TrashAI: AI-Powered Waste Detection And Municipal Notification System

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Abstract- *Trash, commonly referred to as discarded materials or waste, includes items and substances no longer deemed useful or valuable. Improper waste management contributes to environmental issues such as pollution, ecosystem disruption, and health hazards due to the release of harmful substances. Existing waste management systems face significant challenges in sorting, disposal, and efficiency, particularly in rapidly urbanizing areas where the volume and complexity of waste streams are increasing. To address these challenges, an innovative solution leverages advanced technologies like Convolutional Neural Networks (CNNs) and Temporal Convolutional Networks (TCNs). CNNs are leveraged for their exceptional ability to analyze images, enabling precise classification of various waste types, such as biodegradable, recyclable, and hazardous materials. This ensures accurate segregation at the source, minimizing contamination between waste streams. Complementing this, TCNs are employed to process time-series data, allowing the system to detect and adapt to dynamic changes in waste patterns and volumes. These capabilities enable real-time detection of waste and intelligent segregation, significantly reducing manual intervention and human error. These cutting-edge methods enable precise trash classification, real-time waste detection, and intelligent segregation, forming the core of a next-generation waste management system. A Municipality Web App serves as the central hub for monitoring and decision-making, streamlining waste management operations and promoting sustainable practices. By automating and optimizing waste-handling processes, this solution enhances efficiency, minimizes human error, and fosters environmental consciousness. This transformative initiative is designed to revolutionize urban waste management, paving the way for smarter, cleaner cities and contributing to a more sustainable future.*

Keywords- Computer Vision, CNN, RPN, TCN, TrashAI

I. INTRODUCTION

The Smart Waste Management System (TrashAI) is designed to transform traditional urban waste management practices by integrating cutting-edge technologies such as Artificial Intelligence (AI) and Machine Learning (ML). The core objective is to enhance efficiency, accuracy, and responsiveness in waste handling operations across cities. At the heart of this solution lies the TrashNet model, a deep learning-based image classification system capable of identifying and categorizing different types of waste—such as organic, recyclable, and hazardous materials—in real-time. This intelligent classification not only simplifies segregation but also improves recycling processes and reduces landfill dependency. To support real-world deployment, a custom Municipality Web App has been developed. This application serves as a centralized platform for monitoring waste bins, analyzing waste patterns, and generating automated alerts for timely collection. The system employs AI-powered segmentation to detect overflowing bins or misplaced garbage using camera feeds, while automated monitoring ensures minimal human intervention. By addressing critical issues such as delayed waste pickup, improper segregation, and inefficient bin monitoring, this project offers a sustainable, smart solution for urban sanitation. It paves the way for cleaner cities through proactive management, environmental responsibility.

II. LITERATURE SURVEY

This work focuses on the design and implementation of an AI-powered system aimed at enhancing waste management practices within municipalities. The system uses machine learning models (CNN, TCN, LSTM, RNN, and KNN) to identify and classify various types of waste (e.g., plastic, organic, paper) through camera-based visual input. It integrates with cameras (e.g., CCTV or mobile camera) to detect trash in real-time from public spaces or designated monitoring zones. Once trash is detected, notifications are automatically sent to municipal authorities via mobile SMS and email, ensuring prompt action.

Existing garbage classification algorithms have large parameter counts and poor real-time performance. This article uses a self- built garbage dataset and a pre-trained MobileNetV3 model in the PyTorch framework for garbage recognition and classification. Despite reductions, the model's (Zhang X et al., 2024; Gogte P et al., 2025) computational requirements might still pose challenges for deployment on resource-constrained embedded devices. The incorporation of advanced mechanisms like CBAM and Mish activation adds complexity to the model, which may complicate implementation and tuning processes.

The convergence of robotic process automation (RPA) and generative AI (GAI) within the context of Internet of Everything (IoE) services represent a profound paradigm shift (Mingyuan Li et al., 2024; Divyansh Dadheech et al., 2024). This fusion of technologies not only streamlines routine tasks but also catalyses innovation while harnessing the potential of interconnected devices. System integration requires significant technical expertise and resources, potentially posing challenges for organizations with limited capabilities. It increases the risk of data breaches and cyber threats, necessitating robust security measures. It also involves substantial upfront costs, which could be a barrier for some organizations.

