vision is an effort to reinvent serving and delivery systems for a future that desires efficiency and customer-centric experiences.

The IoT-Based Serving LFR Robot with Ultrasonic Sensor, RFID Tag Reader, and WiFi Module project represents an innovative approach to fundamentally alter serving and delivery. This fusion of advanced technologies depicts a future with personalized services, flawless navigation, and wireless connectivity. It promises not only improvements but also a tremendous leap in the serving and delivery domain, creating an inspiring future of connected and effective systems.

3.1.1.1 PURPOSE:

The purpose of this project is to build an IoT-Based Serving LFR Robot using advanced technologies. This system is capable of autonomously traveling defined pathways while recognizing and preventing obstacles coming it's way by using an Ultrasonic Sensor, interacting with RFID-tagged objects with full precision and efficiency. The primary objective is to maximize operational efficiency, enhance the customer experience, and ensure safety. It is done with a strong determination to make the solution future-proof by intelligently integrating IoT and wireless connections.

3.1.1.2 INTENDED AUDIENCE AND READING SUGGESTIONS:

The stakeholders, ranging from roboticists to experienced researchers, along with engineers, and different professionals within the field of technology and automation cover a wide range of audience for this project. Individuals and organizations have invested in the enhancement of serving and delivery operations, this enhancement of customer experiences, and the exploration of emerging technological boundaries will find this project to be highly innovative. Moreover, in big restaurants, and ceremony halls where the workload is high, we can use this automated serving robot which helps the readers to understand and dig more into the aspects like integration of ultrasonic sensors, RFID technology, and Wi-Fi communication.

3.1.1.3 PROJECT SCOPE:

This scope encompasses the smooth integration of an Ultrasonic Sensor used for obstacle detection, the installation of an RFID Tag Reader for precise object interaction, and the establishment of a WiFi Module for fostering the realm of wireless connectivity. The overarching ambition is to proactively address the multifaceted challenges endemic to conventional serving and delivery paradigms while ardently championing the cause of operational efficiency, customer-centricity, safety, and adaptability,

3.1.2 OTHER NON-FUNCTIONAL REQUIREMENTS

3.1.2.1 PERFORMANCE REQUIREMENTS

The explication of performance requirements assumes a critical role in delineating the operational parameters and capacities of the IoT-Based Serving LFR Robot. This facet stands as a linchpin in steering the project towards its predefined objectives. Strict adherence to these prescribed conditions is imperative to ascertain that the robot operates at the zenith of both efficiency and efficacy.

- **Minimum Speed:** A prerequisite for the proficient execution of the robot's duties is its capability to attain a minimum speed of '5' meters per second. This stipulation assumes preeminent significance, for it empowers the robot to adroitly navigate pre-defined trajectories with utmost efficiency, thereby expediting its arrival at a pre-determined terminus. This attribute attains elevated importance in environments characterized by temporal exigencies, such as bustling gastronomic establishments and medical facilities, where expeditious service delivery stands as a paramount concern.

- **Path Following Accuracy:** The fidelity with which the robot adheres to pre-ordained trajectories constitutes a fundamental metric of performance. It is imperative to ensure stringent fidelity to predefined courses. Owing to its commendable precision, the robot exhibits proficiency in executing intricate tasks within user-defined spatial coordinates.

- **Detection Range of the Ultrasonic Sensor:** The Ultrasonic Sensor, entrusted with the pivotal responsibility of obstacle recognition, is envisaged to encompass a detection range of approximately 'Y' meters. This parameter confers upon the sensor the acumen to discern obstacles within a delimited range or under specified contextual conditions. It behooves the robot to possess a discerning sensing range, thereby equipping it to identify and appropriately respond to the diverse array of environmental circumstances within its operational ambit.

- **Response Time for Obstacle Detection and Avoidance:** The temporal interval mandated for the system to detect and circumvent obstacles assumes critical import. Upon the identification of an impediment, the system is enjoined to furnish an expeditious response about the clearance of said obstruction. This criterion imposes a specific temporal threshold of '1' milliseconds or less for the completion of this task. The exigency of this criterion lies in its facilitation of the robot's prompt recalibration of its trajectory in the event of unforeseen obstacles. Robots designed for navigational objectives and equipped with mechanisms for swift responsiveness are poised to navigate with heightened ease and safety.

3.2 APPROVED OBJECTIVES

1. **Order Pickup:** This component entails designing mechanisms on the robot to physically pick up orders from a designated location, such as a kitchen counter or a food preparation area. A combination of robotic arms, grippers, or conveyors can be used to grasp, hold, and transport the orders securely.

2. **Obstacle Avoidance:** Safety is paramount in crowded restaurant spaces, so the system should incorporate obstacle detection and avoidance features. Sensors like ultrasonic sensors, LIDAR, or cameras can be used to detect obstacles in the robot's path. Upon detection, the robot should be capable of adjusting its route to avoid collisions and ensure the safety of customers and staff.

3. **Path Navigation:** Efficient path planning algorithms are crucial to enable the robot to navigate seamlessly through the floor. It refers to the specific goal of developing or implementing a system that can successfully navigate a path from one point to another.

4. **User Interaction:** Developing a user-friendly interface for staff to interact with the robot is essential. This interface allows staff to assign tasks, monitor the robot's operation, and provide any necessary instructions or corrections. It may include a user interface on a mobile device or a dedicated control panel.

5. **Wireless Communication:** Establishing reliable communication between the robot and the restaurant's management system is crucial. This wireless communication allows the robot to receive information about table numbers, order details, and any updates on the status of orders. It might utilize Wi-Fi, Bluetooth, or other wireless protocols to maintain seamless communication.

6. **Table Identification:** To navigate effectively, the robot should be able to identify tables based on table numbers or markers. QR codes or NFC tags may be used to mark tables, and the robot's system can read and interpret these markers to locate tables accurately.

7. **Efficiency and Reliability:** Optimization is required to ensure that the robot operates efficiently in a real-world restaurant environment. This includes streamlining its movements, reducing idle time, and improving order delivery speed. Reliability ensures consistent performance and minimal downtime.

8. **Safety Measures:** Safety is of paramount importance to prevent accidents and ensure the well-being of customers and staff. Safety features may include sensors to detect nearby people, emergency stop mechanisms, and a fail-safe system to halt operations in case of anomalies.

3.3 PROJECT OUTCOMES AND DELIVERABLES

The evolution of autonomous service systems has been marked by the successful execution of the IoT-Based Serving LFR Robot project. This cutting-edge method was developed for gliding effortlessly through crowded cafes. The operational robot can follow programmed routes, avoid obstacles, and interact with clearly marked tools.

This initiative stands out from others like it by providing a unique capacity to meet the diverse regulatory requirements of different types of restaurants. The adaptability of the robot makes it a good fit for the restaurant setting. The WiFi Module is a great addition since it allows anyone to connect wirelessly to the robot, thus increasing its usefulness. The robot can now recognize RFID-tagged objects like tables and chairs owing to the RFID Tag Reader's expanded personalization options. The robot's versatility has been shown through its use in public situations. A complete collection of papers, including firmware wiring diagrams and schematics and User Guides, is used to accomplish these goals. Additionally, a detailed manual for users has been drafted. The longevity of this innovative piece of machinery may be ensured by following the detailed directions provided in this manual.

3.4 COST ANALYSIS

The successful execution of the IoT-Based Serving LFR Robot project requires a budget allocation for the procurement of various components and materials. The following is a breakdown of the budget requirements:

S No.	Name of the component	Quantity	Price (Rs)
1	Arduino ATmega 2560	1	1050
2	Johnson Geared Motor 100 RPM 12V	4	2600

3	Wheel 13mm x 60mm	4	2700
4	L298N Motor Driver	2	500
5	ESP8266-01 Wifi Module	1	420
6	Ultrasonic	1	360
7	IR Sensor Array	1	370
8	RFID Readers and RFID Tags	1	300
9	Trolley	1	2000
10	Jumper Wire	Set of 70 pcs	20
11	Soldering Wiree	1	80
12	Power Supply	1	850
	Total Budget Required		11,250

Table 3.1 Cost Analysis

This comprehensive budget allocation covers the procurement of all necessary components and materials for the project

3.5 RISK ANALYSIS

A comprehensive risk analysis is a critical step in any project, especially one as complex as the IoT-Based Serving LFR Robot. This process involves identifying potential challenges and developing proactive strategies to mitigate them.

Identified Risks:

- **Component Compatibility:** Compatibility of Individual Components Because the potential for the various components to stop interacting with one another is a big concern for this project, ensuring that they are compatible with one another is of the utmost importance. It is vital to reduce the probability of anything like this occurring to ensure that the integration and functioning of these components will go off without a hitch. When issues emerge, they could be the result of incompatibilities between various components of a system.

- **Environmental Factors:** To function properly, the robot will need to be able to adjust to a variety of landscapes and conditions. Both the navigation and functioning of the robot may be hindered by factors such as uneven terrain, impediments, and changing lighting conditions.

- **Power Management:** If you want your batteries to last as long as possible, especially in situations where you might not have easy access to charging stations, you need to pay careful attention to power management. If you want your batteries to last as long as possible, you need to pay close attention to power management. If there is insufficient electricity, the services may have to be altered or temporarily discontinued without prior notice.

- **Software Bugs:** Developing complex software for a robotic system introduces the risk of encountering bugs or errors. These can range from minor glitches to critical failures that affect the robot's performance.

Mitigation Strategies:

- **Thorough Testing:** To minimize the risks associated with component compatibility and software bugs we implemented a testing protocol. Each component underwent individual evaluation to ensure its proper functioning and integration tests were performed to verify if they function correctly when combined.

- **Real-world Field Testing:** To account for factors, we conducted extensive field experiments across multiple locations. These tests aimed to replicate real-life scenarios evaluating the effectiveness of the robot, across terrains varying lighting conditions, and potential obstacles.

- **Battery Capacity Evaluation:** A thorough analysis of the battery capacity was performed to address potential power management difficulties. This analysis included estimating the runtime by figuring out the robot's power needs about the 12V battery's storage capacity.

- **Debugging and Testing Phases:** The software issues were addressed through the debugging and testing processes. A systematic approach was used to debug and test the code thoroughly. Quality assurance measures such as code reviews, unit testing, integration testing, and continuous debugging were woven into the fabric of the development process.

By identifying these risks and implementing mitigation techniques effectively our project team proactively handled anticipated challenges. This ensured a development and implementation process, for our IoT Based Serving LFR Robot.

CHAPTER 4 - PROJECT DESIGN AND DESCRIPTION

4.1 DESCRIPTION

The serving robot is designed to automate service and delivery tasks. It is an innovative alternative used for repetitive and mundane tasks.

The serving robot is made of a sturdy structure, with wheels attached to DC motors which allows for its stable movement and helps it move about its environment.

IR array is placed in front of the robot which detects and monitors the path for any line markings. By detecting and analyzing the IR array data, the robot can adjust its movement and follow the designated path.

The robot uses an ultrasonic sensor attached to the front to detect any obstacles in its path. This sensor emits ultrasonic waves and measures the time taken for the waves to bounce back after hitting an obstacle. Based on the return signal, the robot can detect how far an obstacle is and use preventive measures to avoid any collision.

The robot uses an RFID reader for table detection. All the tables have an RFID tag attached to it. When the robot receives an order it can match the UID of the RFID tag on each table for its destination table.

The ESP8266 module is built into the robot's system and allows for wireless data transfer. This component sets up a communication link with other gadgets like mobile phones and tablets. Users may choose their preferred table number using the slider on the mobile app "Blynk IoT." ESP8266 relays this data to the robot, facilitating natural communication and management.

At the core of the robot's system is an Arduino microcontroller that processes sensor data and controls the robot's movements. Different algorithms are used to interpret data from various sensors used in the robot to make decisions.

The project's ultimate objective is to build a cutting-edge, high-functioning serving robot that can navigate its environment and carry out its tasks without human intervention. By reducing the need for humans to carry out menial tasks, the robot hopes to foster progress in the service industry.

4.2 U.G SUBJECTS

The below-mentioned courses contribute to different aspects of the project

- Electronic Engineering (UEC001): This course provides fundamental electronics knowledge. It helps us understand the working of components and circuits used in the making of this robot.
- Engineering Drawing (UTA015): Drawing is still the most common way to communicate design. The process is called technical drawing or drafting, and while computers have replaced tools such as drafters and T-squares, the principles remain the same. This course explores essential drafting techniques— both analog methods and digital equivalents—in the popular computer-aided design program AutoCAD. It helps us by making us familiar with software like AutoCAD used in the design of the prototype.
- Electrical Engineering (UEE001): Circuit theory, power distribution, and electronics are introduced in this introductory course on electricity. It sheds light on how the robot's electrical systems function.
- Mechanics (UES009): The fundamentals of motion, forces, and mechanical systems are covered in this course. It's important for the robot's wheels, motor control, and mechanical design, all of which contribute to the robot's mobility and stability.
- Engineering Design Project-I (UTA016) and Engineering Design Project (UTA024): These courses are based on the practical application of the engineering skills learned by making projects based on electronics and mechanics.
- IoT Based Systems (UEC715): The concepts and practical uses of IoT (Internet of Things) technology are the focus of this course. The project's goal of developing an Internet of Things–based waiter robot is explicitly addressed. It helps with the planning and execution of the robot's connection and control systems by covering issues including wireless communication, sensor integration, and IoT platforms.

Overall, these courses contribute valuable knowledge and skills required to design, develop, and implement the various aspects of the serving robot project, encompassing electronics, electrical systems, mechanics, design principles, and IoT technologies.

4.3 IEEE STANDARDS USED

The below-mentioned IEEE standards are used for different aspects of the project:

- 2413-2019 - IEEE Standard for an Architectural Framework for the Internet of Things (IoT):

  This standard provides a framework for designing and implementing IoT systems. It is directly relevant to the project as it guides the overall architecture and design considerations for the IoT-based serving robot.

- 802.15.1-2005 - IEEE Standard for Wireless Personal Area Networks (WPAN):

  This standard specifies the wireless medium access control (MAC) and physical layer (PHY) specifications for WPANs, including Bluetooth. It is relevant to the project as it guides the wireless communication aspects between the robot and user devices.

- 802.11-2016 - IEEE Standard for Local and Metropolitan Area Networks:

  This standard pertains to wireless LAN (Wi-Fi) technology. It is relevant to the project's WiFi module and wireless communication, ensuring compatibility and adherence to the standardized protocols for efficient and reliable wireless data transmission.

- 1451.5-2007 - IEEE Standard for a Smart Transducer Interface for Sensors and Actuator:

  This standard focuses on wireless communication protocols and transducer electronic data sheet (TEDS) formats for smart sensors and actuators. It applies to the project's sensor integration, ensuring interoperability and standardized communication protocols.

- 1888-2014 - IEEE Standard for Ubiquitous Green Community Control Network Protocol:

  This standard addresses control network protocols for green community systems, focusing on energy efficiency and sustainability. Although the direct relevance to the project may depend on the specific application, it could guide the implementation of energy-efficient practices and control protocols.

These IEEE standards serve as guidelines and reference points for designing and implementing various aspects of the project, including IoT architecture, wireless communication, sensor integration, and energy efficiency considerations. Adhering to these standards promotes interoperability, reliability, and compatibility with existing systems and technologies.

4.4 SURVEY OF TOOLS AND TECHNOLOGIES

4.4.1. MICROCONTROLLER

4.4.1.1. COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

ESP8266: A low-cost, Wi-Fi-enabled microcontroller, ideal for IoT projects.

ESP32: A versatile microcontroller with Wi-Fi and Bluetooth capabilities, suitable for IoT and robotics.

Arduino Mega 2560: An Arduino board with numerous I/O pins for complex projects.

Arduino UNO: A beginner-friendly microcontroller board, great for learning and prototyping.

Arduino Due: A powerful board for moderate to advanced projects, featuring a 32-bit ARM core.

Arduino Nano: A compact Arduino board suitable for small-scale projects.

Raspberry Pi Pico: A microcontroller board with MicroPython support for diverse applications.

STM32 Nucleo Boards: A series of microcontroller development boards with varying capabilities for embedded systems.

Processing Power:

- **ESP8266:** Low to moderate processing power suitable for simpler tasks.
- **ESP32**: Higher processing power compared to ESP8266, capable of more complex tasks.
- **Arduino Mega 2560:** Moderate processing power suitable for various robotics applications.
- **Arduino UNO**: Basic processing power for simpler robotics tasks.
- **Arduino Due:** Significantly higher processing power compared to UNO, suitable for complex projects.
- **Arduino Nano:** Similar to UNO but smaller in size.
- **Raspberry Pi Pico:** Moderate processing power with dual cores.
- **STM32 Nucleo Boards:** Offer various models with varying processing power, suitable for a wide range of projects.

Memory:

- **ESP8266:** Limited memory.
- **ESP32**: More memory compared to ESP8266.

- **Arduino Mega 2560:** Adequate memory for most robotic applications.
- **Arduino UNO**: Limited memory.
- **Arduino Due**: More memory than UNO.
- **Arduino Nano:** Limited memory.
- **Raspberry Pi Pico:** Limited memory.
- **STM32 Nucleo Boards:** Memory varies depending on the model.

