IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 19, April 2026
Impact Factor: 8.2

A.I. Driven On-Demand Garbage Collection for Smart Cities

Suyash Narsale[1], Varad Yeola[2], Pooja Bhaskar[3], Sampada Mhaske[4], Shrikant Bale[5], Prof. Rahul Ghode[6], Prof. Namdeo Kedare[7]
Student, Department of Information Technology[12345]
Head of the Department, Department of Information Technology[6]
Professor, Department of Information Technology[7]
Dhole Patil College of Engineering, Pune

Abstract: *Traditional garbage collection systems operate on fixed schedules, often resulting in inefficient resource utilization, delayed pickups, and environmental hazards. This paper presents an enhanced Artificial Intelligence-driven on-demand garbage collection system designed for smart cities. The system integrates real-time complaint reporting, AI-based waste classification, and intelligent route optimization to dynamically assign collection tasks.*
The upgraded system introduces a robust backend using Node.js and Express, secure authentication using JWT tokens, real-time communication, and GPS-based tracking for efficient driver coordination. A smart assignment algorithm ensures optimal truck allocation. The platform supports separate dashboards for clients, drivers, and administrative staff, enabling seamless coordination and monitoring. Experimental results demonstrate improved responsiveness, efficient resource allocation, and enhanced user interaction, making the system a scalable solution for modern urban waste management.

Keywords: Artificial Intelligence, Smart Cities, Waste Management, Convolutional Neural Networks (CNN), Route Optimization, Real-time Systems, Internet of Things (IoT), GPS Tracking.

I. INTRODUCTION

Waste management is a major challenge in rapidly urbanizing cities. Traditional garbage collection systems operate on fixed schedules and predefined routes, which often fail to reflect real-time waste generation patterns. This leads to inefficient resource utilization, including unnecessary pickups and unattended overflowing bins, resulting in environmental and public health concerns.

Advancements in Artificial Intelligence and smart city technologies enable the development of adaptive systems that respond dynamically to real-time data. This paper presents an AI-driven on-demand garbage collection system that integrates citizen complaint reporting, image-based waste classification, and intelligent route optimization.

The enhanced system incorporates real-time communication, GPS-based tracking, and a smart assignment algorithm to efficiently allocate collection resources. By combining automation with user participation, the system aims to improve operational efficiency, reduce costs, and support sustainable urban waste management.

II. RELATED WORK

Recent advancements in smart waste management have used Artificial Intelligence, the Internet of Things (IoT), and computer vision to improve efficiency and automation. Convolutional Neural Networks (CNNs) have been widely used for waste classification. IoT-based systems allow for real-time monitoring of bin fill levels.

Several studies have suggested smart waste management solutions that combine image processing and sensor-based monitoring. Deep learning models, particularly CNNs, have shown high accuracy in sorting waste into categories like recyclable and non-recyclable. IoT-enabled systems use sensors to check bin status and send alerts for collection, which reduces the need for manual intervention. Additionally, route optimization tools, such as Google OR-Tools, help

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minimize travel distance and fuel use. However, most existing systems focus on isolated parts, like classification or routing, and lack a fully integrated framework. The proposed system fills this gap by combining real-time citizen reporting, AI-based waste classification, GPS-enabled tracking, and a smart assignment strategy into one platform.

