EnviRoBot: An Innovative AI-Driven Waste Management System Using Unmanned Ground Vehicles (UGVs)

Stachys Thangapapa A E[1], Kogula Nandhitha K[2], Rathnamala S[3], Vijayashanthi T[4]

[1 2]Student, [3]Associate Professor, [4]Assistant Professor,
Dept. of Artificial Intelligence and Data Science, SIT, Kariapatti, Virudhunagar, Tamil Nadu, India

---***---

Abstract - *EnviRoBot is an advanced waste management system designed to address urban waste collection, sorting, and disposal challenges using Unmanned Ground Vehicles (UGVs) integrated with AI and IoT technologies. This paper presents the system's architecture, methodologies, and impact on sustainable urban waste management. Key features include real-time waste detection, automated sorting using AI algorithms, and route optimization with IoT sensors. EnviRoBot is solar-powered, promoting energy efficiency and sustainability. The prototype, built using the Firebird V ATmega2560 board, demonstrates the system's feasibility in real-world conditions, showcasing the potential of AI and IoT in revolutionizing waste management, contributing to cleaner and smarter cities.*

Key Words: Waste Management, AI, IoT, Unmanned Ground Vehicles (UGVs), Smart Cities, Firebird V ATmega2560, Predictive Maintenance, Sustainability.

1.INTRODUCTION

Urban waste management is a growing challenge as cities expand. Traditional methods are often inefficient, costly, and environmentally unfriendly. This paper introduces EnviRoBot, an AI-driven waste management system that leverages Unmanned Ground Vehicles (UGVs) integrated with IoT technologies to automate waste collection, sorting, and disposal. The system is proposed to enhance operational efficiency, reduce human intervention, and promote sustainable waste management practices.

1.1 Background

The increasing volume of urban waste necessitates innovative solutions to ensure effective management. Existing systems struggle with inefficiencies in waste sorting, high operational costs, and limited real-time monitoring. The proposed Firebird V ATmega2560-based prototype of EnviRoBot addresses these issues by integrating AI algorithms for smart sorting and IoT sensors for route optimization, making waste management eco-friendly and more efficient.

1.2 Objectives

The primary objective of EnviRoBot is to develop an autonomous waste management system using Unmanned Ground Vehicles (UGVs) integrated with AI and IoT technologies. This system aims to revolutionize urban waste collection and sorting by automating the entire process, from detection to disposal. EnviRoBot seeks to enhance operational efficiency through real-time monitoring and decision-making, optimize route planning to reduce energy consumption, and utilize AI algorithms for intelligent waste sorting. A key focus is on sustainability, achieved by powering the UGVs with solar panels, thus minimizing the environmental impact. Additionally, predictive maintenance capabilities are integrated to ensure minimal downtime, while the system's data-driven approach aids in policy-making and community engagement, ultimately contributing to smarter, cleaner urban environments.

2. METHODOLOGY

The EnviRoBot system is built around UGVs equipped with AI and IoT capabilities. The prototype, developed using the Firebird V ATmega2560 board, serves as the initial model to test and validate the system's core functionalities. The methodology involves waste detection, sorting, and collection processes, supported by advanced technologies for optimal performance.

2.1 System Design

The UGVs, starting with the Firebird V ATmega2560 prototype, are fitted with sensors for waste detection and identification. AI algorithms are employed for sorting waste into categories, enabling efficient disposal or recycling. IoT sensors monitor the environment and optimize the UGVs' routes, ensuring timely and effective waste collection.

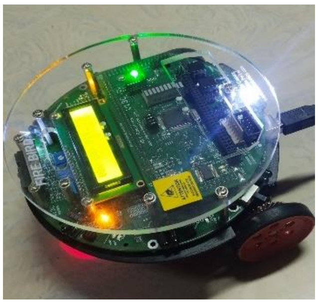

Fig -1: Firebird V ATMEGA2560

2.2 AI and IoT Integration

AI algorithms are used for waste categorization based on size, material type, and other characteristics. IoT sensors provide real-time data, which informs the UGVs' movements, reducing energy consumption and travel time. The integration of AI and IoT facilitates adaptive learning, enabling the system to improve its efficiency over time.

