Intelligent RFID-Based Autonomous Indoor Logistics Robot Using Decision Tree Path Navigation System

Dr. S. Prabu[1], NavinKumar M[2], Nitheshkumar R[3], Paranitharan K[4], Ravishankar S[5]
[1]*M.E., Ph.D HOD, Department of ECE, Mahendra Institute of Engineering and Technology, Mallasamudram, Namakkal, Tamil Nadu, India-637503.*
[2,3,4,5] *UG Students, Department of ECE, Mahendra Institute of Engineering and Technology, Mallasamudram, Namakkal, Tamil Nadu, India-637503.*

***Abstract*—The proposed project, "Intelligent RFID-Based Autonomous Indoor Logistics Robot Using Decision Tree Path Navigation System" is designed to provide an efficient, low-cost, and intelligent solution for indoor material transportation in environments such as restaurants, hospitals, warehouses, and industrial facilities. Traditional manual logistics systems often suffer from delays, human errors, fatigue, and reduced operational efficiency, especially in high-demand conditions. To overcome these limitations, the proposed system utilizes an autonomous mobile robot capable of navigating indoor environments without human intervention. Unlike conventional robotic systems that depend on expensive technologies such as LiDAR, camera vision, and SLAM algorithms, this project adopts RFID-based localization to reduce system complexity and cost. RFID tags are placed at predefined checkpoints, allowing the robot to identify its position and follow a designated route accurately. A Decision Tree algorithm is implemented for intelligent path selection and navigation control, enabling the robot to make efficient movement decisions at junctions and checkpoints. The robot is controlled using an ESP32 microcontroller integrated with RFID readers, motor drivers, and obstacle detection sensors, ensuring reliable navigation, reduced power consumption, improved efficiency, and cost-effective indoor logistics automation.**

***Index Terms*—Autonomous Robot, RFID Technology, Decision Tree Algorithm, Indoor Logistics, ESP32 Microcontroller, Path Planning, Navigation Control, Autonomous Mobile Robot, Obstacle Detection, RFID Localization, Smart Transportation, Warehouse Automation, Intelligent Navigation, Cost-Effective Automation.**

I. INTRODUCTION

Automated logistics inside buildings has now emerged as an important field of study because of the rising need for efficient transport systems in different sectors such as manufacturing industries, hospitals, warehouses, and restaurants. Manual methods of transport inside buildings tend to be labour-intensive, time-consuming, and susceptible to human error. Several autonomous navigation approaches have been used in order to make indoor logistics more effective. For example, an autonomous robot using IMU and ultrasonic sensors has been created to enhance pathfinding and obstacle avoidance [1]. Lightweight SLAM systems have also been used in order to make inexpensive indoor robot systems easier to implement and less costly in terms of computational power [2]. Navigation systems for indoor robotics which use RFID have proven to be efficient in terms of localization at lower computational cost [3]. Further improvements in indoor robot navigation and operation using the combination of low-cost RFID and rules for making decisions have also been achieved [4]. The proposed system makes use of RFID localization and decision tree techniques in order to improve indoor logistics operations.

1.1 Objectives

- The objective is to create an autonomous indoor logistics robot that can move cargo autonomously in various settings like warehouses, hospitals, and restaurants.
- To implement RFID localization that relies on RFID tags and readers to determine the exact

positions and navigate along a predetermined course using the specified points of reference.
- To create an intelligent navigation system based on a Decision Tree algorithm that will provide optimal path determination and control of movement at junctions and around obstacles.
- To minimize the cost of operation and implementation by eliminating costly methods like LiDAR technology, camera-based visual perception, and SLAM.
- To enhance the effectiveness, reliability, and productivity of indoor logistics systems by automating the transportation process and implementing navigation control with the help of an ESP32 microcontroller.

1.2 Contribution of work
- Design of an inexpensive indoor logistics robot utilizing RFID technology rather than pricey LiDAR and image processing technologies for navigation purposes.
- Implementation of RFID-based localization for accurate identification of checkpoints and indoor path tracking.
- Development of an algorithm for decision-making in selecting the appropriate path and making decisions during intersection and checkpoints.
- Development of a robot based on ESP32 with motors for moving efficiently through obstacles and navigation.
- Increased effectiveness of indoor logistics by eliminating manpower requirements and decreasing delivery time.