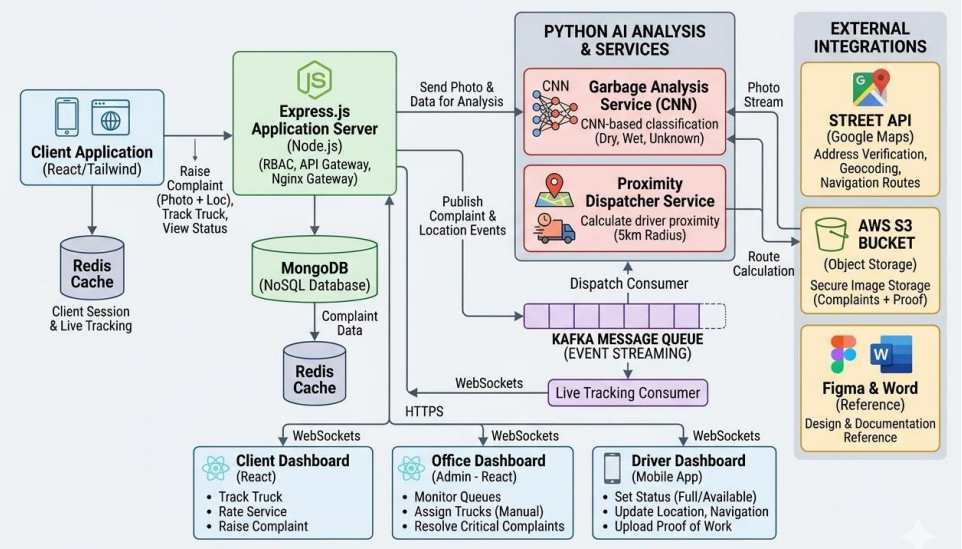
III. PROPOSED ALGORITHM

The proposed system follows a modular architecture consisting of multiple interconnected components:

A. Core Modules

- Complaint Reporting Module
- Image Processing and Classification Module
- Real-time Communication Module
- Smart Assignment Module
- Route Optimization Module
- Driver Dispatch Module
- Administrative Dashboard
- Data Storage and Logging Module

System architecture:



B. System Features

The system is built on a scalable backend architecture using Node.js and Express, ensuring efficient handling of requests and modular development. It incorporates JSON Web Token (JWT) authentication with a 30-day token lifecycle to maintain secure user sessions. Additionally, the platform implements role-based access control, supporting multiple user roles including Client, Driver, Office, and Admin. To ensure transparency and traceability, an activity logging mechanism is integrated for comprehensive audit tracking, while centralized error handling in Express prevents unexpected server crashes.

A smart assignment algorithm is employed to optimize operational efficiency. The system automatically assigns the nearest available driver within a 5 km radius using GPS data. In cases where no suitable driver is found, the complaint is flagged for manual assignment by office personnel, ensuring no request is left unresolved.

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The platform supports real-time communication through live updates and complaint-specific communication channels. Users receive instant notifications upon assignment, and both users and administrators can monitor live tracking updates throughout the complaint resolution process.

The client portal is designed to enhance usability and accountability. It features automatic GPS detection for location accuracy and enforces mandatory image validation during complaint submission. Clients can track complaints in real time and view before-and-after comparisons of resolved issues. Furthermore, the system provides environmental impact metrics, such as CO_2 savings and eco scores, to promote sustainability awareness.

The driver portal enables efficient task execution through continuous GPS tracking using the watchPosition API. Drivers are provided with real-time route visualization, including an ordered sequence of assigned jobs. Upon task completion, proof images must be uploaded, and the system includes GPS error handling and retry mechanisms to ensure reliability.

The office dashboard offers a comprehensive overview of operations through a live city map displaying complaint and vehicle markers. It supports both manual and automatic assignment methods and includes an analytics dashboard that presents AI-based classification distribution, complaint trends, and a driver performance leaderboard.

Finally, the system integrates an advanced map module that provides real-time updates through socket-based communication. It supports automatic resizing, GPS fallback handling, and a multi-map architecture tailored for client, driver, and office interfaces, ensuring a seamless and consistent user experience across all roles.

IV. SOURCE PROGRAM

The system is implemented using a full-stack architecture with a Node.js and Express backend and a React-based frontend. The backend handles authentication using JWT, role-based access control, complaint management, and real-time communication. AI-based garbage classification is integrated through a CNN model service, while route optimization is handled using Google OR-Tools with a Haversine distance-based assignment algorithm. Images (before and after) are stored using MongoDB GridFS, and activity logs are maintained for audit tracking. The frontend provides separate dashboards for client, driver, and office with real-time updates, GPS tracking, and map visualization.