I/O Pins:

- **ESP8266:** Limited I/O pins.
- **ESP32:** Offers a good number of I/O pins.
- **Arduino Mega 2560:** Abundant I/O pins suitable for complex robot designs.
- **Arduino UNO:** Limited I/O pins.
- **Arduino Due:** Offers more I/O pins than UNO.
- **Arduino Nano:** Limited I/O pins.
- **Raspberry Pi Pico:** Moderate number of GPIO pins.
- **STM32 Nucleo Boards:** The number of I/O pins varies by model.

Connectivity:

- **ESP8266:** Built-in Wi-Fi connectivity.
- **ESP32:** Dual-core processor and built-in Wi-Fi and Bluetooth.
- **Arduino Mega 2560:** Limited connectivity options without additional shields.
- **Arduino UNO:** Basic connectivity options.
- **Arduino Due:** Limited connectivity options without additional shields.
- **Arduino Nano:** Basic connectivity options.
- **Raspberry Pi Pico:** No built-in connectivity.
- **STM32 Nucleo Boards:** Connectivity options vary by model.

Community Support:

- **ESP8266:** Strong community support with a wealth of online resources.
- **ESP32:** Strong community support with extensive libraries and documentation.
- **Arduino Mega 2560:** Well-established Arduino community.
- **Arduino UNO:** Extensive Arduino community.
- **Arduino Due:** Strong support but less common.
- **Arduino Nano:** Supported by the Arduino community.
- **Raspberry Pi Pico:** Growing community but less extensive than Arduino or Raspberry Pi.
- **STM32 Nucleo Boards:** Good community support, especially for STM32 microcontrollers.

Cost:

- **ESP8266:** Affordable.
- **ESP32:** Affordable.
- **Arduino Mega 2560:** Affordable.
- **Arduino UNO:** Very affordable.
- **Arduino Due:** Moderately priced.
- **Arduino Nano:** Very affordable.
- **Raspberry Pi Pico:** Very affordable.
- **STM32 Nucleo Boards:** Price varies by model.

Power Efficiency:

- **ESP8266:** Moderate power consumption.
- **ESP32:** Moderate power consumption.
- **Arduino Mega 2560:** Moderate power consumption.
- **Arduino UNO:** Low power consumption.
- **Arduino Due:** Moderate power consumption.
- **Arduino Nano:** Low power consumption.
- **Raspberry Pi Pico:** Low power consumption.
- **STM32 Nucleo Boards:** Power consumption varies by model.

Development Environment:

- **ESP8266:** Arduino IDE with additional libraries.
- **ESP32:** Arduino IDE with additional libraries.
- **Arduino Mega 2560:** Arduino IDE.
- **Arduino UNO:** Arduino IDE.
- **Arduino Due:** Arduino IDE.
- **Arduino Nano:** Arduino IDE.
- **Raspberry Pi Pico:** C/C++ with MicroPython support.
- **STM32 Nucleo Boards:** STM32CubeIDE or Arduino IDE.

Form Factor:

- **ESP8266:** Compact modules.
- **ESP32:** Compact modules.
- **Arduino Mega 2560:** Larger form factor.
- **Arduino UNO:** Standard form factor.
- **Arduino Due:** Larger form factor.
- **Arduino Nano:** Compact form factor.
- **Raspberry Pi Pico:** Compact form factor.

- **STM32 Nucleo Boards:** Varies by model.

Real-Time Capabilities:

- **ESP8266:** Limited real-time capabilities.
- **ESP32:** Better real-time capabilities.
- **Arduino Mega 2560:** Limited real-time capabilities.
- **Arduino UNO:** Limited real-time capabilities.
- **Arduino Due:** Better real-time capabilities.
- **Arduino Nano:** Limited real-time capabilities.
- **Raspberry Pi Pico:** Limited real-time capabilities.
- **STM32 Nucleo Boards:** Good real-time capabilities.

Ultimately, the choice depends on your specific project requirements, including processing power, memory, I/O needs, connectivity, and budget. For a serving robot project, you may want to consider factors like sensor integration, motor control, and communication requirements to make the best choice. The ESP8266 and ESP32 are popular choices for IoT-based robots due to their built-in Wi-Fi and community support, but the Arduino Mega 2560 or Due may also be suitable depending on your needs.

4.4.1.2 PREFERENCE

The choice of the Arduino Mega 2560 among the options can be justified based on several factors:

Abundant I/O Pins: The Arduino Mega 2560 offers a large number of digital and analog I/O pins, making it well-suited for projects that require extensive sensor integration, motor control, and communication interfaces. This abundance of pins allows you to connect and control multiple sensors, actuators, and other peripherals without running out of available pins.

Community Support: The Arduino Mega 2560 is part of the Arduino ecosystem, which boasts a large and active community. This community support means you can find a wealth of online resources, tutorials, and libraries tailored to Arduino boards, making it easier to develop and troubleshoot your project.

Cost-Effective: Arduino Mega 2560 boards are cost-effective, offering a good balance between features and affordability. This is especially beneficial if you are working on a project with budget constraints.

Stability and Reliability: Arduino boards are known for their stability and reliability, which is important for a serving robot that needs to perform consistently and accurately.

Arduino IDE: The Arduino IDE is user-friendly and widely used for programming Arduino boards. It simplifies the development process, making it accessible to both beginners and experienced developers.

Motor Control: The Arduino Mega 2560's multiple PWM pins and motor control libraries make it suitable for controlling motors and achieving precise motion control.

Sensor Integration: The Mega 2560's numerous analog and digital pins allow you to integrate a wide variety of sensors, including ultrasonic sensors, IR sensors, and more, which are commonly used in robotics projects.

Expandability: The Arduino Mega 2560 is compatible with a wide range of shields and add-on modules, providing opportunities for additional functionality and customization.

Availability: Arduino boards like the Mega 2560 are readily available and can be purchased from various suppliers, making it convenient to obtain the hardware for your project.

Ultimately, the preference for the Arduino Mega 2560 is based on its versatility, affordability, and robust community support, making it a popular choice for a wide range of robotics and automation projects.

4.4.1.3. ARDUINO MEGA 2560

The microcontroller board like "Arduino Mega" depends on the ATmega2560 microcontroller. It includes digital input/output pins-54, where 16 pins are analog inputs, 14 are used like PWM outputs hardware serial ports (UARTs) – 4, a crystal oscillator-16 MHz, an ICSP header, a power jack, a USB connection, as well as an RST button. This board mainly includes everything essential for supporting the microcontroller. So, the power supply of this board can be done by connecting it to a PC using a USB cable, battery, or an AC-DC adapter. This board can be protected from unexpected electrical discharge by placing a base plate.

The SCL & SDA pins of the Mega 2560 R3 board connect beside the AREF pin. Additionally, there are two latest pins located near the RST pin. One pin is the IOREF that permits the shields to adjust the voltage offered by the Arduino board. Another pin is not associated & it is kept for upcoming purposes. These boards work with every existing shield although can adjust to the latest shields that utilize these extra pins.

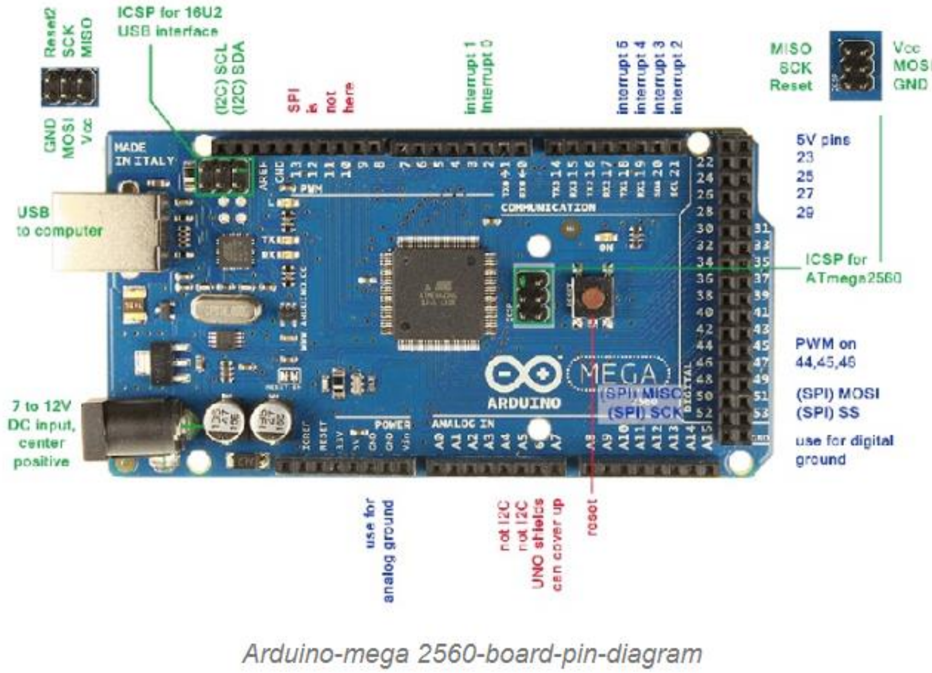


Figure 4.1 Arduino Mega 2560 Board

Voltage Inputs: The board can accept input voltages ranging from 7V to 20V, and it provides regulated 5V and 3.3V outputs for powering components.

Ground Pins: There are multiple ground (GND) pins for connecting various components.

Reset (RST) Pin: The RST pin is used for resetting the board.

Serial Communication: It has multiple serial communication pins (TXD and RXD) for transmitting and receiving data.

External Interrupts: The board has 6 pins for creating external interrupts.

LED: An LED connected to digital pin 13 for real-time programming feedback.

AREF: Analog Reference Voltage pin for analog inputs.

Analog Pins: 16 analog pins (A0 to A15) that can also be used as digital I/O pins.

I2C Communication: Supports I2C communication with pins SDA (20) and SCL (21).

SPI Communication: SPI communication is possible through pins MISO (50), MOSI (51), SCK (52), and SS (53).

Dimensions: The board's dimensions are approximately 101.6mm x 53.34mm.

Shield Compatibility: Compatible with most shields designed for Arduino boards, but ensure voltage compatibility.

Programming: Programmed using the Arduino IDE with C-language sketches. It has a bootloader for easy program uploading via USB.

Multitasking: While Arduino IDE doesn't support multitasking, additional operating systems like RTX and FreeRTOS can be used for multitasking purposes.

Custom Build: Flexible for use in custom-built programs with an ISP connector.

4.4.1.4. ARDUINO MEGA SPECIFICATIONS

The specifications of Arduino Mega include the following.

- The ATmega2560 is a Microcontroller
- The operating voltage of this microcontroller is 5volts
- The recommended Input Voltage will range from 7volts to 12volts
- The input voltage will range from 6volts to 20volts
- The digital input/output pins are 54 where 15 of these pins will supply PWM o/p.
- Analog Input Pins are 16
- DC Current for each input/output pin is 40 mA
- DC Current used for 3.3V Pin is 50 mA
- Flash Memory like 256 KB where 8 KB of flash memory is used with the help of a bootloader
- The static random access memory (SRAM) is 8 KB
- The electrically erasable programmable read-only memory (EEPROM) is 4 KB
- The clock (CLK) speed is 16 MHz
- The USB host chip used in this is MAX3421E
- The length of this board is 101.52 mm
- The width of this board is 53.3 mm
- The weight of this board is 36 g

4.4.2. WIRELESS COMMUNICATION MODULE

4.4.2.1. COMPARISONS AMONG THE VARIOUS AVAILABLE MODULES

ESP8266 Module: A compact Wi-Fi module known for its affordability and ease of use, commonly used for adding Wi-Fi connectivity to various devices.

ESP32 Module: A versatile module featuring both Wi-Fi and Bluetooth connectivity, suitable for a wide range of IoT and wireless communication applications.

Bluetooth Module (HC-05/HC-06 or BLE): Bluetooth modules, including HC-05, HC-06, and BLE modules, enable wireless communication between devices over short distances, with BLE offering low energy consumption.

GSM/GPRS Module: A module that allows devices to connect to the cellular network, commonly used for remote monitoring and communication.

LoRa (Long Range) Module: A module that utilizes LoRa technology for long-range wireless communication, ideal for applications requiring extended coverage.

Zigbee Module: Zigbee modules enable low-power, short-range wireless communication between devices, commonly used in home automation and IoT applications.

Range:

- **ESP8266:** Suitable for short to mid-range communication, typically up to 100 meters indoors.
- **ESP32**: Similar to ESP8266, it offers a range of up to 100 meters.
- **Bluetooth HC-05/HC-06**: Short-range modules with a range of about 10 meters (Bluetooth Class 2).
- **BLE (Bluetooth Low Energy):** Short-range, typically up to 100 meters.
- **GSM/GPRS:** Provides cellular network coverage, offering a wider range, even across long distances.
- **LoRa:** Long-range, capable of several kilometers in open areas.
- **Zigbee:** Typically provides a range of up to 100 meters, extendable with mesh networking.

Power Consumption:

- **ESP8266:** Moderate power consumption, suitable for battery-powered applications.
- **ESP32:** Similar power consumption to ESP8266.
- **Bluetooth HC-05/HC-06:** Low power consumption.
- **BLE:** Very low power consumption, ideal for battery-operated devices.
- **GSM/GPRS:** Higher power consumption compared to WiFi and Bluetooth.
- **LoRa:** Low power consumption, especially in sleep modes, making it suitable for battery-powered devices.
- **Zigbee:** Low to moderate power consumption, depending on the configuration.

Data Rate:

- **ESP8266:** Offers data rates of up to 72.2 Mbps.
- **ESP32:** Provides higher data rates of up to 150 Mbps.
- **Bluetooth HC-05/HC-06:** Supports lower data rates suitable for serial data transfer (typically 1-3 Mbps).
- **BLE:** Offers lower data rates for energy efficiency (typically up to 1 Mbps).
- **GSM/GPRS:** Provides data rates ranging from 9.6 kbps to several Mbps.
- **LoRa:** Offers relatively low data rates (usually in the range of 0.3 to 50 kbps) but excels in long-range communication.
- **Zigbee:** Offers data rates of up to 250 kbps.

Network Topology:

- **ESP8266/ESP32:** Point-to-point and infrastructure (station) modes for WiFi networks.
- **Bluetooth HC-05/HC-06:** Point-to-point (HC-05) or master-slave (HC-06).
- **BLE:** Point-to-point, star, or mesh topology.
- **GSM/GPRS:** Point-to-point or cellular network.
- **LoRa:** Point-to-point and point-to-multipoint, suitable for IoT applications.
- **Zigbee:** Mesh networking with support for multiple devices.

Complexity and Development:

- **ESP8266/ESP32:** Well-documented, extensive community support, and easy integration with Arduino and other platforms.
- **Bluetooth HC-05/HC-06:** Simple to use, suitable for basic projects.
- **BLE:** Requires familiarity with Bluetooth profiles and protocols.

- **GSM/GPRS:** Requires a SIM card and cellular network subscription.
- **LoRa:** This may require additional setup and configuration for specific applications.
- **Zigbee:** Requires Zigbee protocol understanding and may involve a learning curve.

Use Cases:

- **ESP8266/ESP32:** General IoT and robotics projects with WiFi connectivity.
- **Bluetooth HC-05/HC-06:** Short-range projects like remote control and serial data transfer.
- **BLE:** Low-power IoT devices, fitness trackers, and proximity applications.
- **GSM/GPRS:** Remote monitoring and tracking where cellular network coverage is available.
- **LoRa:** Long-range IoT applications such as agriculture, smart cities, and environmental monitoring.
- **Zigbee:** Home automation, industrial automation, and sensor networks.

Cost:

Costs can vary widely based on module type, brand, and features. ESP8266 and HC-05 modules are generally more budget-friendly, while specialized modules like LoRa and Zigbee may be pricier.

4.4.2.2 PREFERENCE

The preference for the ESP8266 module over other communication modules like ESP32, Bluetooth (HC-05/HC-06 or BLE), GSM/GPRS, LoRa, and Zigbee in specific projects, including serving robots, can be influenced by several factors. Let's explore why the ESP8266 module is preferred:

Cost-Effectiveness: The ESP8266 module is known for its affordability. Cost is often a significant consideration in robotics projects, especially for hobbyists and those on a tight budget.

WiFi Connectivity: ESP8266 provides WiFi connectivity, which is well-suited for applications requiring internet access or communication over a local network. For serving robots, where communication with a central control system or user interfaces through mobile apps is essential, WiFi is a practical choice.

Community Support: The ESP8266 platform has a large and active community of developers and hobbyists. This community provides extensive documentation, libraries, and support, making it easier to develop and troubleshoot projects. In robotics, where reliability is crucial, having access to community support can be invaluable.

Ease of Integration: ESP8266 can be seamlessly integrated into the robot's control system, especially when using popular development platforms like Arduino. The abundance of resources and libraries simplifies development, even for individuals with limited experience in wireless communication.

Standard Protocols: The ESP8266 supports standard IEEE 802.11 b/g/n WiFi protocols, ensuring compatibility with existing networks and devices. This compatibility is vital for serving robots that need to communicate with various devices, such as smartphones or tablets, which typically use WiFi for connectivity.

