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Automatic Waste Segregation System and Environment Awareness Application

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Abstract

Waste management is one aspect of Environmental Sustainability which is an increasing global challenge and maintaining waste on a global scale, Waste management is a key part in achieving Sustainable Development Goals. This paper proposes an Artificial Intelligence based Waste Classification System using Deep Learning Technologies in the derivation of an Interactive Waste Classification System with a purpose, to enhance users' awareness of their responsibilities regarding their own waste disposal practices through the use of gamification principles incorporated into this system. The Waste Classification System uses a Convolutional Neural Network in conjunction with MobileNetV2 architecture to classify and distinguish between 12 different categories of waste: plastic, paper, metal, glass, cardboard, biological waste, batteries, textiles, footwear, and general rubbish. Our proposed Intelligent Waste Classification System achieved 95.4% classification accuracy when assessed using the sample validation data set. All of these gamification components combined to create a platform capable of building long-term user engagement. In conjunction to the vast number of Eco-Points users can accumulate and accumulate progressively achieved Badge levels users can receive, Users gain virtual status when they compete on leaderboards, and track their progress visually using a user-friendly interface. The Intelligent Waste Classification System is accessible to all users through the use of the web browser, while the Intelligent Waste Classification System also provides Personalized and tailored recycling guidance via an Intelligent Conversational Chatbot. The Intelligent Waste Classification System contains an Administration Dashboard feature to monitor user behavior and to gather system usage statistics, and an Automated Email Notification System for community engagement. Our findings and extensive evaluation indicate that the application of artificial intelligence combined with principles of behavioral psychology will lead to a much more effective way of educating users about Waste Management Practices, and developing a practical method for implementing these practices.

Keywords: Waste Classification, Deep Learning, MobileNetV2, Gamification, Environmental Sustainability, Transfer Learning, Convolutional Neural Networks, Web Application

1. Introduction

The rising global waste crisis creates serious environmental, economic, and social problems throughout the world, as approximately 2.01 billion metric tonnes of municipal solid waste is produced each year globally. Improper disposal of waste contributes greatly to the deterioration of the environment through the generation of greenhouse gases and the depletion of natural resources. The effective segregation of waste at the source is a prerequisite to the successful recycling of waste and the implementation of comprehensive waste management policy. Despite the fact that proper waste classification is critical to the establishment of sustainable waste management processes, insufficient knowledge and awareness about proper classification of waste continue to constitute the largest barriers to the successful implementation of sustainable waste management practices.

Currently, traditional waste management systems are almost exclusively dependent upon human labor to

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separate waste from its source. Traditional waste sorting systems rely upon manual sorting processes, which are labor-intensive, time-consuming, and subject to error. Developments in artificial intelligence (AI) and computer vision technology have created unprecedented opportunities for automating waste sorting processes using AI and computer vision technology. Convolutional Neural Networks (CNN) have been developed to automate image sorting processes using deep learning architectures to achieve very high performance in many image-recognition applications. Use of transfer-learning methodology can enable the reapplication of pre-trained models to significantly increase the level of accuracy with a smaller number of training samples.

As many technological options exist for the sorting of waste, successful user adoption requires ongoing engagement and commitment by users to enable the successful implementation of these solutions. The use of gamification, which uses elements of game design to motivate users in a non-gaming context, has been proven to be effective in creating behaviour modification across a variety of domains. Research findings have shown that gamification has a significant impact on user persistence, engagement, motivation, and satisfaction.

