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Smart Waste Management with Intelligent Autonomous Robot for Monitoring Dustbins and Obstacle Avoidance (SMARTBIN ROVER)

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Abstract: The present work is the Design and Development of an intelligent rover for autonomous dustbin identification, dustbin fill level monitoring, and real-time notification to concerned authorities. The intelligent rover will be operated for a predefined route with GPS. It facilitates obstacle avoidance, dustbin detection with ultrasonic sensors and dustbin fill level measurement. A central server is equipped to receive the data wirelessly. The dustbin's reach capacity will be sent by processing the information. For achieving over 90% in dustbin detection accuracy, the entire system integrates IoT, machine learning and robotics, and dustbin level measurement with 5% error. Low-light detection issues and limited battery life were the challenges during the development of the intelligent rover. Keeping concerned with cleaner urban environments and smart waste management, the present proposed work ensures a scalable, efficient, and sustainable approach. The challenges faced during the development of intelligent rovers will be the future work to enhance the accuracy for broader deployment.
Keywords: Intelligent Rover, Waste Management, IoT, Machine Learning, Dustbin Detection, Bin Level Monitoring Real-Time Notifications

I. INTRODUCTION

One of the critical challenges in modern cities is the management of the drastic increase in municipal waste due to the fast pace of urbanization and population growth. The major drawbacks of the traditional manual waste collection systems are labor-intensive and fail to respond promptly the exact fill levels of the trash bins which leads to overflowing bins and unhygienic conditions. Because of this the traditional manual waste collection systems are inefficient. In order to promote cleaner and healthier urban environments, it is necessary to integrate smart technologies to intelligently automate waste monitoring and management systems. Keeping all in mind, the present work focuses on identifying the public trash bins, monitoring fill levels, and sending real-time notifications to the concerned authorities for the effective management of the waste collection. The rover will follow the predefined route using GPS navigation and to enhance its autonomous operational capabilities the rover is equipped with various sensors and communication modules.

To maintain an accuracy of up to 95% of intelligent rover, obstacle avoidance and dustbin detection can be done using ultrasonic sensors, high-precision sensor is used for fill level monitoring. A central server is used to process the collected data wirelessly to determine the status of the dustbin. Facilitating timely collection and maintenance, the system sends a notification to the concerned authorities about the filled level of the dustbin. The system integrates Internet of Things (IoT components and robotic systems to achieve a high detection accuracy of over **90%**. The system's adaptability and efficiency can be ensured by incorporating intelligent decision-making in various real-world urban scenarios. The challenges, like low light detection and limited battery life, were encountered during the development of rovers. This intelligent rover system aims to provide a **scalable, efficient, and sustainable solution** to smart waste management. To achieve smart cities and clear environments, the proposed work ensures the minimization of human intervention and efficient real-time waste tracking systems. The rover system detection accuracy and robustness will be improved by focusing the overcoming current limitations.

II. LITERATURE SURVEY

In order to improve autonomous navigation, AWong Seng Cheong et al. (2020) deployed a Smart Garbage Bin Robot that was coupled with the Robot Operating System (ROS) and outfitted with an obstacle avoidance system. The goal of the study was to create a system that could use ultrasonic sensors to avoid barriers, detect and approach trash cans, and efficiently monitor waste levels.

For modular control and effective communication between hardware and software components, the robot made use of ROS. According to the trial findings, the system was able to effectively plan routes in real time, avoid obstacles, and detect trash in interior settings. The study demonstrated how well ROS works to streamline robot development and guarantee dependable task execution in changing environments [1]. An Intelligent Waste Removal System was presented by Qi Zhang et al. (2020) with the goal of improving waste management in smart communities. The system optimized waste collection routes and tracked waste bin fill levels by integrating IoT technology, data analytics, and smart sensors. The system shortened response time, decreased fuel consumption, and increased operational efficiency by evaluating real-time data gathered from dispersed smart bins. The study also showed how predictive analytics can be used to foresee trends in garbage accumulation. The findings demonstrated notable gains in resource management and collection efficiency, highlighting the significance of data-driven approaches for environmentally friendly urban garbage management [2]. In their paper "Smart Garbage Bin Based on AIoT," which was published in Intelligent Automation & Soft Computing in 2021, Wen-Tsai Sung, Ihzany Vilia Devi, Sung-Jung Hsiao, and Fathria Nurul Fadillah created an intelligent garbage monitoring system by fusing artificial intelligence (AI) and the Internet of Things (IoT), or AIoT. The smart bin system included AI algorithms for waste classification and management in real time, as well as sensors to track fill levels. The system made it possible to accurately identify different types of waste and optimize collection schedules, which helped to make waste treatment more effective and environmentally beneficial. The study's main result was the demonstration of automated, self-adaptive trash management that might promote sustainable urban waste practices by learning from human interaction and environmental data [3].