Web Server Hosting: The ESP8266's ability to host web servers is advantageous for serving robots. It enables the creation of user-friendly web-based interfaces for controlling and monitoring the robot's actions. This feature simplifies user interaction and enhances the overall user experience.

OTA Updates: Over-The-Air (OTA) firmware updates are supported by the ESP8266. This capability allows for remote updates and maintenance of the robot's software without physical access to the robot. It ensures that the robot can receive software improvements and bug fixes easily.

Power Efficiency: While not the most power-efficient module available, the ESP8266 includes power-saving modes. In scenarios where the robot operates on battery power or energy efficiency is a concern, these modes help extend battery life.

Range and Performance: The ESP8266 offers a suitable communication range for indoor and short to mid-range outdoor applications. In serving robot applications, where the robot typically operates in indoor environments, this range is adequate.

While other communication modules can perform similar functions, the ESP8266 module's combination of cost-effectiveness, community support, ease of integration, compatibility with standard protocols, web server hosting capabilities, OTA updates, and suitability for indoor range requirements collectively make it a practical and efficient choice for serving robot applications. However, the choice of the communication module should always consider the specific requirements and constraints of the project, and alternative modules should be evaluated accordingly.

4.4.2.3. ESP8266 Wi-Fi MODULE

An ESP8266 Wi-Fi module is a SOC microchip mainly used for the development of end-point IoT (Internet of Things) applications. It is referred to as a standalone wireless transceiver, available at a very low price. It is used to enable the internet connection to various applications of embedded systems.

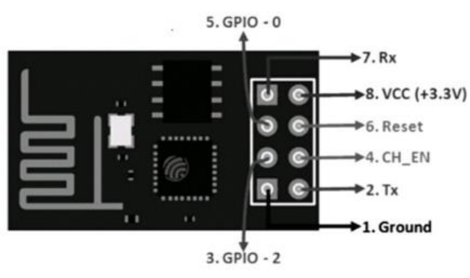
Espressif Systems designed the ESP8266 Wi-Fi module to support both the TCP/IP capability and the microcontroller access to any Wi-Fi network. It provides solutions to meet the requirements of industries of IoT such as cost, power, performance, and design.

It can work as either a slave or a standalone application. If the ESP8266 Wi-Fi runs as a slave to a microcontroller host, then it can be used as a Wi-Fi adaptor to any type of microcontroller using UART or SPI. If the module is used as a standalone application, then it provides the functions of the microcontroller and Wi-Fi network.

The ESP8266 Wi-Fi module is highly integrated with RF balun, power modules, RF transmitter and receiver, analog transmitter and receiver, amplifiers, filters, digital baseband, power modules, external circuitry, and other necessary components.

A set of AT commands is needed by the microcontroller to communicate with the ESP8266 Wi-Fi module. Hence it is developed with AT commands software to allow the Arduino Wi-Fi functionalities and also allows the loading of various software to design their application on the memory and processor of the module.

The processor of this module is based on the Tensilica Xtensa Diamond Standard 106 micro and operates easily at 80 MHz.



Pin Configuration of ESP8266

Figure 4.2 ESP8266-01

Flash Mode: When GPIO-0 and GPIO-1 pins are active high, then the module runs the program, which is uploaded into it.

UART Mode: When the GPIO-0 is active low and GPIO-1 is active high, then the module works in programming mode with the help of either serial communication or Arduino board.

4.4.2.4 ESP8266 -01 Wi-Fi MODULE SPECIFICATIONS

The ESP8266 Wi-Fi module specifications or features are given below:

- It is a powerful Wi-Fi module available in a compact size at a very low price.
- It is based on the L106 RISC 32-bit microprocessor core and runs at 80 MHz
- It requires only 3.3 Volts of power supply
- The current consumption is 100 m Amps
- The maximum Input/Output (I/O) voltage is 3.6 Volts.
- It consumes 100 mA current
- The maximum Input/Output source current is 12 mA
- The frequency of the built-in low-power 32-bit MCU is 80 MHz
- The size of flash memory is 513 kb
- It is used as either an access point station or both
- It supports less than 10 microAmps deep sleep
- It supports serial communication to be compatible with several developmental platforms such as Arduino
- It is programmed using either AT commands, Arduino IDE, or Lua script
- It is a 2.4 GHz Wi-Fi module and supports WPA/WPA2, WEP authentication, and open networks.
- It uses two serial communication protocols I2C (Inter-Integrated Circuit) and SPI (Serial Peripheral Interface).
- It provides 10-bit analog to digital conversion
- The type of modulation is PWM (Pulse Width Modulation)
- UART is enabled on dedicated pins and for only transmission, it can be enabled on GPIO2.
- It is an IEEE 802.11 b/g/n Wi-Fi module with LNA, power amplifier, balun, integrated TR switch, and matching networks.

- GPIO pins – 2
- Memory Size of instruction RAM – 32 KB
- The memory size of instruction cache RAM – 32 KB
- Size of User-data RAM- 80 KB
- Size of ETS systems-data RAM – 16 KB

4.4.3 SENSOR TO FOLLOW THE PATH

4.4.3.1 COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

Infrared (IR) Sensors: IR sensors are commonly used for line following, where the robot follows a predefined path marked by a contrasting line on the ground. These sensors can detect the line's position relative to the robot's center and make steering adjustments to stay on the path.

Color Sensors: Color sensors can be used to track colored lines or markers on the path. They work by detecting the color changes in the surface below the robot. These sensors are suitable for applications where the path is marked with distinct colors.

Reflectance Sensors: Reflectance sensors, also known as reflectance arrays or line sensors, consist of multiple IR or IR-LED/phototransistor pairs arranged in a line. They are designed to detect variations in surface reflectivity and are commonly used for line following.

Proximity Sensors: Proximity sensors, such as capacitive or inductive sensors, can be used to track the presence of conductive or non-conductive objects placed along the path. These sensors are effective for detecting obstacles or markers.

LIDAR Sensors: Light Detection and Ranging (LIDAR) sensors emit laser beams to create detailed maps of the environment. While they are often used for obstacle avoidance, they can also be used for high-precision path tracking when combined with mapping and localization algorithms.

Wheel Encoders: Wheel encoders are used to measure the rotation of the robot's wheels accurately. By tracking wheel rotations and comparing them to the desired path, the robot can make precise adjustments to maintain the correct path.

GPS (Global Positioning System): GPS can be used for outdoor path tracking, especially in large outdoor environments or on predefined routes. However, GPS accuracy can vary, and it may not be suitable for very precise path tracking.

Magnetic Sensors: Magnetic sensors can detect changes in magnetic fields and are sometimes used with magnets or magnetic markers embedded in the path. These sensors are suitable for indoor applications where magnetic markers can be placed on the floor.

Camera-Based Systems: Cameras with computer vision algorithms can be used for path tracking, especially in scenarios where the path is not physically marked. Machine learning and image processing techniques can help the robot recognize and follow the path based on visual cues.

Infrared (IR) Sensors:

- **Principle:** Detects infrared light reflected from a surface.
- **Advantages:** Simple, affordable, suitable for line following.
- **Disadvantages:** Limited to line following applications, sensitivity to ambient light.

Color Sensors:

- **Principle:** Detects and identifies colors by analyzing reflected light wavelengths.
- **Advantages:** Can track colored lines or markers, suitable for versatile path tracking.
- **Disadvantages:** Requires distinct color markings on the path.

Reflectance Sensors (Reflectance Arrays):

- **Principle:** Utilizes IR or IR-LED/phototransistor pairs to detect variations in surface reflectivity.
- **Advantages:** Precise line following, suitable for maze-solving robots.
- **Disadvantages:** Limited to line following applications.

Proximity Sensors (Capacitive or Inductive):

- **Principle:** Detects the presence of objects based on capacitance or inductance changes.
- **Advantages:** Effective for obstacle detection, versatile for various path tracking scenarios.
- **Disadvantages:** Limited to detecting nearby objects.

LIDAR Sensors:

- **Principle:** Emits laser beams to create detailed environment maps.
- **Advantages:** High precision, obstacle avoidance, versatile for complex paths.
- **Disadvantages:** Costly, power-hungry.

Wheel Encoders:

- **Principle:** Measures wheel rotations to calculate distance and direction.
- **Advantages:** Precise tracking, works well with wheel-based motion.
- **Disadvantages:** Limited to wheel-based robots, may require additional sensors for complex paths.

GPS (Global Positioning System):

- **Principle:** Uses satellite signals to determine global position.
- **Advantages:** Suitable for outdoor path tracking over large areas.
- **Disadvantages:** Limited accuracy, not ideal for precise indoor tracking.

Magnetic Sensors:

- **Principle:** Detects changes in magnetic fields.
- **Advantages:** Effective indoor path tracking with magnetic markers.
- **Disadvantages:** Requires magnetic markers on the path, may be affected by magnetic interference.

Camera-Based Systems:

- **Principle:** Uses cameras and computer vision algorithms to track visual cues.
- **Advantages:** Versatile, can track paths without physical markings, adaptable.
- **Disadvantages:** Relies on lighting conditions, and may require complex image processing.

4.4.3.2 PREFERENCE

The preference for an IR sensor array, also known as a reflectance sensor or reflectance array, over other options for path tracking in a serving robot project can be attributed to several factors:

Precise Line Following: IR sensor arrays are specifically designed for line following applications. They consist of multiple IR or IR-LED/phototransistor pairs arranged in a line. This arrangement allows for precise tracking of lines or paths.

Simplicity and Affordability: IR sensor arrays are relatively simple to implement and are cost-effective. They provide an efficient solution for basic path-tracking tasks without the need for complex hardware or expensive sensors.

Versatility: While IR sensor arrays excel at line following, they can also be used for maze-solving robots and other path-tracking applications. Their versatility makes them suitable for a wide range of scenarios.

Sensitivity to Surface Variations: IR sensor arrays can detect variations in surface reflectivity. This means they can handle paths with changes in color or surface texture, making them adaptable to different environments.

Low Power Consumption: IR sensors typically consume minimal power, which is beneficial for prolonging the robot's battery life, especially in applications where long operation is required.

Suitable for Indoor Use: IR sensor arrays are well-suited for indoor path tracking, where they can follow lines or paths marked with contrasting materials.

Integration with Microcontrollers: IR sensor arrays can easily interface with microcontrollers like Arduino, allowing for straightforward integration into your robot's control system.

Availability: IR sensor arrays are readily available as off-the-shelf components, making them accessible for hobbyists and developers.

4.4.3.3 IR SENSOR ARRAY

The IR sensor array is a device that consists of 6 mounted infrared sensors, each capable of detecting black and white colors. An infrared sensor is an electronic device, that emits to sense some aspects of the surroundings. An IR sensor can measure the heat of an object as well as detect the motion. These types of sensors measure only infrared radiation, rather than emitting it which is called a passive IR sensor. Usually, in the infrared spectrum, all objects radiate some form of thermal radiation.

These types of radiation are invisible to our eyes and can be detected by an infrared sensor. The emitter is simply an IR LED (Light Emitting Diode) and the detector is simply an IR photodiode that is sensitive to IR light of the same wavelength as that emitted by the IR LED. When IR light falls on the photodiode, the resistances and the output voltages will change in proportion to the magnitude of the IR light received.

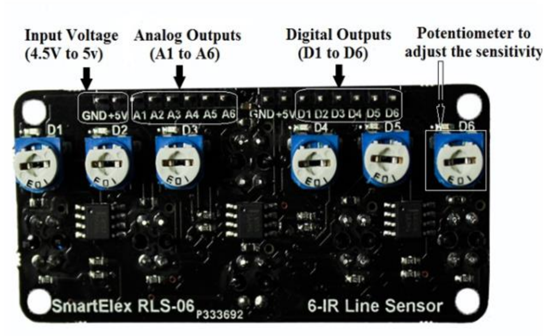


Figure 4.3 IR Sensor Array

This SmartElex RLS-06 Analog & Digital Line Sensor Array has 6 IR LED/phototransistor pairs, making it a great detector for a line-following robot. Each sensor has its own digital and analog output. potentiometer to adjust the sensitivity of the individual sensors.

The TCRT5000 reflectance sensor array is intended as a line sensor, but it can be used as a general-purpose proximity or reflectance sensor. The module is a convenient carrier for eight IR emitter and receiver (phototransistor) pairs evenly spaced at intervals.

Each phototransistor is connected to a pull-up resistor to form a voltage divider that produces an analog voltage output between 0 V and VIN (which is typically 5 V) as a function of the reflected IR. The lower output voltage is an indication of greater reflection.

The outputs are all independent, but the LEDs are arranged in pairs to halve current consumption. The LEDs are controlled by a MOSFET with a gate normally pulled high, allowing the LEDs to be turned off by setting the MOSFET gate to a low voltage. Turning the LEDs off might be advantageous for limiting power consumption when the sensors are not in use or for varying the effective brightness of the LEDs through PWM control.

4.4.3.4 IR SENSOR ARRAY WORKING PRINCIPLE

The working principle of an infrared sensor is similar to the object detection sensor. This sensor includes an IR LED & an IR Photodiode, so combining these two can be formed as a photo-coupler otherwise optocoupler. The physics laws used in this sensor are plank radiation, Stephan Boltzmann & Weins displacement.

IR LED is one kind of transmitter that emits IR radiation. This LED looks similar to a standard LED and the radiation which is generated by this is not visible to the human eye. Infrared receivers mainly detect radiation using an infrared transmitter. These infrared receivers are available in photodiode form. IR Photodiodes are dissimilar as compared with usual photodiodes because they detect simply IR radiation. Different kinds of infrared receivers mainly exist depending on the voltage, wavelength, package, etc.

Once it is used as the combination of an IR transmitter & receiver, then the receiver's wavelength must equal the transmitter. Here, the transmitter is IR LED whereas the receiver is IR photodiode. The infrared photodiode is responsive to the infrared light that is generated through an infrared LED. The resistance of the photo-diode & the change in output voltage is in proportion to the infrared light obtained. This is the IR sensor's fundamental working principle.

Once the infrared transmitter generates emission, then it arrives at the object & some of the emission will reflect toward the infrared receiver. The sensor output can be decided by the IR receiver depending on the intensity of the response.

4.4.3.5. SMARTELEX RLS-06 ANALOG & DIGITAL LINE SENSOR ARRAY SPECIFICATIONS

- **Brand:** SmartElex
- **Operating Voltage (VDC):** 4.5 ~ 5.0
- **Supply Current (A):** 0.1
- **Output Format:** 6 Analog and Digital Voltages
- **Optimal Sensing Distance (mm):** 3
- **Max. Sensing Distance (mm):** 6
- **Mounting Hole (mm):** 3
- **Length (mm):** 34
- **Width (mm):** 70
- **Height (mm):** 10
- **Weight (gm):** 14

4.4.4. SENSOR TO DETECT THE TABLE

4.4.4.1. COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

RFID (Radio-Frequency Identification):

- Attach RFID tags to each table.
- When a table number is sent to the robot, it can query the RFID tags in its vicinity to identify the table with the matching number.

QR Code Labels:

- Place QR code labels on each table, with each QR code containing a unique identifier.
- When the robot receives a table number, it can scan the QR codes to match the received number with the QR code data.

NFC (Near Field Communication):

- Embed NFC tags or stickers on the tables.
- The robot can use an NFC reader to detect nearby tables and match them with the received table number.

Computer Vision (Camera-Based):

- Equip the robot with a camera and use computer vision algorithms.
- When the robot receives a table number, it can capture images of its surroundings and analyze them to identify the table with the corresponding number.

Ultrasound Sensors:

- Install ultrasound transmitters/receivers on tables.
- The robot can emit ultrasound signals and listen for echoes. It can identify tables based on the echoes received.

Bluetooth Beacons:

- Place Bluetooth beacons on tables.
- The robot can detect nearby Bluetooth beacons and determine the table's identity based on the beacon's signal.

WiFi-Based Location Services:

- Implement WiFi-based location services with WiFi access points placed near tables.
- The robot can estimate its location based on WiFi signal strength and determine the nearest table.

Infrared Sensors:

- Equip tables with infrared transmitters and the robot with infrared sensors.
- The robot can detect tables by sensing the infrared signals emitted by them.

Magnetic Markers:

- Attach magnetic markers to tables.
- The robot can use magnetic sensors to detect the presence of these markers and identify the corresponding table.

RFID (Radio-Frequency Identification):

- **Principle:** Uses RFID tags and readers to identify tables.
- **Advantages:** Precise, can uniquely identify tables, reliable.
- **Disadvantages:** The cost of RFID tags and readers, requires infrastructure on tables.

QR Code Labels:

- **Principle:** Relies on scanning QR codes with unique identifiers.
- **Advantages:** Precise, cost-effective, versatile.
- **Disadvantages:** Requires line-of-sight for scanning, may wear out over time.

NFC (Near Field Communication):

- **Principle:** Utilizes NFC tags or stickers on tables.
- **Advantages:** Precise, contactless, fast detection.
- **Disadvantages:** Requires proximity, NFC infrastructure.

Computer Vision (Camera-Based):

- **Principle:** Uses cameras and image processing to recognize tables.
- **Advantages:** Highly versatile, no physical markers required.

- **Disadvantages:** Processing-intensive, affected by lighting conditions.