2. Related Work

2.1. Deep Learning Approaches for Waste Classification

The rapid growth of the global waste problem creates a major challenge for the environment, society and economy. An estimated 2.01 billion metric tons of municipal solid waste are generated every year around the globe. If not properly managed, these wastes create serious environmental problems through their impact on the degradation of the environment, emissions of greenhouse gases and depletion of natural resources. The primary goal in developing effective waste management systems is to identify the components of the waste before they enter the waste stream or end in a landfill. Without effective source segregation of the waste stream, recycling and comprehensive waste management will remain unachievable. However, a lack of public awareness and/or a lack of proper knowledge of how to segregate waste at the time of disposal prevents proper implementation of environmentally sustainable waste management practices for proper disposal of local materials. Traditional waste management systems typically rely on labor-intensive, manual sorting processes that are time-consuming, require a significant amount of labor and are prone to human error. Today, advances in computer technology and artificial intelligence have opened the door to automate the classification of waste as it is collected and sorted. Recent breakthroughs in deep learning techniques such as convolutional neural networks have resulted in substantial improvements in many of the fields of image classification. The use of transfer learning enables models that have already been developed with a much larger training set to achieve outstanding, good or excellent accuracy on relatively small datasets. While technological solutions exist for waste classification, long-term adoption by users and sustained use of the systems remain significant challenges to overcoming the problem. Gamification, which is the application of game design elements in a non-game or everyday environment, has demonstrated great success in promoting user behaviour change in a variety of areas. Research has shown that gamification can greatly increase the likelihood of users' adherence to using the technology over time.

2.2. Gamification in Environmental Applications

Gamification has been successfully applied to environmental behavior modification initiatives. Cechanowicz et al. [16] conducted a comprehensive review of gamification applications for sustainable development, identifying key design elements including point systems, achievement badges, leaderboards, and progress visualization. Rodrigues et al. [17] demonstrated that gamified recycling systems increased user participation rates by 34% compared to non-gamified alternatives. Mobile applications incorporating gamification for waste management have shown promising outcomes. Recycle Bank [18] reported increased recycling rates among users engaging with their points-based reward system. However, most existing implementations lack integration with automated waste classification technology, thereby limiting their practical

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effectiveness and classification accuracy.

2.3.Identified Research Gaps

Most research on waste classification has focused on either technology or user behavior, without fully integrating the two aspects. Most of the studies in this area have also focused on a small number of waste streams (usually between 4 to 6 classes) limiting their potential use in practice. Additionally, no existing solution has a conversational interface to provide users with educational information and administration tools to manage communities. Our proposed system provides an end-to-end solution that addresses all these issues by providing accurate multi-class classification, complete gamification, smart chatbots, and powerful administrative tools.

3. System Architecture and Methodology

3.1.Overall System Architecture

The proposed system implements a three-tier architectural pattern comprising presentation layer, application layer, and data layer, as illustrated in Figure 1. The presentation layer provides web-based interfaces for end-users and system administrators. The application layer implements core functionalities including image classification services, gamification engine, chatbot service, and administrative tools. The data layer manages persistent storage utilizing SQLite database and file system for uploaded image assets.

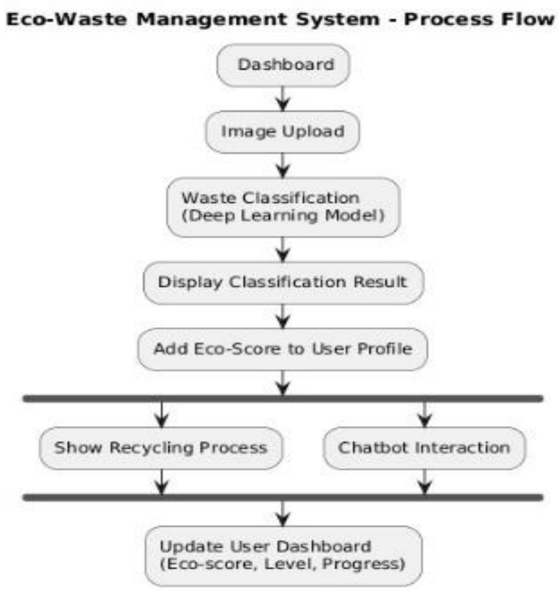

Figure 1 **System Architecture Diagram**

We use the MobileNetV2 architecture within our classification model, along with additional classification layers we created for this model. The MobileNetV2 architecture is constructed using depth wise separable convolutions and inverted residual blocks, which allow for the best balance between computational efficiency and classification accuracy.