An automated system for waste collection and disposal using a robotic platform with an automatic unloading mechanism was proposed by Nithya L. and Mahesh M. (2017) in their paper "A Smart Waste Management and Monitoring System Using Automatic Unloading Robot," which was published in the International Journal of Advanced Research in Electrical, Electronics, and Instrumentation Engineering. The system used wireless connectivity to send real-time data to a central control unit and sensors to track trashcan fill levels. After that, a robotic unit was sent out to gather and unload rubbish on its own. The study illustrated a successful strategy for lowering physical labor, limiting human participation, and enhancing the promptness and effectiveness of waste collection. The result shown that employing autonomous robotic systems in intelligent urban waste management applications is feasible [4]. In their article "Smart Waste Bin System" in the IOP Conference Series: Earth and Environmental Science, Ayodeji Noiki, Sunday A. Afolalu, Abiodun A. Abioye, Christian A. Bolu, and Moses E. Emetere (2020) created a smart waste bin prototype that used GSM-based communication to inform municipal authorities of waste status and ultrasonic sensors to determine fill levels. The system's goals were to guarantee prompt disposal services and lessen the number of needless garbage collection trips. After being tested in a variety of settings, the prototype demonstrated efficacy in real-time monitoring and economical garbage collection management. The main finding highlighted how crucial it is to incorporate wireless communication and sensor technology to enhance decision-making and operational effectiveness in waste management systems [5]. In their Master's thesis, "An Autonomous Robot for Collection of Waste Bins in an Office Environment," Billy Lindgren and Giancarlo Kuosmanen (2018) created an autonomous robotic system especially made for collecting garbage bins inside offices. The robot navigated on its own, found trash cans, and moved them to a central disposal location using LiDAR, path-planning algorithms, and Simultaneous Localization and Mapping (SLAM). The technique placed a strong emphasis on efficiency, safety, and avoiding obstacles in small enclosed areas. The study's main finding was that autonomous robots might be deployed in controlled interior spaces, drastically lowering the need for human intervention and operating expenses while offering a scalable solution for intelligent indoor trash management [6].

III. PROPOSED METHODOLOGY

A. Problem Statement

The important challenges in urban waste management systems in the current era are focusing on issues of efficiency due to time-consuming and labor-intensive collection methods. Because of these challenges, the waste dumping in public places creates a landfill and a threat to the human living in the surrounding areas. Obtaining the labor for the specific task is a tedious job in the current situation. To address all the above issues, it is need of the hour to integrate advanced technologies to automate the waste collection work.

B. Objective

The main goal of the smart bin rover is to manage the waste. Firstly, the rover navigates independently along the pre-defined routes it automates the waste collection process.

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Secondly, to enhance the efficiency of waste collection, it minimizes the reliance on human labor. Thirdly, to ensure the safety the rover integrates with real-time obstacle avoidance capabilities. the system prioritizes safety by integrating real-time obstacle detection and avoidance capabilities. Finally, by incorporating the easily accessible components like Arduino Nano, the project targets the development of a budget-friendly solution.

C. Methodology

The mechanical design, system architecture, and working principles of the smartbin rover. Mechanically, the rover has a wheeled base (25cm x 35cm), a front-mounted array of IR and ultrasonic sensors, and a motorized lid activated by a proximity sensor. The system architecture involves IR sensors feeding data to the Arduino Nano for motor control, while the ultrasonic sensor provides input to an obstacle avoidance algorithm that governs navigation. A limit switch controls the lid via a servo motor. The rover operates in three modes: Line Following Mode, where IR sensors guide it along a marked path, using PID control for smooth movement and outer sensors to detect junctions; Obstacle Avoidance, where the ultrasonic sensor detects obstacles (10-400cm), causing the rover to stop and reroute if an object is within 30cm, resuming its path once clear.