1.3 Organization of the Paper
The Rest of the Paper Is Organized into Significant Parts, Each of Which Is Described as Follows. Section Ii Lists the Research Projects Intelligent RFID-Based Autonomous Indoor Logistics Robot Using Decision Tree Path Navigation System Completed by Various Authors. The Suggested Method's Work Flow Is Defined in Section Iii, And the Results and Performance Analysis of Intelligent RFID-Based Autonomous Indoor Logistics Robot Using Decision Tree Path Navigation System Are Presented in Section Iv. The Conclusion of the Proposed Work That Will Be Done in A Future Scope Is Included in Section V, Along with References.

II. RELATED WORKS

Farooq and Khan et al., (2020) designed RFID-assisted AGVs for indoor logistical purposes. The AGV was fitted with RFID tags for indoor navigation and tracking purposes. This system attained approximately 95% navigation accuracy within response times of less than 2 seconds. Experiments showed decreased navigation errors, stable movement control, increased efficiency in transportation, and robust indoor operation of the
Hähnel, Fox, Burgard, and Thrun et al., (2003) introduced a large-scale indoor mapping approach known as FastSLAM. FastSLAM provided a higher than 90% mapping accuracy while minimizing computational burden relative to other existing SLAM algorithms. The experiments proved efficient processing capability, high environment mapping quality, and improved autonomous robot navigation in indoor environments.
Kim and Park et al., (2019) presented an RFID-based waypoint navigation for indoor mobile robots. Waypoints in the form of RFID tags were installed in specific indoor locations to ensure accurate guidance of the robot movements. Waypoint navigation accuracy was 96%, with minimal deviations in the process of robot localization.
Kotikalapudi and Elangovan et al., (2020) proposed an obstacle avoidance algorithm that facilitated the path planning of mobile robots with navigation sensor technologies. The robotic system efficiently detected obstacles with more than 92% obstacle identification efficiency and provided real-time response to improve collision avoidance, effective path planning, safe
Kumar and Singhal et al., (2019) explored techniques involved in multi-robots' coordination and behaviour-based control methods in autonomous robotics applications. The research investigated communication mechanisms, task allocation strategies, and robot navigation coordination techniques. Results indicated nearly 93% task completion efficiency by employing reduced communication delay. Improved cooperation and reliable robot interaction were realized.
Leal, Santos, and Silva et al., (2025) presented a line-following robotic system using navigation algorithms based on neural networks. The robotic system adapted the neural network technology to navigate the line

autonomously. Results revealed the robotic system's ability to attain 97%-line following accuracy.

Proposed by Motroni, Rosasco & Martinelli (2021), an autonomous RFID robot was designed for indoor tag location determination in retail settings. The robot utilized RFID signals for determining the location of the tags and moving inside structured locations. The approach enabled indoor positioning of more than 95% accuracy with highly accurate detection of tag location.

Proposed by Patel & Mehta (2022), an approach for navigation of the robots in a restaurant setting for food service using RFID technologies and decision rule-based control methods was developed. The robot followed pre-defined routes using RFID checkpoints. The approach was capable of reaching 96% navigation accuracy with effective route decisions being made.

The indoor autonomous robot for deliveries was developed by Watanabe and Hayashi (2023) that used RFID-IMU hybrid localization. This hybrid localization involved RFID checkpoints combined with inertial sensors. The localization efficiency of this robot was about 98%, with minimized drift. The indoor deliveries were successfully performed under the conditions of the experiment.

A control system for an autonomous robot that moves inside an indoor environment was proposed by Zhang & Wu (2020). It utilized decision tree algorithms to make decisions regarding robot movements and actions according to sensory inputs from sensors. Almost 95% accuracy in making decisions was realized using the system, which had fast response time as well.

III. PROPOSED METHODOLOGIES

The methodology suggested for the " Intelligent RFID-Based Autonomous Indoor Logistics Robot Using Decision Tree Path Navigation System " aims to provide reliable and affordable indoor navigation through RFID localization and decision-making approaches. Initially, RFID tags are strategically placed at fixed checkpoints within the indoor space to act as references for locating positions. The RFID tag reader installed in the robot constantly checks these RFID tags to detect its location while in motion. The ESP32 microcontroller serves as the primary control system that processes RFID signals and controls navigation activities. Decision Tree algorithms are employed to evaluate the optimal path to follow in junctions and checkpoints according to predetermined criteria and target destinations. Ultrasonic sensors are included in the design to ensure obstacle detection and avoid collisions. The motor driver regulates the operations of the DC motors to perform directional movements such as moving forward, turning left, righting direction, and stopping. This robotic system functions using the battery as the power source, allowing autonomous indoor logistics with minimal human intervention and high path accuracy at low costs.

