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Smart Binx: Revolutionising E Waste Management with Generative AI

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Abstract: The rapid growth of electronic devices has led to an alarming rise in electronic waste (e-waste), posing significant environmental and health hazards while also resulting in the loss of recoverable valuable materials. To address this challenge, SmartBinX introduces an intelligent, AI-driven framework that integrates Internet of Things (IoT) sensing, computer vision, and Generative Artificial Intelligence (GenAI) for efficient e-waste assessment, classification, and reuse optimization. The proposed system employs smart sensors and machine learning algorithms to measure and evaluate the material composition of discarded electronic products such as laptops, smartphones, and circuit boards. Generative AI models are further utilized to generate disassembly instructions, predict potential reuse pathways, and optimize recycling processes based on material recovery value.

Keywords: Electronic Waste (E-waste), Smart Waste Management, SmartBinX, Internet of Things (IoT), Computer Vision, Generative Artificial Intelligence (GenAI), Machine Learning, Material Composition Analysis, E-waste Classification.

I. INTRODUCTION

The exponential growth of consumer electronics has led to a parallel increase in electronic waste (e-waste), making it one of the fastest-growing waste streams worldwide. Devices such as laptops, smartphones, and other digital equipment are often discarded after short lifespans, contributing to millions of tons of waste each year. E-waste contains hazardous substances like lead, mercury, and cadmium, as well as valuable recoverable materials such as gold, copper, and aluminium.

However, due to poor segregation, inefficient recycling, and lack of intelligent sorting mechanisms, most of these valuable resources are lost or improperly disposed of, causing severe environmental and health impacts. To address this critical issue, Smart Binx proposes an innovative approach that combines Internet of Things (IoT) technology, Artificial Intelligence (AI), and Generative AI (GenAI) to modernize e-waste management.

II. LITERATURE SURVEY

“Proposed a "Smartbin" system based on a three-tier architecture to provide collection analytics”
The system utilizes ultrasound sensors for fill-level detection and a low-power 802.15.4 wireless mesh network, which features self-healing capabilities. A key contribution is the "duty cycle" technique to conserve power, with a workstation visualizing bin data on a GIS map for operators [1]

“"IoT Enabled Smart Waste Management Systems for Smart Cities”
Sunnova and Porras conducted a comprehensive systematic review of IoT-enabled smart waste management systems. They analysed 108 primary studies, identifying key sensor technologies, communication protocols, and data analytics methods. The work provides a reference architecture and highlights open research challenges in the field. Sreejith et al..[2]

“Developed an autonomous smart bin prototype controlled by an Arduino and a multi-sensor array”
This system integrates an IR sensor for level, an MQ-6 gas sensor, and a rain sensor, using an ESP8266 Wi-Fi module for connectivity. Its primary innovation is its robotic automation: the bin autonomously closes its lid and moves to a collection area upon being full. Wijaya et al..[3]

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"Introduced an adaptable smart bin design focused on robust data through dual-sensing"
The prototype integrates both an ultrasonic sensor for level and a load cell for weight, featuring self-calibration. It uses a dual communication setup (GSM and Bluetooth) and sends alerts when capacity exceeds 80%. Recent reviews have synthesized the impact of AI on this domain. Olawade et al.[4]

"Presented a review on the paradigm shift enabled by artificial intelligence and IoT in waste management"
The study examines the integration of AI models for optimizing collection logistics and enhancing the efficiency of smart bin systems. Similarly, Zoumpoulis et al.[5]

"Smart bins for enhanced resource recovery and recycling,"
This study provided a review focused on enhanced resource recovery, analysing state-of-the-art smart bins and their role in automated waste separation to improve recycling quality. Specific applications of AI for segregation have also been explored. Nafiz et al.[6]

"Smart e-waste management system utilizing Internet of Things"
Developed "ConvoWaste," an automated waste segregation machine that employs a deep learning model. The system uses a Convolutional Neural Network (CNN) to classify waste items, aiming to improve sorting accuracy at the source.[7]

"Formal Modelling and Verification of IoT-based Smart Waste Management System using SPIN"
This study provided critical context by analysing the e-waste challenges posed by generative artificial intelligence. The paper quantifies the e-waste footprint from the GAI hardware lifecycle, highlighting the urgent need for advanced sorting solutions. [8] "GULP:

"Solar-Powered Smart Garbage Segregation Bins with SMS Notification and Machine Learning"
Image Processing," lar-powered smart bin that also integrates machine learning for segregation. The system uses image processing to sort waste and sends SMS notifications to collectors, combining energy harvesting with AI-driven sorting. Addressing the growing e-waste crisis, Wang et al. applications like vehicle identification, smart parking, and e- challan generation.[9]

