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A Review on Reward Based Smart Waste Segregation System

AnjaliKrishna Santhosh P.[1], Arathy V. S.[2], Aswathy Sasi[3], Bency Benedict[4], Najla Nazar[5]
[1, 2, 3, 4]*Dept. of CSE Universal Engineering College, Thrissur, Kerala*
[5]*Assistant Professor Dept. of CSE, Universal Engineering College*

Abstract: With the rising issue of municipal solid waste man- agement, especially in populous and fast-growing countries such as India, there is a need for innovative and sustainable solutions. Conventional waste segregation and disposal are bedeviled by inefficiency, human mistake, and lack of public participation, resulting in massive environmental degradation and public health consequences. Although current Internet of Things (IoT) systems provide bin monitoring advancements, they are typically not equipped with intelligent, automatic classification features. This review paper investigates the smart waste segregation system paradigm that employs Machine Learning (ML), i.e., Convolu- tional Neural Networks (CNN), to classify waste in real time based on images. We discuss the limitations of current systems and introduce an end-to-end framework for a new, reward-based smart bin. The suggested system mechanizes the segregation process into plastic, organic, metal, and paper categories while also encouraging user participation in a digital reward point scheme. Through the fusion of ML-based classification, user recognition, real-time monitoring of bins, and a Firebase-hosted reward redemption platform, the suggested system seeks to in- crease segregation precision, minimize manual effort, encourage proper waste disposal habits, and offer a scalable, future-proof solution to support smart city programs.

Index Terms: Smart Waste Management, Machine Learning, Convolutional Neural Networks (CNN), Waste Segregation, Re- ward System, IoT, Smart Cities.

I. INTRODUCTION

The world produces more than 2 billion tonnes of municipal solid waste every year, according to the World Bank, with a projection of climbing steeply by the year 2050 [7]. The problem is most severely experienced in India, where urbanization and shifting consumption patterns have created a critical waste management situation [11]. The mismanagement of segregation of wastes at the source is a basic issue, which re- sults in environmental contamination, public health risks, and wasteful utilization of resources [3,7]. If recyclable materials are combined with organic trash, or if hazardous materials are commingled with general refuse, it makes disposal more difficult, inhibits recycling, and creates major safety risks to sanitation workers and the population [10].The seriousness of the problem is commonly underappreciated. Conventional practices for waste disposal are most often manual, ineffective, and uncleanly, dependent on civic consciousness that is commonly in short supply [8,15]. This leads to filled bins, more usage of landfill space, and the destruction of usable material that can otherwise be recycled [4,11]. The necessity for a more intelligent, effective, and accessible system cannot be greater.By means of the potential of Artificial Intelligence (AI) and the Internet of Things (IoT), this system presents an automated and incentive-based solution to this very critical issue [1,2,5,6]. The system proposed uses a Convolutional Neural Network (CNN) to sort waste materials in real-time while being disposed of [5,13]. This technology removes the possibility of human error in segregation while offering a contactless, hygienic disposal process. In order to deal with the fundamental issue of public involvement, the system combines a strong incentive mechanism, providing users with tangible rewards for environmentally friendly disposal practices [9,12].

Given the shortcomings of current waste management meth- ods, the project puts forth an interconnected smart bin system based on automatic, precise, and convenient waste segregation [3,11]. The proposed solution makes it easy for users to help provide a cleaner living environment by leveraging the potential of AI. This new approach eliminates the need for manual sorting and presents a realistic means of enhancing recycling rates and waste management effectiveness, allowing for more sustainable urban lifestyles [5,7]. Applications of these kinds of technologies have broader environmental and social impacts beyond operational advantages. This kind of system can reduce the total waste pollution burden and trend towards a circular economy by encouraging proper waste disposal on the source end [7,13].

