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Real-Time Waste Segregation System: An AI-Powered Platform for Integrated Municipal Waste Management

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***Abstract* – Urban waste management suffers from several issues like improper waste segregation, collection, coordination between citizens and municipality etc. This paper presents a Real-Time Waste Segregation System, an AI-powered software-based platform for integrated waste classification, citizen participation, collection, and municipal monitoring. It leverages the Google Gemini API for image-based classification of single or multiple waste items into Wet Waste, Dry Waste, E-Waste, Bulk Waste. It also suggests appropriate disposal. The platform comprises four role-based dashboards (Citizen, Workers, Supervisors, Administrators). It allows citizens to raise complaints, request for waste collection, track their request, get reminders, interact with administrators etc. Workers can manage their tasks, attendance, emergency alerts, completion evidence. Supervisors can monitor operations, verify completed tasks. Administrators can manage users, assignments, complaints, feedback, analytics, municipal performance etc. Google Maps is used for location-based operations. Supabase is used for authentication, database, storage, real-time synchronization, access control etc. This system integrates waste identification with collection, verification, monitoring in a unified digital workflow.**

Artificial intelligence, Waste segregation, Google Gemini API, Smart waste management, Image classification, Municipal management, Real-time tracking, Citizen participation, Supabase.

I. INTRODUCTION

Rapid urbanization, population growth, and consumption have led to increased solid waste generation in urban areas. Challenges like improper waste segregation, inefficient waste collection, lack of coordination between citizens and municipality etc. hamper the achievement of clean and sustainable environment.

Waste segregation at the source is crucial for efficient recycling and disposal. Mixing of various waste items hinders the recovery of recyclable waste. Traditional waste management processes heavily rely on manual complaint reporting, collection scheduling, monitoring etc. leading to delays, lack of transparency etc.

With the advances in Artificial Intelligence (AI), image analysis, cloud computing, location based technologies, there are opportunities to enhance these processes. For example, image analysis with AI can help citizens in identifying waste categories. Digital platforms can facilitate citizen-municipality/field worker interaction.

This paper presents a Real-Time Waste Segregation System that integrates AI-based waste classification with municipal waste management operations. It leverages Google Gemini API for image-based classification of single or mixed waste items into Wet Waste, Dry Waste, E-Waste, Bulk Waste.

The platform comprises four role-based dashboards (Citizen, Worker, Supervisor, Administrator). Citizens can detect waste, raise complaints, request for collection, track progress etc. Workers can manage tasks, provide completion evidence. Supervisors can monitor operations, verify completed tasks. Administrators can manage users, requests, assignments, performance information etc.

The key contributions of this work are:

1. Integration of Gemini API-based classification for single and mixed waste images.
2. Citizen services like complaint reporting, collection request, disposal suggestion, reminders, request tracking.
3. Role-based dashboards for citizen, worker, supervisor, administrator.
4. Digital task assignment, attendance, completion evidence, supervisor verification.
5. Centralized municipal monitoring, location-based operations, feedback, analytics etc.

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II. LITERATURE SURVEY

Various studies have focused on AI-based classification, mobile applications, recycling awareness, smart collection systems etc.

Wijendra et al. [1] proposed a mobile-based garbage collection system with route, schedule optimization, AI chatbot, GPS tracking. Route optimization reduced reported travel cost from 172 minutes to 144 minutes. It highlights the use of mobile applications and location-based services, but the focus is mainly on collection optimization.

Aggrawal et al. [2] presented RECYCLE-RIGHT, a waste classification and awareness system. It uses YOLOv8 for image classification and machine learning for text classification. It also provides recycling suggestions, awareness, recycling location finder. The focus is mainly on waste identification and environmental awareness.

Sharma et al. [3] proposed AI-Powered waste classification and recycling optimization with computer vision and Convolutional Neural Networks (CNNs). It classifies materials like plastic, paper, glass, organic waste from images. It focuses mainly on automated waste identification and sorting.

Mali et al. [4] proposed SwachhaSetu, a system that integrates smart bins, live location, geotagged complaints, AI-based waste scanning, administrative monitoring. It shows the use of IoT, predictive analytics for municipal waste collection and monitoring.

Sumithra et al. [5] proposed Think Zero Waste application that connects consumers with recycling organizations. It supports image-based waste classification, pickup schedule, collection tracking, predictive analytics, route optimization. The focus is on recycling participation and collection coordination.

A. Comparative Analysis and Research Gap

Various studies focus on different aspects of waste management like classification, collection scheduling, recycling awareness, municipal monitoring. However, these functionalities are spread across different approaches. This integration opportunity is addressed in the proposed system. It integrates AI-based single and mixed waste classification with citizen services, worker task management, supervisor verification, centralized administration. Unlike other approaches that mainly focus on classification or collection optimization, the proposed platform integrates waste identification with broader municipal service workflow.