Future prospects for AI integration with the Internet of Things (IoT), advancements in machine learning, and the importance of collaborative frameworks and policy initiatives were discussed (David B. Olawade et al., 2024; Asif Iqbal Middya et al., 2024). In conclusion, while AI holds significant promise for enhancing waste management practices, addressing challenges such as data quality, privacy concerns, and cost implications is paramount. Inadequate or biased data hinders the performance of AI models and limit their applicability. Involves collecting and processing sensitive data, raising issues related to data privacy and security. Unauthorized access or data breaches could compromise individual privacy and erode public trust. Requires significant upfront investment in specialized hardware, software, and infrastructure which can be a barrier, especially for regions with limited financial resources.

The integration of artificial intelligence (AI) and information and communication technology (ICT) (Aya Idrissi et al., 2025) has emerged as a promising solution to revolutionize waste management practices. This systematic literature review, which examines the application of AI and ICT in SWM over the past 5 years (2018–2023) and analyses 152 research papers, explores their integration at various stages. Heavily dependent on the quality and availability of data. Incomplete or inaccurate data hinders the performance of AI models. Requires substantial financial investment, posing a challenge for regions with limited resources. Necessitates specialized technical expertise, which may not be readily available in all waste management organizations.

III. STUDIES AND FINDINGS

Recent advancements in artificial intelligence (AI) and Internet of Things (IoT) technologies have significantly transformed the landscape of urban and institutional waste management. Several studies have explored AI-driven waste classification using image-based recognition systems. State-of- the-art deep learning models such as MobileNetV3, YOLO (You Only Look Once), EfficientNet, and ResNet have demonstrated high accuracy in classifying solid waste materials. These models, especially when fine-tuned using transfer learning techniques, achieved classification accuracies ranging from 90% to 98% on benchmark datasets such as TrashNet and TACO. The use of transfer learning has proven particularly effective in scenarios with limited annotated data, allowing for robust performance even in constrained environments.

IoT-enabled smart bin systems have also been a focal point in modern waste management solutions. These smart bins are typically equipped with ultrasonic sensors, weight sensors, and in some cases, gas sensors for monitoring fill levels and detecting hazardous waste. The integration of real-time sensor data allows for dynamic scheduling of waste collection, significantly reducing incidents of bin overflow and promoting timely waste disposal. Findings from several implementations have reported up to a 60% reduction in overflow incidents, emphasizing the practical benefits of IoT deployment in waste infrastructure. Such smart systems have been tested and implemented both in municipal frameworks and within educational institutions, the latter also serving to promote sustainability awareness among students and staff.

In addition to waste classification and monitoring, the optimization of waste collection routes has been an area of active research. Studies have employed various AI algorithms including Genetic Algorithms (GA), Ant Colony Optimization (ACO), and Reinforcement Learning (RL) to enhance the efficiency of waste collection logistics. These approaches have successfully reduced fuel consumption and collection time by approximately 30% to 40% compared to traditional static route models. The implementation of such intelligent routing mechanisms contributes not only to operational cost savings but also to reductions in carbon emissions, aligning with broader environmental sustainability goals.

Medical waste management represents another critical domain where AI and IoT integration has shown significant promise. Research presented at the 2024 IEEE CALCON conference introduced an AI-powered medical waste management system that utilizes sensor-based monitoring and image classification algorithms to automate the identification and categorization of hazardous waste materials. The deployment of gas and proximity sensors, in conjunction with AI models, enhances safety, ensures regulatory compliance, and minimizes human contact with potentially infectious materials. This approach has been particularly relevant in hospital and clinical environments, where waste segregation is essential to preventing contamination and improving public health outcomes.

Furthermore, institutions of higher education have served as testbeds for deploying smart waste management systems. These environments have leveraged AI and machine learning (ML) to enable autonomous waste sorting using smart bins. Studies have shown that such implementations not only streamline waste handling but also cultivate environmentally responsible behavior among campus communities. The systems typically collect data on usage patterns, enabling administrators to analyze trends and refine sustainability strategies. Dashboards and visual analytics have further facilitated data-driven decision-making.