Ultrasound Sensors:

- **Principle:** Utilizes ultrasound signals and echoes for detection.
- **Advantages:** Contactless, works in various lighting conditions.
- **Disadvantages:** Limited range, potential interference.

Bluetooth Beacons:

- **Principle:** Deploys Bluetooth beacons on tables.
- **Advantages:** Versatile, works well indoors, good range.
- **Disadvantages:** Requires beacon infrastructure.

WiFi-Based Location Services:

- **Principle:** Estimates location based on WiFi signal strength.
- **Advantages:** Works well indoors, scalable, good accuracy.
- **Disadvantages:** Requires WiFi infrastructure.

Infrared Sensors:

- **Principle:** Detects infrared signals from tables.
- **Advantages:** Contactless, works in various lighting conditions.
- **Disadvantages:** Limited range, may require precise alignment.

Magnetic Markers:

- **Principle:** Relies on magnetic markers on tables.
- **Advantages:** Contactless, low-cost.
- **Disadvantages:** Requires magnetic markers, may be affected by external magnetic fields.

4.4.4.2 PREFERENCE

RFID (Radio-Frequency Identification) is preferred over other options for table detection in certain scenarios due to its specific advantages:

Precision: RFID provides precise and unique identification. Each RFID tag has a unique identifier, ensuring that tables can be accurately and uniquely identified. This is crucial in applications where precise table recognition is essential.

Reliability: RFID is a reliable technology with a high read accuracy rate. It can consistently and accurately detect RFID tags, reducing the chances of errors or misidentifications.

Contactless: RFID is a contactless technology, which means there is no physical contact required between the reader and the tag. This is hygienic and reduces wear and tear on the components.

Fast Detection: RFID detection is typically fast and efficient. The moment an RFID tag comes into the reader's range, it can be detected, making it suitable for applications where speed is important.

4.4.4.3. RFID READER AND RFID TAG

RFID (radio frequency identification) is a form of wireless communication that incorporates the use of electromagnetic or electrostatic coupling in the radio frequency portion of the electromagnetic spectrum to uniquely identify an object, animal, or person.

Figure 4.4 RFID Reader and Tag

There are three main types of RFID systems: low frequency (LF), high frequency (HF), and ultra-high frequency (UHF). Microwave RFID is also available. Frequencies vary greatly by country and region.

- **Low-frequency RFID systems:** These range from 30 KHz to 500 KHz, though the typical frequency is 125 KHz. LF RFID has short transmission ranges, generally anywhere from a few inches to less than six feet.

- **High-frequency RFID system:** These range from 3 MHz to 30 MHz, with the typical HF frequency being 13.56 MHz. The standard range is anywhere from a few inches to several feet.
- **UHF RFID systems:** These range from 300 MHz to 960 MHz, with the typical frequency of 433 MHz, and can generally be read from 25-plus feet away.
- **Microwave RFID systems:** These run at 2.45 Ghz and can be read from 30-plus feet away.

The frequency used will depend on the RFID application, with actual obtained distances sometimes varying from what is expected. For example, when the U.S. State Department announced it would issue electronic passports enabled with an RFID chip, it said the chips would only be able to be read from approximately 4 inches away. However, the State Department soon received evidence that RFID readers could skim the information from the RFID tags from much farther than 4 inches -- sometimes upward of 33 feet away. If longer read ranges are needed, using tags with additional power can boost read ranges to 300-plus feet.

4.4.4.4 RFID READER AND RFID TAG WORKING PRINCIPLE

Every RFID system consists of three components: a scanning antenna, a transceiver, and a transponder. When the scanning antenna and transceiver are combined, they are referred to as an RFID reader or interrogator. There are two types of RFID readers -- fixed readers and mobile readers. The RFID reader is a network-connected device that can be portable or permanently attached. It uses radio waves to transmit signals that activate the tag. Once activated, the tag sends a wave back to the antenna, where it is translated into data.

The transponder is in the RFID tag itself. The read range for RFID tags varies based on factors including the type of tag, type of reader, RFID frequency, and interference in the surrounding environment or from other RFID tags and readers. Tags that have a stronger power source also have a longer read range.

RFID tags are made up of an integrated circuit (IC), an antenna, and a substrate. The part of an RFID tag that encodes identifying information is called the RFID inlay. There are two main types of RFID tags:

- **Active RFID:** An active RFID tag has its power source, often a battery.
- **Passive RFID:** A passive RFID tag receives its power from the reading antenna, whose electromagnetic wave induces a current in the RFID tag's antenna.

There are also semi-passive RFID tags, meaning a battery runs the circuitry while communication is powered by the RFID reader.

Low-power, embedded non-volatile memory plays an important role in every RFID system. RFID tags typically hold less than 2,000 KB of data, including a unique identifier/serial number. Tags can be read-only or read-write, where data can be added by the reader or existing data overwritten.

The read range for RFID tags varies based on factors including the type of tag, type of reader, RFID frequency, and interference in the surrounding environment or from other RFID tags and readers. Active RFID tags have a longer read range than passive RFID tags due to the stronger power source.

Smart labels are simple RFID tags. These labels have an RFID tag embedded into an adhesive label and feature a barcode. They can also be used by both RFID and barcode readers. Smart labels can be printed on-demand using desktop printers, whereas RFID tags require more advanced equipment.

4.4.4.5 RFID READER RC522 AND RFID TAG SPECIFICATIONS

- Highly integrated analog circuitry to demodulate and decode responses.
- Supports ISO/IEC 14443 A/MIFARE.
- Typical operating distance in reading/Write mode up to 50 mm.
- Supports ISO/IEC 14443 A higher transfer speed communication up to 848 kBd.
- SPI up to 10 Mbit/s.
- FIFO buffer handles 64 bytes send and receive.
- Flexible interrupt modes.
- Power down by software mode.
- Programmable Timer.

- 2.5 V to 3.3 V power supply.
- CRC coprocessor.
- Internal self-test.
- **Input Supply Voltage:** 3.3V (Do not use 5V supply).
- **Operating Current:** 13 ~ 26 mA.
- **Operating Frequency:** 13.56 MHz.
- **SPI Data Rate:** 10 Mbit/s.
- **Operating Distance (Reading/Write Mode):** 50 mm.
- **Dimensions:** Length 60 mm, Width 39.5 mm, Height 5 mm.
- **Weight:** 20 gm.

4.4.5 SENSOR FOR OBSTACLE DETECTION

4.4.5.1 COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

Ultrasonic Sensors: These sensors emit frequency sound waves and measure the time it takes for the echoes to return. They are commonly used in detecting obstacles within, to medium ranges finding applications in robotics and automotive industries.

Infrared (IR) Sensors: IR sensors utilize light to detect the presence of objects. They work by emitting IR light and measuring its reflection or interruption. These sensors are best suited for obstacle detection within medium ranges. Are commonly used in proximity sensors and motion detectors.

Lidar (Light Detection and Ranging): Lidar sensors emit laser pulses. Measure the time it takes for the light to bounce back. By creating 3D maps of their surroundings they excel in long-range obstacle detection. Lidar finds applications in drones, vehicles, and mapping purposes.

Radar Sensors: Radar sensors rely on radio waves to detect objects and determine their distance and speed. They are widely utilized for long-range obstacle detection capabilities in maritime and aviation industries where navigation collision avoidance is crucial.

Camera-Based Systems: These systems employ one or more cameras to capture information, about the environment. Computer vision methods are utilized to identify and monitor objects making them well-suited for a range of applications involving obstacle detection. These include surveillance, autonomous vehicles, and robotics.

Capacitive Sensors: Capacitive sensors can detect the changes in capacitance which is caused by the proximity of objects. They often find their application in touch sensing and proximity detection in electronics and industrial automation.

Time-of-Flight (ToF) Sensors: ToF sensors can calculate distances by measuring the time it takes for light or laser pulses to travel to an object and return. They find their applications in proximity sensing, gesture recognition, and obstacle detection.

Sonar Sensors: Sonar sensors work on the same principle as ultrasonic instead they have different working environments i.e in water or underwater environments. They emit sound waves and measure the time it takes for echoes to return.

Mechanical Bumpers: Mechanical bumpers are devices that physically can contact an obstacle when they come into contact with it. They find their applications in robotics for immediate collision detection.

Ultrasonic Sensors:

- **Principle:** Emit high-frequency sound waves and measure the time it takes for the echoes to return.
- **Advantages:** Simple to use and cost-effective.
- **Disadvantages:** Limited accuracy at longer distances.

Infrared (IR) Sensors:

- **Principle:** Detect the presence of objects by emitting IR light and measure the reflection or interruption of the emitted light.
- **Advantages:** Inexpensive, Suitable for short-range detection, and commonly available.
- **Disadvantages:** It has limited range as compared to other sensors also it is susceptible to interference from sunlight.

Lidar (Light Detection and Ranging):

- **Principle:** Emit laser pulses and measure the time it takes for light to bounce back.
- **Advantages:** Provides highly accurate, long-range detection capabilities.
- **Disadvantages:** Expensive than other options, affected by fog, rain, or dust.

Radar Sensors:

- **Principle:** Use radio waves to detect objects, and measure distance and speed by analyzing the reflected signals.
- **Advantages:** Long-range detection capabilities, including through obstacles like walls.
- **Disadvantages:** Relatively expensive, limited accuracy for precise obstacle localization.

Camera-Based Systems:

- **Principle:** Use of one or more cameras to capture visual information about the environment, employment of computer vision techniques to track and recognize objects.
- **Advantages:** Visual information about surroundings, and works in varied environments.
- **Disadvantages:** Requirement of significant computational resources.

Capacitive Sensors:

- **Principle:** Detect variations in capacitance caused by proximity of objects.
- **Advantages:** Detection of both metallic and non-metallic objects.
- **Disadvantages:** Limited detection range, susceptible to interference.

4.4.5.2 PREFERENCE

The preference for an ultrasonic sensor, over other options for obstacle detection in a serving robot project can be attributed to several factors:

- **Accuracy and Precision:** Ultrasonic sensors are majorly known for high accuracy and precision in measuring short-range distances. In environments like restaurants and hospitals, where the trolley has to navigate through tight spaces and avoid obstacles without any error, the accuracy of ultrasonic sensors is valuable.
- **Non-Contact Sensing**: The non-contact principle of ultrasonic sensors i.e. emitting sound waves and measuring their reflection, minimizes wear and tear on the sensors as a result making them suitable for environments where hygiene and maintenance places an important part, such as hospitals and food service areas in restaurants.
- **Adaptability:** These sensors are versatile as well as can perform well in varied environments, including both indoor and outdoor settings. They can effectively detect obstacles like tables, chairs, and people in both restaurant dining areas and hospital corridors.
- **Cost-Effectiveness:** Ultrasonic sensors offer a relatively cost-effective solution for obstacle detection rather than lidar or radar. They are particularly important in applications where cost constraints are a consideration, targeting our industry of interest.
- **Reliability:** Ultrasonic sensors are very reliable in a variety of conditions including low light, which can be common in both restaurants and hospital settings. Their robust ability makes them efficient for obstacle detection in these environments.

- **Integration with IoT:** Ultrasonic sensors easily integrate with IoT-based systems as compared to other sensors as well as their capability of working seamlessly with microcontrollers and IoT-based platforms that allow for real-time obstacle detection and navigation control.

4.4.5.3 ULTRASONIC SENSOR

An ultrasonic sensor is a versatile electronic sensor that operates on the principles of echolocation, the same as how bats and dolphins navigate. By emitting high-frequency sound waves, often beyond the range of human hearing, it then measures the time it takes for these sound waves to bounce off objects and return to the sensor. By calculating the time of flight, the sensor determines the distance to the object. Ultrasonic sensors have a wide range of applications, including measuring wind speed and direction, determining tank or channel fluid levels, detecting approaching objects and tracking their positions, and even medical ultrasonography for imaging purposes.

At the core of the ultrasonic sensor is the transducer, responsible for both emitting and receiving ultrasonic waves. Commonly used transducers include piezoelectric and capacitive types. Piezoelectric crystals change size and shape in response to voltage, generating sound waves, while capacitive transducers rely on electrostatic fields between a diaphragm and a backing plate. These sensors are valued for their accuracy, versatility, and non-contact operation, making them integral components in modern technology across various industries.

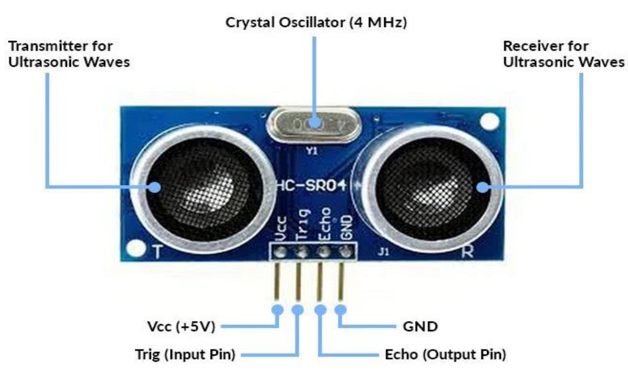


Figure 4.5 Ultrasonic Sensor

Ultrasonic sensors typically feature several pins, each with a specific function. The pin configuration may vary by sensor model:

- **VCC or V+:** This pin serves as the power supply input, usually connected to a positive voltage source (e.g., +5V or +3.3V).
- **GND:** The ground pin connects to the system's ground reference.
- **Trig (Trigger):** The Trigger pin initiates the emission of an ultrasonic pulse when it receives a pulse from the microcontroller.
- **Echo:** The Echo pin is responsible for receiving and measuring the returning ultrasonic echoes. It generates a pulse whose width is proportional to the time taken for the echo to return.
- **OUT:** In some sensor models, the OUT pin functions as the output pin, indicating the presence or distance of an object.
- **NC (No Connection):** This pin may be present in some sensors but is not connected or utilized.

4.4.5.4. ULTRASONIC SENSOR WORKING PRINCIPLE

An ultrasonic sensor operates on the transmission and reception of high-frequency sound waves. It operates on the "time of flight" principle, where it emits a burst of ultrasonic sound waves, and then the sensor determines the distance to a target by measuring time lapses between the sending and receiving of the ultrasonic pulse. By applying a simple distance formula for calculation, the sensor efficiently determines the exact distance between the robot and any obstacles that are in its way. For presence detection, ultrasonic sensors detect objects regardless of the color, surface, or material (unless the material is very soft like wool, as it would absorb sound.) To detect transparent and other items where optical technologies may fail, ultrasonic sensors are a reliable choice.

In the case of our serving trolley, the robot is equipped with an ultrasonic sensor, which emits high-frequency sound waves throughout its surroundings. As these sound waves encounter objects like tables or walls, they reflect as echoes. The sensor's receiver detects these echoes and precisely measures the time it takes for them to return. Should an obstacle come too close, the control system instructs the robot to alter its course to prevent a collision. This real-time application exemplifies how ultrasonic sensors provide critical distance measurements and facilitate obstacle avoidance in automated systems, ensuring safe and efficient navigation in complex environments.

4.4.5.5. ULTRASONIC SENSOR HC-SR04 SPECIFICATIONS

- **Power Supply:** DC 5V
- **Working Current:** 15mA
- **Working Frequency:** 40Hz
- **Ranging Distance:** 2cm – 400cm/4m
- **Resolution:** 0.3 cm
- **Measuring Angle:** 15 degree
- **Trigger Input Pulse width:** 10uS
- **Dimension:** 45mm x 20mm x 15mm

4.4.6. MOTOR DRIVER FOR MOTOR CONTROL

4.4.6.1. COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

L298N: L298N is a dual H-bridge motor driver that can control two DC motors or one stepper motor. It is mostly used in robotics and small electronic projects for its simplicity and reliability.

A4988 and DRV8825: These are stepper motor drivers used in 3D printers and CNC machines, capable of providing micro-stepping capabilities and precise control of stepper motors.

DRV8833: A dual H-bridge motor driver designed for small robots and projects. It can control two DC motors or one stepper motor.

L6203: It is a dual full-bridge driver designed for high-power DC motor control applications, such as electric scooters and electric vehicles.

MC33926 and LMD18200: These motor drivers are designed for higher currents and are used in applications like motorized vehicles and industrial machinery.

TIP120 and ULN2003A: These are Darlington transistor arrays that can be used for simple low-power motor control in DIY projects and small appliances.

Raspberry Pi Motor HAT and Arduino Motor Shield: These are add-on boards for Raspberry Pi and Arduino microcontrollers that provide motor control capabilities, making them ideal for educational projects.

L298N Motor Driver:

- **Principle:** It switches the polarity of the motor terminals to achieve forward, backward, and braking actions.
- **Advantages**: Simple and widely available, can handle moderate currents and voltages.
- **Disadvantages:** Generate significant heat during operation, inefficient due to voltage drops across its transistors.

A4988 and DRV8825 Stepper Motor Drivers:

- **Principle:** These drivers use pulse-width modulation (PWM) to control the current supplied to the windings of stepper motors.
- **Advantages:** Efficient and less heat generation.
- **Disadvantages**: Higher cost compared to simple DC motor drivers.

MC33926 and LMD18200 Motor Driver:

- **Principle:** Uses PWM to regulate current to the motor windings. It supports micro-stepping and higher current ratings.
- **Advantages:** Suitable for high-current stepper motors, precise control, and position holding.
- **Disadvantages:** Relatively complex setup and cost.