II. LITERATURE SURVEY

An intelligent fusion-based approach to the automatic clas- sification of waste materials from images was proposed by Kashif Ahmad, Khalil Khan, and Ala Al-Fuqaha in 2020 [1]. Accurate waste sorting is a key but problematic element in efficient waste management systems. In this article, a new ”double fusion” framework is proposed that best fuses several deep learning models to enhance reliability in classification. The suggested methodology is characterized by a three-step procedure: deep feature extraction through pre-trained models (AlexNet, GoogleNet, VggNet, ResNet), classification with Support Vector Machines (SVM), and vast model ability fusion. The innovation at its core is in the fusion stage, where it investigates two feature-level fusion approaches-Discriminant Correlation Analysis (DCA) and direct concatenation-and four score-level fusion approaches, which include Particle Swarm Optimization (PSO), Genetic Algorithms (GA), and Induced Ordered Weighted Averaging (IOWA). The ”double fusion” approach then blends the top performance from the feature- level and score-level fusion stages with a last optimization step. Tested on a benchmark set of 2,527 images divided over six categories of waste, the double fusion with PSO proposed here attained an impressive accuracy of 94.38%, showing a clear improvement of 3.58% over previous state-of-the-art approaches and providing a solid baseline for autonomous waste classification systems.

A deep learning approach to automated classification of recyclable waste was introduced by Md. Mosarrof Hossen, Molla E. Majid, Saad Bin Abul Kashem, and others in the year 2024 [2]. Effective sorting of waste is an international challenge of significant importance for ensuring sustainable waste management and recycling practices. This paper pro- poses a new convolutional neural network (CNN) model called RWC-Net (Recyclable Waste Classification Network) to clas- sify waste into six categories: cardboard, glass, metal, paper, plastic, and litter, from the TrashNet dataset of 2,527 images. The given methodology is characterized by some major steps: data preprocessing, extensive data augmentation to handle class imbalance, image normalization, and classification by a hybrid model. The RWC-Net model capitalizes on the rela- tive strengths of two pre-trained networks, DenseNet201 and MobileNet-V2, and adds auxiliary outputs with a tailored loss function for improved learning. The performance of the model was strictly assessed using a 5-fold cross-validation approach. In addition, model reliability was illustrated qualitatively by Score-CAM (Class Activation Mapping) saliency maps, which offer visual explanations of model predictions. The suggested RWC-Net recorded an impressive overall accuracy of 95.01% better than multiple state-of-the-art models as well as current techniques on the same benchmark, thus proving its potential as a robust solution for automated waste sorting systems.

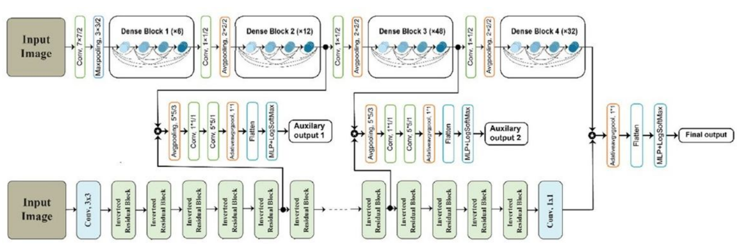

Fig. 1. Architecture of the RWC-Net model for recyclable waste classification.

Mohammadhossein Ghahramani, MengChu Zhou, Anna Molter, and Francesco Pilla put forward an IoT-based route suggestion framework for smart waste management in 2022[3]. Urban waste management is becoming a crucial issue as a result of swelling populations and consumption patterns, which in turn causes ineffective utilization of resources and expensive operating expenses. This work proposes a model that maximizes waste collection routes through the use of Internet of Things (IoT) sensors, artificial intelligence (AI), and spatial boundaries. The suggested system is divided into several phases: monitoring bin status using API, bin selection based on priority, and route optimization with evolutionary algorithms. The model utilizes a genetic algorithm (GA) in conjunction with an artificial neural network (ANN) to optimize the total travel distance with spatial proximity and bin fullness levels in consideration. Discrete and continuous optimization scenarios are adopted and compared. Experimen- tal results show that the discrete optimization model performs better than the continuous model in convergence speed and solution quality. The research also compares the suggested discrete model with other evolutionary algorithms, verifying its efficacy in reality, like Dublin Docklands area, using data from smart bins offered by Bigbelly and Futurestreet.

A intelligent waste management system through deep learning and IoT technologies was suggested by Nicholas Chieng Anak Sallang, Mohammad Tariqul Islam, Mohammad Shahidul Islam, and Haslina Arshad in 2021 [4]. Urbanization and population increase have contributed towards effective waste collection and segregation as an imperative issue glob- ally.

