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Original Article

Efficient Smart Waste Management Using Dynamic Route Optimization System and Dijkstra's Algorithms

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Abstract

Efficient waste management is an essential requirement for modern cities due to increasing population, urbanization, and the growing volume of municipal waste. Traditional waste collection systems usually follow fixed schedules and routes, which often lead to inefficient resource usage, delayed waste pickup, and overflowing bins. To address these challenges, the Smart Waste Management and Dynamic Route Optimization System is developed to improve waste monitoring and collection through a technology-driven approach. The main objective of this phase is to design and implement client-side components that allow users to access key system functionalities in an organized manner. The proposed work for smart waste management system using Dynamic Route Optimization algorithm is designed to improve the efficiency of waste collection through a web-based platform. The system provides a secure interface where administrators can monitor bin levels, view alerts, and manage waste collection activities through a centralized dashboard. When bins reach a predefined threshold, notifications are generated and sent to assigned employees via SMS using the Twilio messaging service with relevant bin and location details. Additionally, a route optimization module applies Dijkstra's algorithm to determine the shortest path between multiple bin locations, reducing travel distance and improving collection efficiency.

Keywords: *Dijkstra's Shortest Path Algorithm, Dynamic Route Optimization, Operational Efficiency, Smart Waste Management, Threshold-based Alerting*

Introduction

Urban waste management requires efficient monitoring and timely collection to maintain public hygiene. Although many cities use IoT sensors to track bin levels through centralized dashboards, task assignment and communication with collection staff are often handled manually, causing delays and coordination issues. The Smart Waste Management and Dynamic Route Optimization System is developed to improve waste collection efficiency using a technology-based approach. The system allows administrators to monitor bin status through a centralized dashboard and send SMS alerts to employees via Twilio when bins reach a defined threshold level. It also applies Dijkstra's algorithm to determine the shortest collection route between bin locations, reducing travel distance and improving operational efficiency.

The remaining sessions are divided into literature review, next discussed proposed work, result and discussion are explained in the paper, conclusion and future work has been given in last paragraph.

Literature Survey

1. Presented a smart waste management and classification system integrating IoT, deep learning, and edge–cloud computing. The system uses grid-based waste segmentation and a VGG16 convolutional neural network to classify waste into biodegradable and non-biodegradable categories, further separating non-biodegradable waste into plastic, glass, and metal. The architecture reduces latency through hybrid edge-cloud deployment and achieves over 90% classification accuracy, improving real-time monitoring and automation in smart cities.
2. Developed an RFID-based smart waste management system using self-describing waste objects. Each waste item carries digital information stored in RFID tags to assist users in selective sorting and enable smart bins to track bin contents without relying on external databases.

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The system improves recycling efficiency by allowing bins and collection vehicles to automatically identify waste type, ownership, and estimated weight, enhancing transparency and sorting accuracy.