III. PROPOSED METHODOLOGY

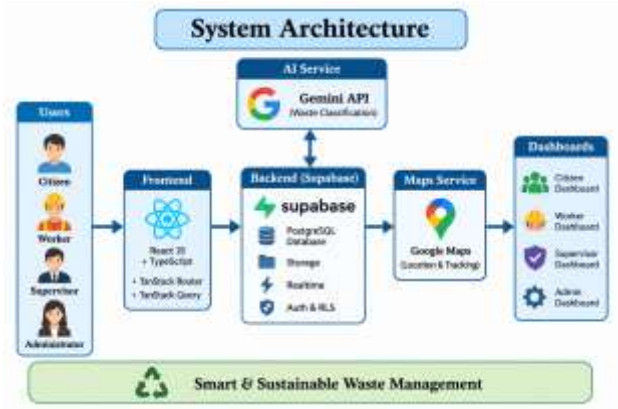

Fig: System Architecture of the Proposed Real-Time Waste Segregation System.

The proposed system follows a centralized web-based architecture. Citizens, Workers, Supervisors, Administrators can access the application through React 19 and TypeScript based frontend. Backend services like authentication, PostgreSQL database, storage, real-time synchronization, role-based access control are provided by Supabase. Google Gemini API is used for AI-based waste classification. Google Maps is used for location selection, task tracking. The four role-based dashboards provide integrated waste identification, collection management, task monitoring, administrative operations.

III. SYSTEM IMPLEMENTATION

The system is implemented as a web-based application using React 19, TypeScript. It uses Supabase as backend platform.

The frontend provides different interfaces for the four user roles. TanStack Router is used for navigation. TanStack Query is used for data retrieval, synchronization. The AI detection module interacts with Gemini API to process the submitted images. It displays the classification results with disposal recommendations.

Citizen Dashboard integrates waste detection with complaint reporting, collection request, tracking, reminders, awareness, feedback etc. Worker Dashboard provides task access, attendance, emergency alerts, location information, completion evidence submission.

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Supervisor Dashboard supports operational monitoring, overdue task identification, completed task verification. Administrator Dashboard provides centralized management of users, requests, assignments, citizen messages, feedback, municipal performance information.

Backend integrates these modules through PostgreSQL records, storage services, authentication, real-time synchronization. Google Maps is used for location-related functionalities. Once a task is verified, authorized administrators can send completion confirmation email to citizen.

This implementation integrates citizen requests with worker activities, supervisor verification, administrative monitoring in a single application.

V. RESULTS AND DISCUSSION

The implemented system integrates AI-based waste identification with citizen services, municipal operations. The functional outcomes can be discussed in the following areas.

A. Waste Classification: It integrates Gemini API for image-based analysis of single or mixed waste items. It categorizes the classification results into four waste categories with disposal suggestions. The reliability of classification depends on image quality, API interpretation. For quantitative accuracy, it needs evaluation with labelled image dataset.

B. Citizen Services: It provides services like complaint reporting, collection request, request tracking, reminders, interaction with administrators. It provides a common interface for waste-related interactions.

C. Worker and Supervisor Operations: It allows workers to manage tasks, attendance, emergency alerts, completion evidence. It allows supervisors to monitor progress, identify overdue tasks, verify completed tasks.

D. Administrative Monitoring: It allows administrators to manage users, complaints, collection requests, assignments, citizen feedback. It provides map-based view, analytics for geographical, operational monitoring.

E. Tracking, Synchronization: It uses unique tracking identifiers, status information, Supabase Realtime for request tracking, synchronization across relevant interfaces. It provides notifications, completion emails for service activity updates.

A. Functional Evaluation Scenarios

The major functionalities can be evaluated using the scenarios listed in Table I.

TABLE I. FUNCTIONAL EVALUATION SCENARIOS

Module	***Evaluation scenario***
AI Detection	Submit a single-waste image
Mixed Detection	Submit an image with multiple waste items
Citizen Services	Submit a complaint, collection request
Request Tracking	Check request status, history
Worker Dashboard	Update an assigned task
Attendance	Perform check-in, check-out
Supervisor Dashboard	Verify completion evidence
Administrator Dashboard	Assign, manage requests
Maps	Select, view task locations
Notifications	Check request and task updates
Feedback	Submit a rating, comment
Completion Email	Send confirmation after verification

The proposed architecture shows how these modules are integrated in a centralized platform. However, for quantitative performance, systematic testing is required for classification accuracy, API response time, notification delivery performance, operational efficiency etc. It depends on internet connectivity for cloud-based services, external API integration. The classification results can vary based on image quality, lighting, visibility of waste materials.

VI. CONCLUSION AND FUTURE WORK

This paper presented a Real-Time Waste Segregation System that integrates AI-based waste classification with citizen participation, municipal waste management operations. It leverages Google Gemini API for image-based classification of single or mixed waste items into Wet Waste, Dry Waste, E-Waste, Bulk Waste.

It comprises four role-based dashboards for citizen services, worker task management, supervisor verification, centralized administration. Google Maps is used for location-based operations. Supabase is used for authentication, database, storage, real-time synchronization, role-based access control.

It integrates waste identification with complaint reporting, collection request, task execution, verification, administrative monitoring in a unified digital approach for municipal waste management.

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Future work can include evaluating classification performance with larger labelled image datasets. Enhancing reliability under various environmental conditions. Measuring response time, operational efficiency. Further improvements can include multilingual support, optimized collection route, offline task updates, integration with IoT-enabled smart waste bins.

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