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Smart Waste Management Using Deep Learning and Block Chain

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Abstract: *This study explores the use of machine learning (ML) to improve Linux process scheduling, focusing on predicting CPU burst times by analyzing process attributes. The objective is to reduce Turn-around-Time (TaT) by accurately forecasting burst times and adjusting time slices accordingly. The Linux Kernel scheduler (v2.4.20-8) is modified to implement this predictive scheduling. Using the Waikato Environment for Knowledge Analysis (Weka), an open-sthisce ML tool, we evaluate various algorithms to determine the most effective method for this task, with the C4.5 Decision Tree algorithm yielding the best results. The modified scheduler reduces TaT by 1.4% to 5.8% due to fewer context switches, demonstrating the potential of predictive scheduling in enhancing operating system performance..*

Keywords: Smart Waste Management, YOLO V8, Blockchain, Waste Classification, Image Classification, Recycling, Data Security, Sustainability, AI, Environmental Impact

I. INTRODUCTION

Waste management is a critical pillar in the global transition toward sustainable development. With the surge in population, industrialization, and rapid urbanization—especially in fast-developing countries like India—the volume of solid waste generated has reached alarming levels. Efficient Solid Waste Management (SWM) has become indispensable to mitigate environmental degradation, protect public health, and optimize resource utilization[1].

Traditionally, solid waste includes various forms such as trash (dry waste like paper and cardboard), garbage (wet waste), refuse (a mix of dry and wet), and rubbish (which may also include construction debris). Managing these heterogeneous waste types requires meticulous classification and segregation, a process often done manually, posing health hazards to workers despite safety precautions. Conventional systems in India lack the scalability, speed, and accuracy needed to handle the growing volume of waste effectively. Though some automation techniques involving magnets, water jets, and robotics exist, they are either inefficient in real-time scenarios or prohibitively expensive to implement widely[2].

In response to these challenges, the "Smart Waste Management Using Deep Learning and Blockchain" this study introduces a novel, technology-driven solution that decentralized data management to transform traditional waste handling practices. Leveraging YOLOv8 a cutting-edge real time object detection model—the system automates the classification of waste images into categories such as plastic, metal, paper, glass, cardboard, and more. This intelligent classification enhances the efficiency of segregation and encourages users to engage in proper disposal and recycling behaviors. The overall waste management techniques that are being currently adopted in India are inadequate. In a country like India – where more than seventy per cent of the citizens are residing in small towns and villages - efficient waste management has to be performed by automating the classification of wastes generated.Automation is essential since it not only improves public health but also reduces the cost of collecting and separating the trash[4-5].

Segregating the wet wastes is done first and then metal and iron particles are separated with the use of magnets. There are also methods that utilize water jets for classifications. But some wastes are still segregated by workers manually. Even though there are safety precautions adopted, it is still highly risky and dangerous for the manual labour. If this

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process is completely automated, then the segregation process can continue without human intervention. There are some robotic processes for this purpose, but installing them is tedious and expensive [6]. But an AI based solution can reduce the machinery cost and size and also make the segregation process easier. The goal here is to process the image and categorize it into their specific classes. Many CNN algorithms are available for the classification. Here, a deep learning approach is proposed for solid waste segregation. Wastes are generated at an uncontrollably high pace, hence automating trash segregation calls for an extremely effective categorization model. Numerous approaches using sensors and machine learning techniques are put out in the literature to deal with this problem. These are unreliable and inefficient in real-time scenarios [6-7].

Nowadays, with the Internet of Things on stage, smart bins are making the segregation process easier, and Deep Learning may be adopted for this purpose . Deep learning and image processing techniques are used for waste material detection and classification. The general population would not need to be concerned about dumping of their garbage in the appropriate container because the intelligent bin would be able to make that determination for them. This would also make the bins more user-friendly. By integrating automated image-based waste classification with secure blockchain storage, this study aims to revolutionize waste management processes while supporting broader environmental sustainability goals. Through this combination of real-time object detection and transparent data handling, the system offers a scalable and sustainable approach to addressing the pressing global issue of solid waste management[8].

II. RELATED WORK

Hossain, A., et al. (2021),[9] emphasizes the effectiveness of Convolutional Neural Networks (CNNs) in classifying various types of waste. The study reports high classification accuracy when sorting waste into categories such as plastic, paper, and metal, thereby significantly reducing manual effort and improving recycling outcomes. CNNs proved to be robust and scalable tools for real-world waste management systems. However, the paper notes a major limitation — the reliance on large, well-labeled datasets for training. Inadequate or imbalanced datasets can impair model performance, indicating the need for continuous data collection and annotation for optimal results.