TIP120 and ULN2003A Stepper Motor Drivers:

- **Principle:** These advanced drivers use Trinamic's proprietary technology, including stealthChop for quiet operation and stallGuard for motor monitoring.
- **Advantages:** Exceptionally quiet and efficient operation, superior control.
- **Disadvantages:** Relatively expensive, requires firmware configuration for optimal performance.

Raspberry Pi Motor HAT and Arduino Motor Shield:

- **Principle:** They use integrated motor driver chips to control motor direction and speed.
- **Advantages:** Convenient motor control, easy integration with popular development boards.
- **Disadvantages:** Limited to lower-power motors, may consume GPIO pins on the microcontroller.

4.4.6.2 PREFERENCE

Simplicity: The L298N is relatively straightforward to use and understand, making it a good choice for beginners and educational purposes, it has a simple design and basic control interface which makes it accessible for those who are new to electronics and robotics.

Wide Availability: L298N motor drivers are widely available and cost-effective, making them a popular choice for DIY projects. You can find them in many electronics stores and online marketplaces.

Suitable for Small to Medium Projects: The L298N can handle moderate currents and voltages, making it suitable for small to medium-sized projects, such as robotic platforms, small vehicles, and basic automation tasks.

DC and Stepper Motor Compatibility: It can control both DC motors and stepper motors, providing versatility in various applications. This flexibility is advantageous when you need a motor driver that can handle different motor types within the same project.

No Microcontroller Dependency: While it can be controlled by microcontrollers like Arduino or Raspberry Pi, the L298N can also operate without a microcontroller. This standalone capability is useful for simple projects where advanced control is not required.

4.4.6.3 L298N MOTOR DRIVER

The L298N motor driver is a dual H-Bridge motor driver that allows the control of speed and direction of two DC motors consecutively. This module can drive DC motors that have voltages between 5 and 35V, with a peak current ranging up to 2A, which also results in the voltage used at the motor VCC. This module also comprises an onboard 5V regulator which can be either enabled or disabled using a jumper. If the motor supply voltage ranges up to 12V it can enable the 5V regulator and the 5V pin is used as output, for example for powering our Arduino board. But if the motor voltage is greater than 12V we disconnect the jumper because those voltages will cause damage to the onboard 5V regulator.

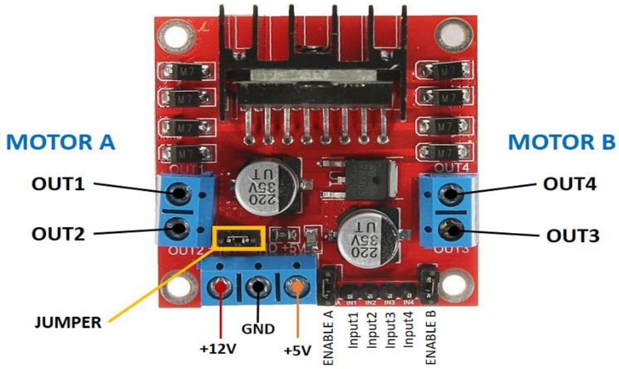


Figure 4.6 L298N Motor Driver

Next are the logic control inputs, enable A and enable B pins which are used for enabling and controlling the speed of the motor. If a jumper is present on this pin, the motor will be enabled and work at maximum speed, and if we remove the jumper, we can connect a PWM input to this pin, and in that way, it controls the speed of the motor. If we connect this pin to a Ground the motor will be disabled. Next, pins are the input 1 and input 2 pins which are used for controlling the rotation direction of motor A, and the inputs 3 and 4 for motor B. Using these pins we control the switches of the H-Bridge inside the L298N IC. If input 1 is LOW and input 2 is HIGH the motor will move forward, and vice versa, if input 1 is HIGH and input 2 is LOW the motor will move backward. In case both inputs are the same, either LOW or HIGH the motor will stop. The same applies for the inputs 3 and 4 and the motor B.

4.4.6.4 L298N MOTOR DRIVER WORKING PRINCIPLE

The L298N motor driver module operates on the H-Bridge technique for controlling the direction of rotation of a DC motor by changing the polarity of its input voltage. An H-Bridge circuit consists of four switching elements, like transistors (BJT or MOSFET), with the motor being at the center forming an H-like configuration. Input IN1, IN2, IN3, and IN4 pins control the switches of the H-Bridge circuit inside the L298N IC. The direction of the current flow can be changed by activating two particular switches at the same time, this way the rotation direction of the motor can be changed as well. This can be done in the following three cases:

- **Case 1:** When S1, S2, S3, and S4 all switches are open then no current flows to motor terminals. So, in this case, the motor is stopped i.e. (not working).

- **Case 2:** When the switches S1 and S4 are closed, the motor left terminal gets a positive (+) voltage and the motor right terminal gets a negative (-) voltage. So, in this case motor starts rotating in a particular direction i.e.(clockwise).
- **Case 3:** When the S2 and S3 switches are closed, the right motor terminal gets a positive (+) voltage and the left motor terminal gets a negative (-) voltage. So, in this case, the motor starts rotating in a particular direction i.e.(anticlockwise).

L298N motor driver module uses the PWM technique to control the speed of rotation of a DC motor. In this technique, the speed of a DC motor can be controlled by changing its input voltage. This is a technique where the average value of the input voltage is adjusted by sending a series of ON-OFF pulses. The average voltage is proportional to the width of the pulses, these pulses are known as the Duty Cycle. If the duty cycle is higher, then the average voltage is applied to the DC motor (High Speed), and the lower the duty cycle, the less the average voltage is applied to the DC motor(Low Speed).

4.4.6.5 L298N MOTOR DRIVER SPECIFICATIONS

- **Driver Model:** L298N 2A
- **Driver Chip**: Double H Bridge L298N
- **Motor Supply Voltage (Maximum)**: 46V
- **Motor Supply Current (Maximum):** 2A
- **Logic Voltage:** 5V
- **Driver Voltage:** 5-35V
- **Driver Current**:2A
- **Logical Current:**0-36mA
- **Maximum Power (W):** 25W
- Current Sense for each motor
- Heatsink for better performance
- Power-On LED indicator

4.4.7. MOTORS

4.4.7.1. COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

Johnson Geared Motor (Original):

- **RPM:** 100
- **Voltage:** 12V DC
- **Torque:** Varies by model
- **Manufacturer:** Johnson Electric

Maxon DC Geared Motor:

Maxon offers a wide range of geared motors that can be customized to your specifications.

- **RPM:** Available in various speeds
- **Voltage:** 12V DC (customizable)
- **Torque:** Customizable
- **Manufacturer:** Maxon Motor

Faulhaber DC Gear Motor:

Faulhaber motors are known for their precision and quality.

- **RPM**: Available in various speeds
- **Voltage:** 12V DC
- **Torque**: Varies by model
- **Manufacturer**: Faulhaber

Pololu DC Gear Motor:

Pololu offers affordable geared motors suitable for robotics.

- **RPM:** Available in various speeds
- **Voltage**: 12V DC
- **Torque**: Varies by model
- **Manufacturer**: Pololu

NEMA 17 Stepper Motor:

Stepper motors provide precise control but don't have a specific RPM; they move in steps.

- **Steps per Revolution**: Typically 200
- **Voltage:** 12V DC (customizable)
- **Holding Torque:** Varies by model

NEMA 23 Stepper Motor:

NEMA 23 stepper motors are larger and provide more torque compared to NEMA 17 motors.

- **Steps per Revolution**: Typically 200
- **Voltage**: 12V DC (customizable)
- **Holding Torque:** Varies by model

Brushless DC Motor (BLDC):

BLDC motors offer high efficiency and precise control.

- **RPM:** Available in various speeds
- **Voltage:** 12V DC (customizable)
- **Torque:** Customizable

Servo Motor:

Servo motors provide precise control and are commonly used in robotics applications.

- **RPM:** Available in various speeds
- **Voltage:** 12V DC (customizable)
- **Torque:** Customizable

4.4.7.2 PREFERENCE

The preference for a Johnson geared motor with the specific specifications of 100 RPM and 12V DC for robotics may not be universal including some as follows:

Compatibility: The Johnson geared motor, continues to be compatible with the model working on which makes it easy for replacements and upgrades.

Proven Reliability: The Johnson geared motor has a track record of reliability in similar robotics applications, it is preferred for its proven performance and longevity.

Availability: Availability of spare parts and replacement motors is crucial for continuous operation. The Johnson motors are readily available and well-stocked, which makes it a convenient choice.

Consistency in Performance: The Johnson geared motor has provided consistent and satisfactory performance for our trolley, it may make sense to continue using it for reliability.

Cost-Effectiveness: Johnson Motors might be competitively priced for the performance it offers.

Easy Integration: The Johnson motor is designed with specific interfaces or mountings that are compatible with our trolley's structure, it can simplify the integration process.

Specific Torque Characteristics: The Johnson geared motor has unique torque characteristics that are ideal for our application, which is a reason for our preference.

4.4.7.3 JOHNSON GEARED MOTOR

The Johnson Geared motor is famous for its compact size and massive torque. The motor comes with a metal gearbox and off-centered shaft, also shaft has a metal bushing for wear resistance. Johnson Electric is known for producing reliable motors, making this motor suitable for applications where consistent and long-term performance is crucial. The geared design allows for precise control over the motor's speed and motion, making it a good choice for robotics where accuracy is important.

Figure 4.7 Johnson Geared Motor

Operating at 12V DC makes it compatible with a wide range of power sources and control systems commonly used in robotics. Geared motors are often designed to be compact, which can be advantageous for applications with limited space. These motors find their applications in robotics, automation, and automotive systems. This type of motor is suitable for robotics applications where you need a reliable, low-voltage motor with a specific speed requirement (100 RPM) and the ability to control motion precisely.

4.4.7.4. JOHNSON GEARED MOTOR WORKING PRINCIPLE

A Johnson Geared Motor is a type of electric motor that consists of a gearbox to control the speed and torque of the motor's output shaft. At the core of the Geared Motor is an electric motor, which can be either an AC motor or a DC motor. The choice of motor type depends on the specific application's requirements. The gearbox is an important component of a Johnson Geared Motor. It consists of a set of gears with different sizes and configurations. The gearbox connects to the motor's output shaft and the load to be driven. The primary use of the gearbox is to alter the speed and torque of the output shaft. It accomplishes this by using various gear ratios to achieve the desired reduction or increase in speed and torque. If the application requires higher torque and lower speed, the gearbox provides speed reduction. Conversely, if a higher speed with less torque is needed, the gearbox increases the speed. The output shaft of the geared motor is where the mechanical work is delivered. The speed and torque of this shaft are determined by the configuration of the gearbox and the control settings applied to the motor.

4.4.7.5. JOHNSON GEARED MOTOR SPECIFICATIONS

- **Operating Voltage (VDC):** 6~18
- **Nominal Voltage (V):** 12
- **Rated Base Motor RPM:** 18000
- **Gear Material:** Metal
- **Rated Speed (RPM):** 100
- **Stall Torque (N-cm):** 235
- **Rated Power (W):** 8
- **Load Current Max (mA):** 900
- **Shaft Diameter (mm):** 6
- **Shaft Length (mm):** 30

- **Gearbox Diameter (mm):** 37
- **Motor Diameter(mm):** 27
- **Motor Length (mm):** 64
- **Weight (gm):** 177
- **Operating Temperature (°C):** -30 to 60

4.4.8 BATTERY FOR POWER SUPPLY

4.4.8.1 COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

Valve Regulated Lead-Acid (VRLA) Battery: VRLA batteries, including Absorbent Glass Mat (AGM) and Gel cell batteries, are maintenance-free and sealed lead-acid batteries. They are well-suited for applications like uninterruptible power supplies (UPS), emergency lighting, and some portable devices.

Lithium-Ion (Li-ion) Battery: These batteries are known for their high energy density, lightweight, and long cycle life. They are commonly used in portable electronic devices, electric vehicles (EVs), and smart trolleys. They offer a good balance between energy capacity and weight, making them ideal for mobile applications.

Lithium Iron Phosphate Battery: LiFePO4 batteries are a subset of lithium-ion batteries with specific advantages, including a longer lifespan, increased safety, and stable performance.

Nickel-Metal Hydride Battery: NiMH batteries are rechargeable and offer a good compromise between capacity and cost. They are commonly used in cordless phones, power tools, and portable electronics they are more environment friendly.

Alkaline Battery: Alkaline batteries are non-rechargeable and are widely available in various sizes (e.g., AA, AAA, C, D). They are suitable for low-drain devices like remote controls, flashlights, and clocks.

Sealed Lead-Acid (SLA) Battery: These batteries are similar to VRLA batteries but often used in larger, high-capacity applications, such as emergency backup systems, electric wheelchairs, and larger uninterruptible power supplies.

Valve Regulated Lead-Acid (VRLA) Battery:

- **Principle:** VRLA batteries use lead dioxide and sponge lead for the positive and negative plates, sulfuric acid as the electrolyte, and a valve-regulated design to recombine hydrogen and oxygen for maintenance-free operation.
- **Advantages:** Reliable and cost-effective, maintenance-free.
- **Disadvantages:** Bulky, limited cycle life.

Lithium-Ion (Li-ion) Battery:

- **Principle:** Li-ion batteries use lithium cobalt oxide or other lithium compounds as the cathode and carbon as the anode to create a voltage potential between them.
- **Advantages:** Lightweight, long cycle life.
- **Disadvantages:** More expensive, environmental concerns for disposal.

Lithium Iron Phosphate (LiFePO4) Battery:

- **Principle:** LiFePO4 batteries use lithium iron phosphate as the cathode material, offering stability and longer cycle life.
- **Advantages:** Long cycle life and durability.
- **Disadvantages:** Slightly heavier and bulkier.

Nickel-Metal Hydride (NiMH) Battery:

- **Principle:** NiMH batteries use a nickel oxide-hydroxide cathode and a hydrogen-absorbing alloy anode to store energy through reversible electrochemical reactions.
- **Advantages:** Good balance between capacity and cost.
- **Disadvantages:** Memory effect (partial discharge) if not properly managed.

Alkaline Battery:

- **Principle:** Alkaline batteries use zinc as the anode, manganese dioxide as the cathode, and an alkaline electrolyte to generate electricity through chemical reactions.
- **Advantages:** Widely available and affordable, long shelf life.
- **Disadvantages**: Non-rechargeable.

Sealed Lead-Acid (SLA) Battery:

- **Principle:** SLA batteries are similar to VRLA batteries and use lead dioxide and sponge lead plates with sulfuric acid as the electrolyte.
- **Advantages:** Cost-effective,well-established technology.
- **Disadvantages:** Heavy and bulky.

4.4.8.2 PREFERENCE

Here are some reasons the Homelite 5G VRLA UPS battery is preferred:

Maintenance-Free Operation: VRLA (Valve Regulated Lead-Acid) batteries, including the Homelite 5G, are known for their maintenance-free operation. They are sealed and designed to be hassle-free, making them a practical choice for applications where regular maintenance is impractical or not preferred.

Reliability: VRLA batteries have a reputation for reliability and consistent performance. They are commonly used in critical backup power systems, such as uninterruptible power supplies (UPS).

Cost-Effectiveness: VRLA batteries are often more cost-effective than some alternative options.

Proven Technology: Lead-acid batteries, including VRLA types, have been used for decades and are a well-established technology. They have a track record of performance in various applications, including those that require continuous, long-term operation.

Ease of Sourcing: VRLA batteries are widely available, making it easy to source replacements or additional batteries when needed.

Widespread Compatibility: VRLA batteries like the Homelite 5G are available in various sizes and voltage ratings, making them compatible with a wide range of equipment and power requirement.

4.4.8.3 HOME LITE 5G VRLA UPS BATTERY

A VRLA UPS battery is a sealed lead-acid battery designed for uninterruptible power supply (UPS) systems and backup power applications. Their sealed design prevents the escape of gases and eliminates the need for regular maintenance, such as adding water which makes them "maintenance-free" batteries. These batteries come in various voltage ratings, with 12V being a common configuration for use in many UPS systems. These batteries are used to provide backup power to critical equipment and systems during power outages. They are commonly employed in settings where continuous power supply is essential to prevent data loss, protect sensitive equipment, or ensure the smooth operation of important functions. VRLA UPS batteries are known for their reliability and consistent performance. These batteries are designed to be compatible with a variety of UPS systems and can be easily integrated into existing power backup solutions.

4.4.8.4 HOME LITE 5G VRLA UPS BATTERY WORKING PRINCIPLE

The Homelite 5G VRLA (Valve Regulated Lead-Acid) UPS (Uninterruptible Power Supply) battery is a type of sealed lead-acid battery that operates on the principles of lead-acid battery chemistry. It consists of a lead dioxide (PbO2) positive plate, a sponge lead (Pb) negative plate, and a sulfuric acid (H2SO4) electrolyte. These components are enclosed in a sealed, maintenance-free design, which is a characteristic feature of VRLA batteries. The "VRLA" in the name stands for "Valve Regulated Lead-Acid." VRLA batteries, including the Homelite 5G, incorporate a valve-regulated design that controls the internal pressure and prevents the release of gases during normal operation. This sealed design eliminates the need for periodic maintenance, such as adding water to the cells, which is typical for traditional flooded lead-acid batteries. The primary purpose of the Homelite 5G VRLA UPS battery is to provide reliable backup power. The battery stores electrical energy and, when needed, delivers it to the connected load to maintain power continuity during outages.

