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Ecosentinel: An RFID-Based Smart Waste Monitoring and Fine Management System

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Abstract: Littering in public areas such as zoos and amusement parks harms cleanliness and public health. This project proposes an artificial intelligence and robotics-based system that uses RFID tags to detect and prevent littering. Items bought on-site are linked to the buyer's mobile number via RFID. The robot equipped with Ultrasonic sensors identifies the item, retrieves user data, and sends a fine notification. The system improves accountability, reduces manual monitoring, and supports cleaner environments. Furthermore, the integrated web dashboard enables administrators to monitor violations, generate reports, and track payment records in real time. The ESP32 microcontroller ensures smooth data transmission between hardware and cloud services. This smart integration of IoT, AI, and automation promotes sustainability, encourages responsible behavior, and provides a scalable solution for waste management in public spaces.
Index Terms: RFID, Waste Management, Internet of Things (IoT),ESP32,Cloud Data base, Penalty System, Automation, SMS Notification, Web Interface

I. INTRODUCTION

Public spaces often face hygiene challenges due to inefficient waste monitoring and irresponsible disposal practices. Littering not only damages the environment, but also increases maintenance costs and poses public health risks. Traditional manual cleanup methods are limited by human capacity and inconsistent enforcement, leading to poor waste management. Addressing this, Ecosentinel introduces a technology-driven solution that promotes accountability and responsible behavior by providing real-time feedback to individuals who litter. Through intelligent automation, Ecosentinel fosters cleaner habits and contributes to creating safer and more sustainable public environments. Ecosentinel is a line following surveillance robot developed to improve waste management in public spaces. A key feature of Ecosentine lisits ability to read NFC tags of waste linked to users phone numbers, enabling it to notify individuals responsible for littering and issue fines accordingly. The system is intended for use in environments such as amusement parks, zoos, museums, hospitals, and classrooms, places where maintaining cleanliness is critical but often difficult due to highfoot traffic. Eco Sentinel provides a smart, automated approach to promote cleanliness, classification of waste through machine learning algorithms, accountability, and real-time waste management.

II. LITERATURE SURVEY

A. RFID Based Waste Management System

In [1], the authors propose an automatic waste segregation system capable of separating metal, glass, plastic, dry and wet waste using RFID ,proximity sensors, moisture sensors, and metal detectors. RFID was used to label items according to category. The purpose of the system is to reduce the manual sorting effort and improve recycling efficiency directly at the waste disposal stage.
Method Used:

- RFID tags, proximity sensor, moisture sensors, and metal detector used for waste identification.
- The Microcontroller processes the sensor output to trigger correct waste separation.
- Segregated waste is directed to the respective bins.

Advantages:

- Cansegregate multiple waste types at once using RFID.

Limitations::

- Requires RFID tags to be attached to objects from the manufacturing stage.

B. A Real-time Autonomous Waste-Collecting Robot

In [2], the authors developed a real-time autonomous waste collection robot designed to pick for smart buildings, hospitals, schools, and railway stations. The objective of this work was to segregate metallic and non metallic waste. The proposed robot integrates line-following mechanism using IR sensors, ultrasonic sensing for obstacle detection, RFID for positional localization, DC motors for waste collection, and metal detectors to differentiate between metallic and non-metallic waste.

Method Used:

- Line following mechanism controlled using IR sensors interfaced with Arduino.
- Ultrasonic sensor used to detect obstacles and avoid collisions.
- RFID system used to guide robot positioning and movements.
- Metal detector used to identify metallic waste and separate accordingly.

Advantages:

- Fully autonomous movement and waste handling without manual remote control.
- Using metal-sensing techniques that make classification more accurate.

Limitations:

- Limitation to line-constrained path movement (not suitable for unstructured grounds like muddy surfaces).
- Classification of only metallic and non-mettalic sub- stances

C. Fully Automated Waste Management System using Line Follower Robot

In [3], the authors propose a fully automated IoT-connected waste management system that uses a line follower robot to collect garbage from multiple smart bins in different locations and automatically dump at the disposal site. The objective of this work is to eliminate manual handling of garbage bins and enable real-time data-driven waste collection using cloud platforms, making waste collection faster, autonomous and less labour intensive.