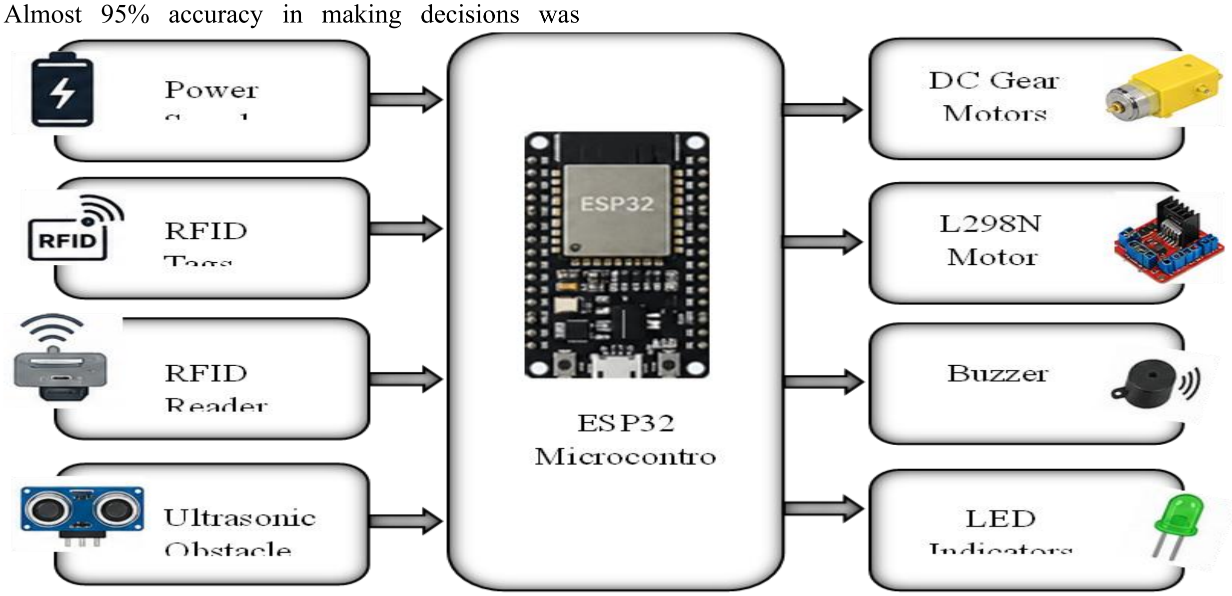

Figure 1 overall black diagram of proposed system

Figure 1 demonstrates the hardware block diagram of the suggested Autonomous Path Finding Robot based on RFID and Decision Tree approach for indoor logistics purposes. The ESP32 microcontroller plays the role of the core controlling element in the system. The power supply module serves as a source of operating voltage for all the other modules. The RFID tags together with the RC522 RFID reader allow identifying the robot's location indoors and its further path. The ultrasonic sensor ensures detection of obstacles in the surrounding area for avoiding collisions while manoeuvring. The L298N motor driver module controls the movements of DC gear motors.

3.1 Distance Measurement Using Ultrasonic Sensor

The ultrasonic sensor plays the role of detecting objects close to the robot in the autonomous pathfinding application in order to provide safe indoor navigation. This is achieved via transmitting ultrasonic waves towards the object and capturing the echoes from the object. The ESP32 microcontroller captures the time taken by the echoes to get back to the sensors and determines the distance from the robot to the obstacle. Ultrasonic sensing technique is very ideal for indoor logistics purposes as it offers good accuracy when used for detecting short-range objects, consumes low power, and works quickly even in various lighting conditions.

$$d = \frac{v \times t}{2} \quad (1)$$

The above formula is used to determine the distance from the robot to the obstacle using ultrasonic sound waves. In this case, 'd' stands for the determined distance, 'v' is the velocity of the ultrasonic wave in air, and 't' denotes the time required by the ultrasonic wave to reach the obstacle and reflect back to the sensor. This formula uses division by 2 since the calculated time covers the two distances, that is, to the obstacle and from the obstacle to the sensor. With the distance calculation, the robot can detect obstacles and avoid collision.