2.3 Solar Power Utilization

EnviRoBot uses solar panels to power the UGVs, minimizing energy costs and environmental impact. This green approach aligns with the system's sustainability goals and contributes to reducing the carbon footprint of urban waste management.

2.4 Prototype Development

The initial prototype, utilizing the Firebird V ATmega2560 board, was developed to test key functionalities such as line following, waste detection, and basic sorting algorithms. This prototype serves as a crucial step in refining the system design, validating control algorithms, and assessing hardware-software integration in a controlled environment.

3. FEATURES OF ENVIROBOT

- **Automated Sorting**: AI algorithms sort waste materials, enhancing the recycling process.
- **Real-time Monitoring**: IoT sensors provide continuous feedback, allowing dynamic adjustments to routes and operations.
- **Predictive Maintenance**: The system predicts mechanical failures and schedules maintenance, reducing downtime.
- **Community Engagement Tools**: Provides data to city authorities and communities, promoting awareness and participation in waste management.
- **Blockchain for Waste Tracking**: Ensures transparency in waste disposal and recycling processes, enhancing accountability.

4. IMPLEMENTATION DISCUSSION

The waste classification model was designed to differentiate between biodegradable and non-biodegradable waste using deep learning techniques. The chosen model architecture was VGG16, a convolutional neural network, which was fine-tuned to adapt to our dataset.

4.1 Data Preparation

The dataset was divided into training and testing sets, with images resized to 60x60 pixels for uniformity. Data augmentation techniques were applied to increase the diversity of the training data, preventing overfitting and improving model robustness.

4.2 Model Architecture

We employed the VGG16 architecture, pre-trained on ImageNet, and fine-tuned it for our classification task. The top layers of the model were replaced to suit the binary classification of waste.

4.3 Training & Evaluation

The model was trained with early stopping to avoid overfitting. The model was evaluated on the test dataset to measure its accuracy and other performance metrics. The model's performance was evaluated using accuracy, precision, recall, and F1 score. The following confusion matrix illustrates the model's effectiveness.

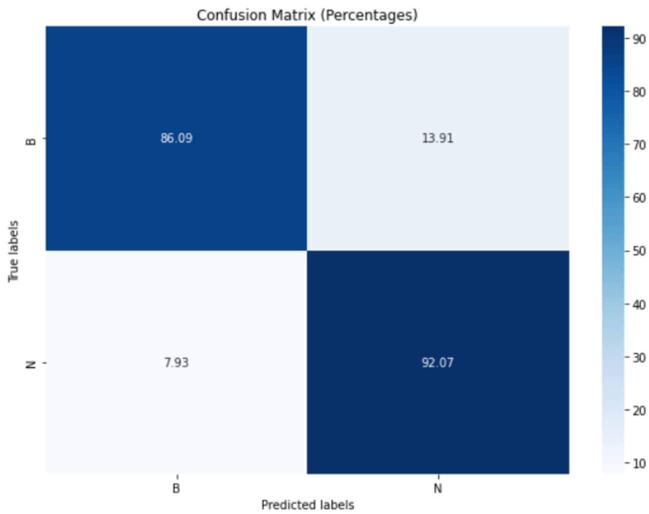

Fig -2: Confusion matrix

Fig -3: Example output

4.4 Results

The model achieved a test accuracy of 87.36%. The classification report indicated strong performance across both biodegradable and non-biodegradable categories:

Table -1: Classification report

Class	Precision	Recall	F1 Score
Biodegradable	0.9346	0.8034	0.8640
Non-biodegradable	0.8276	0.9438	0.8818

5. APPLICATIONS

- **Urban Waste Management**: Efficient waste collection, sorting, and disposal in residential, commercial, and industrial areas.
- **Large Events and Festivals**: Temporary deployment for waste management in large gatherings, reducing environmental impact and promoting recycling.
- **Remote and Hard-to-Reach Locations**: Ideal for areas where traditional waste management methods are not feasible, providing a sustainable alternative.
- **Industrial Waste Management**: Continuous waste handling for industries requiring uninterrupted waste management, enhancing operational efficiency.
- **Environmental Monitoring**: Supports environmental monitoring by collecting and analysing waste data, enabling targeted interventions in high waste generation zones.
- **Urban Planning and Resource Allocation**: Provides valuable data to city authorities for better urban planning and efficient resource allocation in waste management.
- **Policy Development**: Data-driven insights support policy-makers in crafting regulations that enhance waste management practices.
- **Regulatory Compliance**: Ensures transparency and accountability in waste disposal and recycling using blockchain technology, aiding compliance with environmental laws.
- **Community Engagement**: Engages communities with real-time data, raising awareness and promoting participation in waste reduction initiatives.

