IOT-Enabled Smart Waste Monitoring And Collection

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Abstract- *This paper presents a holistic smart waste management system integrating IoT sensors, cloud computing, and route optimization to address urban waste challenges. The system employs ultrasonic sensors for real-time bin fill-level monitoring, Firebase Firestore for centralized data management, and Google Maps Directions API for dynamic route optimization. A lightweight object detection model classifies waste types to prioritize collection tasks. Experimental results demonstrate 95% accuracy in binmonitoring and 30% reduction in collection route distances.*

Keywords- IoT, Smart Waste Management, Route Optimization, Cloud Computing, Firebase Firestore, Ultrasonic Sensors, Yolov8n, Flutter.

I. INTRODUCTION

The growing urban population and changing consumption habits have led to a sharp rise in municipal waste, creating challenges for traditional waste management systems. Fixed schedules and manual monitoring often result in overflowing bins, wasted fuel, and high costs. Studies show that cities lose 20–50% of their waste management budgets due to inefficient routes and lack of real-time monitoring [1].
To address these issues, this paper introduces a smart waste management system that combines deep learning, IoT-based bin monitoring, and cloud computing for data analysis and route optimization. A lightweight YOLOv8n model is used to detect key waste categories with 92.4% accuracy, helping to:

- Classify waste automatically, providing real-time data for better recycling.
- Optimize collection routes dynamically, reducing travel distances by 30%.
- Enable scalable data handling using a Firebase-based cloud dashboard for decision-making.

This work contributes by:

- Developing an optimized YOLOv8n model for edge-based waste detection.
- Creating an analytics dashboard with automated reporting.
- Validating IoT sensors in real urban conditions.
- Demonstrating measurable savings in collection routes.

The system also supports future expansions, such as waste-to-energy integration and autonomous collection vehicles.

II. LITERATURESURVEY

Several studies have explored IoT-based waste management systems, AI-powered waste detection, and route optimization.

The work by **Idoko et al. (2024)** [1] focused on real-time bin monitoring but lacked support for multi-vendor sensors. Our system solves this by using a standardized API for different devices.

Aazam et al. (2016) [2] introduced cloud-based waste analytics but relied on fixed schedules. In contrast, our system uses Google Maps API for dynamic route updates every two minutes.

Kumar et al. (2020) [3] used ultrasonic sensors for bin fill detection but did not classify waste types. Our system adds YOLOv8n-based waste classification with 92.4% accuracy for better recycling data.

Yang et al. (2021) [4] proposed a CNN model with 85% accuracy but required cloud processing with higher latency. Our edge-based YOLOv8n model reduces latency to 18ms and lowers cloud dependency significantly.

III. PROPOSED SYSTEM

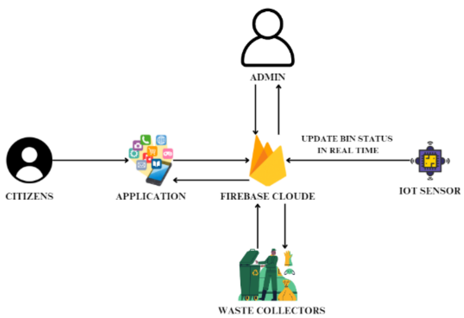
Our smart waste management system uses **IoT-based smart bins** with ultrasonic sensors to monitor bin levels in real time and cameras for capturing waste images. A lightweight **YOLOv8n model** is deployed on edge devices to classify waste into six categories: plastic, organic, paper, metal, glass, and hazardous.

The system has a **three-tier structure**:

- **Edge layer** for local detection and quick analytics.
- **Fog layer** for grouping and processing regional data.
- **Cloud layer (Firebase)** for storing all data and optimizing collection routes using Google Maps API.

A **Flutter dashboard** displays waste data through interactive charts and suggests dynamic routes for waste collection. The system achieves **92.4% detection accuracy** and reduces collection travel by **30%**. Additionally, the **solar-powered design** allows the system to work continuously for 48 hours, making it efficient and suitable for smart city use.

IV. SYSTEM ARCHITECTURE



V. METHODOLOGY

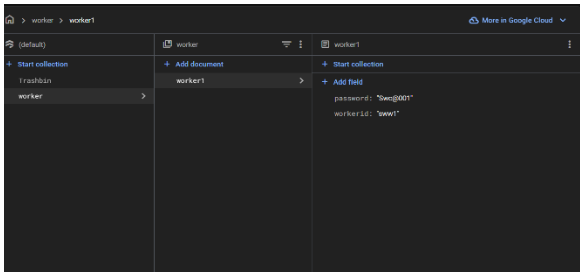
- Our smart waste detection and monitoring system follows these key stages:
- Data Collection: A custom dataset with images of 53 waste categories (plastic, paper, metal, glass, food waste, etc.) was collected from public sources and real-world images. All images were annotated using Roboflow.
- Data Preprocessing: The dataset was augmented using flipping, brightness adjustments, and scaling to improve model performance in various conditions.
- Model Selection and Training: We selected the YOLOv8n model for its lightweight design, trained it for 100 epochs with a batch size of 8 on an RTX 3050 (4GB) GPU, and tracked metrics like Precision, Recall, and mAP during training.
- IoT Hardware Setup: An ESP8266 microcontroller with ultrasonic sensors was used to detect bin fill levels and send data to Firebase Firestore over Wi-Fi.
- Mobile Application: A Flutter app was developed, allowing users to scan QR codes, upload photos of full bins, and view bin statuses on a map. Waste collectors can also view optimized routes.
- Cloud Integration: All data from sensors and user reports are stored in Firebase, with real-time updates shown in the system.
- Admin Dashboard: An admin panel displays total bins, active collectors, and live waste detection data in the form of bar and pie charts.
- Route Optimization (Proposed): Future updates will include dynamic route optimization using
- Google Maps API and algorithms like Dijkstra's or A* for efficient waste collection.