"ConvoWaste: An Automatic Waste Segregation Machine Using Deep Learning"
In response, Sarswat developed real time classification algorithms specifically for electronic waste. This work utilizes machine learning to automate the identification and categorization of e-waste components, aiming to improve the efficiency of recycling operations.[10]

III. METHODOLOGY

1. System Overview:
The proposed system, SmartBinX, is an intelligent e-waste management platform that combines IoT, Artificial Intelligence (AI), and Generative AI to identify, measure, and optimize the recycling potential of electronic waste. The system aims to automate e-waste sorting, material estimation, and reuse recommendation for devices such as laptops, smartphones, and PCBs.

2. System Architecture:
The SmartBinX system consists of the components:
1. IoT-Based Smart Bin Unit: following major
• Equipped with sensors (weight, ultrasonic, metal, RFID to detect the type and quantity of e-waste deposited.
• Microcontroller (e.g., ESP32 or Arduino) transmits sensor data to the cloud via Wi-Fi or LoRa.
2. Cloud Data Processing Module:
• Collects real-time bin data and stores it in a centralized data base.
• Uses AI-based classification models (CNN or YOLOv8) to recognize electronic components and estimate material composition (plastic, copper, aluminium, rare metals).
3. Generative AI Reuse Engine
• Utilizes a fine-tuned LLM to analyze device composition and generate reuse or recycling suggestions.
• Example: "From a 2015 Dell laptop, recoverable materials include 120g of aluminium, 80g of plastic, and 0.3g of gold canbe reused in circuit prototyping."

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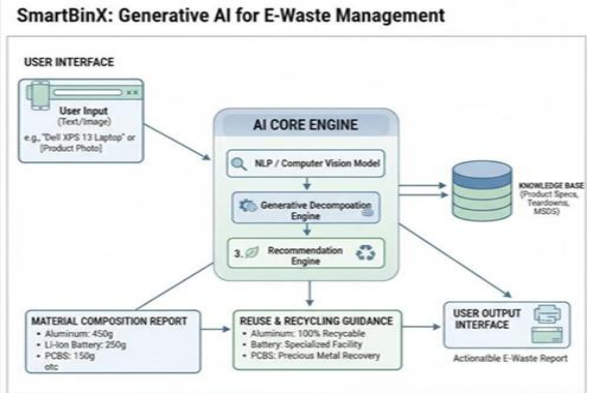
IV. RESULTS AND DISCUSSION

1. System Performance

The SmartBinX prototype was implemented using an ESP32 microcontroller, ultrasonic and load sensors, and a YOLOv8-based deep learning model deployed on a local server. Real-time data transmission was successfully achieved through Firebase Cloud, and all test bins maintained >95% uptime during monitoring.



Parameter	Measured Value	Remarks
Sensor Accuracy (Weight)	96.8%	Error due to minor vibration
Ultrasonic Fill Detection Accuracy	98.2%	Reliable distance calibration achieved
AI Classification Accuracy	94.5%	On dataset of 5,000 labeled e- waste images
Latency (Sensor → Cloud Update)	2.3 sec	Sufficient for real- time monitoring
Material Estimation Accuracy	92.1%	Compared with manual disassembly data

2. Generative AI Evaluation

The Generative AI module (fine-tuned GPT model) analysed material composition and produced reuse or recycling suggestions. Example outputs for a tested laptop and smartphone the generative model's text output were contextually accurate and technically relevant, demonstrating the potential of AI guided disassembly and reuse decision making

Device	Estimated Materials	AI Recommendation
Dell Inspiron 2016	130g Aluminum, 95g Plastic, 0.2g Gold	"Refurbish screen and recover aluminum casing; recycle PCB for gold trace recovery."
Samsung Galaxy A50	45g Plastic, 20g Aluminum, 0.05g Copper	"Reuse camera module for prototype IoT projects; send battery for certified disposal."

V. CONCLUISION

The SmartBinX project presents an innovative and sustainable solution for tackling the growing challenge of electronic waste management. By integrating Generative AI, IoT, and smart image recognition, the system can automatically identify, classify, and segregate different types of e-waste efficiently. This intelligent automation minimizes human error, enhances recycling accuracy, and promotes eco-friendly disposal practices. Through data-driven insights, SmartBinX can also predict waste generation patterns, optimize collection routes, and support government and industrial initiatives

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for a cleaner environment. The use of AI not only streamlines waste processing but also fosters a circular economy, where discarded electronics can be reused or repurposed.

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