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The research presents a CNN-based model implemented on TensorFlow Lite, coupled with hardware modules like Raspberry Pi 4, camera modules, ultrasonic sensors, servo motors, GPS, and LoRa modules, in order to automatically detect, classify, and segregate waste. The system classifies waste into types such as paper, plastic, glass, metal, and cardboard by utilizing a SSD MobileNetV2 Quantized CNN model. The IoT infrastructure facilitates real-time tracking of waste fill levels and remote reporting of bin status. This reduces enormously operational efficiency, the need for human intervention, and improves the cleanliness of the city. The research shows the effective usability of integrating deep learning and IoT for smart city applications in a sustainable manner.

A model for efficient garbage classification and segregation utilizing deep learning and IoT technologies was proposed by Jenilasree Gunaseelan, Sujatha Sundaram, and Bhuvaneswari Mariyappan in 2023 [5]. The study proposed an advanced smart waste management system that leverages a sophisti- cated hybrid deep learning architecture for highly accurate waste classification. The core of their model integrates a modified ResNeXt convolutional neural network, enhanced with horizontal and vertical blocks and CBAM attention modules, alongside a ResNet-50 model, working in parallel to classify waste into eight categories including biodegradable, non-biodegradable, hazardous, plastic, metal, paper, glass, and cardboard with a remarkable 98.9% accuracy. This AI-driven classification system is implemented in a hardware prototype featuring a Raspberry Pi-based smart bin equipped with a Pi camera for image capture, ultrasonic sensors for fill level monitoring, thermal sensors for fire detection, a GSM module for data communication, and a solar panel for sustainable power. The system automatically directs waste to the correct compartment using servo mechanisms, provides real-time bin status updates to authorities, and supports efficient waste management through IoT-enabled data analytics, representing a significant advancement over earlier sensor-based systems by utilizing visual recognition for precise, multi category segregation.

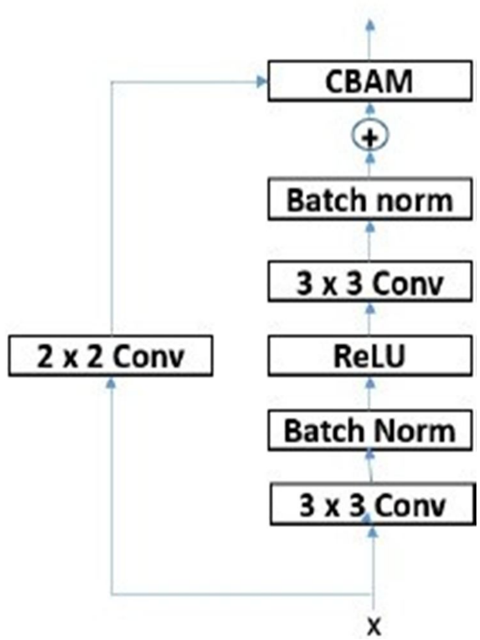

Fig. 2. Structure diagram of modified ResNext.

An automatic waste segregation utilizing IoT and ma- chine learning technologies was proposed by Prof. Pranali G. Chavhan, Ms. Vijayshri Nitin Khedkar, Ms. Manya Gupta, and Ms. Kashish Agarwal in 2024 [6]. The study introduces an automated waste management system that integrates IoT for data acquisition, a deep learning model for classification, and a Streamlit web application for user interaction. The core of their model utilizes a ResNet-101 Convolutional Neural Network (CNN), implemented with the Keras framework, to classify waste materials from images into categories such as organic, recyclable, and non-recyclable, achieving a reported accuracy of over 95%. This AI component is supplemented by an IoT subsystem comprising sensors and cameras for real-time bin level monitoring and data collection, and a Robotic Process Automation (RPA) module built with UIPath to automatically send email alerts to authorities. The entire system is unified through a custom Streamlit dashboard, providing an acces- sible interface for real-time monitoring, data visualization, and system management, thereby presenting a comprehensive, automated solution for smart urban waste segregation.