V. SIMULATION RESULTS

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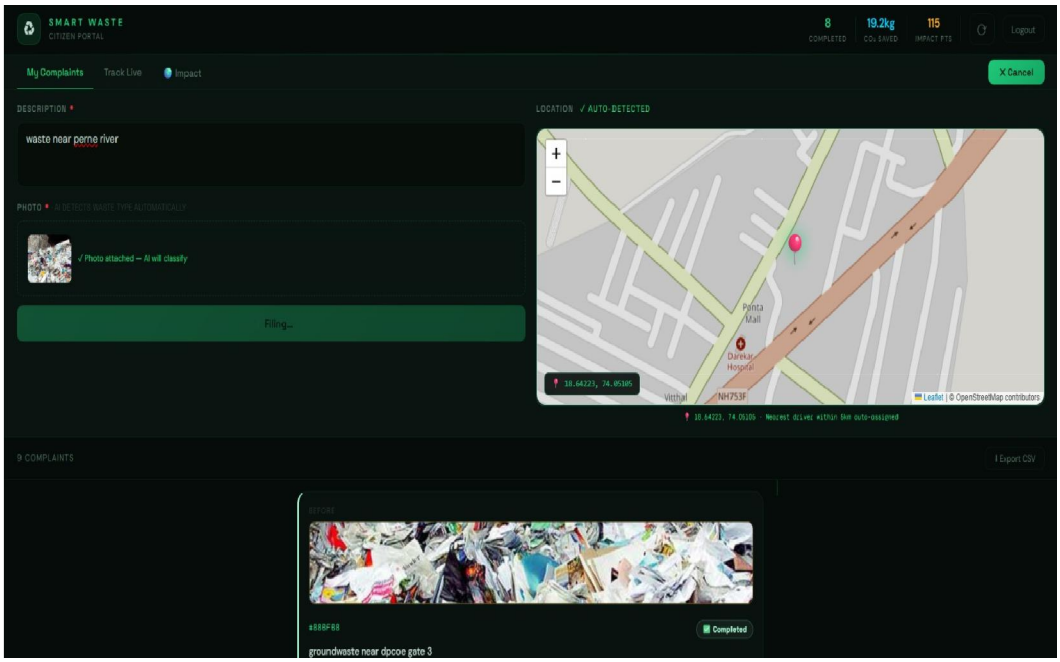