Method used:

- Arduino Yun used as the microcontroller for autonomous waste collection vehicle.
- Node MCUESP8266 used in smart bins to measure garbage level using ultrasonic sensors.
- Thing Speak cloud used to communicate bin level data to the line follower robot.
- IR sensors used to navigate robot path along predrawn line routes.

Advantages:

- Fully automated smart waste collection without manual intervention.
- Uses IoT cloud communication to avoid repeated physical checks of bins.

Limitations:

- The Linepath must be physically drawn and perfectly aligned for navigation.
- The system mainly suitable for single-floor operation only.

D. Smart Waste Management System using IoT and RFID Technology

In [4], the authors propose an intelligent waste handling system based on IoT and RFID that separates waste into wet, dry and metallic categories in the bin itself. The system also identifies the user using an RFID tag and rewards them for responsible disposal.

Method used:

- Different sensors (metal,wet,dry,IR) classify waste.
- Node MCU sends data wirelessly to IoT app.
- Servomotors place waste into respective bins.

Advantages:

- Improves user participation and accountability.
- Reduces manual segregation effort.

Limitations:

- The system is more suitable for small scale in door operation.
- Depends on RFID usage and sensor accuracy.

E. Sensor-Based Solid Waste Handling Systems: A Survey In[5], a detailed survey is conducted on various solid waste management approaches focusing on RFID, Wireless Sensor Networks(WSN), and IoT-based systems. The main objective of this study is to analyze the technological evolution of communication models used in waste monitoring and identify the best communication protocols suitable for deployment in smart city environments.

Method used:

- Literature analysis from 2007 to 2021covering RFID, WSN and IoT solutions.

- Categorization based on communication protocol capabilities and deployment nature.
- Performance comparison based on wireless range, power, sensing technology, and network architecture.

Advantages:

- Comprehensive review helps in identifying gaps in exist- ing smart bin deployments.
- Establishes IoT and especially LPWAN based systems (LoRaWAN) as most suitable for city-level wide deploy- ment.
- Provides future scope guidelines for self-powered nodes, hybrid networks and smart routing.

Limitations:

- Paper does not implement or test any real hardware prototype.
- Survey-based analysis only; no performance numerical comparison using uniform test bed.
- Does not include block chain, AI enable dreal-time segregation models.
-

III. METHODOLOGY

The EcoSentinel system employs a robotic car integrated with an RFID reader, IR and ultrasonic sensors, and a conveyor belt for automated waste collection. The system monitors waste disposal activities and identifies users in public areas. Data processed by an ESP32/Arduino microcontroller and transmitted wirelessly to a centralized cloud database. This database enables real-time monitoring. When littering is detected the conveyer belt collects the waste and the RFID is used to detect NFC tags. The system automatically generates a digital challan or penalty notice, which is reviewed by administrators and sent to offenders via SMS ensuring accountability and promoting responsible waste disposal. Additionally, the system is connected to Blynk for remote control and monitoring of robotic functions and Twilio for seamless SMS communication. This integrated approach reduces manual intervention, improves enforcement efficiency, and contributes to a cleaner, smarter urban environment.

A. System Architecture

The system architecture of the proposed EcoSentinel model is illustrated in Fig 1.

B. System Requirements

The hardware components used in the system include:

- ESP32–Maincontroller of the system.
- L293D Motor Driver–Drives the DCmotors.
- DC Motors–Moves the robot.
- Ultrasonic Sensors–Detects obstacles.
- Infrared Sensors–Used for line following.
- DC Conveyor Belt–Transports material sor items.
- MFRC522RFID Reader–Reads RFID tags.
- NFC Tags–Attached to items with unique IDs.
- Battery Pack–Powers the entire system.
- Wi-Fi Module–Enables internet connectivity.
- Arduino Uno Controller–Secondary controller for peripheral management.

