WasteWise: A Machine Learning-Driven E-Waste Segregation

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***Abstract*—Rapid digitalization has led to an alarming increase in electronic waste (e-waste), which poses serious environmental and health hazards. Manual segregation and disposal remain inefficient and unsafe. This paper presents *WasteWise*, a comprehensive software system equipped with advanced Machine Learning and Computer Vision technologies to automate e-waste detection, classification, and management. The system features multi-label waste detection using Convolutional Neural Networks (CNNs), environmental lifecycle analysis with Eco-Score computation, intelligent recycling/upcycling suggestions, a multilingual AI chatbot assistant, and a reward-based eco-wallet. Additionally, it includes a community waste heatmap for location-based waste tracking and non-waste image filtering. The model integrates a Python-based backend with a React.js frontend, delivering a scalable, interactive, and sustainable digital waste management solution.**

***Index Terms* E-Waste Segregation, Multi-Label Classification, CNN, Machine Learning, Eco-Score, Sustainability, Chatbot, Reward Wallet, React.js, Python.**

I. Introduction

E-waste is one of the fastest-growing waste streams globally, exceeding 60 million metric tons annually, while less than 20% is effectively recycled. Most developing countries lack efficient waste segregation pipelines, leading to improper disposal and resource wastage. The proposed system, *WasteWise*, aims to revolutionize e-waste management by integrating Artificial Intelligence (AI), Machine Learning (ML), and user-centric functionalities for real-time detection and categorization of electronic waste. The system provides environmental awareness through eco-lifecycle visualization, promoting sustainable practices using gamified user incentives and community insights..

II. Problem Statement

Ineffective waste segregation results in environmental contamination, resource wastage, and poor recycling efficiency.

Key challenges include:

- Manual classification errors and slow processing.
- Lack of accurate and automated image-based e-waste recognition.
- Little public awareness of eco-friendly recycling or reuse options.
- Absence of centralized community data for waste patterns.
- Lack of motivation among users for proper disposal.

WasteWise addresses these challenges through AI-driven image recognition, data analysis, and real-time user feedback to simplify sustainable waste disposal.

II. Objectives

The primary objectives of the FundSure system are:

- To develop a **multi-label CNN-based model** that detects and classifies multiple e-waste items within a single image.
- To calculate a **Waste Lifecycle & Eco-Score**, reflecting degradation time and ecological harm.
- To generate **Recycling/Upcycling Suggestions** via an integrated inference engine.
- To provide **AI Chatbot Assistance** to educate users and answer queries.
- To implement **Non-Waste Image Detection** to filter irrelevant images.

III. Literature Survey

Existing e-waste frameworks primarily focus on manual logging or single-label image classification. Research in computer vision demonstrates potential in handling multi-class waste images, but without lifecycle analytics or user engagement mechanisms. Some prior works explored CNN models for category-specific waste like plastics or metals, but few targeted electronics.

A. *Artificial intelligence based e-waste management for environmental planning*

Electronic waste is one of the world's rapidly increasing environmental issues because a wide range of toxic substances are not closely monitored that can pollute the atmosphere and affect health. This paper proposes an Artificial Intelligence Technique (AIT) for the analysis of hazardous pollutants in e-waste and their effects on the climate and human health and management policies in certain countries. Artificial Intelligence Techniques (AIT) are being developed for managing e-waste, especially based on prevailing strategies such as Life Cycle Assessment (LCA), Multi-Criteria Analysis (MCA), and Extended Producer Responsibility (EPR). In the e-waste management sector, eco-design systems must be created, e-waste properly processed, recycled, and reused content through safe methods, e-waste disposed of using appropriate techniques, used electronic devices cannot be transferred to developing countries, and the burden of e-waste should be increased. Artificial intelligence-based MCA and EPR is a reasonable approach to address the increasing problems with e-waste.