6. ADVANTAGES

- **Enhanced Efficiency**: Automates waste sorting and collection, reducing manual labour.
- **Sustainability**: Solar-powered UGVs promote eco-friendly waste management practices.
- **Scalability**: The system can be scaled to meet the needs of different urban settings.
- **Data-Driven Decision Making**: Offers valuable insights for policy-makers through automated data analysis.

7. LIMITATIONS

- **Initial Cost**: High initial investment for UGVs and technology integration.
- **Technical Challenges**: Requires advanced technical support and regular maintenance.
- **Weather Dependence**: Solar power efficiency can be affected by weather conditions.

8. IMPACT

EnviRoBot significantly impacts urban waste management by introducing a highly efficient, automated, and sustainable solution that addresses the growing waste challenges of modern cities. Its AI-driven sorting and real-time waste detection capabilities enhance operational efficiency, drastically reducing the need for manual labour and associated costs. By leveraging solar power, EnviRoBot not only minimizes the environmental footprint of waste collection but also supports the broader goal of sustainable urban living. The system's predictive maintenance ensures reduced downtime, leading to continuous and reliable waste management operations.

Moreover, EnviRoBot empowers city planners and policy-makers with valuable data, enabling more effective decision-making and resource allocation. Its blockchain-based tracking system fosters transparency and accountability, setting new standards for regulatory compliance in waste disposal and recycling. The integration of IoT enhances the real-time monitoring of waste levels and vehicle performance, optimizing route planning and reducing emissions from unnecessary travel. By engaging communities through interactive data and insights, EnviRoBot fosters greater public participation in waste reduction efforts, driving behavioural change toward more sustainable practices.

Overall, EnviRoBot not only revolutionizes waste management but also contributes to cleaner, healthier, and smarter urban environments. Its adaptable design allows it to be scaled and customized for various settings, making it a versatile solution that can address diverse waste management needs globally.

9. CONCLUSIONS

EnviroBot demonstrates how AI and IoT technologies can transform urban waste management. The system's innovative approach to waste detection, sorting, and collection improves operational efficiency while promoting sustainability. Future developments will focus on expanding its capabilities and integrating more advanced AI algorithms for even greater impact.

ACKNOWLEDGEMENT

The authors would like to acknowledge the support of the development team and all contributors who assisted in the creation of the EnviRoBot system.

REFERENCES

[1] N. C. A. Sallang, M. T. Islam, M. S. Islam and H. Arshad, "A CNNBased Smart Waste Management System Using TensorFlow Lite and LoRaGPS Shield in Internet of Things Environment," in IEEE Access, vol. 9, pp. 153560153574, 2021, doi: 10.1109/ACCESS.2021.3128314.
keywords: {Waste management; Monitoring; Acoustics; Internet of Things; GSM; Microcontrollers; Deep learning; Waste classification; CNN; object detection; LoRaGPS shield; Internet of Things},

[2] G. Cicceri et al., "An Intelligent Hierarchical CyberPhysical System for Beach Waste Management: The BIOBLU Case Study," in IEEE Access, vol. 11, pp. 134421134445, 2023, doi: 10.1109/ACCESS.2023.3317689.
keywords: {Climate change; Cyberphysical systems; Multirobot systems; Autonomous aerial vehicles; Computer vision;Waste management; Intelligent systems;Oceans; Intelligent cyberphysical systems; multirobot systems; unmanned aerial vehicles; computer vision; unmanned ground vehicles; beach waste management},

[3]Fire Bird V ATMEGA 2560 Hardware Manual, IIT Bombay

[4] e Yantra Resource http://elsi.eyantra.org/resource