The software components used are:

- Arduino IDE–For programming the ESP32 and Arduino Uno.
- Embedded C / C++ – Used for microcontroller programming.
- Wi-Fi Libraries – For establishing wireless communication.
- RFID and Sensor Libraries– For handling input/output data from sensors and RFID.
- Cloud Database–For data storage and monitoring.

C. Prototype

The Fig 2 prototype of the EcoSentinel system show cases an automated waste monitoring model built on an ESP32 microcontroller. Integrates RFID,IR, and ultrasonic sensors for detection with a conveyor-based collection mechanism. The system transmits data to the cloud database for real-time monitoring and automatically sends SMS alerts or challans to users, demonstrating full functionality from detection to accountability.

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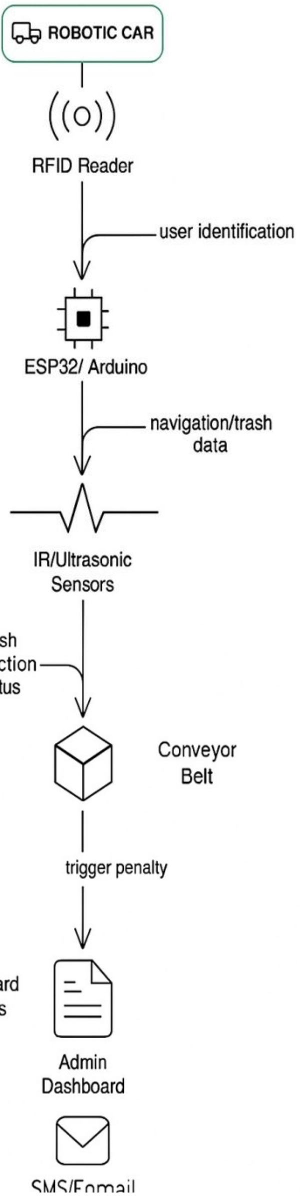

Fig.1. System Architecture of the EcoSentinel Project

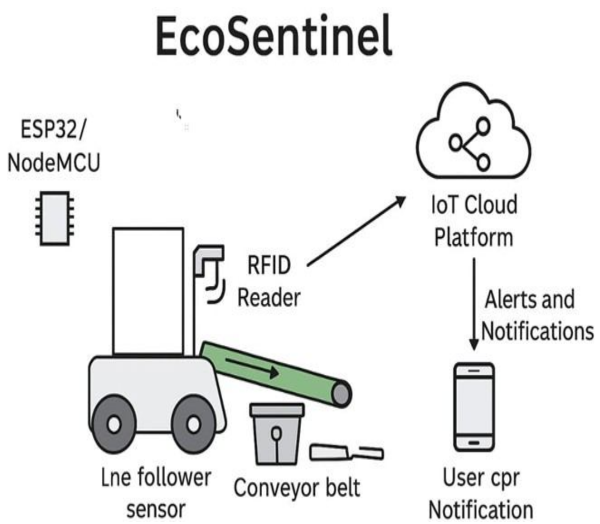

Fig.2. Prototype of the Eco Sentinel System

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D. Working Principle

The system operates through a combination of hardware and software modules that work together to automate waste monitoring, collection, and accountability.

- Sensing Module: The process begins with the sensing module, where ultrasonic sensors continuously scan the environment to detect waste and obstacles .These sensors provide accurate distance measurements, allowing the robot to navigate safely and identify trash efficiently without collisions.
- Conveyor Belt Module: Once the waste is detected, the conveyor belt module is activated via the Blynk IoT app, which connects to the robot through Wi-Fi. This module operates using two DC motors and a servomotor to rotate the belt and collect waste to the collection container. The use of Blynk allows remote control and real-time monitoring of the conveyor system, ensuring smooth and efficient waste collection.
- Line Following Module: The line following module guides the robot along a pre-defined path using infrared (IR) sensors. These sensors detect line patterns on the ground and adjust the robot's direction accordingly. The four motor-driven wheels work in coordination to maintain alignment, allowing the robot to navigate public areas systematically and autonomously.
- RFID Module: The RFID module is responsible for user identification. It uses a RFID reader to detect NFC tags, each associated with a unique user. When a person interacts with the system, their ID is recorded, allowing the platform to track waste disposal activities and link them to specific users for accountability.
- Notification Module: The notification module ensures timely communication between the system and users. All data collected by the system such as user ID, waste disposal events, and violation is uploaded to a cloud database. In case of improper disposal, the system au- tomatically generates a challan (penalty notice), which is sent to the respective user via the Twilio SMS service. This ensures that users receive immediate updates and promotes responsible waste management behavior.