Sutherland, W., et al. (2020),[10] examined the role of artificial intelligence in enhancing recycling efficiency. The paper illustrates how AI-powered systems can automate the waste sorting process, thereby reducing dependency on manual labor and minimizing human error. The implementation of intelligent sorting significantly improved resource allocation and operational performance in waste management facilities. Nonetheless, the study highlights a critical barrier to adoption — the high initial cost of deploying AI-based systems, which may deter smaller organizations or municipalities from integrating such solutions despite their long-term benefits.

According to Gary White et al. (2020), [11] smart bins, when combined with a compaction system that would improve the capacity of the bins, would automatically send real-time collection notifications to the appropriate parties.The scientists have presented Waste Net. They establish that an automatic trash classification system at the edge would make it possible for smart bins to make quick choices without requiring connection to the cloud. On the dataset used for testing, their model demonstrated an accuracy of prediction that was 97%. This level of categorization accuracy would reduce some of the more typical issues that arise with smart bins, such as recycling contamination.

Zheng, Z., et al. (2018), [12] this case study presents a blockchain-based system to ensure transparent waste disposal and recycling. It offers secure, immutable data and builds trust in the management process. The system supports accountability and fraud prevention. However, its complexity and need for technical expertise can hinder adoption in low-resource areas.

Borgia, E., et al. (2019), [13] explores the transformative potential of blockchain in the field of waste management. The authors demonstrate how blockchain enhances transparency, traceability, and security by allowing immutable and verifiable records of waste tracking from generation to disposal. The integration of blockchain helps prevent fraud, ensure regulatory compliance, and build trust among stakeholders. However, the study also identifies scalability as a significant drawback, as the computational and energy demands of blockchain can become a bottleneck in large-scale deployments, requiring further technological refinement to address these constraints.

Jung et al. (2017), [14] have introduced ResNet-based algorithms for the categorization and localisation of vehicles by making use of recordings taken from real traffic surveillance systems. They used a method known as Joint Fine-tuning (JF) to increase the classification performance, and they proposed a dropping CNN method to generate a synergy effect with the JF. Both of these were done in order to improve performance. For the purpose of localization, they implemented the fundamental ideas behind the most cutting-edge region-based detector in combination with a backbone convolutional feature extractor by employing 50 and 101 layers of residual networks and then combining the results of both of these into a single model.

III. PROBLEM FORMULATION

In the current era of rapid urbanization and increased consumption, waste generation has become a critical environmental issue. Traditional waste management systems largely depend on manual sorting and classification of waste, which are prone to inefficiencies, human error, and lack of scalability. These methods often lead to improper waste segregation, reduced recycling rates, and increased landfill usage. Furthermore, current digital solutions for waste tracking and management are limited in terms of data integrity, transparency, and security, as they commonly rely on centralized databases that are vulnerable to tampering and breaches.

To address these pressing challenges, there is a need for an automated, intelligent system capable of real-time waste detection, classification, and recommendation for recycling or reuse. At the same time, ensuring the authenticity, immutability, and transparency of the classification data is essential to foster trust among stakeholders and to maintain an auditable record of waste handling activities.

The core problem addressed in this research is twofold. Firstly, there is a critical need to develop an intelligent system that can accurately and efficiently classify various types of waste—such as plastic, glass, metal, cardboard, and others—in real time, with minimal human intervention. Manual waste sorting is not only labor-intensive but also prone to errors, which hampers effective recycling and leads to environmental degradation. Secondly, ensuring the security, integrity, and transparency of the data generated during the waste classification process presents another major challenge. Conventional systems rely on centralized databases that are vulnerable to tampering and unauthorized access. Therefore, this research aims to explore how a decentralized architecture, powered by blockchain technology, can securely store classification results and user activity data, ensuring immutability and traceability. By addressing these two challenges—automated waste classification and secure, transparent data management—this work seeks to lay the foundation for a smart, scalable, and sustainable waste management system.

IV. PROPOSED WORK

The proposed system aims to automate the process of waste classification and encourage sustainable practices using advanced technologies. Traditional waste management systems often rely on manual sorting, which is inefficient, error-prone, and costly. To address these limitations, this project employs the YOLO V8 (You Only Look Once, Version 8) deep learning model for real-time object detection and classification of waste materials. The goal is to enhance accuracy and speed in identifying various waste categories such as plastic, glass, metal, paper, and more from uploaded images by users.

The system allows users to interact via a user-friendly web interface where they can register, log in, and upload images of waste. Once an image is uploaded, YOLO V8 processes it and identifies the category of waste it belongs to. Based on this classification, the system offers actionable suggestions on how the waste can be recycled or reused. This not only educates users about sustainable waste practices but also encourages environmentally responsible behavior.

