

<Conference abbreviation>

<Conference Series name>

<Volume number and Year> <DOI Number>

Ask Your Trash: A Smart Bin System for Waste Segregation and Tracking

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Abstract.

This paper presents Ask Your Trash, an IoT-based waste management system with a database tracking layer that enables accountability via QR-based user registration. Unlike current smart bins, which mostly track waste fill levels, Ask Your Trash ensures complete auditability through linking of USER_ID with BIN_ID based on waste type (determined through classification by a CNN with 94.64% accuracy). This ensures creation of a continuous database entry. Hence, disposal of waste becomes a traceable process since every waste user is assigned an identity. Using MobileNetV2 (94.83% validation, 94.64% test accuracy on 3,080 unseen images), the system achieves 42 ms per image classification speed on a Raspberry Pi 4B. Comparatively, Custom CNN (77.08%), EfficientNetB0 (92.11%), and ResNet50 (92.09%) models do not exhibit comparable accuracy-speed tradeoff. With actual validation based on 500 images captured via the Pi Camera v2 in Pune, the model achieves 94.8% accuracy. The combined use of sensors (ultrasonic, load cell, moisture), CNN-based classification, QR-based identification and tracking, database storage, and mobile app-based visualizations results in up to 80% reduction in manual work and user accountability for waste sorting.

Keywords: Internet of Things; Smart Waste Management; Waste Segregation; QR Code Tracking; Smart City Infrastructure

1. INTRODUCTION

Urbanization and population expansion have resulted in an increased number of wastes that highlight the inefficiency of current waste management models. Traditionally, these methods rely on manual checks and scheduled collections, which do not suit dynamic urban environments [1], [2]. Hence, waste bins either overflow or are picked up while being still empty, creating inefficiencies and causing pollution problems [2]. Another substantial limitation is that information about waste bin capacity and composition is often unavailable and unobtainable. There are no insights into waste amounts and types, which results in inefficient service delivery. This problem makes it more difficult to segregate waste, which negatively impacts sustainability goals [3]. Development in IoT technologies has led to the creation of innovative smart waste bins that monitor bin capacity and send this data to the centralized system [1], [4]. However, at this stage, current approaches pay too much attention to technology rather than its users. The proposed “Ask Your Trash Smart Bin System” can resolve these problems by integrating sensor-based monitoring, QR code-driven user engagement, and centralized data management. This approach enhances transparency, optimizes collection, and promotes responsible waste disposal behaviour.

2. RELATED WORK

Waste management research has increasingly adopted digital technologies, beginning with IoT-based monitoring [1]. Early studies used sensors such as ultrasonic sensors to monitor bin fill levels and optimize collection schedules [2], [3]. Later systems introduced digital platforms to encourage user participation through reward-based waste disposal [3]. Wireless communication further enabled automated transmission of bin data to centralized dashboards, reducing manual inspections and supporting city-wide scalability [4], [5]. QR-code technologies improved secure and traceable user interactions [9] by linking physical waste disposal with digital user records [6], [7], [8], [10]. Building on these developments, the Ask Your Trash Smart Bin System integrates waste monitoring with individual user-level tracking. It records waste type and mass in a centralized database linked to user accounts, enabling users to view their disposal history through a mobile application. A planned reward mechanism will assign points based on waste categories and quantities, which can be redeemed through partner companies.

System	IoT Monitoring	User Interaction	AI Waste Classification
[2] IoT waste monitoring architecture	Yes	No	No
[3] Reward-based garbage monitoring	Yes	Yes	No
[8] IoT garbage monitoring framework	Yes	No	No
[10] Smart garbage monitoring using IoT	Yes	No	No
This work	Yes	Yes	Yes

Table 1. Analysis of the proposed architecture with existing research.

3. SYSTEM ARCHITECTURE

The proposed Ask Your Trash Smart Bin System uses a multi-layer architecture integrating IoT, AI, and software for automated waste classification, monitoring, and user tracking. The Smart Bin Layer includes ultrasonic, load cell, and moisture sensors, a camera, Raspberry Pi, and QR-based bin identification. The Intelligence Layer uses MobileNetV2 for image-based waste classification. The Application Layer provides a mobile application and admin dashboard for tracking disposal activities and monitoring waste data. The Data Management Layer stores and synchronizes user, bin, and waste information.

