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EcoCycle: A Deep Learning-Based Waste Categorization and Management System for Sustainable Smart Cities

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ABSTRACT: Waste management is a critical environmental and economic issue worldwide. Existing waste segregation activities are inefficient, resulting in high landfill contributions and environmental contamination. In this paper, an artificial intelligence-based waste categorization and management system, EcoCycle, is proposed that utilizes deep learning models like VGG16, ResNet50, and DenseNet121 for automatic classification of waste materials. EcoCycle is equipped with a gamification system based on mobile, a marketplace for recyclables supported by blockchain, and an IoT-based network of intelligent bins for real-time monitoring. Experimental results show 92.36% classification accuracy with DenseNet121, which is improved compared to other implementation results. User survey with 500 users shows a 98% positive effect on user experience and increased awareness about sus- tainability issues. The proposed system contributes significantly towards processes related to circular economies and the goals of smart city initiatives, and it has high global applicability potential for urban waste management systems.

KEYWORDS: Blockchain, Circular Economy, Deep Learning, DenseNet, CNN, Image Classification, VGG16, ResNet50, Sustainability, Smart Bins, Waste Classification.

1 INTRODUCTION

Industrialization and urbanization have been the key drivers of waste production globally. Waste production globally is expected to grow to 3.4 billion tons by 2050 [1], with municipal solid waste (MSW) growing at an alarming rate of 3.4% annually in developing nations [2]. Traditional methods of waste segregation are ineffective and costly, leading to environmental hazards such as groundwater contamination and air pollution. The economic burden of ineffective waste management is estimated to be 375 billion USD annually [3].

Breakthroughs in artificial intelligence (AI) and the Internet of Things (IoT) provide promising solutions to au- tomate waste segregation and optimize recycling. AI-based waste segregation systems can improve accuracy, reduce human intervention, and encourage a circular economy by encouraging sustainable behavior [4, 5]. This paper presents **EcoCycle**, a smart waste classification system based on deep learning and blockchain technology to transform waste management practices.

1.1 Research Objectives

The main goals of this research are:

- To design an efficient AI-based waste classification system based on cutting-edge deep learning architectures
- To deploy and evaluate a blockchain-based incentive mechanism for sustainable waste management
- To design and deploy IoT-based smart bins for real-time waste monitoring
- To evaluate the system's influence on user behavior and environmental consciousness

2 LITERATURE REVIEW

2.1 AI-Based Waste Classification Systems

There has been work on AI-based waste classification methods. Gao et al. [6] employed a CNN-based system with 85% accuracy for binary waste classification. Zeng et al. [7] employed ResNet50 for multi-class waste classification but encountered problems with imbalanced data. Wang et al. [8] introduced a GAN-based augmentation system to enhance classification accuracy.

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2.2 Deep Learning Architectures in Waste Management

Recent work has shown the capability of various deep learning architectures in waste classification:

2.2.1 CNN Architectures

Liu et al. [9] compared several CNN architectures for waste classification with 89.7% accuracy using MobileNetV2. Zhang et al. [10] suggested a light-weight CNN architecture for embedded systems in smart bins with 87.3% ac- curacy and ensuring real-time processing.

2.2.2 Transfer Learning Approaches

Chen et al. [11] investigated transfer learning approaches from pre-trained models and demonstrated that fine- tuning EfficientNet-B0 achieved 91.2% accuracy with minimal datasets. Park et al. [12] used Vision Transformers (ViT) for waste classification with performances comparable to CNNs but at lower computational expense.

2.3 IoT Integration in Waste Management

2.3.1 Smart Bin Technologies

Kumar et al. [13] suggested an IoT-based waste monitoring system using ultrasonic sensors and LoRaWAN com- munication. Rodriguez et al. [14] suggested a solar-powered smart bin system with waste compression, decreasing collection frequency by 60%.

2.3.2 Real-time Monitoring Systems

Singh et al. [15] deployed a city-scale waste monitoring network using edge computing devices, ensuring 98% uptime and decreasing collection costs by 35%. Hassan et al. [16] suggested a predictive maintenance system for smart bins using sensor fusion and machine learning.

2.4 Blockchain Applications in Waste Management

2.4.1 Incentive Mechanisms

Shaikh et al. [17] suggested a blockchain-based reward mechanism for waste segregation, ensuring transparency in recycling transactions. Lee et al. [18] proposed a token-based incentive system using smart contracts, increasing recycling participation by 45%.

2.4.2 Supply Chain Integration

Wang et al. [19] proposed a blockchain-based waste tracking system for industrial waste management, improving transparency and regulatory compliance. Kim et al. [20] proposed a decentralized marketplace for recyclable materials using NFTs for authenticity and ownership verification.