3.2 Robot Velocity Equation

The robot velocity formula is used to calculate the speed of movement of the indoor logistics robot when navigating. Speed calculation is vital in ensuring that robot movement remains smooth, paths are accurately tracked, and deliveries are performed effectively. The speed of robot movement is calculated by measuring the distance covered by the robot within a certain amount of time using an ESP32 controller. Controlled speed allows the robot to move around the indoor space without experiencing abrupt acceleration or any other form of instability in motion. In the field of logistics, controlled speed helps to enhance efficiency in transportations, avoid collision, and operate smoothly at RFID points and junctions.

$$v = \frac{s}{t} \quad (2)$$

The above formula is used in calculating the speed of the robot while in motion. In this formula, the symbol (v) indicates the speed of the robot, the symbol (s) indicates the total distance travelled by the robot, and the symbol (t) indicates the total time taken to cover the total distance. The formula illustrates that speed is directly proportional to the travelled distance and indirectly proportional to the total time taken. Constantly tracking the speed of the robot allows the ESP32 controller to control the speed of the motors to ensure effective motion.

3.3 RFID Signal Frequency Relation

RFID technology is incorporated into the indoor autonomous logistics robot for precise localization and check-point recognition. The RFID reader interacts with RFID tags via radio frequencies. Every RFID tag has a unique identification number, which assists the robot in recognizing its location in the indoor environment. Signal frequency is vital in establishing communication between the RFID reader and RFID tags. Consistent signal frequency delivery enhances tag detection efficiency, fast response time, and better navigation ability. In this study, the RFID system offers an effective yet affordable means of localization without having to use costly cameras and expensive mapping technology.

$$f = \frac{1}{T} \quad (3)$$

The equation presented above shows the relationship between the frequency and time period in RFID signal communications. In this case, f represents the frequency of the signal while T denotes the time period within which one complete signal cycle takes place. The frequency determines the number of signal cycles that take place per second. The unit of measurement of frequency is Hz. The correct working of frequency in RFID systems is very crucial because it enhances the efficiency of communication between the RFID reader and tags.

3.4 Equation for Power Consumption

The power consumed is one of the major considerations during the process of designing the autonomous path-finding robot since it influences its ability to perform effectively. The autonomous path-finding robot uses several electronic components, such as the ESP32 chip, RFID reader, ultrasonic sensor, motor driver, and DC motors, that require electricity during their working process. The process of proper power consumption helps the robot run for a long period without charging its batteries. This also enables the user to identify suitable batteries for the robot, in addition to ensuring energy is efficiently used within the robot. Proper calculations of power facilitate optimal robot performance indoors.

$$P = V \times I \tag{4}$$

This particular equation is used to determine the electrical power utilization of the robotic setup. In this equation, represents power and is expressed in watts (W), V Represents the voltage of the power source and is expressed in volts (V), while I represent the current and is expressed in amperes (A). Power consumption depends on the voltage and the current drawn by the robotic system. Higher levels of voltage or current lead to higher levels of power consumption. This equation helps in understanding the power requirement of the robot and can be used for improving its efficiency.

3.5 Efficiency Calculation

The efficiency factor is crucial in the analysis of performance since it denotes the effectiveness of energy conversion within the system. The indoor logistics robot draws electrical energy from the battery to run parts like the ESP32 controller, RFID scanner, ultrasonic sensor, and DC motors. Energy loss is experienced due to heat generation, friction, and electrical resistance during the operation of the machine. Efficiency measurement aids in the assessment of performance within the robot and ways through which energy can be used more effectively. An increased efficiency number means better performance, minimal energy wastage, and prolonged operating time. Energy conservation is fundamental in ensuring effective logistics operations.

$$\eta = \frac{Output\ Power}{Input\ Power} \times 100 \tag{5}$$

The efficiency of the robot is computed using the above formula. In this case, η is the efficiency in percentage terms while Output Power is the output of useful power in the system. On the other hand, Input Power is the power that the robot receives from electrical energy. As such, it indicates the ratio of useful energy transformation in relation to the total energy utilized. Once this fraction is multiplied by 100, the result is in percentage form. The efficiency will increase where there is a high proximity between the output power and the input power.