The paper "Smart Waste Management: A Paradigm Shift Enabled by Artificial Intelligence" by David B. Olawade , Oluwaseun Fapohundac, Ojima Z. Wada, Sunday O. Usman, Abimbola O. Ige,Olawale Ajisafe, Bankole I. Oladapo in 2024 provides a comprehensive overview of how Artificial Intelligence (AI)is transforming waste management systems [7]. It explains that traditional waste management struggles with inefficiencies in collection, sorting, recycling, and monitoring due to poor infrastructure, high costs, and lack of public awareness. The paper highlights how AI technologies-such as machine learning, neural networks, and image recognition- enhance efficiency by automating processes like waste segre- gation, optimizing collection routes, predicting waste genera- tion, and improving recycling quality. It discusses applications of AI in smart bins, robotic sorting, and real-time waste monitoring integrated with IoT and sensor networks. The study also identifies challenges such as data quality, privacy, ethical concerns, and high implementation costs. Finally, it empha- sizes that integrating AI with IoT, deep learning advancements, and strong collaboration among policymakers, researchers, and industry can enable sustainable, cost-effective, and intelligent waste management systems for a cleaner and greener future.

Fig. 3. Artificial Intelligence Techniques in Waste Management.

The paper "Design and Development of an Advanced Waste Segregation System" by Jatin Bora, Dharmesh Lodhi, Arpita Gupta in 2025 presents an automated approach to efficient waste management using Arduino-based control and multi- sensor integration [8]. The system focuses on minimizing human involvement in waste handling to reduce health risks and improve hygiene. It employs infrared (IR), proximity, and moisture sensors to detect and classify waste into dry, wet, and metallic categories, while a DC motor and servo mechanism automate the sorting process. A TFT display provides real-time data on waste quantities, ensuring continuous monitoring and control. This automated system achieves approximately 89% sorting accuracy with a processing rate of 150 kg/hour, making it suitable for both municipal and industrial applications. By combining microcontroller technology, sensor networks, and real-time monitoring, the model enhances recycling efficiency, reduces landfill waste, and supports sustainable waste man- agement. Overall, it demonstrates a cost-effective, scalable, and hygienic solution to address modern waste segregation challenges.

This research paper presents a proposed blockchain-enabled automatic reward system by Shaik Vaseem Akram ,Sultan S. Alshamrani ,Rajesh Singh ,Mamoon Rashid ,Anita Gehlot, Ahmed Saeed AlGhamdi ,Deepak Prashar in 2021 designed to enhance Solid Waste Management (SWM) by actively involving individuals and ensuring an eco-friendly urban envi- ronment [9]. The proposed architecture integrates Internet of Things (IoT) devices with a blockchain network to create a secure, transparent, and traceable system. Customized sensor nodes are embedded in waste bins, utilizing load cell and level sensors to capture real-time data on the quantity and level of waste. This sensory data is then transmitted to a cloud server through a LoRa-enabled wireless gateway. A Python- based Flask server API is employed to bridge the cloud data to the blockchain network, where the waste quantity is registered as a new transaction. The core function of the system is the automatic reward mechanism, which is executed based on the quantity of waste recorded. Additionally, the system addresses security concerns in the private blockchain by introducing a Trust Point score for miner fog nodes, which authenticates their Proof-of-Work (PoW) submissions, thereby ensuring the secure and immutable logging of all transactions and the transparency of the reward process.

The paper “Automatic Waste Segregation and Management” by Cherry Agarwal, Bhavesh Yewale,Chaithali Jagadish in 2020 [10] focuses on developing an automated system for efficient waste classification and monitoring using Arduino UNO and various sensors. The system is designed to separate waste into wet, dry, and metallic categories using moisture, capacitive, and inductive sensors. A conveyor belt mechanism detects and directs the waste to appropriate bins through servo motors, reducing human intervention and promoting hygiene. Each bin is equipped with ultrasonic sensors that monitor waste levels, and when full, a GSM and GPS module sends alerts and location details to the concerned authorities for col- lection. The entire setup is programmed in Embedded C using the Arduino IDE, ensuring real-time automation and remote monitoring. This model not only minimizes manual effort and operational costs but also aligns with the smart city concept by supporting sustainable and efficient waste management. The paper concludes that such systems can be further enhanced with solar power and digital image processing to improve segregation accuracy and energy efficiency.