4. Proposed an IoT-based municipal solid waste management system for smart cities using sensor-equipped smart bins. The system monitors bin fill levels, temperature, humidity, and fire hazards, and transmits data via wireless networks to a central control hub and supports future waste generation forecasting using historical data, improving scheduling efficiency, reducing operational costs, and minimizing overflow-related environmental risks.
5. Introduced an automated machine learning-based smart waste management system focusing on sensor-driven container fill-level prediction. The system applies a Random Forest classifier to analyze temporal sensor data for accurate waste level detection. The model improves operational efficiency by reducing human intervention, supporting predictive waste collection, and enabling intelligent classification of industrial and municipal waste types such as plastic, paper, and metal.
6. Identifies emerging research directions such as IoT-based infrastructure, big data analytics, blockchain integration, waste-to-energy systems, citizen engagement, and policy framework for holistic, technology-driven, and sustainability-focused waste management models for future urban ecosystems.
7. Developed a wireless sensor network (WSN)-based architecture for solid waste monitoring. Sensor nodes inside bins transmit real-time fill-level data to a centralized server to optimize collection routes, reduce fuel consumption, and minimize unnecessary vehicle deployment.
8. Proposed an IoT-based smart garbage bin system using ultrasonic sensors and GSM communication and sends automated alerts when bins reach a predefined threshold, reducing manual inspection and improving collection efficiency.
9. Presented a smart city waste management framework integrating IoT, cloud computing, and data analytics to enables real-time monitoring and dynamic scheduling of collection vehicles to improve sustainability and operational efficiency.
10. Designed a bin monitoring system using ultrasonic sensors to detect waste levels and transmit data to a central control station. The focus was on preventing overflow and improving municipal waste collection planning.
11. Introduced the Smart Bin system, which uses sensor-equipped bins and a cloud-based visualization platform to allow administrators to monitor bin status and optimize waste collection routes in real time.
12. Developed a location-based waste collection system combining GPS and cloud computing. The system improves vehicle routing decisions using real-time bin status and geographical data.
13. Implemented a real-time bin level detection system using ultrasonic sensors. Data is transmitted wirelessly to municipal authorities, enabling proactive waste management and reduced environmental pollution.
14. Proposed an IoT-enabled service model integrating sensors, cloud platforms, and mobile applications. The system supports real-time monitoring and predictive waste collection in smart cities.
15. Designed a cloud-based IoT waste monitoring system with a web interface for tracking bin status. The system improves scheduling and reduces manpower requirements.
16. Developed a dynamic vehicle routing model that accounts for time windows and real time traffic conditions. The goal was to minimize fuel consumption and reduce operational costs.
17. Proposed a centralized integrating IoT sensors and cloud storage to support data-driven decision-making for city-wide bin monitoring. Developed an IoT-based waste management system using RFID and wireless communication to track bins and vehicles, improving automation in municipal operations [18].
18. Conducted a comprehensive survey on IoT-based waste management systems, analyzing system architectures, communication protocols, and future research challenges.[19] Presented a mathematical optimization model for waste collection scheduling aimed at reducing pollutant emissions and operational costs.

Methodology

The system operation begins with administrator authentication to ensure secure access to the management platform. After successful login, the administrator accesses the dashboard interface, which displays the operational status of deployed waste bins. The system continuously monitors bin levels and identifies containers that reach the predefined threshold limit. When a bin exceeds the threshold value, the administrator initiates an alert notification through the platform. The system sends an SMS message to the assigned employee using the integrated messaging service, providing details such as bin identification and location. After receiving the notification, the employee is guided through an optimized waste collection route generated using the shortest-path algorithm. Following the suggested route, the employee reaches the designated location and performs the waste collection task.