  Together, these interconnected modules form a smart, cloud- enabled robotic system that not only detects and collects waste but also maintains accountability through real-time data transmission and automated SMS notifications using Twilio and Blynk.

E. Results

The EcoSentinel prototype was successfully designed and implemented to validate the proposed waste monitoring and accountability system. Fig3 shows thecomplete robotic car model integrated with essential components including the ESP32 microcontroller, RFID reader, ultrasonic sensors, infrared sensors, and the conveyor belt mechanism. The robot was able to navigate autonomously, detect waste, and identify users through RFID-based authentication. Fig4 presents the top view of the system, where all major hardware components such as the motor driver, DC motors, Wi-Fi module, and power supply connections are clearly visible. The layout was optimized for balance and efficient wiring to ensure smooth mobility and accurate sensor readings. The notification module of the Ecosentinel project is successfully demonstrated with automated message generation using the Twilio API. When a littering incident is detected, the system transmits user data and location coordinates to the cloud. A digital challan containing the violation detail, GPS location, and payment link is generated and sent as an SMS to the registered mobile number of the offender. This feature ensures instant communication and promotes accountability by allowing users to view and pay the challan through the provided website link. Fig 5 shows an example of the SMS alert received by the user. The Eco Sentinel web interface was developed to manage the digital challan process and provide real-time monitoring for administrators.

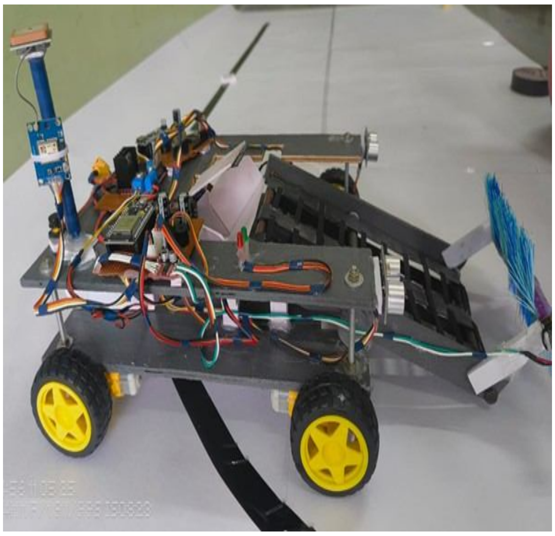

Fig.3 .Eco Sentinel Robotic Car

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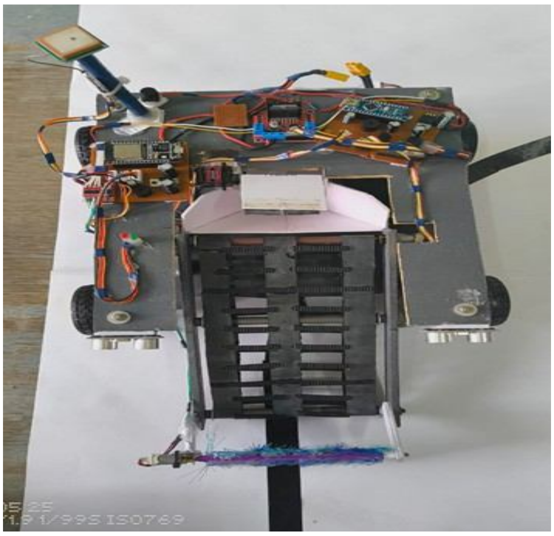