In terms of overall system impact, the integration of AI and IoT technologies in waste management has led to measurable improvements in efficiency, safety, and environmental performance. Increased recycling rates, optimized routing strategies, and real-time monitoring have collectively contributed to the development of smarter and more sustainable urban waste ecosystems. Findings across the reviewed studies indicate that these systems are effective in reducing operational costs, minimizing human exposure to hazardous waste, and promoting behavioral change in waste disposal practices. Moreover, the growing use of predictive analytics allows municipalities and institutions to plan proactively based on historical data and usage trends.

IV. PROPOSED SYSTEM

The process starts with acquiring images from two primary sources: a training dataset and real-time road cameras. These sources feed into two separate pipelines—Model Training and Operational. In the Model Training Pipeline, the system begins with model development, followed by trash dataset acquisition. The collected images undergo preprocessing to clean and standardize them, and then segmentation is applied to isolate trash regions. Feature extraction is performed to identify relevant characteristics of the trash, which are then used in the classification stage to categorize different types of waste. Afterward, the model is built and trained using these classifications and stored in the Municipality Database Server for future use. In parallel, the Operational Pipeline uses real- time images from road cameras. These images go through the same preprocessing, segmentation, and feature extraction steps. The trained model is then deployed to make predictions on these images, determining the type of trash detected. Based on the predictions, the system performs trash segregation and displays the data on the Municipality Dashboard. The final phase involves the Action Systems. When trash is identified and categorized, the system triggers alerts through a Notification System as shown in the System Architecture Diagram in Fig 1.

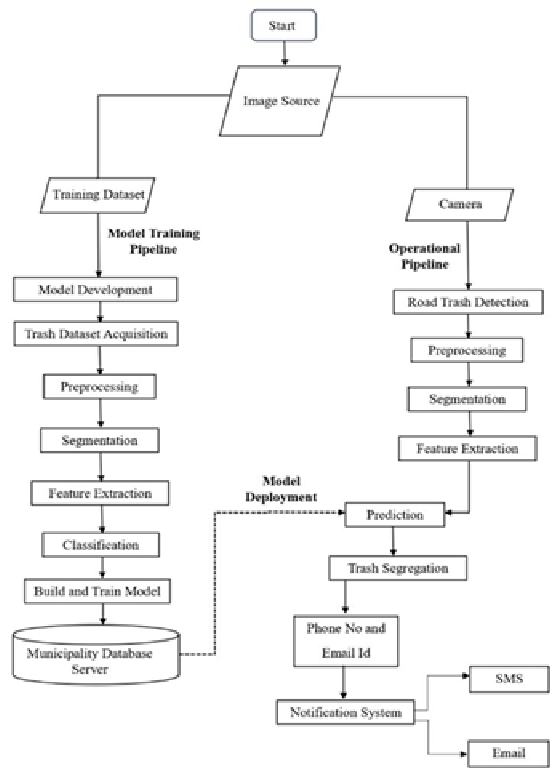

Fig 1. System Architecture Diagram

modules. The Municipality Trash Management Web acts as a central dashboard for monitoring and decision-making. TrashNet: Build and Train trains CNN and TCN models for trash classification and trend prediction. The Trash Detector uses computer vision and RPNs to identify waste in images or video. The Trash Segregator automatically directs classified waste into the correct bins. The Alert Generator sends notifications when bins are full or hazardous waste is detected. Lastly, the End User Interface provides an easy-to-use platform for uploading images, viewing results, and interacting with the system.

TrashNet Model with CNN

The TrashNet Model is the cornerstone of the TrashAI system, designed to achieve precise and accurate classification of diverse types of waste. Utilizing Convolutional Neural Networks (CNNs), the TrashNet undergoes rigorous training on a diverse dataset comprising annotated images of various waste items. This training process enables the model to learn intricate patterns and features associated with different types of waste, ensuring robust classification capabilities.

Real-Time Trash Detection with TCN

In addition to classification, the TrashAI system integrates Temporal Convolutional Networks (TCNs) to enable real-time detection of waste objects. Unlike traditional CNNs, TCNs excel in capturing temporal dependencies in sequential data, making them ideal for dynamic and real-time applications such as trash detection. By leveraging TCNs, the TrashAI system can promptly detect and localize waste objects in images or video streams, facilitating swift responses to changing waste scenarios.