An IoT-based smart waste management system designed to improve garbage segregation and collection efficiency using real-time level monitoring was presented by Mary P. Varghese, V.S. Anooja, R. Akhila, M. Krishnakumar, and Arun Xavier in 2024 [11]. The rapid growth in urbanization and population has led to a significant increase in municipal solid waste, posing major challenges for traditional management systems that rely on fixed collection schedules, often resulting in inefficient resource allocation, overflowing bins, and envi- ronmental pollution. This study introduces a smart waste management (SWM) system that leverages Internet of Things (IoT) technology to address these issues. The proposed system utilizes sensor-equipped smart garbage bins that monitor their fill levels in real-time. Key components include level sensors to detect how full a bin is, a communication module (using LoRa for long-range, low-power data transmission), and a Raspberry Pi controller that orchestrates the system. The data from the bins is sent to a central management platform, allowing authorities to optimize collection routes dynamically, reduce operational costs, and prevent overflow. A crucial feature of this system is its focus on waste segregation; the smart bins can be designed with separate compartments for different types of waste (e.g., dry and wet), and use sensors and cameras to automatically sort trash, thereby enhancing recycling efforts. Visual LED indicators (green, yellow, red) on the bins provide immediate feedback on fill status to both waste collectors and the public. This work highlights the role of IoT in creating a more sustainable, efficient, and responsible waste management process for modern urban areas.

A reward-based system for monitoring garbage bins and encouraging proper waste disposal using IoT and sensor technologies was presented by Deepti Aggarwal, Sonu Mittal, Kamal Upreti, and Pinki Nayak in 2024 [12]. Improper waste disposal, particularly near water bodies, is a significant envi- ronmental and public health challenge driven by overflowing bins and a lack of public incentive. This study introduces a system designed to lure people to use dustbins by offering them financial rewards, thereby contributing to cleaner cities and supporting the smart city vision. The proposed system is defined by two main components: a hardware unit attached to the dustbin and a mobile application for the user. The hardware uses an Arduino Uno microcontroller to coordinate an IR sensor, which detects when waste is thrown into the bin, and a Bluetooth module (HC-05) for communication. A unique QR code is attached to each bin for identification. The process involves a user scanning the QR code with the Android app, which verifies the bin’s location to prevent fraud. Upon successful waste disposal detected by the IR sensor, reward points are credited to the user’s account via the Bluetooth connection. These points can be redeemed for vouchers from platforms like Amazon and Flipkart. The application also includes a feature to display nearby bin locations and their fill-level status (e.g., green for available, red for full), aiding both users and municipal authorities in monitoring and collection. This work provides a practical, cost-effective solution that leverages behavioral incentives to address urban waste management problems.

A model for the intelligent classification of municipal waste using a hierarchical deep learning framework was presented by Sakshi Tiwari, Snigdha Bishi, and Kanchan Sharma in 2025 [13]. Waste management is a critical challenge in rapidly urbanizing regions like Delhi-NCR, where heterogeneous waste streams complicate segregation and recycling efforts. This study introduces WasteIQNet, a hybrid deep learning model designed for fine-grained waste classification across 18 categories structured under Wet and Dry waste types. The proposed model integrates MobileNetV3 for semantic feature extraction with GraphSAGE to capture structural relationships among image representations. To address class imbalance and feature sparsity, the architecture incorporates Feature-wise Attention (FWA), Top-K Mixture of Experts (TopK-MoE), and advanced regularization techniques such as Dynamic Sparse Training (DST) and Model-Agnostic Meta-Learning (MAML). A novel Hierarchical Tree Loss function is introduced to penalize semantically distant misclassifications based on a predefined waste taxonomy. The model is trained and eval- uated on the WEDR dataset, a curated collection of 360,000 images reflecting real-world waste conditions across Delhi’s major landfill zones. WasteIQNet achieves a peak classification accuracy of 97.87%, demonstrating substantial improvements in interpretability and generalization. This work contributes a scalable, robust, and deployment-ready solution tailored for real-time smart city waste segregation initiatives.