Figure 4.8 Homelite 5G VRLA UPS Battery

4.4.8.5 HOME LITE 5G VRLA UPS BATTERY SPECIFICATIONS

- **Usage:** Electric Power
- **Discharge rate:** High Discharge rate
- **Rechargeable:** Chargeable
- **Electrolyte:** Acid
- **Separator:** AGM
- **Lead time:** 15-20 days
- **Capacity(Ah):** 7.5
- **Type:** Lead-acid batteries
- **Nominal Voltage:** 12V
- **Shape:** Rectangle
- **Specifications:** 151*64*94*100 mm

4.4.10 WHEELS

4.4.10.1 PREFERENCE

Rubber-type wheels are chosen for our smart-serving IT-based trolley as they are designed to provide durability, optimal performance, and noise reduction in a variety of room settings. These wheels play a crucial role in ensuring smooth and efficient mobility for the trolley, which may be used to transport food items. Here are some factors of the wheels which made us prefer them:

High-Quality Rubber Composition: The wheels are made up of premium quality rubber compound that holds the capacity of excellent grip, shock absorption, and resilience. This rubber composition ensures smooth and quiet movement while minimizing vibrations.

No Marking and Tread Pattern: Rubber-type wheels are often non-marking; they won't leave scuff marks or damage the floor surface. The tread pattern on the rubber wheels is designed to provide superior traction, even on smooth surfaces. This ensures stability and prevents slippage when the trolley is in motion.

Load Capacity: These wheels are engineered to support the specific load capacity of the trolley, which can vary depending on the intended use. These wheels hold the capacity to work with heavy deliverables with stability.

Smooth and Quiet Operation: Rubber-type wheels are known for their silent operation. They absorb shocks and vibrations, making them ideal for server room environments where noise and vibrations can be disruptive to equipment.

Durability: The composition of these wheels provides resistance to wear and tear, ensuring a long service life, even under constant use. This durability is essential to maintain the trolley's reliability and reduce maintenance costs.

Temperature Resistance: The rubber wheels are often designed to withstand a wide range of temperatures. This is important, especially in server rooms, where temperature control is crucial for equipment performance.

Easy Maintenance: Rubber wheels are easy to maintain and clean, as they resist the accumulation of debris and can be quickly wiped clean to ensure continued smooth operation.

Braking System Compatibility: These wheels also be designed to work in conjunction with a braking system, which is essential for securely locking the trolley in place when needed.

4.4.9.3 EASYMECH HEAVY DUTY WHEELS

The EasyMech Heavy Duty(HD) Disc Wheel 100mm Dia (Gray) comes with a high-quality silicon rubber grip to give you excellent traction when needed most.

- 100% branded Robotic wheels.
- It features high-quality material.
- Each wheel is tested for loads up to 20kg.
- It comes with a Silicon rubber grip for excellent traction.

Figure 4.9 EasyMech Heavy Duty Wheels 100mm

4.4.9.4 EASYMECH HEAVY DUTY WHEELS SPECIFICATION

Color: Grey

Internal Diameter (ID) (mm): 11

Load Capacity (Kg/Wheel): 20

Tyre Grip Material: Silicon Rubber

Weight (gm): 216/Wheel

Wheel Body Material: ABS + 20% Glass Fiber

Wheel Diameter (mm): 100

Width (mm): 26

Shipment Weight: 0.25 kg

Shipment Dimensions: 11 × 11 × 5 cm

4.4.9 MOBILE APPLICATION

4.4.9.1 COMPARISONS AMONG THE VARIOUS AVAILABLE OPTIONS

Blynk: Blynk is an IoT platform designed for rapid IoT development and prototyping. It offers a user-friendly mobile app and a cloud-based service that allows you to easily create IoT projects and control devices using a smartphone or tablet. Blynk supports a wide range of microcontrollers and hardware, making it a popular choice for makers and developers looking for a quick and simple way to build IoT applications.

AWS IoT Core: Amazon Web Services offers IoT Core, a cloud-based platform for connecting and managing IoT devices. It provides secure, scalable, and efficient communication between IoT devices and the cloud, making it suitable for a wide range of applications.

Google Cloud IoT Core: Google's IoT Core allows you to securely connect and manage IoT devices on Google Cloud. It provides device registration, management, and real-time data ingestion services for IoT applications.

PlatformIO: An open-source IoT platform that supports various development boards and platforms. It provides a unified development environment for programming and managing IoT devices.

Cayenne: Cayenne is a drag-and-drop IoT project builder that simplifies the process of creating IoT solutions without extensive coding. It offers a user-friendly interface for creating IoT applications and monitoring devices.

Microsoft Azure IoT Hub: Part of the Microsoft Azure cloud platform, IoT Hub allows you to connect, monitor, and manage IoT devices. It offers robust security features and cloud integration for IoT applications.

Eclipse IoT: Eclipse IoT is a set of open-source projects that can be used to create IoT solutions. It offers a range of tools, frameworks, and protocols for IoT development and device management.

ThingsBoard: ThingsBoard is an open-source IoT platform for data visualization and device management. It allows you to monitor and control IoT devices and collect data for analysis.

MQTT (Message Queuing Telemetry Transport): MQTT is a lightweight messaging protocol used for communication between IoT devices and a broker. While not a full IoT platform, it's a critical protocol often used in conjunction with other platforms for data exchange between devices and the cloud.

4.4.9.2 PREFERENCE

The preference for using Blynk as an IoT platform for our smart serving trolley depends on some potential reasons which are as follows:

User-Friendly Interface: Blynk is often known as a user-friendly mobile app and a drag-and-drop interface. This simplicity gives it an edge, especially when we want to create a user-friendly control interface for our smart serving trolley that can be easily operated by staff.

Rapid Prototyping: Blynk is designed for rapid prototyping and development, making it an excellent choice for quickly getting a smart trolley project up and running. It's well-suited for developers who want to build a functional prototype with minimal effort.

Mobile Control: Blynk's mobile app allows you to control IoT devices from a smartphone or tablet. This is ideal for a serving trolley since it enables easy and convenient control, such as adjusting settings, monitoring inventory, or interacting with customers.

Device Compatibility: Blynk supports a wide range of microcontrollers and hardware platforms, which means having flexibility in choosing the hardware components for our trolley.

Community Support: Blynk has an active and supportive community of users and developers. This adds value for troubleshooting issues and finding solutions to common challenges in our project.

Cost-Efficiency: Blynk offers a free tier with some limitations, making it cost-effective for small-scale or prototype projects.

4.4.9.3 BLYNK APP

Blynk is a comprehensive IoT platform for iOS or Android that enables the prototyping, deployment, and remote management of connected electronic devices at any scale i.e. to control Arduino, Raspberry Pi, and NodeMCU via the Internet. This application is used to create a graphical interface or human-machine interface (HMI) by compiling and providing the appropriate address on the available widgets.

Whether it's personal IoT projects or commercially connected products in the millions, Blynk empowers users to connect their hardware to the cloud and create iOS, Android, and web applications, analyze real-time and historical data from devices, remotely control them from anywhere, receive important notifications, it can display sensor data, it can store data, visualize it.

The major components of the platform are as follows:

Blynk.Console: It is a feature-rich web application catering to different types of users. It includes the configuration of connected devices on the platform, including application settings. Device, data, user, organization, and location management.

Blynk App: It can create amazing interfaces for projects using various widgets that are provided as well as provide automation of connected device operations. The app is easily downloadable which makes it ready for end users. It also offers the facilities to customize the app according to our needs i.e. company logo, app icon, theme, and colors, and publish it on the App Store and Google Play under your company's name.

Blynk Server: It is responsible for all the communications between the smartphone and hardware. The Blynk Cloud can be used to run on a private Blynk server locally. It's open-source, can easily handle thousands of devices, and can even be launched on a Raspberry Pi.

Blynk Library: It is a user-friendly and portable C++ library that comes pre-configured to work with hundreds of development boards. It implements a streaming connection protocol, allowing for low-latency and bi-directional communication.

Blynk.Inject A micro-service that facilitates claiming device ownership by users and organizations provisioning devices with WiFi credentials so they can connect to the end-user WiFi networks.

4.5 SYSTEM ARCHITECTURE

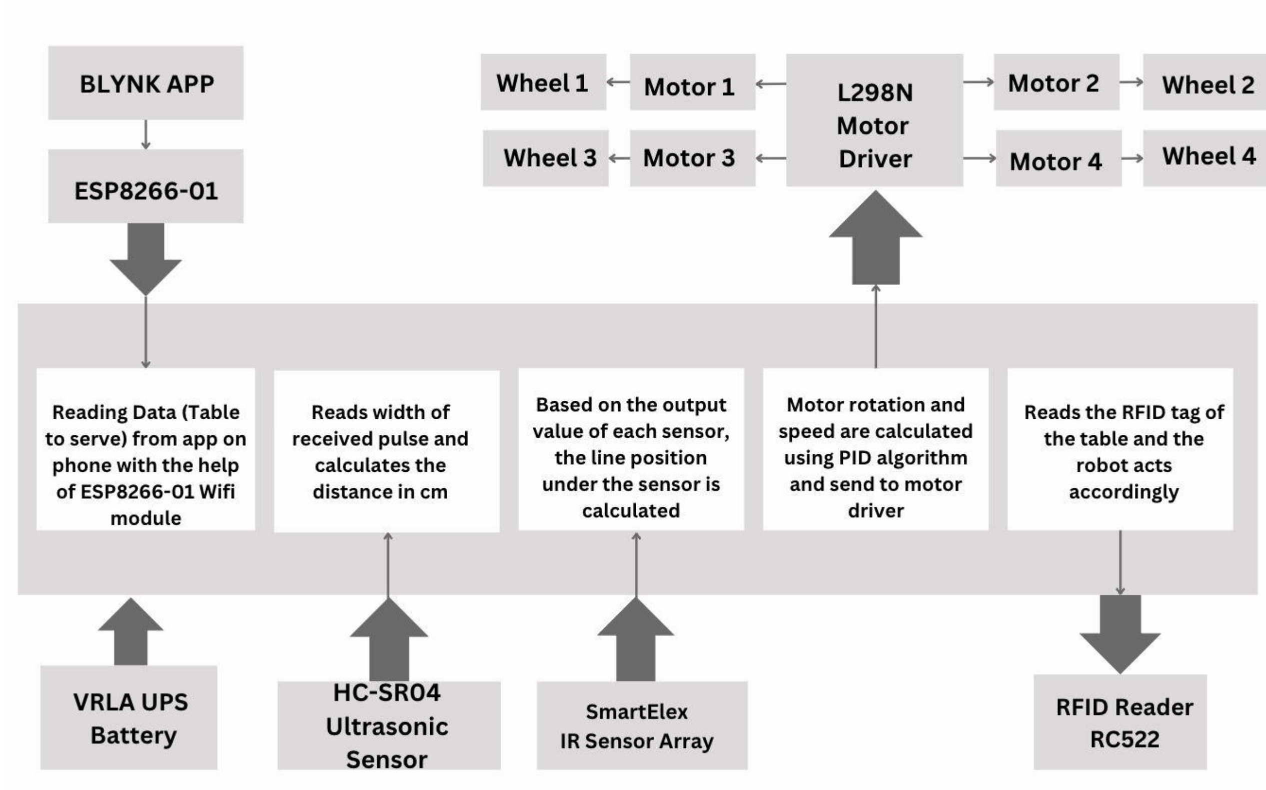


Figure No. 4.10 Block Diagram

4.6 ANALYSIS

4.6.1 COMPONENT FUNCTIONALITY AND LOGIC

- The Arduino microcontroller takes in information from a variety of sources and processes it according to the logic it was designed to follow.
- The IR sensor array picks up the floor line and feeds that information back to the Arduino, allowing for line tracking.
- The robot's ultrasonic sensor uses distance measurements to identify potential hazards.
- ESP8266 WiFi Module: Connects wirelessly to the diner's phone and retrieves the reservation's table number.
- The RFID reader may then match the received table number with the RFID tag's ID to determine which table it belongs to.
- The L298N Motor Driver is a motor controller that takes direction signals from an Arduino and drives the motors accordingly.
- The Arduino Microcontroller is the hub of the system, taking data from several sensors and directing the actions of the other blocks.
- The Arduino receives guidance for line following from the IR Sensor Array and information about the presence of obstacles from the Ultrasonic Sensor.
- The Arduino communicates with the ESP8266 WiFi Module to get the table number from the phone and with the RFID Reader to compare the table number for identification.
- The Arduino controls the motion and placement of the L298N Motor Driver.

4.6.2 SYSTEM INTEGRATION

- The Arduino is the central part that analyzes data, lines up features, and exerts command over the blocks.
- The IR Sensor Array and the Ultrasonic Sensor feed the information for processing to the Arduino.
- It receives the table number from the ESP8266 WiFi Module and the RFID Reader checks the number and finds the right table.
- Based on information collected from the robot's line follower and obstacle detector, the Arduino directs the L298N Motor Driver to move the robot forward.
- Arduino helps ultrasonic sensors to optimize their range and accuracy to detect obstacles.