Waste Segregation Module

This module represents a significant advancement in waste management technology, enabling the system to intelligently segregate waste items into recyclables, organic waste, and non- recyclables. Leveraging advanced algorithms and machine learning techniques, this module categorizes waste items with high accuracy, optimizing downstream recycling processes and resource recovery efforts. By streamlining waste segregation, the TrashAI system contributes to more efficient and sustainable waste management practices.

Alert to Municipality

An integrated alert mechanism ensures proactive responses to critical waste management events detected by the TrashAI system. Upon detecting anomalies, critical events, or issues, the system automatically generates alerts and notifies municipal authorities via SMS or email. This proactive approach enables swift responses and interventions, minimizing potential disruptions and optimizing waste management operations.

V. RESULTS

This work effectively applied Convolutional Neural Networks (CNNs) and Temporal Convolutional Networks (TCNs) for accurate trash classification and real-time detection. The system achieved a classification accuracy of 97%, a precision of 90%, a recall of 91%, and an F1-score of 90.5%, indicating strong

The smart waste management system consists of six key

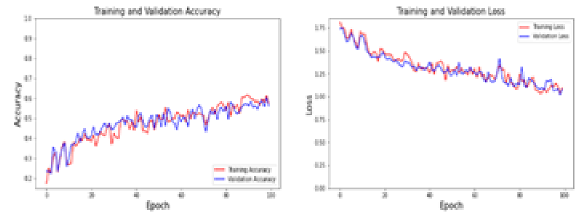

Fig 2. Training and Validation Accuracy and Loss

performance in identifying various waste types.

The training and validation graphs of the TrashAI project demonstrate the effective learning and performance of the deep learning model used for waste classification. The accuracy graph shows that both training and validation accuracy steadily increase over epochs, with the two curves closely following each other, as shown in Fig 2. This indicates that the model is generalizing well to unseen data and is not overfitting. Simultaneously, the loss graph displays a consistent decrease in both training and validation loss, with both curves maintaining a similar pattern. This reflects stable learning and convergence, confirming that the model is successfully minimizing prediction errors. Overall, the alignment of accuracy and loss across training and validation sets signifies that the TrashAI model is well-trained and reliable for real-world waste detection and classification tasks.

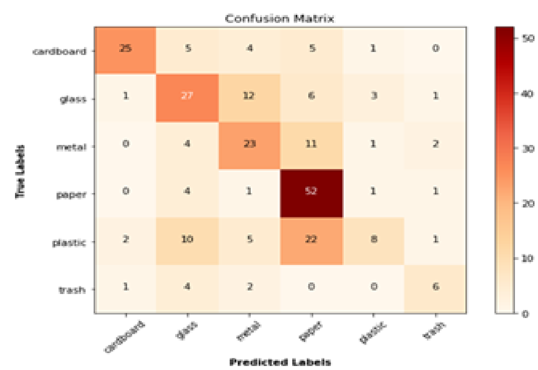

Fig 3. Confusion Matrix

Fig 3. displays the confusion matrix for the TrashAI project, which evaluates the classification performance of the AI model used to categorize various types of waste. A confusion matrix provides a detailed breakdown of actual versus predicted class labels. Each row represents the actual class, while each column represents the predicted class. The diagonal values indicate correct predictions, showing how many instances were classified correctly for each class. For instance, a value of 25 in the top-left cell means 25 samples were correctly identified as that class. The center value of 52 signifies a strong performance for that specific class, where most of the predictions were accurate. Off-diagonal values represent misclassifications — where the model predicted the wrong class. For example, in the second row and third column, the number 12 indicates that 12 samples of one class were mistakenly classified as another. This highlights potential confusion between visually similar waste types. The heatmap color intensity gives a quick visual indication of accuracy. Darker red hues along the diagonal suggest strong performance, while lighter colors in off-diagonal positions show areas needing improvement. Overall, the TrashAI model demonstrates solid classification capabilities, especially for some waste types. However, it shows minor confusion between classes, which could be improved with additional data and model fine- tuning. This analysis is essential for identifying strengths and optimizing weak points in the system.