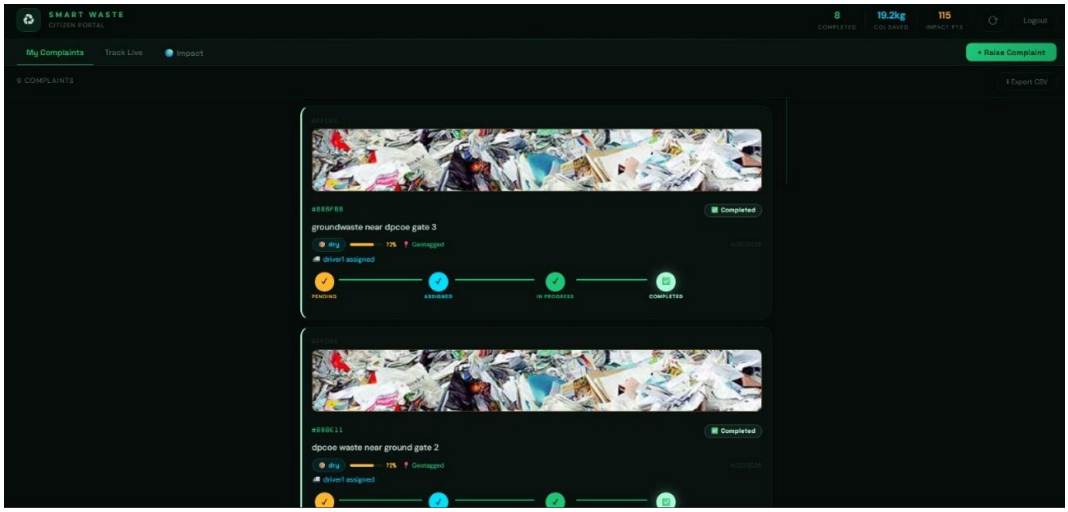

DOI: 10.48175/IJARSCT-34490

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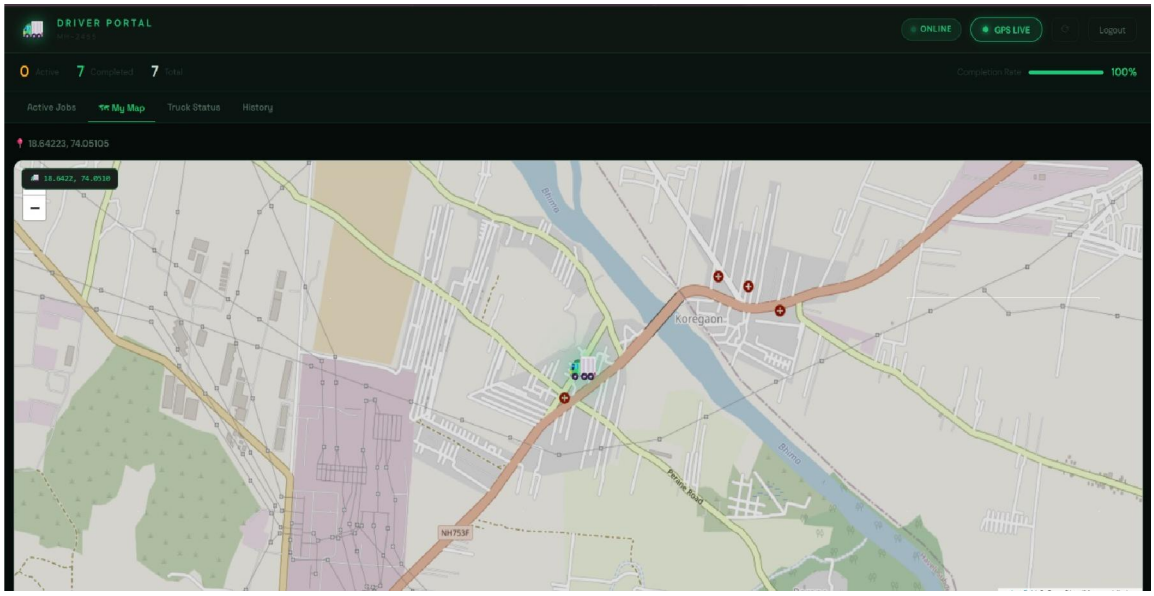

1. Implementation

The system was implemented using a Node.js and Express backend with JWT-based authentication and role-based access control. AI-based garbage classification was performed using a CNN model, while real-time communication using GPS integration. Google OR-Tools was used for route optimization, and MongoDB with GridFS handled data and image storage. The frontend dashboards for client, driver, and office were developed to support real-time monitoring and interaction.

2. Test Cases

The system was tested using 50 complaint scenarios and approximately 1000 images under varying real-world conditions such as lighting changes, occlusions, and urban backgrounds. Test cases covered the complete workflow, including complaint submission, AI-based waste classification, smart driver assignment, fallback to office allocation, and real-time tracking. Driver functionalities such as GPS updates, truck status handling, and proof image upload were also verified. The office dashboard was evaluated for priority-based sorting and manual assignment. Overall, the system performed reliably across all modules with consistent real-time responsiveness.

3. Metrics

Performance evaluation was based on the following metrics:
Classification Accuracy: ~80%
Latency: ~100 ms
Improved assignment success rate
Reduced pending complaints using auto-assign feature

4. Results

The proposed AI-driven garbage collection system demonstrated significant improvements in operational efficiency and responsiveness. Real-time complaint integration reduced the average waste collection response time compared to traditional fixed schedules. The image-based waste classification model achieved high accuracy in identifying different waste categories, enabling better segregation at the source. Optimized routing using GPS and AI algorithms minimized

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fuel consumption and travel distance for collection vehicles. Additionally, the system effectively reduced instances of overflowing bins by prioritizing high-urgency requests. User participation increased due to the ease of reporting through the platform, enhancing overall system reliability. These results indicate that the proposed solution is scalable and effective for sustainable urban waste management.

5. Analysis

The system used a Node.js and Express backend with JWT-based authentication and role-based access control. AI-based garbage classification was done using a CNN model. Real-time communication was achieved through GPS integration. Google OR-Tools facilitated route optimization, and MongoDB with GridFS managed data and image storage. The frontend dashboards for clients, drivers, and the office were created to support real-time monitoring and interaction.

VI. CONCLUSION AND FUTURE WORK

This study presents an advanced AI-driven on-demand garbage collection system that integrates real-time data processing, intelligent assignment, and user-centric design. The system successfully addresses limitations of traditional waste management by enabling dynamic, efficient, and transparent operations.

Future work includes:

- Improving AI model accuracy using larger datasets
- Integrating real-time traffic data into routing
- Expanding IoT sensor deployment
- Enhancing predictive analytics for waste generation
- Scaling deployment across larger urban environments

The proposed solution represents a significant step toward sustainable and intelligent urban waste management systems.

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