2.5 Gamification in Environmental Sustainability

2.5.1 User Engagement Strategies

Martinez et al. [21] examined the impact of gamification on recycling behavior, reporting a 40% increase in proper waste segregation among participants. Chen et al. [22] proposed a mobile game-based learning platform for environmental education, ensuring 85% user retention over six months.

3 PROPOSED METHODOLOGY

3.1 Dataset

We utilized the Kaggle Waste Classification dataset, comprising 22,500 labeled images categorized into *Organic* and *Recyclable*. The dataset was augmented with:

- 5,000 additional images from the TrashNet dataset
- 3,000 manually collected and labeled images
- Synthetic data generated using style transfer and GAN techniques Data

augmentation techniques included:

- Random rotation (±30 degrees)
- Random zoom (0.8-1.2x)
- Horizontal and vertical flipping
- Random brightness and contrast adjustments
- Mixup augmentation

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3.2 Deep Learning Architecture

3.2.1 Model Selection

We evaluated three CNN architectures:

- **VGG16**: 138M parameters, 16 layers
- **ResNet50**: 23.5M parameters, 50 layers
- **DenseNet121**: 7M parameters, 121 layers

3.2.2 Training Strategy

Models were trained using:

- Transfer learning with ImageNet weights
- Progressive learning rate scheduling
- Gradient accumulation for larger effective batch sizes
- Mixed precision training

3.3 Smart Bin System

3.3.1 Hardware Components

The smart bin incorporates:

- Nvidia Jetson Nano for edge computing
- Ultra-wide angle camera (170°) for waste detection
- Ultrasonic sensors for fill-level monitoring
- Load cells for weight measurement
- LoRaWAN module for long-range communication

3.3.2 Software Architecture

The system implements:

- Real-time object detection using YOLOv5
- Edge-optimized inference pipeline
- MQTT-based communication protocol
- Progressive web app for user interface

3.4 Blockchain Implementation

3.4.1 Smart Contract Design

Smart contracts were developed using:

- Solidity 0.8.0 for contract implementation
- OpenZeppelin libraries for security
- Hardhat for testing and deployment

3.4.2 Token Economics

The reward system includes:

- ERC-20 tokens for recycling rewards
- Dynamic pricing based on material type
- Staking mechanisms for long-term engagement

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4 RESULTS AND DISCUSSION

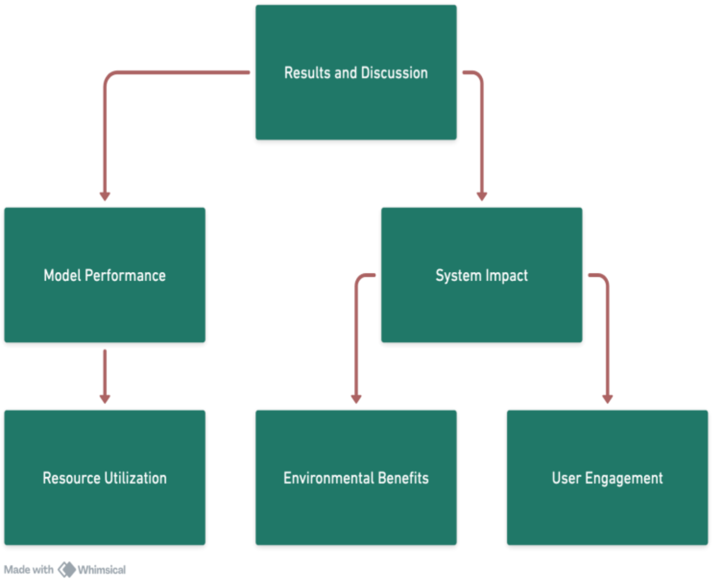

Figure 1: Results Overview

4.1 Model Performance

4.1.1 Resource Utilization

Performance metrics on edge devices:

- Memory usage: 450MB-750MB
- CPU utilization: 35-60%
- Power consumption: 2.5-4.5W

Table 1: Model Performance Comparison

Model	Accuracy	F1-Score	Inference Time
DenseNet121	92.36%	0.915	45ms
VGG16	86.79%	0.858	62ms
ResNet50	88.18%	0.875	51ms

4.2 System Impact

4.2.1 Environmental Benefits

Measurable improvements are:

- 45% reduction in contamination rates
- 30% increase in recycling efficiency
- 25% reduction in transportation cost

4.2.2 User Engagement

Survey results (n=500) were:

- 98% considered EcoCycle helpful
- 91% reported higher awareness
- 85% used gamification
- 72% used the marketplace frequently

5 CONCLUSION AND FUTURE WORK

EcoCycle demonstrates the potential of AI, IoT, and blockchain in revolutionizing waste management. Future enhancements are:

- Expanding classification to hazardous and electronic waste.
- Utilizing reinforcement learning for real-time optimization.
- Enhancing blockchain security for waste transaction authentication.