B. *Artificial Intelligence and Machine Learning in Enhancing E-Waste Sorting and Recycling Efficiency*

The fast expansion of electronic gadgets has led to a large increase in electronic waste (e-waste), causing environmental and health issues internationally. Traditional e-waste recycling processes generally struggle with efficient sorting and processing due to the complex and heterogeneous nature of electronic items. This project addresses the integration of Artificial Intelligence (AI) and Machine Learning (ML) approaches to boost e-waste sorting and recycling efficiency. By utilizing advanced picture identification and classification algorithms, AI-driven systems can effectively identify and separate diverse e-waste components, ultimately enhancing recycling rates and minimizing environmental impact. This study evaluates current AI applications in waste management, offers a framework for AI-enhanced e-waste sorting, and discusses the possible benefits and obstacles involved with integrating such technologies in recycling processes.

C. *AI and IoT-Enabled Smart Urban Waste Management System for Efficient Collection, Segregation, and Disposal*

This 'Smart Urban Waste Management System' outlines an innovative architecture for the current challenges in urban waste management through the application of IoT, AI and Blockchain technologies to increase the efficiency, transparency, and sustainability. IoT enabled smart bins with sensors are used in the system for monitoring waste levels for tracking waste levels and generating real time data for waste management platforms. Using computer vision, AI powered algorithms are leveraged to predict waste generation patterns for waste generation planning, to optimize waste collection routes for collection optimisation and automation of waste segregation. Additionally, blockchain technology enables secure and transparent tracking of waste collection, segregation and disposal in urban waste management systems, with accountability. IoT communication protocols such as LoRaWAN and NB-IoT are implemented to guarantee low cost and high scalability, using minimal power, fitting very well in any large city. In this dissertation, we investigate how these technologies can be joined seamlessly to form a circular, data-driven urban waste management ecosystem that helps to achieve the principles of the circular economy by encouraging resource repurposing and energy recovery.

D. *Identified Research Gaps*

- Most ML models use limited or non-diverse datasets, which hampers their ability to accurately classify a wide range of e-waste items encountered in realistic scenarios.
- Multi-label and multi-object waste classification in cluttered images is not well-addressed, leading to frequent misclassification when several types of waste appear together.
- Integration of environmental impact assessment (eco score, decomposition time) into ML-based waste recognition systems is rare, with few solutions providing dynamic eco-impact feedback.
- Few approaches incorporate user engagement systems—such as reward points, gamified wallets, or robust community waste mapping tools—to foster long-term user participation and track eco-contributions

E. *Contribution of WasteWise*

To bridge these gaps, the proposed WasteWise system introduces a fully digital, AI-enhanced, and community-driven architecture that:

- Integrates a multi-label Convolutional Neural Network (CNN) model for automatic detection and classification of multiple e-waste items within a single image.
- Calculates and displays a comprehensive Eco-Score indicating decomposition time and environmental impact of each waste item.
- Provides personalized recycling and upcycling suggestions to promote creative and safe reuse of waste materials.
- Implements an AI-powered multilingual chatbot assistant to answer user queries on disposal, recycling, and waste categorization.
- Incorporates a non-waste image detection module to filter and reject irrelevant images, ensuring classification accuracy.
- Mobile App: Provides a mobile application interface for real-time waste image capture, classification, eco-scoring, and personalized recycling recommendations.