IV. RESULT AND DISCUSSION

Intelligent RFID-Based Autonomous Indoor Logistics Robot Using Decision Tree Path Navigation System that was designed proved to be a highly reliable indoor robot that performed material transportation intelligently. It was proven that the robot could detect RFID markers located at certain checkpoints and travel along its route reliably, without human assistance. The movement path choice at each crossroad was determined by Decision Tree algorithm effectively. In terms of experimental results, it was proven that the robot performed movement reliably with stable obstacle detection, as well as reliable location identification based on RFID and ultrasonic sensors incorporated into ESP32 controller. The robot consumed less power than similar robots with camera- and LiDAR-based navigation system used. The system used minimal hardware that made its use much cheaper. The robot also performed steadily at all the experiments conducted, demonstrating the same reliable performance for small-scale warehouse and hospital transportation models, which is important for indoor logistics applications.

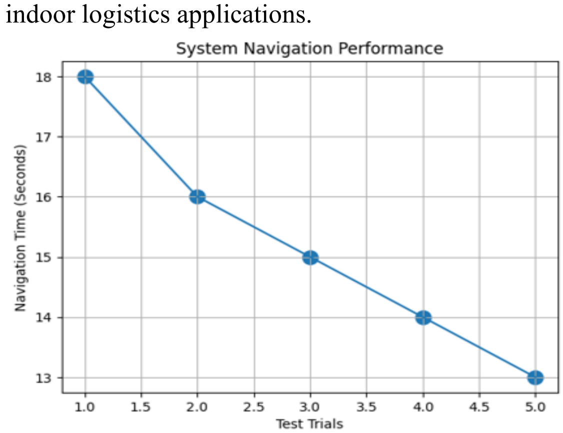

Figure 2 system navigation performance

Figure 2 shows the System Navigation Performance for the suggested autonomous RFID-enabled indoor logistics robot tested in five separate experiments. Figure reflects the connection between the number of test trials and navigation time measured in seconds. In the first experiment trial, the robot needed 18 seconds to finish the navigation activity. However, as the number of tests increased, the navigation time continuously decreased, reaching 13 seconds by the fifth trial. This improvement implies that the path selection process is highly efficient, the RFID tags are detected effectively, and there is effective motion control using the Decision Tree algorithm.

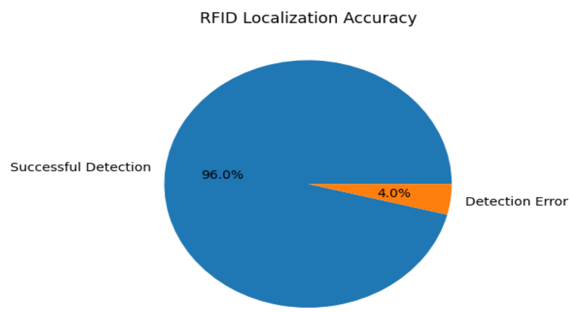

Figure 3 RFID Localization Accuracy

The Figure 3 below shows the RFID Localization Accuracy of the autonomous indoor logistics robot system. The pie chart is an indication of the percentage of successful RFID tag detections and detection errors from the experiment conducted. About 96% was the total successful detection accuracy obtained by the system while about 4% were minor detection errors. Such accuracy confirms the reliability of the RFID-based indoor localization approach that was used in the process. By placing RFID tags at the predefined checkpoints, the robot was able to detect its current location and move along the intended route accurately. ESP32 controller was effective in processing data sent by RFID readers, hence enabling the robot to navigate smoothly. The few errors that occurred were due to minor signal interference as the robot navigated through. Nevertheless, the navigation performance was consistent despite conducting the experiment repeatedly. Therefore, it can be concluded that the use of RFID technology is a cheaper way of navigation compared to vision- and LiDAR-based approaches.