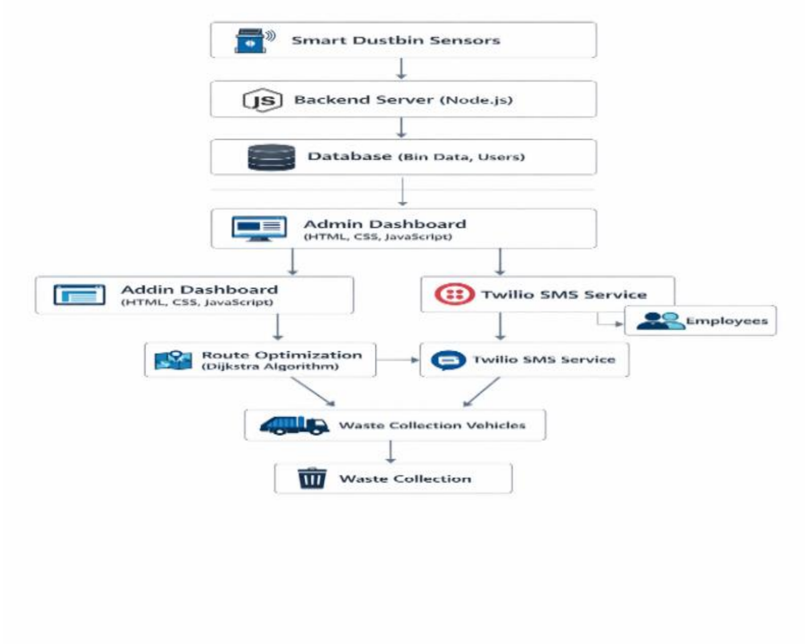

Figure.1. Proposed Work for Smart Waste Management System

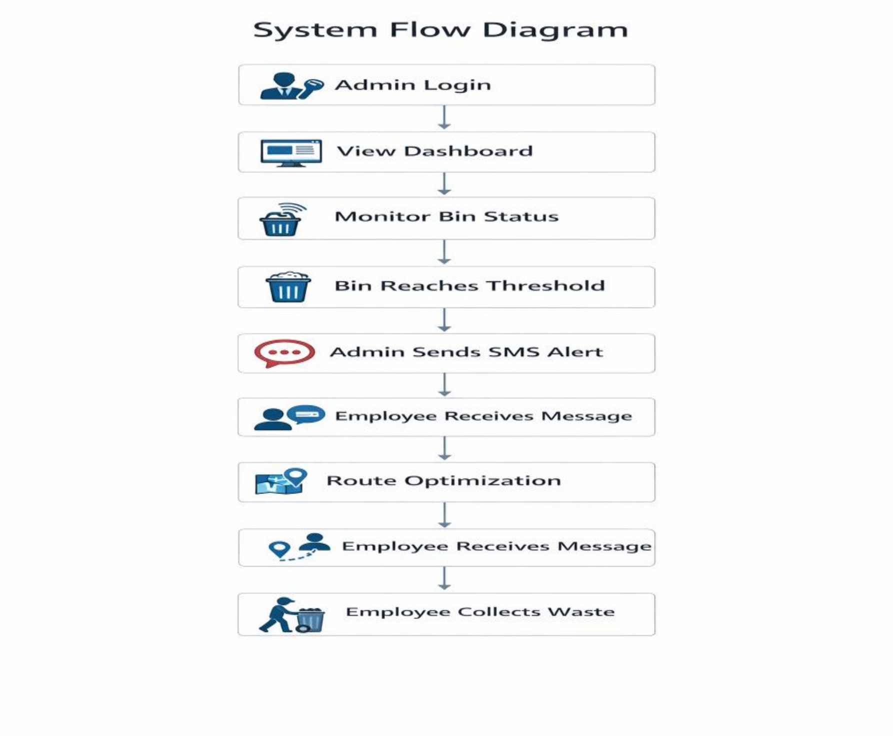

Figure.2. System Flow for Smart Waste Management System

The system database consists of multiple structured datasets that support monitoring, communication, and route planning operations. The Admin dataset stores administrative account information such as name, password, used for system authentication and management. The Dustbin dataset maintains records of deployed bins including bin ID, geographical location, region, latitude, longitude, threshold level, and current fill level for monitoring purposes. The Employee dataset contains details of waste collection staff such as employee ID, name, phone number, assigned region, and operational status. The Alert dataset records notification events generated when bins reach the defined threshold level, including alert ID, associated bin ID, employee ID, message content, alert time, and processing status. Additionally, the Route dataset stores routing information such as route ID, employee ID, starting location, destination location, travel distance, and calculated route path used for optimized waste collection.

The system is developed and tested on a laptop equipped with a 12th Generation Intel Core i5-1235U processor (1.30 GHz), 8 GB RAM, and a 64-bit Windows operating system (x64 architecture), providing adequate computational capacity for application development, database processing, and server execution. The frontend is implemented with HTML, CSS, and JavaScript to provide a responsive dashboard for monitoring bin status and managing alerts. Backend operations are handled using Node.js, which manages application logic, database connectivity, and integration with external services such as Twilio for SMS notifications. A MySQL database is used to maintain records related to bins, employees, alerts, and route data. Development and testing are performed using IDEs like Visual Studio Code with Git-based version control to track project updates. This setup provides a reliable platform for implementing, testing, and maintaining the system.