In the study by Muhammad Azlan Bakar, Yusnaidi Md Yu- sof, Suriani Mohd Sam, Azizul Azizan, Noor Azurati Ahmad, Hafiza Abas, and Noraimi Shafie (2023) [14], a low-cost IoT- based model for smart waste management was developed to automate garbage segregation and bin-level monitoring. The system architecture comprises three layers-perception, mid- dleware, and application-where sensors and actuators detect waste type and fill levels. It employs a Raspberry Pi 4 Model

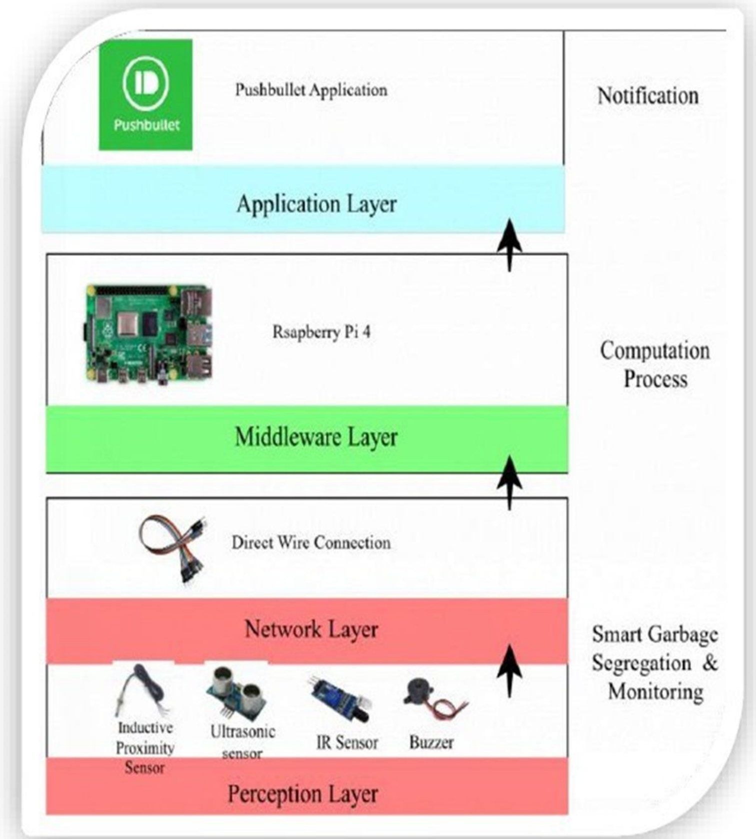

Fig. 4. Architecture of proposed layer.

In the study by Saraswathi P., Vidya Janani V., Loghitha K. Y., Poorvaja J. V., Prabha M., and Dhiyanesh B. (2024) [15] titled "Optimizing Waste Management Systems: A Technolog ical Approach," the authors propose an IoT-based smart waste management model that automatically segregates waste into wet and dry categories. The system integrates soil moisture sensors to detect the moisture content of waste and ultrasonic sensors to identify the presence and fill level of garbage within the bin. Controlled by an Arduino microcontroller, a servo motor operates the bin lid, tilting it toward the appropriate compartment-right for dry waste and left for wet waste based on sensor readings. The entire setup minimizes human in- tervention and enhances segregation efficiency by ensuring automatic classification and disposal of waste. The model is cost-effective, scalable, and environmentally sustainable, serving as a step toward smarter and cleaner urban waste management practices

III. LITERATURE COMPARISON AND ANALYSIS

This section provides a comparative analysis of existing works in smart waste management, grouped by their pri- mary functions: *waste classification*, *IoT-based monitoring* and *reward-based incentive mechanisms.*

B as the central controller, integrating an inductive proximity sensor to detect metal, an infrared sensor for motion detection, and an ultrasonic sensor for measuring waste levels. When the bin reaches 80% capacity, alerts are sent via the Pushbullet app to municipal authorities. Experimental results showed high sensor accuracy, with optimal performance achieved when the ultrasonic sensor was positioned at a 105° angle and notifications delivered in an average of 1.3 seconds. This model offers an efficient, affordable solution for smart cities by combining automation, real-time monitoring, and effective waste segregation.

