SwatchhAI: An Android-Based Smart Waste Segregation and Collection System Using Convolutional Neural Networks

[1]G. Parvathi Devi, [2]B. Varun Reddy, [3]P. Raghava Patel, [4]Priyanshu Rai

[1]Assistant Professor, [234]B.Tech Students,
[1234]Department of CSE (AI & ML)
[1234]CMR Technical Campus, Hyderabad

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ABSTRACT

Rapid urbanization has intensified the challenges of municipal solid waste management, particularly in ensuring proper waste segregation at the source. This paper presents SwatchhAI, an Android-based smart waste segregation and collection system that leverages Convolutional Neural Networks (CNN) and cloud-based services to automate waste classification without the need for physical sensors or IoT hardware. The proposed system allows users to capture or upload images of waste materials through a Flutter-based mobile application. These images are processed by a CNN model deployed using TensorFlow Lite, which classifies waste into three categories: dry, wet, and hazardous. The system integrates Firebase for secure user authentication, real-time database management, and cloud storage. Additional features include GPS-based waste pickup requests, real-time tracking, push notifications, and a reward-based incentive mechanism. Experimental evaluations demonstrate an overall classification accuracy of 85–92%, confirming the viability of the proposed approach. The system contributes to smart city initiatives by promoting responsible waste disposal and reducing environmental pollution through intelligent, scalable, and cost-effective technology.

I. INTRODUCTION

Urban waste management is one of the most pressing environmental challenges facing modern cities. Improper disposal and the absence of waste segregation at the source lead to contamination of recyclable materials, increased landfill burden, and heightened environmental and public health risks. Traditional waste management systems rely on manual sorting, which is labor-intensive, error-prone, and exposes workers to health hazards.

The proliferation of smartphones and advancements in artificial intelligence (AI) present a compelling opportunity to build accessible, software-driven solutions to this problem. SwatchhAI addresses these challenges by providing an intelligent, sensor-free waste classification system deployable on any Android device. The application uses deep learning—specifically a Convolutional Neural Network—to analyze waste images and produce real-time segregation guidance.

Unlike existing smart waste management approaches that require costly IoT sensors, SwatchhAI operates entirely through the device camera and on-board AI inference, making it practical for large-scale adoption across both urban and rural environments. The system also integrates cloud services for waste pickup coordination and gamified user incentives, completing a full waste management workflow within a single mobile application.

II. RELATED WORK

Several studies have explored automation in waste management. Sensor-based systems employing moisture, metal, and infrared sensors have been proposed for automated waste bin classification [1]. While effective, such approaches incur significant deployment and maintenance costs. Image-based classification using deep learning has emerged as an alternative: Aral et al. (2018) demonstrated the feasibility of CNN-based recyclable waste classification with high accuracy on the TrashNet dataset [2]. Minouei et al. (2021) integrated MobileNet architectures into Android applications for real-time garbage detection, reporting accuracy above 88% [3].

Firebase-integrated mobile applications for waste reporting have been explored in smart city contexts, though few combine AI-driven classification with full-cycle waste collection management. The present work extends these efforts by unifying CNN-based classification, cloud backend, GPS-enabled pickup, and a reward mechanism into a single, cohesive Android platform.

III. PROBLEM DEFINITION

The core problem addressed is the widespread lack of proper waste segregation at the source, particularly in household and semi-public settings. Key contributing factors include:

- Dependence on manual segregation, leading to frequent classification errors.
- Low public awareness about correct waste disposal practices.
- High cost and complexity of existing IoT and sensor-based smart bin solutions.
- Absence of real-time feedback mechanisms to guide users during disposal.

These issues collectively result in reduced recycling efficiency, increased environmental contamination, and higher operational costs for municipal waste authorities.

IV. PROPOSED SYSTEM

A. System Overview

SwatchhAI is a multi-layered, sensor-free waste management system built as a Flutter-based Android application. The architecture comprises three primary layers: the User Layer (mobile application), the AI Processing Layer (CNN-based image classification), and the Backend and Cloud Layer (Firebase services).

B. System Architecture

The User Layer provides user-facing modules including authentication (login/signup), the AI Waste Scanner, waste pickup request submission, GPS-based tracking, a rewards dashboard, and a waste education module. Once a waste image is submitted, it is passed to the AI Processing Layer where preprocessing, feature extraction, and CNN-based classification occur entirely on the device using TensorFlow Lite. The result—along with bin color recommendations—is returned to the user in real time. User data, pickup requests, and images are stored and synchronized via Firebase Firestore, Firebase Storage, and Firebase Authentication. Push notifications and GPS-based location services are leveraged for pickup coordination between users and administrators.

C. Waste Classification using CNN

The system employs a Convolutional Neural Network as the core classification algorithm. The training dataset consists of labeled waste images distributed across three classes: dry waste (plastics, paper, glass, metals), wet waste (food scraps, organic/biodegradable matter), and hazardous waste (batteries, chemicals, medical waste).

Each input image undergoes the following preprocessing pipeline prior to model inference:

- Resizing to a fixed input dimension (e.g., 224 × 224 pixels).
- Pixel value normalization to the range [0, 1].
- Noise reduction to enhance image clarity.
- Data augmentation during training (rotation, flipping, scaling) to improve generalization.

The CNN architecture consists of convolutional layers (feature extraction of edges, textures, and shapes), pooling layers (dimensionality reduction), and fully connected layers (classification). The trained model is exported to TensorFlow Lite (.tflite) format, reducing model size and enabling efficient on-device inference without requiring internet connectivity.