Result and Discussion

Figure.3. provide administrators to securely access the Smart Waste Management system by entering their username and password. After successful authentication, the administrator can open the dashboard to monitor bins, manage alerts, and control system operations.

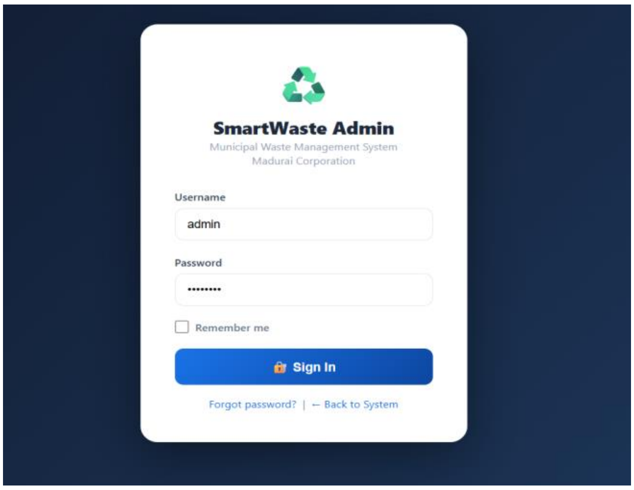

Figure.3. Admin Login Page

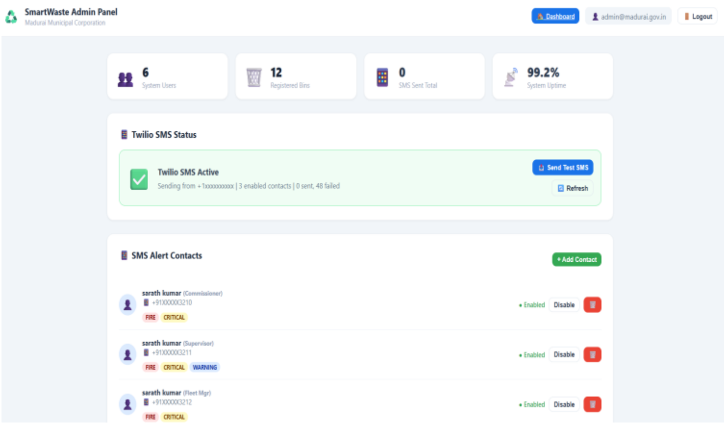

Figure.4. SMS Alert Page

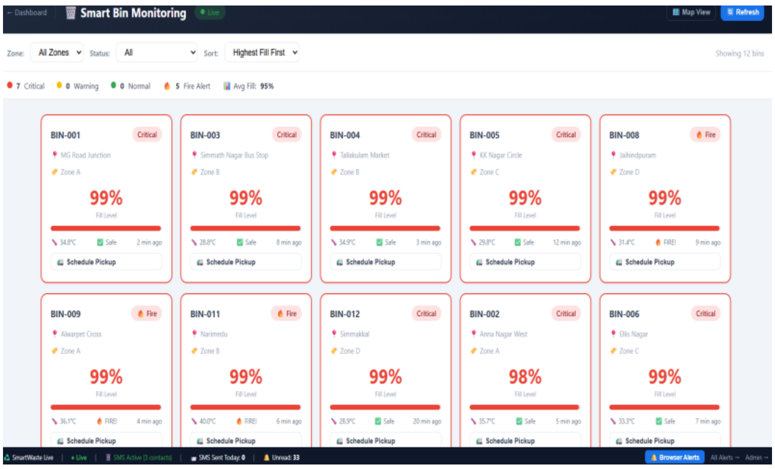

Figure.5. Smart Bin Monitoring Level

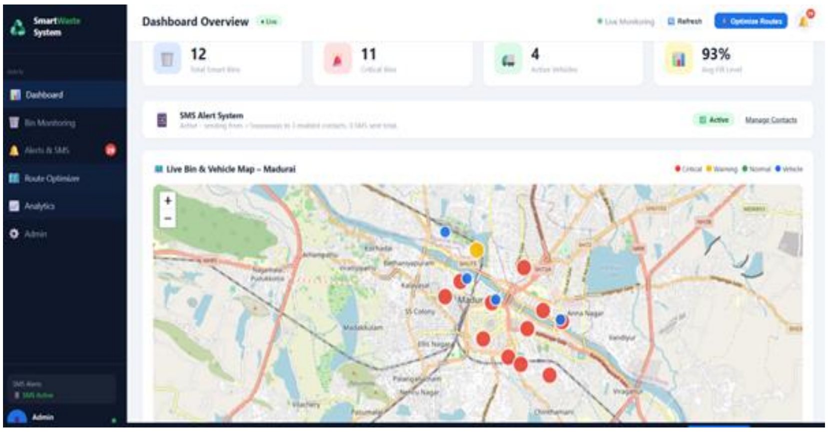

Figure.6. Dijistra Algorithm for Finding Dustbins

Figure.6. shows the with real-time system information such as total bins, critical bins, active vehicles, and average fill level. It also displays a live map for monitoring bin locations and their status.

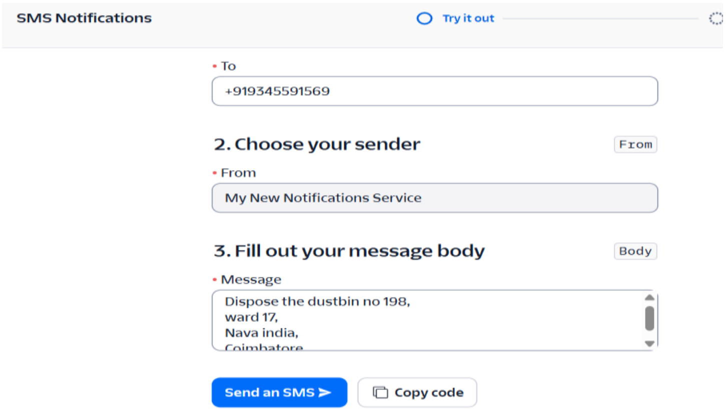

Figure.7. SMS alerts to Municipal Employees

Figure.7. allows the administrator to send SMS alerts to municipal employees by entering the phone number, selecting the sender, and composing the message with dustbin details.

Conclusion

Smart Waste Management and Dynamic Route Optimization System provides a digital platform to improve municipal waste collection operations through monitoring, communication, and route planning. The system enables administrators to observe bin status through a centralized dashboard and send SMS alerts to assigned employees when bins reach the defined threshold level. This approach helps reduce delays in waste collection and improves coordination between administrative staff and field workers. The integration of route optimization using Dijkstra's algorithm supports efficient navigation between multiple bin locations, reducing travel distance and fuel consumption. Overall, the system demonstrates how a web-based management platform combined with automated notification and route calculation can enhance the effectiveness of waste collection processes and support cleaner urban environments. The current implementation uses simulated bin-level data instead of real-time input from physical sensors. Dustbin status values are manually generated for testing and demonstration purposes, which means the system does not receive live environmental data from IoT devices deployed in actual waste bins. As a result, the monitoring process does not fully reflect real-world conditions. Integration with sensor-based hardware would be required to support continuous, real-time waste level detection in practical deployments. Future development can focus on integrating IoT-based sensors with waste bins to provide real-time fill-level data directly to the system. This will enable automatic monitoring without relying on manually generated values. The platform can also be enhanced by incorporating mobile applications for field employees, real-time traffic data for improved route planning, and advanced analytics to support predictive waste collection and better resource management.

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Conflicts of interest
The authors declare that there are no conflicts of interest regarding the publication of this paper.

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