TABLE I
ASTE CLASSIFICATION USING MACHINE LEARNING / DEEP LEARNING

Ref.	Model / Method	Acc. (%)	Key Features	Remarks
[1]	Double fusion CNN + SVM (AlexNet, VGG, ResNet)	94.38	Multi-CNN fusion with PSO, GA optimization	Established baseline for DL classification.
[2]	RWC-Net (DenseNet201 + MobileNetV2)	95.01	Hybrid CNN with Score-CAM	Enhanced robustness and interpretability.
[5]	ResNeXt + ResNet-50 + CBAM	98.9	Attention-based hybrid CNN + IoT	Highest accuracy; multi-class sorting.
[6]	ResNet-101 (Keras) + IoT Integration	> 95%	Deep learning with Streamlit dashboard	Balanced accuracy and usability.
[13]	WasteIQNet (MobileNetV3 + GraphSAGE + MoE)	97.87	Hierarchical hybrid for 18 categories	Scalable and generaliz-able.

TABLE II
IOT-BASED SMART WASTE MONITORING AND MANAGEMENT SYSTEMS

Ref.	Technology Used	Function	Efficiency	Unique Aspects
[3]	IoT + AI (ANN + GA)	Route optimization for waste collection	High	Dynamic route plan-ning and monitoring.
[4]	CNN + IoT (LoRa, GPS, Sensors)	Image-based detection and IoT monitoring	High	Real-time bin tracking and communication.
[11]	IoT + LoRa + Raspberry Pi	Fill-level detection and segregation	High	LED indicators and re-mote routing.
[14]	Low-cost IoT + Sensors	Metal, dry/wet detec-tion	Moderate	Cost-efficient and re-sponsive system.
[15]	IoT + Arduino	Wet/Dry segregation	Moderate	Servo-controlled auto-matic classification.

TABLE III
REWARD-BASED AND INCENTIVE-DRIVEN SYSTEMS

Ref.	Technology Used	Purpose / Function	Result	Highlights
[9]	Blockchain + IoT + LoRa	Automatic reward generation via blockchain	Transparent and efficient	Secure and traceable reward transactions.
[12]	IoT + Arduino + App	QR-based user reward system	Functional (prototype verified)	App-based incentive for public engagement.

The reviewed literature highlights a steady evolution in smart waste management technologies, transitioning from ba- sic sensor-driven segregation to intelligent, AI-enabled, and incentive-driven systems.Early systems utilized sensor-based hardware ([8], [10]) to categorize waste into wet, dry, or metallic types. These solutions were low-cost but lacked adaptability for complex waste mixtures. With the adoption of IoT frameworks ([3], [4], [11], [14], [15]), real-time data monitoring, fill-level detection, and optimized collection routes became feasible, improving municipal efficiency though clas- sification precision remained limited. Machine learning and deep learning models ([1], [2], [5], [6], [13]) significantly ad- vanced automation and accuracy, achieving results above 95%, with hybrid architectures ([5], [13]) exceeding 98%. These high-performing systems established benchmarks for scalable, automated segregation in smart city environments.Reward- oriented systems ([9], [12]) emphasized user participation via IoT and blockchain incentives, yet lacked AI integration for classification. The proposed model addresses this limitation by merging CNN-based image classification, IoT-enabled moni- toring, and a Firebase-backed digital reward mechanism. This combination ensures high precision (approximately 95–98%) while fostering community engagement.

In summary, deep learning approaches provide superior automation, IoT architectures enhance operational efficiency, and reward-based systems strengthen public participation. The proposed system unifies these strengths into a comprehensive and sustainable framework for next-generation smart waste management.

IV. CONCLUSION

The reviewed literature collectively highlights the remarkable evolution of smart waste management systems-from early sensor-driven and rule-based models to intelligent, AI- and IoT-enabled solutions. Traditional segregation methods, though cost-effective, were limited in precision and scalability. The emergence of deep learning models, particularly CNN and hybrid architectures, has greatly enhanced classification accuracy, with recent systems achieving above 95–98% perfor- mance. IoT integration further improved real-time monitoring, route optimization, and automated data collection, thereby reducing manual intervention and operational inefficiency.

However, most existing solutions focus primarily on automation and technical performance, overlooking active user engagement and behavioral incentives. Reward-based and blockchain-supported mechanisms, though promising, have yet to be widely integrated with AI-driven classification systems. This gap highlights the potential for holistic systems that not only automate segregation but also motivate users to participate in responsible disposal practices.