To ensure secure and immutable record-keeping, the platform integrates blockchain technology. Every classification result, along with relevant user data, is stored on the blockchain, ensuring that the information is tamper-proof and transparently managed. Blockchain's decentralized nature also supports traceability and trust, as no central authority can alter or delete the data. This feature is particularly crucial in building accountability into the waste management system.

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Moreover, the system includes three user roles: students (general users), employees (verifiers), and admins (managers). While users upload images and receive suggestions, employees validate the accuracy of classifications and update suggestions if needed. Admins oversee platform operations, manage blockchain records, and maintain user and category databases. This modular architecture ensures efficient workflow, robust data handling, and a scalable framework suitable for urban or institutional deployment.

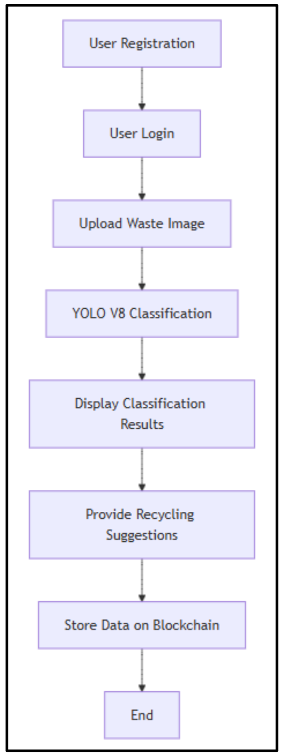

Fig 1. Work Flow of proposed system

IMPLEMENTATION AND OPTIMIZATION

The system's frontend is built using standard web technologies—HTML, CSS, and JavaScript—to offer a responsive and user-friendly interface. Through this interface, users can register, log in, and upload images of waste items. An OTP-based verification mechanism is integrated to ensure authenticity during registration. Once an image is uploaded, it is sent to the backend for classification, and the result is displayed along with actionable recycling suggestions.

The backend is implemented using Python and Django, where the YOLOv8 model is integrated to handle the image classification task. YOLOv8 is known for its real-time performance and high accuracy, making it ideal for classifying multiple waste types from images with varying quality and backgrounds. The system processes each image, detects objects, and maps them to specific waste categories. These results are then linked to the user's session and stored in a database for easy retrieval and tracking.

In terms of blockchain integration, the project uses Solidity to write smart contracts and Ganache as the local Ethereum blockchain emulator for testing. Web3.py is used to interact with the smart contracts from the Python backend. Classification records, including the image hash, classification label, and timestamp, are stored on the blockchain, ensuring immutability and traceability. This not only prevents data tampering but also creates a transparent log of waste disposal activities that could be audited in the future.

To improve performance, the project incorporates several optimization techniques. First, a lightweight version of YOLOv8 (such as YOLOv8n) is used to ensure fast inference times without compromising accuracy. For faster processing, model inference is handled asynchronously using Celery and RabbitMQ, allowing multiple image uploads

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to be processed in parallel. Additionally, waste images are stored in IPFS (InterPlanetary File System), while only their hash is saved on-chain to reduce blockchain bloat.

Finally, the system is designed to be scalable and maintainable. It supports the addition of new waste categories without major code changes and uses modular coding practices to isolate core functionalities like user management, classification, and blockchain logging. Future enhancements can include multilingual support, integration with recycling services, and deployment on cloud platforms for better accessibility and uptime.

V. RESULT AND DISCUSSION

The project successfully classified waste images using the YOLOv8 model with high accuracy and speed. Users could upload waste images, receive real-time classification results, and get recycling suggestions. Data was securely stored on the blockchain, ensuring transparency and integrity.

The object detection model demonstrates strong classification capabilities across most waste categories, as evidenced by the normalized confusion matrix. High accuracy is observed for classes such as Clothes (100%), BrownGlass (95%), CardBoard (84%), and Green Class (96%). These classes show minimal misclassification, indicating that the model effectively learns their visual features. However, certain categories like Battery (55%) and Paper (52%) show lower classification accuracy, often being misidentified as Background or other similar-looking classes. This suggests a need for further refinement in differentiating between objects with overlapping visual features.

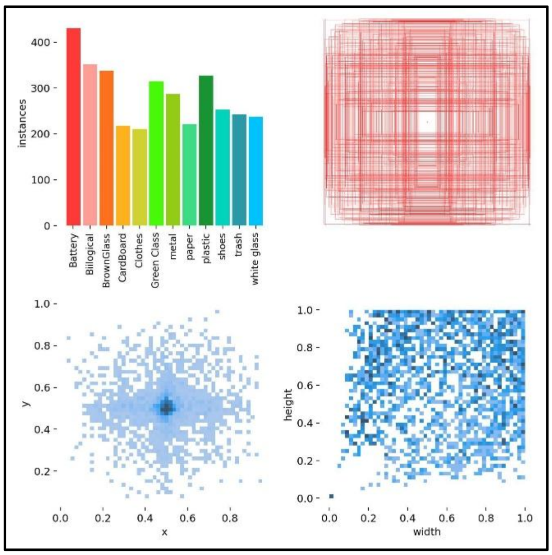

Fig-2: Dataset distribution

The dataset analysis and bounding box heatmaps illustrate important patterns in the training data. The instance distribution chart indicates a relatively balanced dataset, though Battery has slightly higher representation. The heatmaps of bounding box center locations and dimensions reveal that most objects are centered in the images and vary in size, providing the model with diverse training scenarios. This spatial distribution contributes to the model's robust generalization across multiple object types.