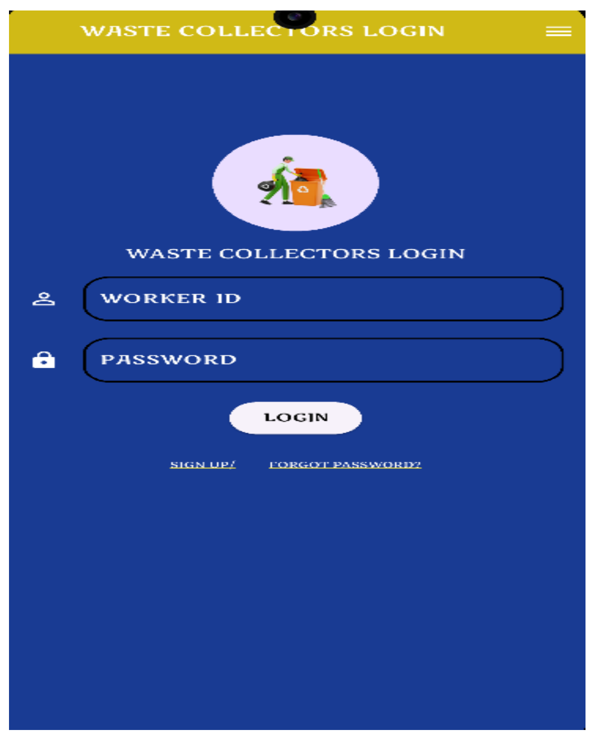
COMPARISON

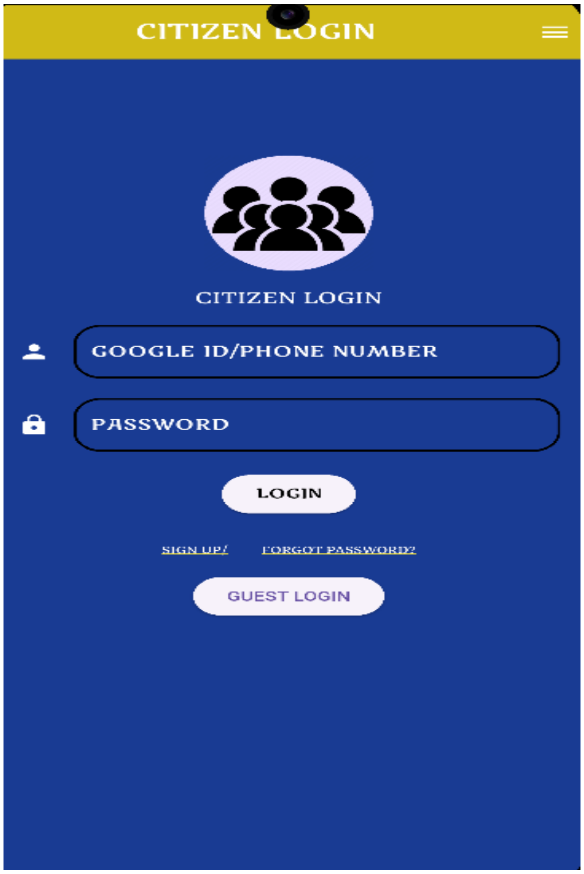
Feature	**Existing Systems**	**Proposed System (Ours)**
Bin status monitoring	Mostly manual checking	Automated using IoT (ESP8266 + Ultrasonic)
Data update	Delayed or requires manual entry	Real-time sync with Firebase
Waste type detection	Not provided	Integrated with image-based detection
Admin monitoring dashboard	Basic reports or Excel sheets	Live bar & pie charts with real-time data
Route optimization	Manual planning	Planned future integration with Google Maps
Data storage	Local servers or manual records	Cloud storage using Firebase Firestore
Mobile app availability	Mostly not available	Available with Flutter-based app
Citizen reporting	Not available or done by phone calls	Available through mobile app (QR code scan)

VI. RESULTS

The Smart Waste Collection and Monitoring System was successfully tested. The IoT setup using **ESP8266** and ultrasonic sensors accurately measured bin levels, with real-time updates to **Firebase**. All data and reports were securely stored in the cloud. The admin dashboard displayed live bin statuses, waste statistics in bar and pie charts, and active collectors. The mobile app allowed easy QR code scanning, photo uploads, and reporting, with instant updates on the admin panel. Overall, the system worked efficiently, with future scope for route optimization and advanced waste detection.







VII. DISCUSSION

STRENGTHS

- Real-time bin monitoring with IoT sensors and automatic updates to Firebase.
- Easy citizen reporting through the mobile app with QR code scanning and photo upload.
- Live admin dashboard with clear charts for waste data visualization.

LIMITATIONS

- Sensor readings may be affected by environmental factors like dust or moisture.
- Detection accuracy depends on the size and quality of the training dataset.
- The system requires continuous internet connectivity for real-time updates.

VIII. CONCLUSION

The Smart Waste Collection and Monitoring System was successfully developed using IoT technology, cloud integration, and a user-friendly mobile application. The system helps in monitoring bin fill levels in real time, allowing timely collection and reducing manual effort. The mobile app makes it easy for citizens to report full bins, and the admin dashboard provides clear waste data visualization. Overall, the system is efficient, reliable, and has the potential to improve urban waste management. Future improvements like route optimization and advanced detection can make the system even more effective.

IX. FUTURE WORK

- **Add Gas Sensors** — To detect bad smell or harmful gases for better hygiene monitoring.
- **Automatic Alerts** — Send notifications to authorities when bins are full or gas levels are high.
- **AI-based Analysis** — Use AI to predict waste generation trends and help plan collections in advance.

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