4.7 CIRCUIT DIAGRAM

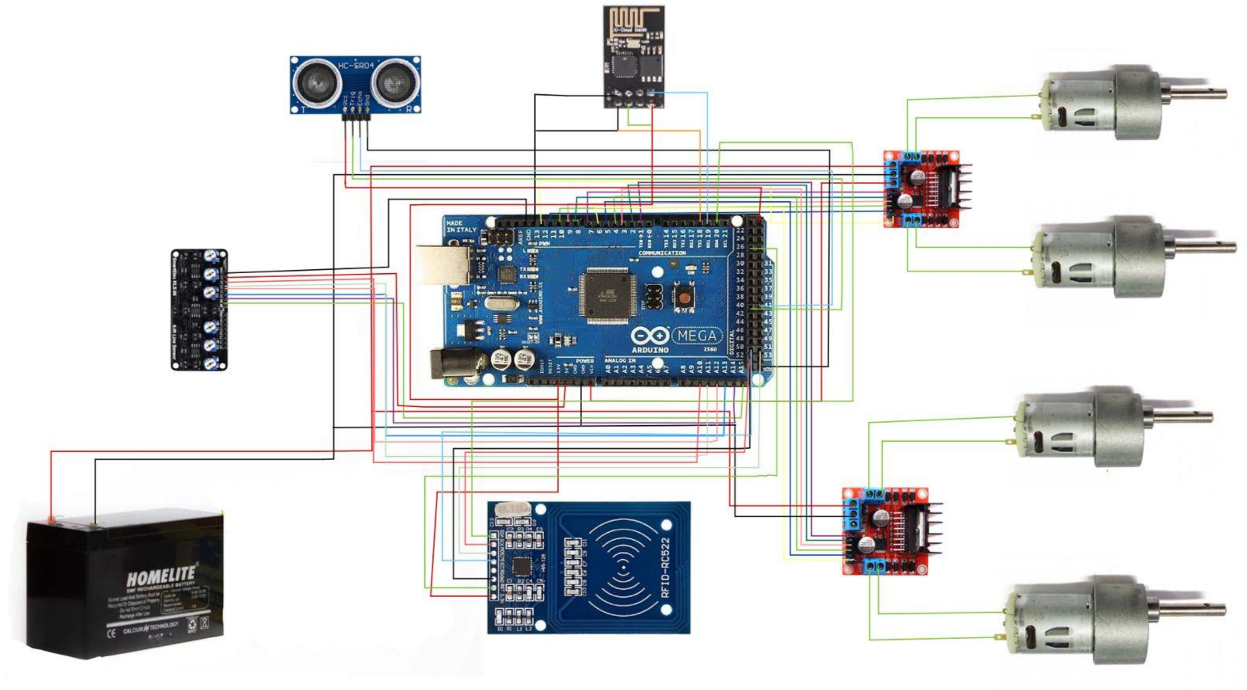
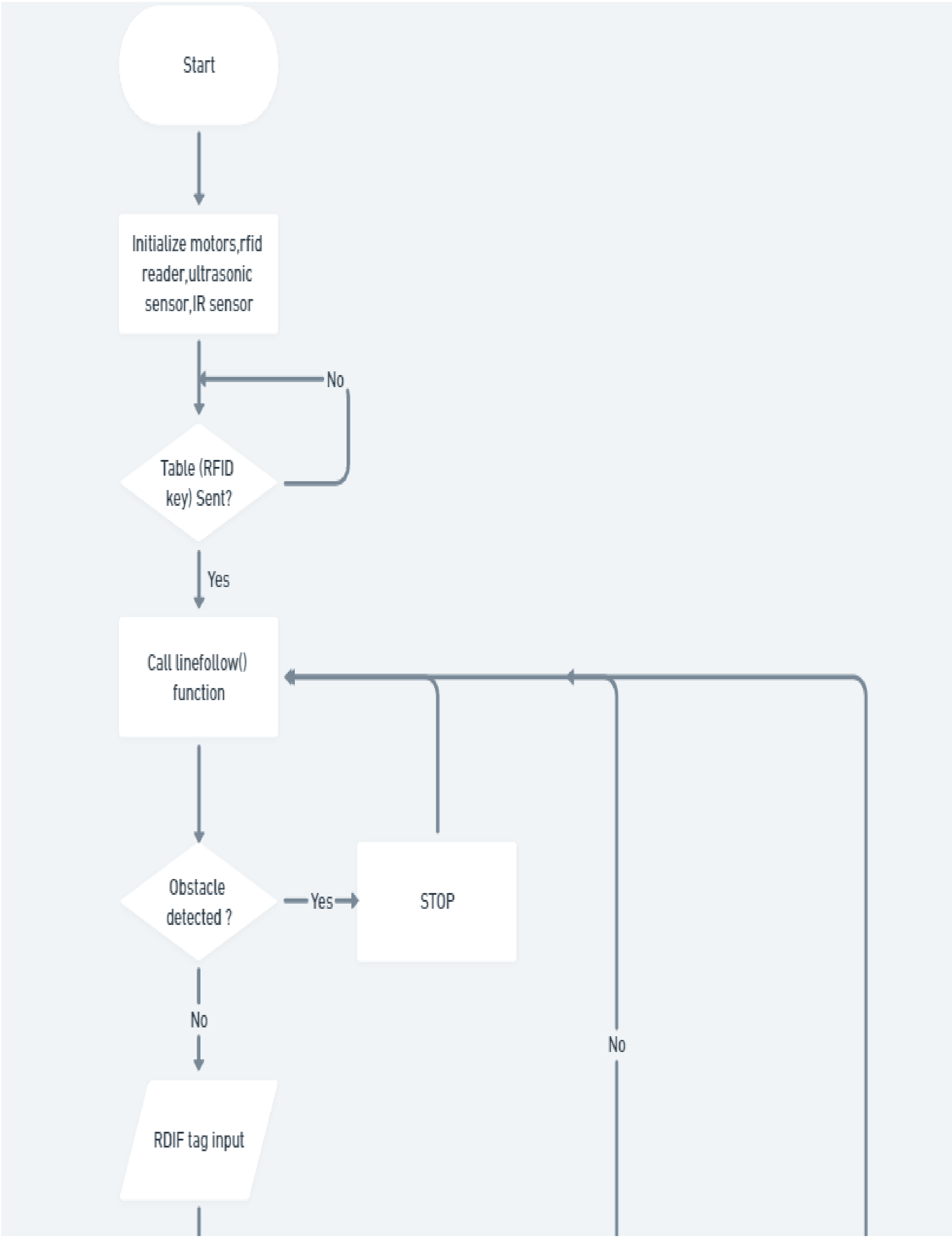
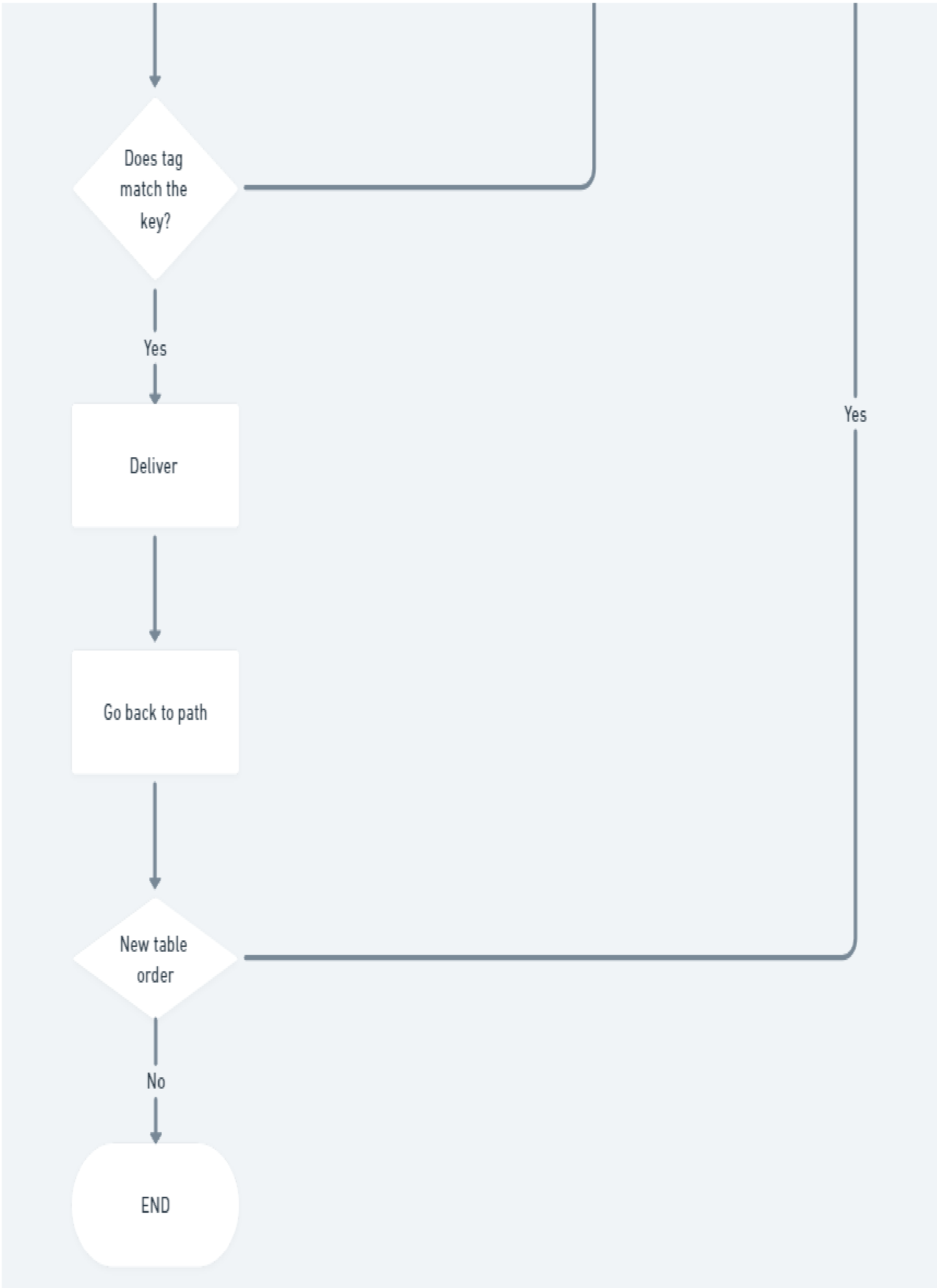


Figure No. 4.11 Circuit Diagram

4.8 FLOWCHART OF CODE




Does tag match the key?
Yes
Deliver
Go back to path
New table order
Yes
No
END

4.9 CODE

```
#include<Servo.h>
#include <NewPing.h>
#include <SPI.h>
#include <MFRC522.h>
#define BLYNK_TEMPLATE_ID "TMPL3YxsiHHRp"
#define BLYNK_TEMPLATE_NAME "capstone"
#define BLYNK_AUTH_TOKEN "mVy15bEwRTkl2ojDW8d83h7-zQJVKoES"

/* Comment this out to disable prints and save space */
#define BLYNK_PRINT Serial


#include <ESP8266_Lib.h>
#include <BlynkSimpleShieldEsp8266.h>
//Motor1
#define enA 12
#define in1 10
#define in2 11
//Motor2
#define enB 1
#define in3 2
#define in4 3
//Motor3
#define enC 7
#define in5 9
#define in6 8
//Motor4
#define enD 6
#define in7 5
#define in8 4

//////////////////////ULTRASONIC//////////////////////////////
#define TRIG_PIN A9
#define ECHO_PIN A8
#define MAX_DISTANCE 250
NewPing sonar(TRIG_PIN, ECHO_PIN, MAX_DISTANCE);

//**********6 Channel IR Sensor Connection**********//
#define ir1 A10
```

```
#define ir2 A11
#define ir3 A12
#define ir4 A13
#define ir5 A14
#define ir6 A15
//**********************************************//

///////////////////////////////////////////////
/////////////////RFID////////////./////////////// 
#define SS_PIN 20
#define RST_PIN 24
MFRC522 mfrc522(SS_PIN, RST_PIN);
// Create MFRC522 instance.
/////////////////////////////////////

//distance ultrasonic
int distance=150;

// Your WiFi credentials.
// Set password to "" for open networks.
char ssid[] = "Malavika";
char pass[] = "Malu_1967";

// Hardware Serial on Mega, Leonardo, Micro...
#define EspSerial Serial1

// or Software Serial on Uno, Nano...
//#include <SoftwareSerial.h>
//SoftwareSerial EspSerial(2, 3); // RX, TX

// Your ESP8266 baud rate:
#define ESP8266_BAUD 38400

ESP8266 wifi(&EspSerial);

// This function will be called every time Slider Widget
//In the Blynk app write values to the Virtual Pin V1
BLYNK_WRITE(V1)
{
  int pinValue = param.asInt(); // assigning incoming value from pin V1 to a variable
```

```
  // process received value
}
  switch(pinValue)
  {
      case 1:String rfidkey="D6 EX 7E 07";
             break;

      case 2:String rfidkey="A6 FX 6F 09";
             break;

      case 3:String rfidkey="D2 EF 9F 03";
             break;

      case 4:String rfidkey="C6 FE 7G 05";
             break;

      default:String rfidkey="B3 FE 8E 08";
              break;
  }
void setup() {
  pinMode(enA, OUTPUT);
  pinMode(enB, OUTPUT);
  pinMode(enC, OUTPUT);
  pinMode(enD, OUTPUT);
  pinMode(in1, OUTPUT);
  pinMode(in2, OUTPUT);
  pinMode(in3, OUTPUT);
  pinMode(in4, OUTPUT);
  pinMode(in5, OUTPUT);
  pinMode(in6, OUTPUT);
  pinMode(in7, OUTPUT);
  pinMode(in8, OUTPUT);

  //IR ARRAY
  pinMode(ir1, INPUT);
  pinMode(ir2, INPUT);
  pinMode(ir3, INPUT);
  pinMode(ir4, INPUT);
  pinMode(ir5, INPUT);
  pinMode(ir6, INPUT);
  //All motors are off
```

```
  digitalWrite(in1, LOW);
  digitalWrite(in2, LOW);
  digitalWrite(in3, LOW);
  digitalWrite(in4, LOW);
  digitalWrite(in5, LOW);
  digitalWrite(in6, LOW);
  digitalWrite(in7, LOW);
  digitalWrite(in8, LOW);


  //////////////RFID//////////
  Serial.begin(9600);   // Initiate a serial communication
  SPI.begin();      // Initiate  SPI bus
  mfrc522.PCD_Init();   // Initiate MFRC522
 Serial.println("Approximate your card to the reader...");
  Serial.println();
}

void loop() {

  distance=readping();
 // Serial.print(distance);
  Blynk.run();

  linefollow();
  // put your main code here, to run repeatedly:


}
void linefollow()
{


    int s1 = digitalRead(ir1);
    int s2 = digitalRead(ir2);
    int s3 = digitalRead(ir3);
    int s4 = digitalRead(ir4);
    int s5 = digitalRead(ir5);
    int s6=  digitalRead(ir6);
    distance=readping();
    Serial.println(distance);
```

```
    readRFID();
    if(distance>0 && distance<50)
    {
      movestop();
    }
    else
    {
      if((s1 ==0)&&(s2 ==0)&&(s3 ==0)&&(s4 ==0)&&(s5 ==0)&&(s6 ==0))
      {
        forward();

      }
      else if((s2 ==0)&&(s3 ==0)&&(s4 ==0)&&(s5 ==0))
      {
        forward();

      }
      else if((s1 ==1)&&(s6 ==0))
      {
        right();

      }
      else if((s1 ==0)&&(s6 ==1))
      {
        left();

      }
      else
      {
        movestop();

      }
    }



}
void forward()
{
  //Speed
  analogWrite(enA, 255);
```

```
  analogWrite(enB, 255);
  analogWrite(enC, 255);
  analogWrite(enD, 255);
  //Direction
  digitalWrite(in1, HIGH);
  digitalWrite(in2, LOW);
  digitalWrite(in3, HIGH);
  digitalWrite(in4, LOW);
  delay(500);
  digitalWrite(in5, HIGH);
  digitalWrite(in6, LOW);
  digitalWrite(in7, HIGH);
  digitalWrite(in8, LOW);
  delay(500);

}
void movestop()
{
    digitalWrite(in1,LOW);
    digitalWrite(in2,LOW);
    digitalWrite(in3,LOW);
    digitalWrite(in4,LOW);
    digitalWrite(in5,LOW);
    digitalWrite(in6,LOW);
    digitalWrite(in7,LOW);
    digitalWrite(in8,LOW);
}
void backward()
{
    //Speed
  analogWrite(enA, 255);
  analogWrite(enB, 255);
  analogWrite(enC, 255);
  analogWrite(enD, 255);
  //Direction
  digitalWrite(in1, LOW);
  digitalWrite(in2, HIGH);
  digitalWrite(in3, LOW);
  digitalWrite(in4, HIGH);
  delay(2000);
  digitalWrite(in5, LOW);
```

```
  digitalWrite(in6, HIGH);
  digitalWrite(in7, LOW);
  digitalWrite(in8, HIGH);
  delay(2000);

}
void left()
{
    movestop();
    analogWrite(enB, 255);
    digitalWrite(in3, HIGH);
    digitalWrite(in4, LOW);
    delay(2000);

}
void right()
{
    movestop();
    analogWrite(enA, 255);
    digitalWrite(in1, HIGH);
    digitalWrite(in2, LOW);
    delay(2000);
}

int readping()
{
  delay(50);
  int cm = sonar.ping_cm();
  delay(50);
  return cm;
}
void readRFID()
{ if ( ! mfrc522.PICC_IsNewCardPresent())
  {
    return;
  }
  // Select one of the cards
  if ( ! mfrc522.PICC_ReadCardSerial())
  {
    return;
  }
```

```
  //Show UID on serial monitor
  Serial.print("UID tag :");
  String content= "";
  byte letter;
  for (byte i = 0; i < mfrc522.uid.size; i++)
  {
     Serial.print(mfrc522.uid.uidByte[i] < 0x10 ? " 0" : " ");
     Serial.print(mfrc522.uid.uidByte[i], HEX);
     content.concat(String(mfrc522.uid.uidByte[i] < 0x10 ? " 0" : " "));
     content.concat(String(mfrc522.uid.uidByte[i], HEX));
  }
  Serial.println();
  Serial.print("Message : ");
  content.toUpperCase();

  if (content.substring(1) == rfidkey) //change here the UID of the card/cards that you want to give access
  { Serial.println("Authorized access");
     Serial.println();
    deliver();
  }
  else
  {
    Serial.println(" Access denied");
    Serial.println();

    //delay(3000);

  }
}
void deliver()
{
  turnright();
  movestop();
  forward();
  delay(2000);
  movestop();
  delay(5000);
  uturn();
  movestop();
  forward();
  delay(2000);
```

```
  turnright();
  delay(1000);
}
void turnright()
{
     analogWrite(enA, 255);
  analogWrite(enB, 255);
  analogWrite(enC, 255);
  analogWrite(enD, 255);
  //Direction
  digitalWrite(in1, HIGH);
  digitalWrite(in2, LOW);
  digitalWrite(in3, LOW);
  digitalWrite(in4, HIGH);
  digitalWrite(in5, HIGH);
  digitalWrite(in6, LOW);
  digitalWrite(in7, LOW);
  digitalWrite(in8, HIGH);
  delay(500);
}
void uturn()
{
     analogWrite(enA, 255);
  analogWrite(enB, 255);
  analogWrite(enC, 255);
  analogWrite(enD, 255);
  //Direction
  digitalWrite(in1, HIGH);
  digitalWrite(in2, LOW);
  digitalWrite(in3, LOW);
  digitalWrite(in4, HIGH);
  digitalWrite(in5, HIGH);
  digitalWrite(in6, LOW);
  digitalWrite(in7, LOW);
  digitalWrite(in8, HIGH);
  delay(1000);
}
```

4.10 VERIFICATION AND VALIDATION

- **Simulation:** Use simulation software to model and simulate the behavior of the block diagram. The matching of the block interactions, outputs, and inputs with the desired functionality needs to be checked.
- **Component Testing:** To make sure that every part functions correctly and satisfies the requirements, we have to test each one separately. Examples of these components are the IR Sensor Array, Ultrasonic Sensor, WiFi Module, RFID Reader and L298N Motor Driver.
- **Integrity testing:** Examine how well the blocks communicate and are in sync with one another. Verify the data flow, functionality, communication protocols, and action coordination.
- **Testing in the real world:** Install a physical serving robot prototype and carry out testing in a range of settings. Line following, obstacle detection, WiFi connectivity, RFID tag reading, and **motor control, should all be evaluated.**
- **Functional validation:** It is the process of comparing the serving robot's observable behavior during testing to the functionality that was specified in the project requirements. Make sure that the system achieves the specified goals and that the block diagram appropriately depicts the anticipated behavior.

You may be certain that the block diagram appropriately depicts the desired behavior of the serving robot by carrying out exhaustive testing and validation using these techniques. An enhanced and dependable system design will result from the identification and resolution of any problems or inconsistencies via analysis and testing.