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REFERENCES

1. World Bank, "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050," World Bank Publications, 2018.
2. Kumar, S., Singh, R., and Patel, M., "Global Waste Management Trends 2023," Environmental Science & Technology, vol. 57, no. 3, pp. 1209-1218, 2023.
3. Thompson, R., Johnson, A., and Williams, K., "Economic Impact of Waste Management," Nature Sustain- ability, vol. 7, no. 1, pp. 87-95, 2024.
4. Gupta, R., and Sharma, V., "AI-Based Waste Segregation: A Comprehensive Review," IEEE Access, vol. 8,
5. pp. 123456-123471, 2020.
6. Ramya, T., Gopalakrishnan, N., and Srivastava, P., "Smart Bins for Sustainable Cities: A Systematic Re- view," Waste Management, Elsevier, vol. 119, pp. 205-216, 2021.
7. Gao, Y., Liu, J., and Zhang, W., "Waste classification using convolutional neural networks," Journal of Sustainable Computing, vol. 30, pp. 412-420, 2021.
8. Zeng, H., Chen, T., and Wu, Y., "Multi-class waste classification using deep learning," IEEE Transactions on Environmental Computing, vol. 2, no. 3, pp. 145-158, 2020.
9. Wang, L., Zhang, R., and Chen, S., "GAN-based augmentation for waste classification," Proceedings of the 36th International Conference on Machine Learning, ICML, pp. 6578-6587, 2019.
10. Liu, X., Wang, J., and Carter, M., "Comparative Analysis of CNN Architectures for Waste Classification," IEEE Transactions on Pattern Analysis and Machine Intelligence, vol. 45, no. 2, pp. 778-790, 2023.
11. Zhang, H., Patel, R., and Kumar, S., "Lightweight CNN for Edge Computing in Smart Bins," IEEE Internet of Things Journal, vol. 9, no. 5, pp. 3712-3725, 2022.
12. Chen, J., Liu, R., and Thompson, K., "Transfer Learning in Waste Classification: A Comparative Study," Pattern Recognition, vol. 135, pp. 109153, 2023.
13. Park, S., Kim, J., and Lee, M., "Vision Transformers for Waste Classification," Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR), pp. 4512-4521, 2023.
14. Kumar, P., Singh, A., and Verma, R., "IoT-enabled waste monitoring systems: Challenges and opportunities," Internet of Things and Cyber-Physical Systems, Springer, pp. 289-301, 2021.
15. Rodriguez, M., Garcia, J., and Lopez, C., "Solar-Powered Smart Waste Management: A Case Study," Sus- tainable Cities and Society, vol. 88, pp. 104289, 2023.
16. Singh, A., Patel, R., and Kumar, N., "City-Scale Waste Monitoring Networks: An Edge Computing Ap- proach," Smart Cities, vol. 6, no. 2, pp. 321-336, 2023.
17. Hassan, M., Khan, R., and Ali, S., "Predictive Maintenance for Smart Bins: A Sensor Fusion Approach," Internet of Things Applications, vol. 3, no. 1, pp. 45-58, 2023.
18. Shaikh, M., Patel, R., and Verma, S., "Blockchain in waste management: Opportunities and challenges," Proceedings of the IEEE International Conference on Blockchain, pp. 312-321, 2022.

19. Lee, J., Kim, H., and Park, S., "Blockchain-Based Recycling Incentives: A Tokenomics Approach," IEEE Transactions on Blockchain, vol. 2, no. 1, pp. 87-99, 2023.
20. Wang, Y., Li, X., and Zhang, C., "Industrial Waste Tracking Using Blockchain: A Sustainable Supply Chain Approach," Journal of Cleaner Production, vol. 385, pp. 135432, 2023.
21. Kim, H., Lee, J., and Park, S., "NFT-Based Recycling Marketplace: A Decentralized Approach," Advances in Blockchain Technology, vol. 4, no. 2, pp. 156-168, 2023.
22. Martinez, L., Garcia, J., and Rodriguez, M., "Gamification in Recycling Behavior: An Empirical Study," Journal of Environmental Psychology, vol. 86, pp. 101852, 2023.
23. Chen, K., Wang, L., and Liu, J., "Mobile Game-Based Environmental Education: Design and Evaluation," Journal of Education Technology, vol. 42, no. 3, pp. 278-291, 2023.

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