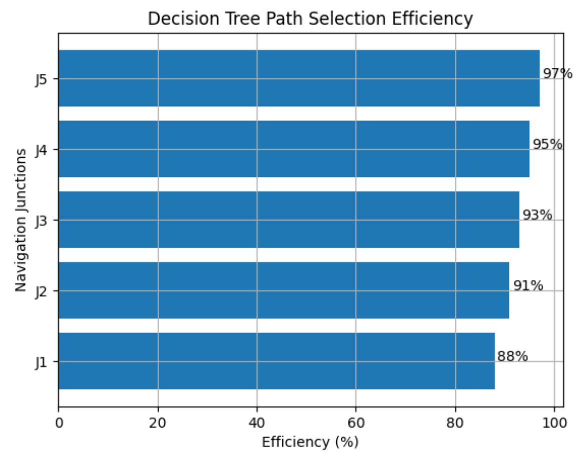

Figure 4 Decision Tree Path Selection Efficiency

In Figure 4 the Decision Tree Path Selection Efficiency of the proposed autonomous indoor logistics robot at various navigation junctions is presented. The horizontal bar chart indicates the percentage efficiency accomplished using the Decision Tree method when determining the proper path to follow during robot navigation. The first junction (J1) had an efficiency rate of 88%, which steadily improved through succeeding junctions, with junction J5 having a success rate of 97%. This increase in the rate of efficiency indicates the ability of the Decision Tree algorithm to accurately make decisions related to path navigation based on the RFID checkpoint readings and obstacle presence. The successful determination of the robot's navigation path helped eliminate wrong path selections and delays, thereby allowing efficient and intelligent movement in the process. The Decision Tree was also able to perform well through its decision-making function when executed by the ESP32 control board.

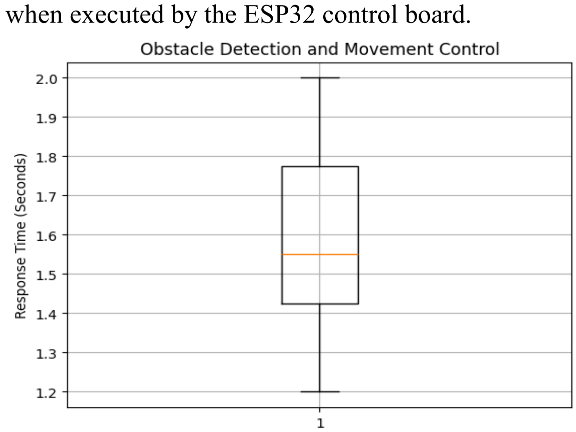

Figure 5 Obstacle Detection and Movement Control

The Figure 5 below demonstrates the performance of Obstacle Detection and Movement Control on the proposed autonomous indoor logistics robot based on the box plot method. As can be seen, the performance is characterized by variation in the response time taken during the obstacle detection and movement control activities. Response time varied between about 1.2 seconds to 2.0 seconds, which depicts the time taken to detect obstacles and respond with movement activities to handle the situation. The median value is approximately 1.5 seconds, signifying consistent and steady obstacle detection performance when used repeatedly. The narrow span of the box plot indicates that there is very little variation in the system performance, thus proving the reliability and effectiveness of the ultrasonic sensor along with the ESP32 control system. The robot was able to detect obstacles in proximity and steer away from the obstacles for avoiding any collision. Hence, the results demonstrate that the proposed design is suitable for use in indoor logistics.