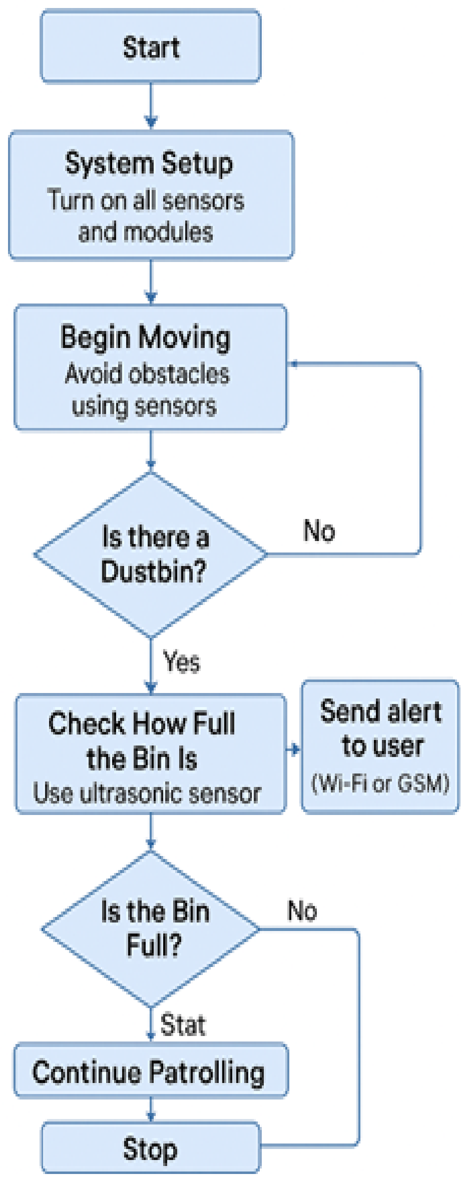

Fig. 1 Flow Chart

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D. Hardware Components

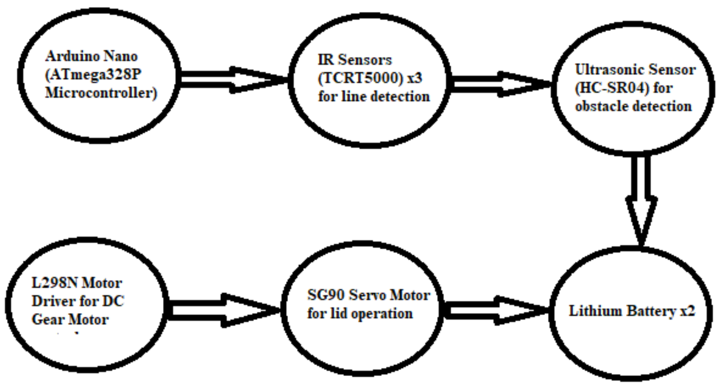

Fig. 2 Hardware components

E. Software Components

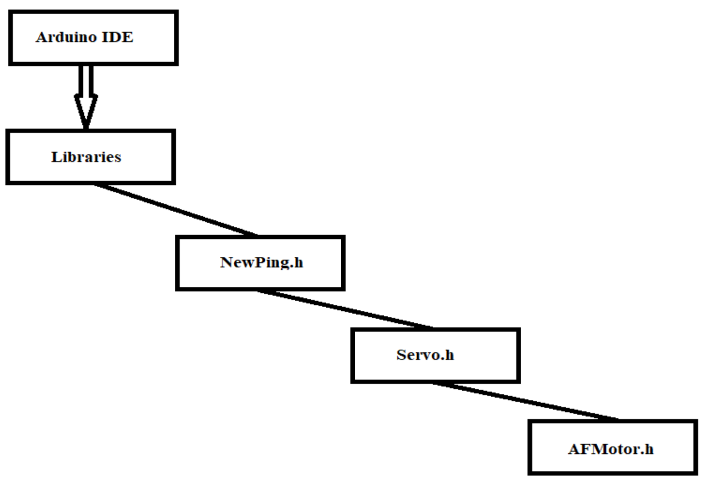

Fig. 3 Software Components

F. Predefined Route Map

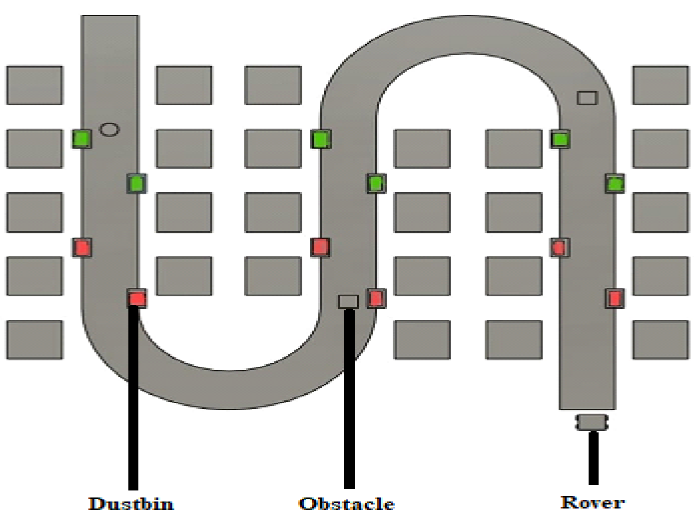

Fig. 4 Predefined route map

G. Design Modelling

For effective navigation, the smartbin rover's system architecture combines a number of sensors and parts. An ultrasonic sensor that recognizes obstructions and permits rerouting, as well as infrared sensors for course tracking controlled by an Arduino Nano, are essential parts. The rover has two main modes of operation: Obstacle Avoidance, where an ultrasonic sensor causes the rover to halt and avoid obstructions before continuing on its path, and Line Following Mode, where IR sensors use PID control to maintain the line. The rover can function independently and effectively in its surroundings because to this design.

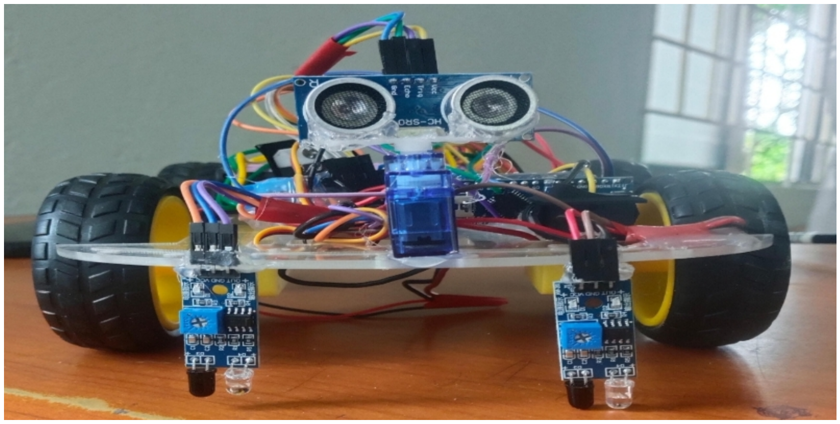

Fig. 5 Intelligent Smart bin rover

IV. RESULT AND DISCUSSION

An inventive and effective method for automated garbage management is demonstrated by the smartbin rover project. Important accomplishments include hands-free disposal using a servo motor, automated operation for structured areas, obstacle avoidance using ultrasonic sensors, and an affordable, scalable design. Future improvements are suggested, such as voice control for user engagement, solar power for energy efficiency, and IoT integration for remote monitoring. All things considered, the study demonstrates how embedded technologies may be used effectively to support cleaner and more sustainable ecosystems.

Accuracy of Path Following: 92%
Battery Life: 6 hours (continuous)
Obstacle Detection Range: 10 cm to 400 cm
Response Time: <0.8s

V. CONCLUSION

The design and implementation of an intelligent rover system that can recognize dustbins on its own, track their fill levels, and provide real-time alerts to the relevant authorities is successfully demonstrated in this study. The system demonstrates a successful integration of robotics, machine learning, and the Internet of Things, with a detection accuracy of over 90% and a fill-level measurement error margin of less than 5%. The rover follows a predetermined GPS-based path and guarantees dependable obstacle avoidance, bin identification using ultrasonic technology, and wireless data transfer to a central server. The prototype has shown itself to be a scalable, effective, and sustainable urban waste management system, despite issues like low-light detection and short battery life. These results demonstrate its potential for wider use with upcoming improvements that solve present drawbacks.

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