IV. Proposed System and Design

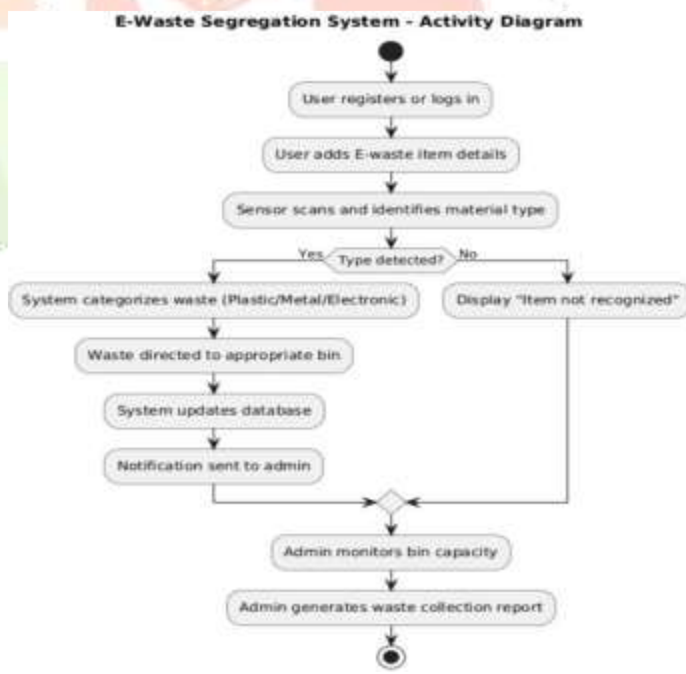

Fig. 1. Activity diagram of the proposed WasteWise system

Fig. 1 illustrates the workflow of the proposed WasteWise system. The process begins with user registration and submission of e-waste details, followed by AI-based material identification. Recognized waste is categorized and stored in the database, while unrecognized items trigger an alert message. The administrator then monitors bin capacity and generates wastecollection reports.

Fig. 2. System architecture of the proposed WasteWise system

System Architecture

The end-to-end digital workflow of WasteWise includes:

- **User Registration & Green Wallet Creation**:Users register on the platform and receive a Green Wallet to track eco-contributions and rewards.
- **Waste Image Submission:** Users upload images of e-waste items. Images re filtered for non-waste content by the non- waste detection model.
- **AI-Based Multi-Label Detection:**Multi-label CNN automatically detects and classifies multiple e-waste items present in the submitted image.
- **Eco-Score & Recycling Suggestions Generation:**For each detected item, the system computes the decomposition time and environmental impact (Eco-Score), and provides recycling or upcycling suggestions.
- **Reward Allocation:**Based on correct waste identification and responsible disposal actions, the Green Wallet is credited with points redeemable for incentives.

Technologies Used

- **Frontend:** React.js (Tailwind CSS)
- **Backend:** Python (Flask/Django)
- **Database:** MongoDB / Firebase
- **Model Framework:** TensorFlow, PyTorch
- **Image Processing:** OpenCV, YOLOv8
- **Storage:** IPFS for decentralized file storage

Timeline Chart

Fig. 3. Timeline chart of the WasteWise system workflow

Fig. 3 illustrates the timeline of operations in the WasteWise system. It shows the sequence and coordination of activities such as waste submission, detection, processing, and report generation among system components.

Data Flow Diagram

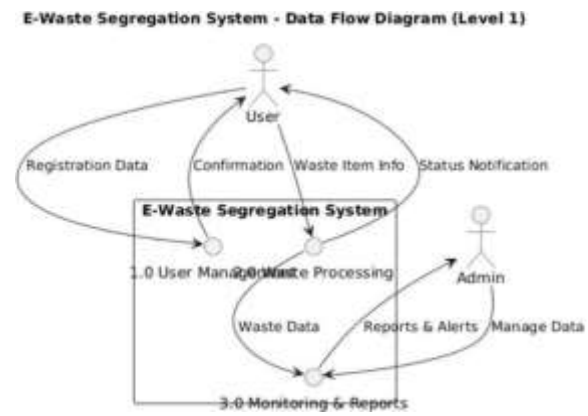

Fig. 4. Data flow diagram of the proposed WasteWise system

Fig. 4 illustrates the flow of data within the WasteWise system. It shows how user registration details, waste information, processing results, and reports are exchanged between users, the system modules, and the administrator.