However, further data augmentation or class rebalancing may help boost performance for underperforming categories.

The training and validation performance metrics of the object detection model over time. The training losses—including box loss, classification loss, and distance focal loss—decrease consistently, which indicates that the model is learning well from the data. Validation losses also show a downward trend initially and then plateau, which is a healthy sign of model generalization without overfitting. These metrics confirm that the model is successfully minimizing errors during training and evaluation

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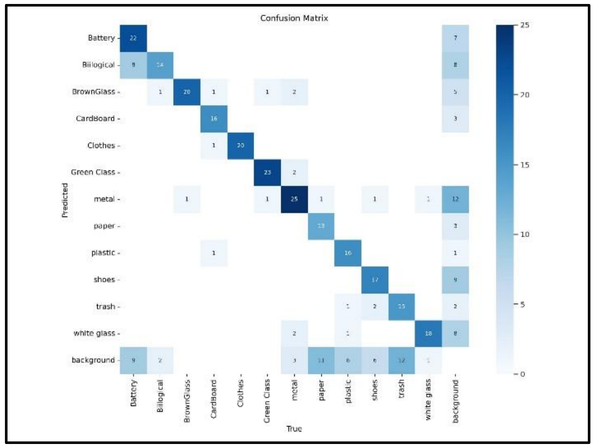

Fig-3: Confusion matrix

The confusion matrix displayed in the image illustrates the performance of the YOLOv8 model in classifying various types of waste into categories such as battery, plastic, metal, paper, clothes, and more. The diagonal elements represent correct classifications, with high values in categories like "metal" (25), "green glass" (23), and "white glass" (18), indicating strong accuracy in those classes. Off-diagonal elements show misclassifications, such as "biological" being confused with "battery" and some background items incorrectly classified as waste. Overall, the matrix demonstrates that the model performs well on most classes, with room for improvement in distinguishing closely related or visually similar waste types.

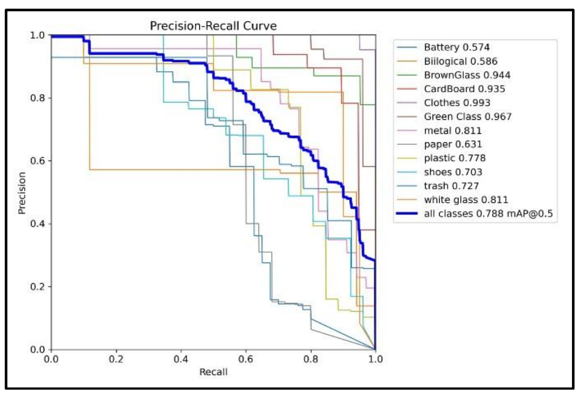

Fig-4: Precision-recall Curve

Finally, the precision and recall metrics demonstrate steady improvement across epochs, indicating better object detection accuracy and coverage. Similarly, the mAP@0.5 and mAP@0.5:0.95 values, which are standard measures of detection performance, increase and stabilize at satisfactory levels. Overall, the model shows good convergence and robust performance, both in terms of localization and classification accuracy.

VI. CONCLUSION

This demonstrates how emerging technologies can be integrated to address real-world environmental challenges. By automating the classification of waste through advanced deep learning techniques and ensuring secure data storage using blockchain, the system significantly improves the efficiency, accuracy, and transparency of waste management processes. This innovation reduces dependency on manual sorting, which is often error-prone and labor-intensive, while also encouraging users to adopt environmentally responsible behavior through personalized recycling suggestions.

The use of YOLOv8 provides real-time, high-accuracy object detection, allowing the system to classify diverse waste types from user-uploaded images swiftly and reliably. Meanwhile, the blockchain component guarantees that

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classification data and user interactions remain immutable, verifiable, and resistant to tampering, ensuring a high level of trust and security in the system. This dual-technology approach lays a strong foundation for smarter and more sustainable waste handling practices. In conclusion, this case study not only provides a technological solution to modern waste management problems but also acts as a catalyst for promoting environmental awareness and responsible recycling habits. It represents a significant step toward achieving smarter cities and a cleaner, greener planet.

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