The proposed Reward-Based Smart Waste Segregation System effectively addresses this gap by merging CNN-based visual classification with IoT monitoring and a digital incentive platform. This integration promotes both environmental sus- tainability and public involvement, aligning with the broader objectives of smart city development. Future research should emphasize large-scale deployment, adaptive learning for di- verse waste streams, and secure reward management through decentralized technologies such as blockchain, ensuring trans- parent, efficient, and citizen-centric waste management ecosys- tems.

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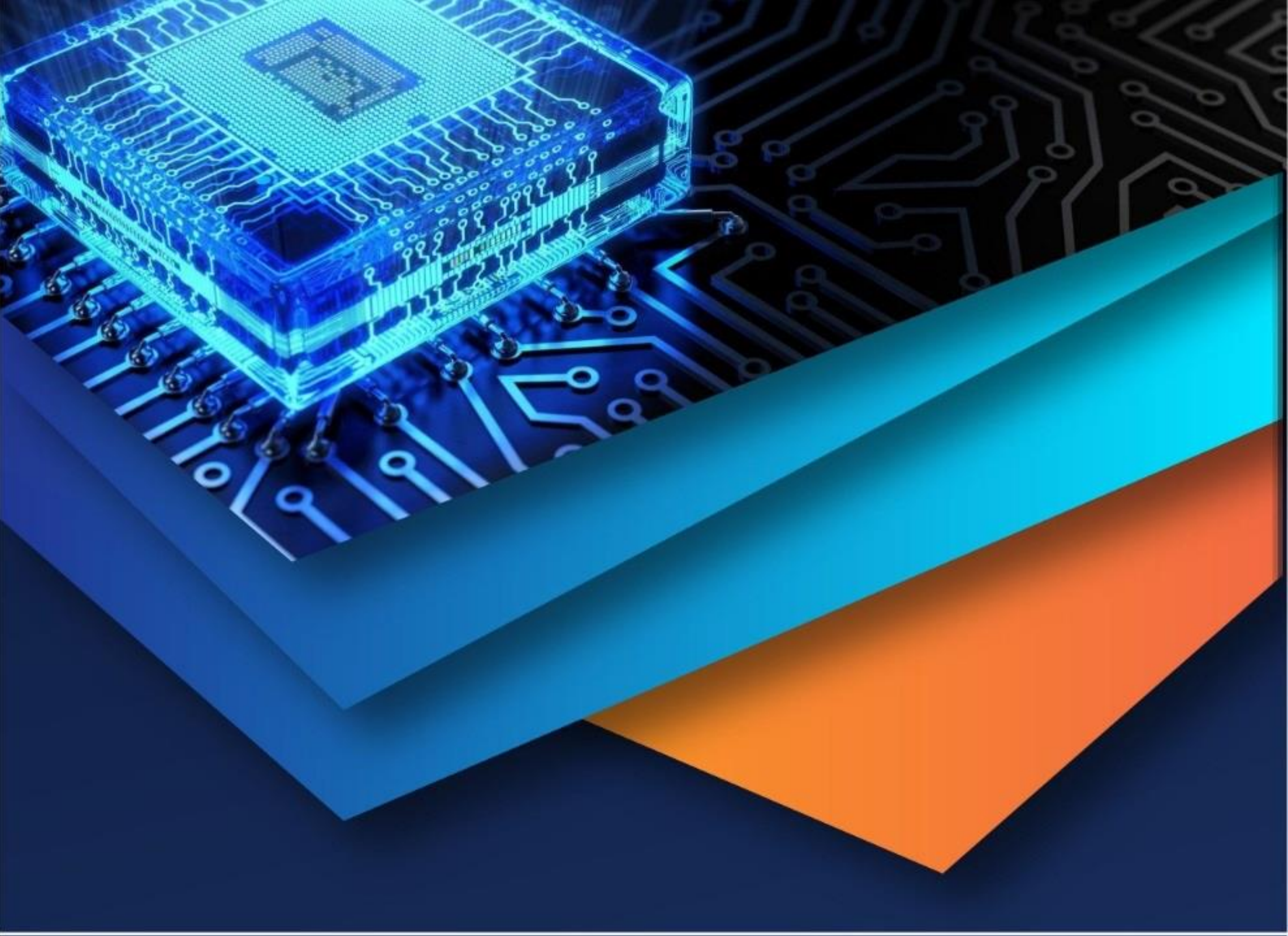

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