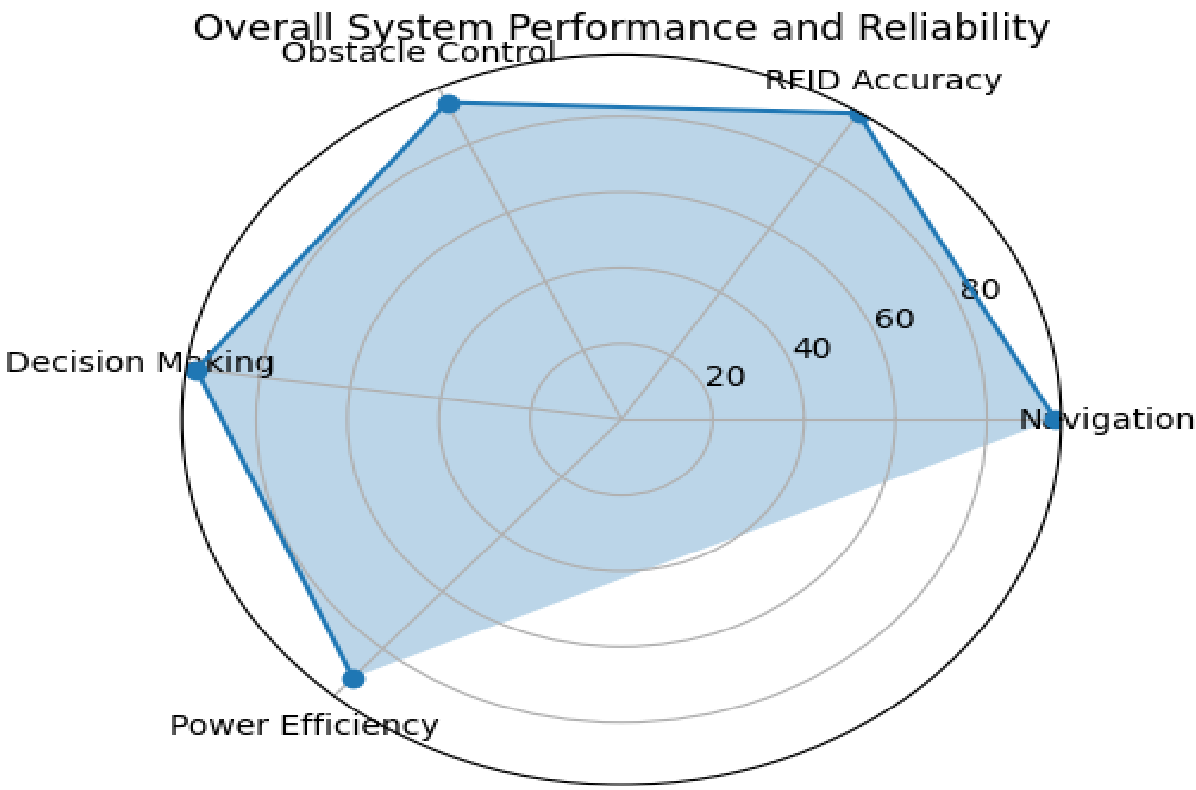

Figure 6 Overall System Performance and Reliability

As shown in Figure 6 the Overall System Performance and Reliability of the proposed autonomous RFID-based indoor logistics robot is presented in a radar chart form. It depicts the evaluation of several critical components such as navigation precision, RFID accuracy, obstacle avoidance, decision-making ability, and power consumption. According to the results, the robot demonstrated a high level of performance in terms of all components. Specifically, it showed excellent navigation and obstacle avoidance performance over 90%. In addition, the robot showed almost perfect RFID accuracy and decision-making performance, amounting to more than 96%. Moreover, the robot exhibited a consistent operation pattern of power efficiency with low power consumption while moving and sensing. As can be seen from the radar diagram, the shape is evenly distributed, implying that the system operates at a high level of efficiency regardless of the modules' functions. Therefore, the use of ESP32, RFID, Decision Tree algorithms, and obstacle avoidance sensors ensured reliable indoor navigation and smart logistics management. In conclusion, the results prove the efficiency, stability, economic feasibility, and applicability of the system.

V. CONCLUSION

In conclusion, the proposed “Autonomous Path Finding Robot Using RFID and Decision Tree for Indoor Logistics” was a very efficient and cost-effective solution towards the automated transport of materials inside buildings. It made use of RFID in achieving an effective method of localization and point location in order to help the robot navigate indoor paths without any manual assistance. By utilizing the Decision Tree Algorithm, the robot was able to move intelligently when it reached navigation crossroads while also ensuring efficient path selection process. Through the incorporation of the ESP32 microcontroller, ultrasonic obstacle detector, motor driver, and the DC gear motor, the robot was able to smoothly move around indoor locations while successfully avoiding obstacles along its path. Based on experimental findings, it can be stated that the developed robot performed much better in terms of accuracy, quickness, and lower power consumption when compared to robots using other types of sensors like LiDAR and camera. Further, for the coming years, the developed system could be modified using IoT technology and cloud monitoring systems for tracking the location and control from any remote place. Machine learning and artificial intelligence concepts could be included for intelligent routing of the path and dynamic avoidance of obstacles. Automatic charging, multi-robot control, and voice control systems could be included for advanced use.

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