D. Key Features

- AI Waste Scanner: Real-time classification of waste into dry, wet, or hazardous categories with bin-color recommendations.
- Waste Pickup Request: Users submit GPS-tagged pickup requests with waste images, stored in Firebase Firestore.
- Real-Time Tracking: Users monitor pickup request status through live Firebase updates.
- Reward System: Points are credited to users for responsible waste submissions, redeemable for vouchers.
- Admin Dashboard: Administrators view, accept, and update pickup requests; monitor user activities.
- Education Module: Guidance on waste categories and disposal best practices.

V. IMPLEMENTATION

A. Technology Stack

The application is developed using Flutter (Dart) for the cross-platform mobile frontend, ensuring compatibility with Android devices running Android OS. TensorFlow Lite is integrated for on-device CNN inference. Firebase services (Authentication, Firestore, Storage, Cloud Functions) constitute the backend. The development environment is Android Studio.

B. Hardware Requirements

- Processor: Any Snapdragon-class or equivalent smartphone SoC.
- RAM: Minimum 2 GB (4 GB recommended for optimal performance).
- Storage: Minimum 500 MB free space.
- Camera: Required for real-time waste image capture.

C. CNN Training and Deployment

The CNN model was trained on a labeled waste image dataset encompassing thousands of samples across the three target categories. Training was performed using TensorFlow on a GPU-enabled workstation. Post-training, the model was converted to TensorFlow Lite format using TensorFlow's built-in conversion utilities. The .tflite model file was bundled within the Flutter application as an asset, enabling offline classification with sub-second inference times on mid-range Android hardware.

D. Firebase Integration

Firebase Authentication provides secure email/password-based user registration and login. Upon registration, user profiles (including role, reward points, pickup count, and account creation timestamp) are stored in Firebase Firestore. Waste images associated with pickup requests are stored in Firebase Storage. Cloud Firestore's real-time listener capabilities are used to push pickup status updates to the user's mobile application without requiring manual refresh.

VI. RESULTS AND ANALYSIS

The trained CNN model achieves an overall classification accuracy of approximately 85–92%, depending on dataset quality and image clarity. Performance analysis by waste category reveals:

- Dry Waste: Highest classification accuracy due to distinct visual features (consistent colors, rigid shapes of plastics, paper, metals).
- Wet Waste: High accuracy for recognizable organic materials; performance decreases slightly for non-uniform food waste.
- Hazardous Waste: Slightly lower accuracy attributable to limited training samples and visual similarity with dry waste categories (e.g., empty medicine bottles resembling plastic containers).

All seven functional test cases—covering user authentication, waste classification, invalid input handling, pickup submission, and status tracking—passed successfully. The application demonstrates consistent real-time performance, with AI inference completing within approximately 200–500 milliseconds on tested Android devices.

Table I: Summary of Functional Test Cases

TC ID	Test Case	Input	Expected Output	Result
TC-01	User Registration	Valid name, email, password	Account created in Firebase	Pass
TC-02	Invalid Login	Wrong credentials	Error message shown	Pass
TC-03	Waste Classification	Clear waste image	Correct category (Dry/Wet/Hazardous)	Pass
TC-04	Invalid Image Input	Blurry/unclear image	Low confidence warning shown	Pass
TC-05	Pickup Request	Location + waste type submitted	Request stored in Firebase	Pass
TC-06	Track	User checks	Real-time status displayed	Pass

	Pickup Status	request status		
TC-07	Reward Points Update	Successful waste submission	Points credited to user account	Pass

VII. DISCUSSION

SwatchhAI demonstrates that effective waste segregation can be achieved through a purely software-based approach, without the high cost and maintenance overhead associated with sensor-based smart waste systems. The combination of on-device CNN inference and cloud-based coordination creates a responsive, scalable solution suitable for diverse deployment contexts.

The reward mechanism introduces a behavioral incentive layer absent from most existing systems, encouraging consistent user engagement and potentially improving long-term adoption rates. The admin dashboard provides operational oversight, enabling waste authorities to coordinate collection activities based on real-time data rather than fixed schedules.

Key limitations of the current implementation include the relatively small training dataset for the hazardous waste category and the absence of IoT-based bin-fill monitoring. Classification accuracy for ambiguous waste items (e.g., laminated paper, composite packaging) remains an area for improvement.

VIII. FUTURE SCOPE

The SwatchhAI system offers significant potential for enhancement and scale-up. Proposed future directions include:

- Advanced Model Architectures: Integration of transfer learning models such as MobileNetV3 or EfficientNet for improved accuracy on limited datasets.
- Expanded Waste Categories: Extension of classification to more granular subcategories (e.g., e-waste, biomedical waste) for specialized municipal requirements.
- IoT Integration: Incorporation of smart bin sensors to provide bin-fill monitoring and automated collection triggers.
- Route Optimization: Integration of mapping APIs with machine learning–based route optimization algorithms to improve collection vehicle efficiency.
- Municipal System Integration: API connectivity with government and municipal waste management platforms for real-time operational coordination.
- Multilingual Support: Localization for broader accessibility across linguistic communities.
- Cloud Analytics Dashboard: Data visualization tools for authorities to analyze waste generation trends and optimize resource allocation.

IX. CONCLUSION

This paper has presented SwatchhAI, an Android-based smart waste segregation and collection system that leverages Convolutional Neural Networks and cloud technology to address the inefficiencies of traditional waste management. The system achieves classification accuracy in the range of 85–92%, provides real-time user feedback, and integrates a complete waste pickup workflow within a sensor-free, cost-effective mobile application. By demonstrating the practical applicability of AI and mobile computing to a critical environmental challenge, SwatchhAI contributes to the broader agenda of smart, sustainable cities. The system's modular architecture ensures it can be iteratively enhanced and scaled to meet evolving urban waste management needs.

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