CHAPTER 5 - IMPLEMENTATION AND EXPERIMENTAL RESULT

5.1 HARDWARE RESULTS

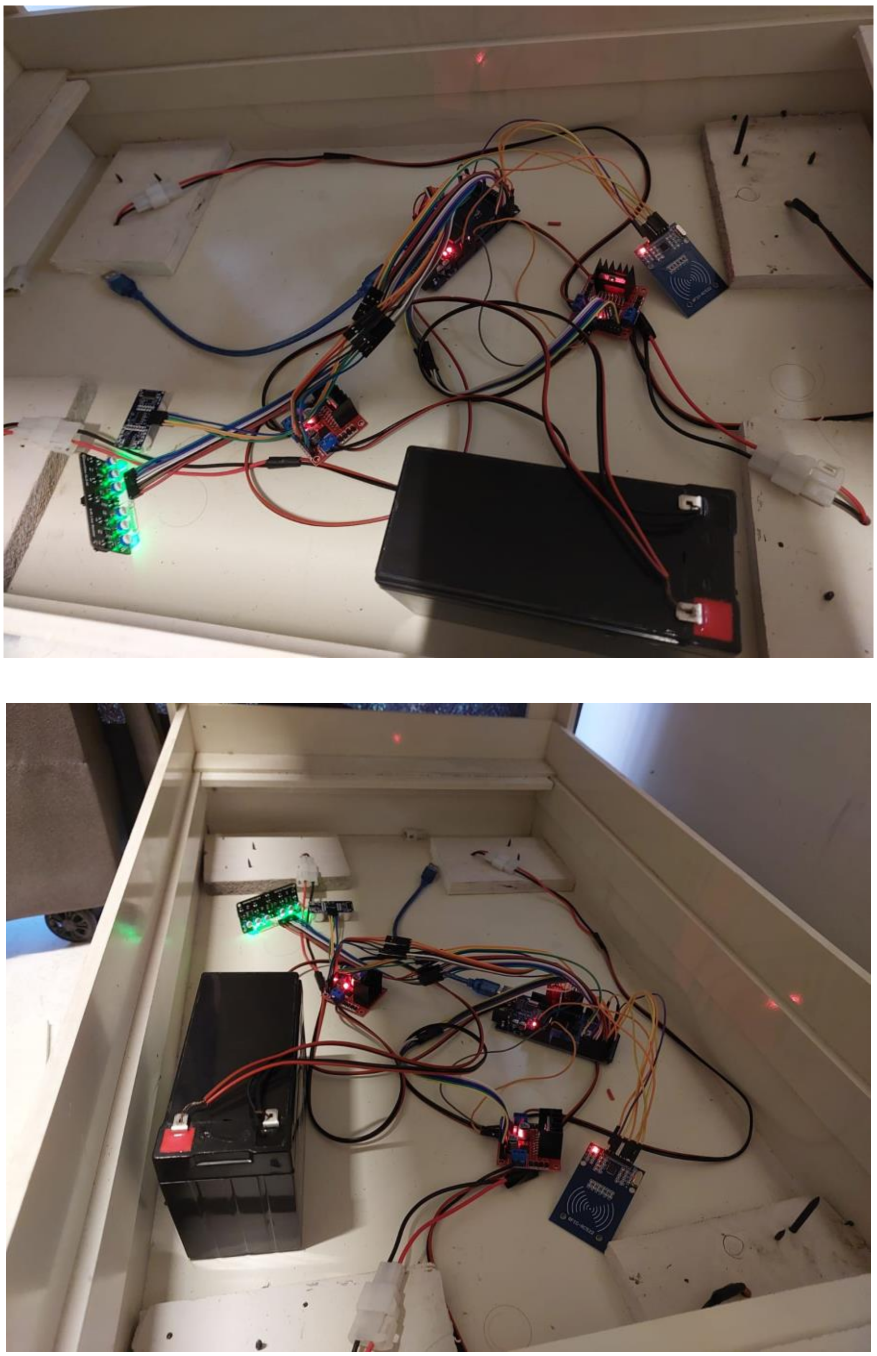


Figure No. 5.1 Circuit of Final Prototype

5.2 STRUCTURE RESULTS

Figure No. 5.2 Structure of Final Prototype

CHAPTER 6 - OUTCOMES AND PROSPECTIVE LEARNING

6.1 OUTCOMES

The outcomes of the serving robots are:

- **Enhanced Efficiency:** By automating repetitive processes, serving robots may dramatically enhance operational efficiency. They may operate without exhaustion, but lowering the time necessary to perform varied tasks and improving production.
- **Improved Customer Experience:** Robots can provide customers with consistent service. They can efficiently interact with them to improve the customer experience. The chance of human error is also minimized thus improving the degree of satisfaction of the customers.
- **Workforce Support:** Serving robots can assist humans by taking over tedious, mundane, and repetitive tasks like taking things from one place to another, allowing them to focus on more complex and meaningful activities. This can help decrease the workload on employees and improve job satisfaction.
- **Safety and Reliability:** The sensors and navigation systems of the robot help it to navigate its environment. The robot can check its environment for obstacles and use its sensors to avoid any accidents in the workplace.
- **Cost Reduction:** Using the serving robot can help reduce labor costs. By automating repetitive tasks there is overall less need for labor and the labor is only needed for complex tasks.
- **Learning and Adaptation:** Serving robots can learn and adapt to their surroundings. Using AI and ML the serving robots can improve themselves through learning and in the end become more efficient and effective.
- **Potential for Innovation:** The development of serving robots opens up new opportunities for innovation and technological advancements. Integrating them with other emerging technologies, such as IoT and AR, can further enhance their capabilities and create novel applications.

Overall, serving robots offer a wide range of benefits, including improved efficiency, enhanced customer experience, workforce support, safety, cost reduction, learning capabilities, and opportunities for innovation. Their deployment in various industries holds the potential to transform how tasks are performed and services are delivered.

6.2 PROSPECTIVE LEARNINGS

- Understanding of IoT principles and concepts – IoT principles and concepts for serving robots involve connectivity and data collection, sensor integration, analysis, cloud computing, automation, and decision-making. This helps the robot to connect to the internet, integrate sensors, and collect and analyze data. It can then be monitored and controlled remotely, using cloud resources, automate tasks, make intelligent decisions, and communicate with other devices using standardized protocols.
- Electronics and circuit design skills – Electronics and circuit design skills on serving robots involve understanding electronic components, designing circuits and PCBs, programming microcontrollers like Arduino, integrating sensors, controlling motors, managing power, and troubleshooting. These skills are important for designing, making, and managing the serving robot.
- Programming skills – Programming skills in C and C++ are essential for serving robots. C/C++ provides low-level control and efficiency and can be used with microcontrollers like Arduino. while Python offers ease of use, a wide range of libraries, and rapid prototyping capabilities. These languages enable sensor integration, control, decision-making, communication, simulation, and visualization in the context of robotic systems.
- Sensor integration and data processing – Sensor integration and data processing are essential for a robot's ability to do tasks efficiently as well as for them to precisely perceive their surroundings and make judgments that will help them complete their jobs successfully.
- Wireless communication configuration and implementation –For serving robots to be capable of connecting wirelessly, transmitting sensor data, receiving instructions, and interacting with external systems, as well as enhancing their capabilities and enabling effective operation in a variety of environments, wireless communication configuration and implementation are essential.
- Problem-solving and troubleshooting abilities – For serving robots to identify faults, self-calibrate, manage failures gracefully, and offer effective assistance for maintenance and recovery, problem-solving and troubleshooting skills are essential. These skills help serving robots function well across a range of operating settings in terms of overall dependability, uptime, and performance.

- Project management skills – For the development and deployment of service robots to be successful, project management expertise is required. Planning and scheduling, team coordination, resource allocation and management, risk management, stakeholder management, quality assurance, and documentation are some of these skills. Serving robot projects are finished on schedule, within budget, and in accordance with stakeholder expectations thanks to effective project management.
- Opportunity for innovation and creativity – The utilization of serving robots offers significant prospects for the advancement of innovation and the cultivation of creativity. Research and development in various domains, including task automation, human-robot interaction, personalization, collaboration, autonomous navigation, multi-robot systems, augmented intelligence, and ethical considerations, offer promising opportunities for scholars and practitioners to explore new frontiers and devise innovative solutions that augment the capabilities and effectiveness of service robots.
- Collaboration and communication skills – Serving robots must have the ability to collaborate and communicate to operate in teams, engage with people, and adapt to a variety of contexts. The aforementioned talents comprise a wide range of elements about the interaction between humans and robots. These include non-verbal communication, cooperation and coordination, context awareness, explainability, multimodal communication, distant communication, and flexibility to user preferences. The enhancement of usability, acceptability, and performance of serving robots in many application areas is achieved via the development and refinement of these abilities.
- Practical application of IoT in robotics and automation – The Internet of Things (IoT) has the potential to play an important role in robotics and automation for service robots in a wide range of real-world contexts. Some instances are as follows: Keeping track of stock, finding one's way around, collaborating with robots, etc.

CHAPTER 7 - PROJECT TIMELINE

7.1 WORK BREAKDOWN

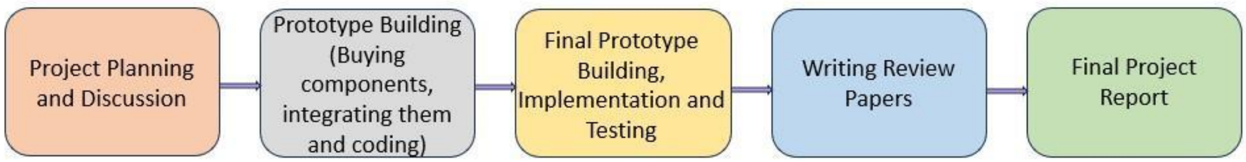


Figure No. 7.1 Work Breakdown

7.2 PROJECT TIMELINE

Mannandeep Sondh (402006011)																															
		Jan			Feb			Mar			Apr			May			Jun			July			Aug			Sept			Oct		
S.No.	Activity	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E
1	Project Planning and Discussion																														
2	Abstract																														
3	Study from Research papers								M						E														M		
4	Prototype Building								S						S														S		
5	Implementation of Final Prototype								T						T														T		
6	Review Paper 1																														
7	Review Paper 2																														
8	Final Report																														

Table No. 7.1 Overall Gantt Chart

7.3 INDIVIDUAL GANTT CHARTS

Malavika Ajay Nair (402006002)																															
		Jan			Feb			Mar			Apr			May			Jun			July			Aug			Sept			Oct		
S.No.	Activity	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E	S	M	E
1	Project Planning and Discussion																														
2	Abstract																														
3	Study from Research papers								M						E														M		
4	Prototype Building								S						S														S		
5	Implementation of Final Prototype								T						T														T		
6	Review Paper 1																														
7	Review Paper 2																														
8	Final Report																														

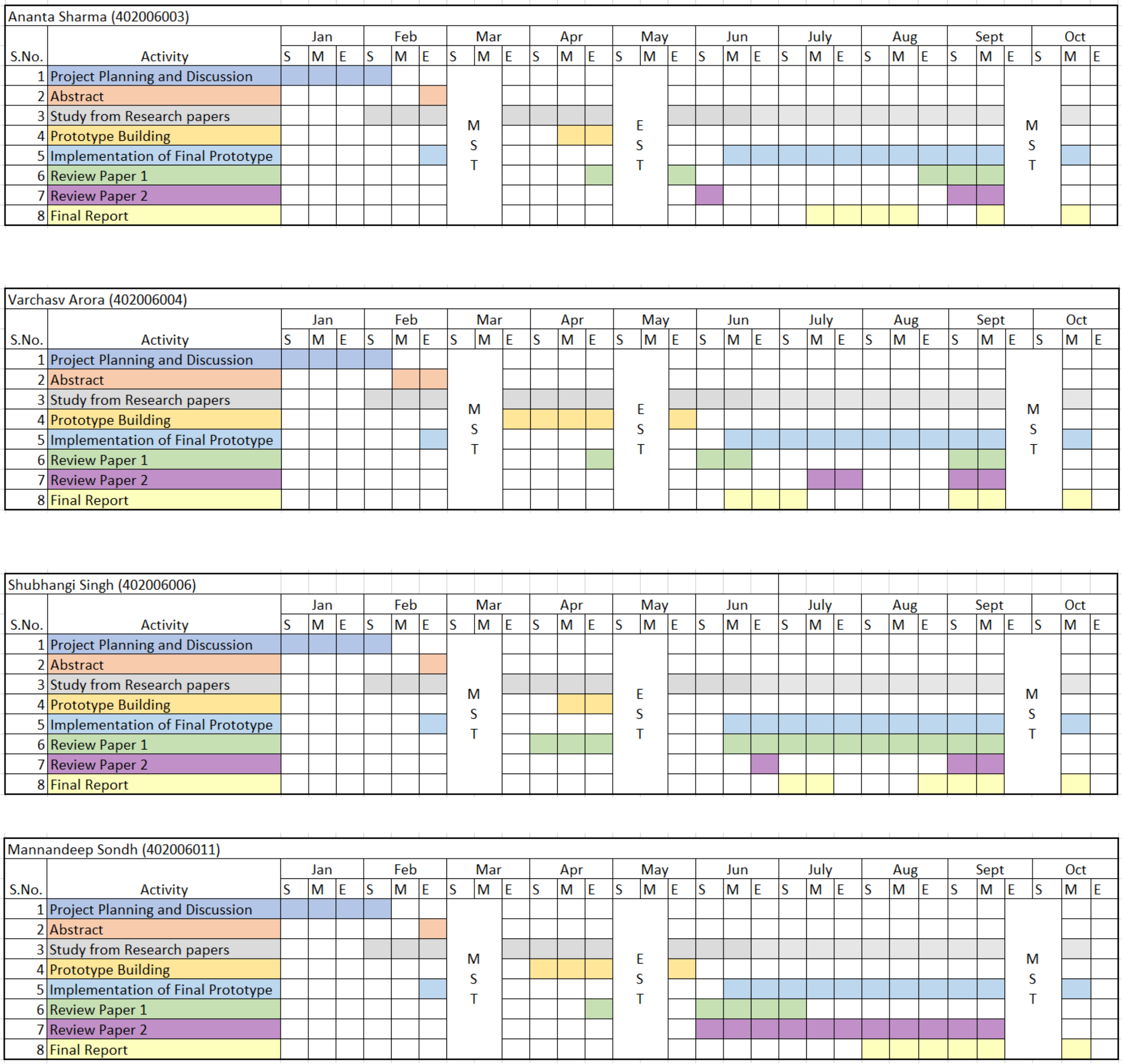


Table No. 7.2 Individual Gantt Charts

CHAPTER 8 - CONCLUSION AND FUTURE WORK

8.1 CONCLUSION

Ultimately, the use of autonomous robotic systems for service delivery has shown great potential in various sectors and environments. With their ability to perform repeated tasks, interact with customers, and navigate complex environments, they have demonstrated their usefulness as useful resources in various fields, such as hospitality, healthcare, and commerce, among others.

There remains great potential to help robots acquire knowledge and improve their performance in several essential areas. Firstly, the advancements in artificial intelligence and machine learning algorithms have the potential to improve robots' understanding and responsiveness to human needs and preferences. It’s about improving communication and understanding by developing natural language processing skills.

Furthermore, robotic systems that can effectively handle unexpected situations and dynamically adapt to changing conditions are becoming more and more in demand. Problem-solving and decision-making abilities of robots can be improved through the use of algorithms relearning, which allows them to navigate effectively in complex and dynamic environments.

8.2 FUTURE WORK

Future work in the field of serving robots encompasses several promising avenues for improvement and expansion, contingent upon the project's existing status and objectives. Key areas of focus include advancing path navigation through the incorporation of advanced sensor technologies and the development of sophisticated navigation algorithms. Object recognition capabilities can be extended to enable the robot to identify and interact with a broader range of objects and items within its operating environment. In cases involving multiple serving robots, research into methods for effective multi-robot coordination in shared environments becomes paramount. The integration of natural language processing (NLP) can enhance the robot's interactivity and usability, allowing it to understand and respond to voice commands or written requests.

The implementation of a smart ordering system can streamline customer interactions by enabling orders through a mobile app or kiosk. Further, there is scope for the improvement of localization and mapping techniques, resulting in more detailed environmental awareness. Autonomous charging mechanisms may be developed to increase operational efficiency, ensuring the robot can independently return to a charging station as needed. Continuous user feedback can guide user interface enhancements to deliver a more enjoyable and seamless customer experience. Additionally, the inclusion of remote monitoring and control features, robust safety mechanisms, and energy-efficient design practices is essential to guarantee safe and reliable operation. Future work also encompasses the scaling of deployment in diverse real-world scenarios, followed by data analytics to glean insights into performance and operational efficiency. The exploration of integration with the Internet of Things (IoT) devices and the pursuit of market expansion opportunities are further areas for consideration, promising to enhance the capabilities and reach of serving robots across industries and global markets. In summary, future endeavors in serving robot projects revolve around perpetual refinement and innovation, aiming to create advanced, efficient, and user-friendly systems that align with the evolving demands of businesses and customers.

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