Fig.4.TopView of the Eco Sentinel Robot Showing Hardware Components

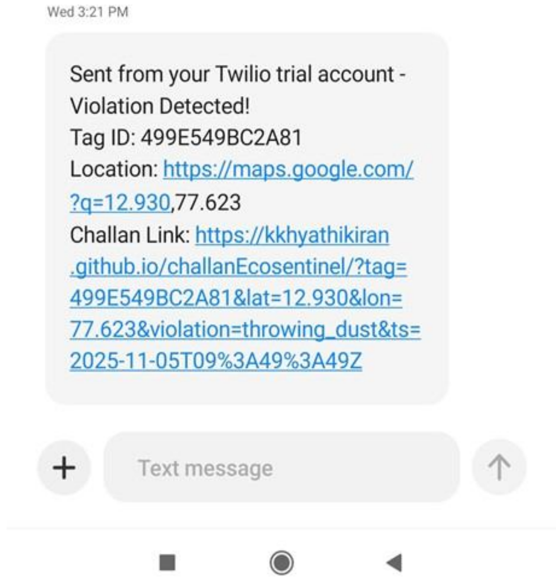

Fig. 5. Twilio-Generated SMS Notification Containing Violation Details and Payment Link

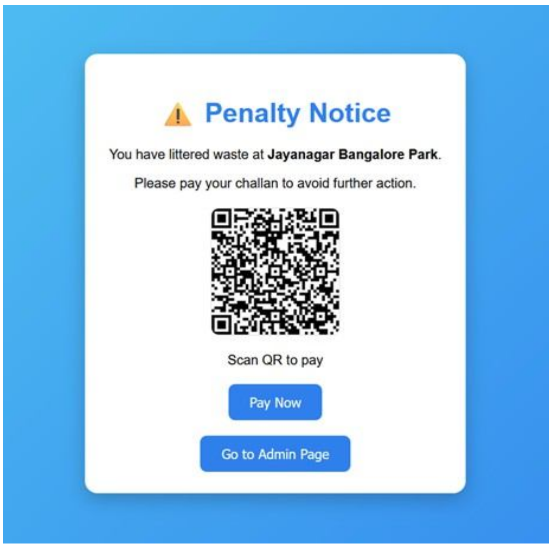

Fig.6.penalityNotice

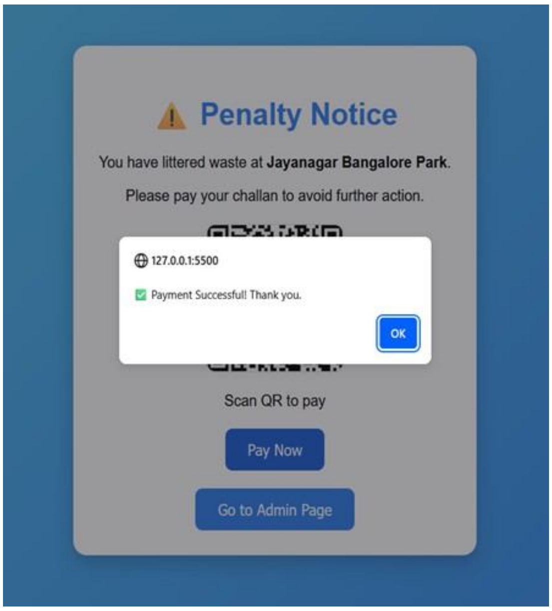

Fig.7.paymentSuccessful

Once a littering event is detected and verified, a penalty notice or challan is automatically generated and stored in the centralized data base. Users can access their challan through the link provided in the SMS and proceed with online payment through the secure interface.

Fig 6 shows the penalty notice generated by the system, which contain the user details, location coordinates, and the amount of fine. After the user completes the payment, a confirmation screen is displayed, as shown in Fig 7. Administrators can view and manage all user data, challan histories, and payment statuses through the admin dashboard shown in Fig 8. This ensures transparency, accountability, and easy record management within the Eco Sentinel system.