VI. CONCLUSION

This work represents a significant advancement in modernizing waste management practices through the application of artificial intelligence and machine learning. By addressing existing challenges and embracing emerging technologies, it sets the foundation for a more sustainable and efficient waste management approach in urban environments. Key milestones achieved include the development of a robust Municipality Web App, successful construction and training of the TrashNet model, and integration of real-time trash detection and segmentation capabilities. The system's ability to accurately classify and segregate waste, along with proactive alert generation, demonstrates its strong potential to enhance operational efficiency and support environmental sustainability. Looking ahead, the TrashAI system holds immense promise for future expansion and improvement. Future enhancements include smart bins with sensors and cameras for automated waste alerts, drone-based trash detection in hard-to- reach areas, and edge AI deployment for real-time offline detection. Integration with municipal dashboards and a multilingual voice-alert system will enhance monitoring and accessibility.

REFERENCES

[1] Abderrahim Lakhouit, "Revolutionizing urban solid waste management with AI and IoT: A review of smart solutions for waste collection, sorting, and recycling", (2025), Results in Engineering, Vol. 25, 104018. DOI: 10.1016/j.rineng.2025.104018

[2] Abimbola O. Ige, Bankole I. Oladapo, David B. Olawade, Ojima Z. Wada, Olawale Ajisafe, Oluwaseun Fapohunda, Sunday O. Usman, "Smart waste management: A paradigm shift enabled by artificial intelligence", (2024), Waste Management Bulletin, Vol. 2, Issue 2, pp. 244 - 263. DOI: 10.1016/j.wmb.2024.05.001

[3] Aditya Sunit Paul, Akanksha Malakar, Divyansh Dadheech, Sonali Vyas, "Revolutionizing Ocean Cleanup: AI and Robotics Tackle Pollution Challenges", (2024), Artificial Intelligence and Edge Computing for Sustainable Ocean Health. The Springer Series in Applied Machine Learning. Springer, Cham. pp. 343 - 358. DOI: 10.1007/978-3-031-64642-3_15

[4] Asif Iqbal Middya, Maqsud Alam Mallick, Sandip Kumar Karmakar, Sarbani Roy, "AI Powered Medical Waste Management with IoT", (2024), IEEE Calcutta Conference (CALCON), Kolkata, India, pp. 1 - 6. DOI: 10.1109/CALCON63337.2024.10914143

[5] Aya Idrissi, Jamal Benhra, Mounia El Haji, Rajaa Benabbou, "Solid waste management through the application of AI and ICT: a systematic literature review", (2025), Journal of Environmental Engineering and Science, Vol. 20, Issue 2, pp. 88 - 121. DOI: 10.1680/jenes.23.00110

[6] Chun-Ming Yang, Mingyuan Li, Qiansha Zhang, Wei Lo, "Increased Productivity and Reduced Waste with Robotic Process Automation and Generative AI- Powered IoE Services", (2024), Journal of Web Engineering, Vol. 23, Issue 1, pp. 53 - 87. DOI: 10.13052/jwe1540-9589.2313

[7] Gogte P, Katariya N, Madan B, Mehta A, Nair S, "Smart waste management and air pollution forecasting: Harnessing Internet of things and fully Elman neural network", (2025), Waste Management & Research. DOI: 10.1177/0734242X241313286

[8] Hieu M. Tran, Hung V. Pham, Minh T. Vu, Son Vu Truong Dao, Tuan M. Le, "An Integrated Learning Approach for Municipal Solid Waste Classification", (2024), IEEE Access, Vol. 12, pp. 176569 - 176585. DOI: 10.1109/ACCESS.2024.3495982

[9] Liwei Shi, Xinlong Zhang, Xueyong Tian, Yuanqing Luo, "Garbage Classification Algorithm Based on Improved MobileNetV3", (2024) IEEE Access, Vol. 12. DOI: 10.1109/ACCESS.2024.3381533

[10] Thangavel V, "Sustainable Development of Effective Smart Waste Management Practices by AI & ML Techniques in Higher Educational Institutions", (2024), International Journal of Advances in Engineering and Management (IJAEM), Vol. 6, Issue 11, pp. 563 - 581. DOI: 10.35629/5252-0611563581