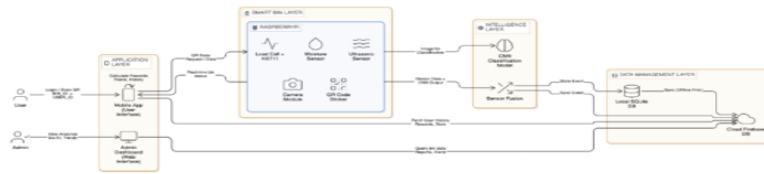


Figure 3.1. System architecture diagram

4. METHODOLOGY

The model was trained using public Kaggle datasets, including TrashNet, Garbage Classification Dataset, and Waste Classification Dataset, along with a custom dataset, comprising 20,506 images across five classes: cardboard, glass, metal, paper, and plastic.

The data were divided into 70% training, 15% validation, and 15% testing sets, with 3,080 test images. Images were resized to 224×224 pixels and normalized, while training augmentation included rotation, shifting, zooming, flipping, brightness adjustment, and shearing. MobileNetV2 was selected for its lightweight architecture and suitability for Raspberry Pi 4B deployment. Training used a two-phase Adam optimization strategy with categorical cross-entropy, initially freezing the base model and subsequently fine-tuning deeper layers. Data augmentation and class balancing improved generalization and minority-class performance.

5. MODEL EVALUATION

The model was evaluated using 5-fold stratified cross-validation on the full dataset and a holdout test set of 3,080 images (15%). Performance was assessed using macro-averaged Accuracy, Precision, Recall, and F1-score. Custom CNN, EfficientNetB0, and ResNet50 were trained under identical conditions for baseline comparison.

Model	Validation Acc.	Test Acc.	Pi 4B Inference	Parameter(M)
Custom CNN	81.17%	77.08%	90ms	5.1
EfficientNetB0	93.93%	92.11%	67ms	5.3
ResNet50	94.21%	92.09%	112ms	23.5
MobileNetV2	94.83%	94.64%	42ms	2.3

Table 5.1.1. Performance comparison of baseline models and MobileNetV2

MobileNetV2 provides the best trade-off for edge deployment. Although EfficientNetB0 and ResNet50 achieve over 95% accuracy, their inference speeds are unsuitable for real-time Raspberry Pi 4B deployment. MobileNetV2 achieves 94.83% accuracy with a 42 ms inference time (23.81 FPS), while using 78% fewer parameters and providing 5.7× faster inference.

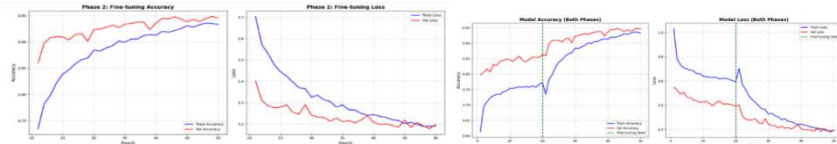


Figure 5.2.1 Model training performance

Per-Class Performance:

Class	Samples	Accuracy
cardboard	465	96.77%
glass	753	95.62%
metal	563	93.96%
paper	651	94.16%
plastic	648	93.06%

Detailed Classification Report:

	precision	recall	f1-score	support
cardboard	0.976	0.968	0.972	465
glass	0.942	0.956	0.949	753
metal	0.969	0.940	0.954	563
paper	0.952	0.942	0.947	651
plastic	0.907	0.931	0.919	648
accuracy			0.946	3080
macro avg	0.949	0.947	0.948	3080
weighted avg	0.947	0.946	0.947	3080



Figure 4. Sample predictions on real-world test images, Mobile application interface, and Database

The SmartBin mobile application supports user authentication, QR-code bin scanning, waste tracking, reward management, and account administration. It uses Firebase Realtime Database for real-time monitoring of users, bins, and waste data. An offline-first architecture stores sensor data locally in SQLite and automatically synchronizes unsynced records with Firebase when connectivity is restored, ensuring data consistency and reliable monitoring.

6. RESULTS AND CONCLUSION

MobileNetV2 achieved the best performance with 94.64% accuracy and 24 FPS on Raspberry Pi 4B, outperforming EfficientNetB0 and ResNet50. Although plastic–glass misclassification remains a limitation, additional multi-angle training data can improve performance. The proposed Edge AI system enables automated waste sorting, reducing labor costs and improving recycling efficiency.

7. REFERENCES

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