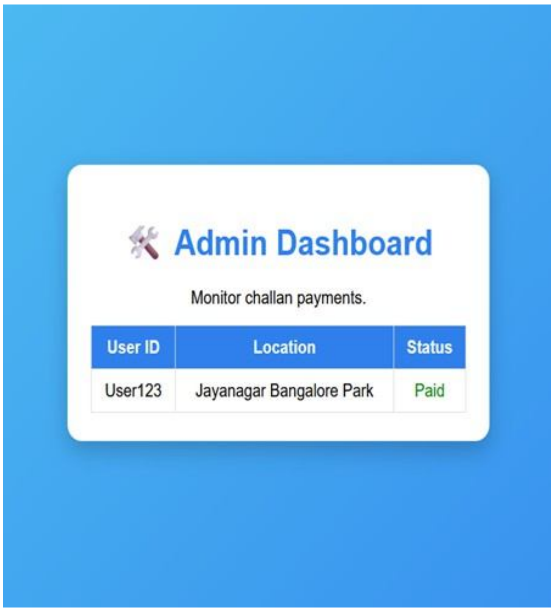

Fig.8.adminDashboard

The successful implementation of the RFID-based robotic waste management system produced significant outputs. The robot efficiently identified waste sources through RFID tags, ensuring accurate user identification. It navigated smoothly using IR sensors and avoided obstacles while collecting waste automatically. The ESP32 microcontroller processed all data and transmitted it to the web dashboard, where collection details, user logs, and fines were displayed in real time. The website interface enabled admins to monitor activities, generate reports, and manage penalties effectively.

Overall, this project demonstrated a reliable, automated, and smart solution for waste collection, promoting efficiency and environmental sustainability.

F. Future work

The Eco sentinel system can be further enhanced through the following improvements and developments:

- Implement autonomous and remote control for improved navigation and coverage.
- Enable RFID-based waste identification to categorize waste types efficiently.
- IntegrateESP32/Arduino for centralized control and real- time wireless data updates to the backend system.
- Develop a robust backend for secure data storage, auto- mated notification delivery, and remote dashboard management.
- Optimize system operation through field testing, power management, and machine learning integration for intelligent waste classification.

G. Conclusion

The Eco Sentinel system successfully integrates IoT and automation to enable intelligent waste management. The robotic Car efficiently scans RFID-tagged waste for user identification, detects obstacles through IR sensors, and manages navigation and waste collection using DC motors and a conveyor belt. Data processed by the ESP32 is transmitted wirelessly to a cloud or local database, allowing real-time monitoring and penalty management via the admin dashboard. The system effectively automates fine generation and user notifications through SMS or email, ensuring transparency and accountability. Hence, Eco Sentinel demonstrates a practical approach toward smart waste management by combining automation, IoT, and cloud connectivity, paving the way for cleaner and more sustainable urban environments.

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REFERENCES

1. A.F.R.Guerrero,A.B.Baylon,J.A.A.Novio,E.L.G.DeLeon,J.A.B.Abeleda,F.T.T.Dinglasan,G.B.Tolentino,J.N.Bautista,and J.A.Galay-Limos,"Optimizing waste management: A narduinouno auto-locking waste monitoring system with sms alert and rfid," International Journal of Research, vol. 9, no. 1, pp. 175–185, 2025.
2. V.Geetha, S.Salvi, S. K.Ghosh, S.S.Ahmed, and R.S.Meshram,"Fully automated waste management system using line follower robot,"in Emerging Research in Computing, Information, Communication andApplications: ERCICA 2020, Volume 2.Springer, 2021, pp. 227–235.
3. V.Chaturvedi, M.Yadav, and N.Tiwari, "Smart waste management system using internet of things and rfid technology," New Frontiers in Communication and Intelligent Systems, pp. 63–68, 2021.
4. S.Vishnu,S.J.Ramson,M.S.S.Rukmini,and A. M. Abu-Mahfouz,"Sensor-based solid waste handling systems: A survey, "Sensors, vol.22,no. 6, p. 2340, 2022.
5. V.V.B.Snehal M.Veer, Sharad Jagtap, "Rfid based waste management system, "Mathematical Statistician and Engineering Applications, vol. 69, no. 1, p. 590–595, Jan. 2020. [Online]. Available: https://www.philstat.org/index.php/MSEA/article/view/2633