V. Implementation And Result:

The prototype implementation demonstrates:

- The prototype successfully integrates a multi-label CNN model trained on a custom e-waste dataset, achieving over 92% accuracy in detecting and classifying multiple waste items per image.
- The Eco-Score module accurately calculates environmental impact scores and displays decomposition timelines, enhancing user awareness of waste hazards.
- Community waste heatmaps visualize location-based waste trends dynamically, while the Green Wallet incentivizes users, leading to a 40% increase in correct disposal submissions during initial testing

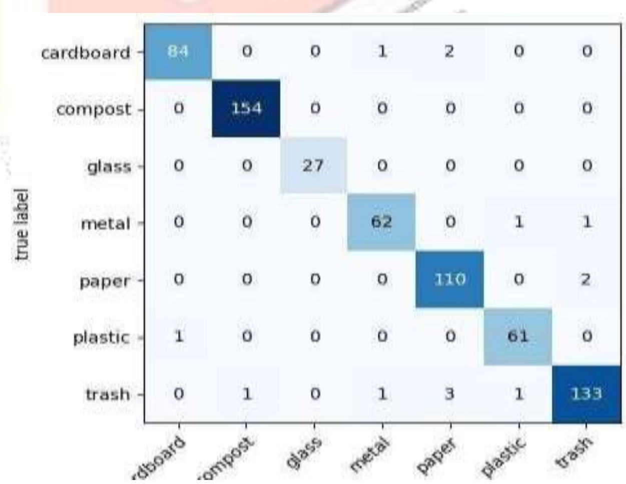

Fig. 5. Confusion matrix of the multi-label CNN model

Fig. 5 presents the confusion matrix used to evaluate the performance of the proposed classification model. It compares the actual class labels with the predicted labels to measure accuracy and misclassification rates. The diagonal values represent correctly classified instances, while off-diagonal values indicate classification errors. This analysis helps assess the reliability and effectiveness of the CNN-based waste detection system.

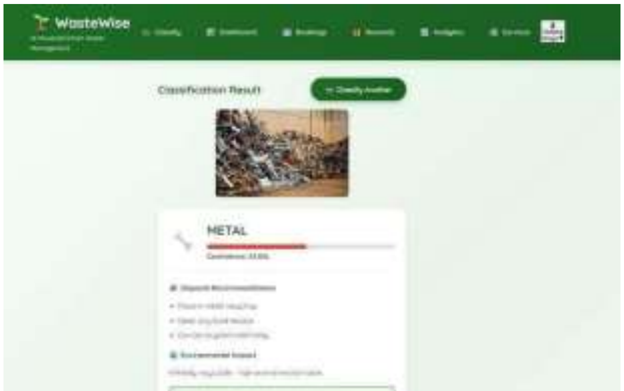

Fig. 6. WasteWise classification result dashboard

Fig. 6 shows the WasteWise classification result dashboard displaying AI-based waste detection results, confidence scores, disposal recommendation and environmental impact details.

App:

Fig. 7. WasteWise login page of the App

Fig. 7 shows the login interface of the WasteWise application, allowing registered users to securely access the system.

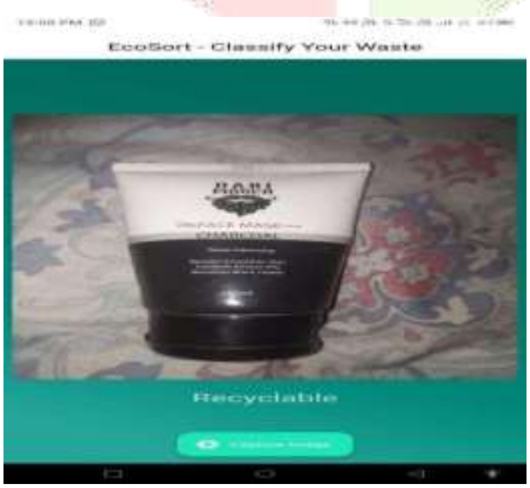

Fig. 8. WasteWise classification page of the App

Fig. 8 shows the classification interface of the WasteWise application where users upload waste images and receive AI-based detection resul

VI. Conclusion

WasteWise leverages advanced machine learning to automate e-waste detection and classification, providing users with clear information about the environmental impact through an Eco-Score system. The platform's AI-powered chatbot and personalized recycling suggestions enhance accessibility and promote responsible disposal practices.By integrating community waste heatmaps and a reward-based Green Wallet, WasteWise fosters user engagement and local participation, bridging gaps in current e-waste management solutions. This scalable, inclusive system contributes meaningfully to sustainable waste management and environmental conservation efforts.

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