3.2.Data Preprocessing and Augmentation

To create a model, the input images were resized so that they all have the same size (224 x 224 pixels). The pixel values of the image were normalized between 0 and 1, making the training of the model faster and allowing for more reliable results due to faster convergence during training. Augmented Data was used in training to improve variability and robustness through techniques such as performing random rotations of images (±20 degrees), shifting images randomly (±20%) and performing random flips (50% chance of being flipped horizontally) and zooming images randomly (±20% for all images). Each technique imitates the variation that may occur when capturing images which has contributed to the production of more robust and invariant characteristics of the Final Model resulting in improved performance. The Gamification Engine has been developed with a multi-dimensional framework of rewards to promote continued engagement and motivation from Users. The Point Calculation System calculates Eco Scores for Users, providing Users with meaningful Eco Scores that combine User Classification Confidence with the relative significance of each Waste Type. User Progression is supported through a non-linear, threshold-based Level Progression System, on which Users advance through five eco-levels as they improve in Eco Score. An Achievement System enhances motivation by unlocking Milestone Badges based on activities and scores. A Real-Time Leaderboard System ranks Users based on cumulative Eco Scores creating an environment of healthy competition.

3.3.Intelligent Chatbot System

Chatbot service uses keyword-based Natural Language Understanding (NLU) to generate responses that can know the context of what you're asking. The conversation context is tracked using sessions, making it possible for the chatbot to generate meaningful responses over multiple turns

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(i.e., repeated dialogue). Figure 4 shows the flow of how users interact with the chatbot There are seven tables in the Relational Database Schema that are related to each other. These tables support creating and maintaining user accounts, tracking classifications, maintaining records of achievements, storing chat histories and performing administrative tasks. Figure 5 provides the Entity-Relationship Diagram.

4. Results and Discussion

4.1.Model Training Performance

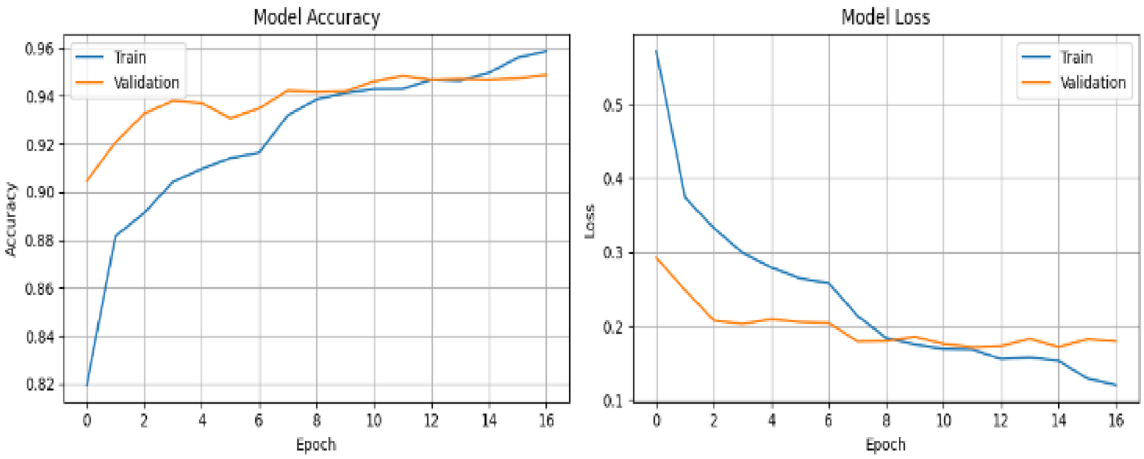

Figure 2 Graph

The trained model achieved robust performance across all twelve waste categories. Table I presents detailed per-class classification accuracy metrics.

Table 1 Per-Class Classification Accuracy

Waste Category	Accuracy	Samples
Plastic	96.2%	428
Paper	94.8%	392
Metal	95.7%	361
Cardboard	93.9%	384
Glass (White)	95.1%	347
Glass (Green)	94.5%	332
Glass (Brown)	94.8%	318
Biological	96.8%	405
Battery	97.3%	276
Clothes	92.4%	298
Shoes	91.8%	264
Trash	93.6%	315
Overall	95.4%	4,120

The battery category achieved the highest accuracy (97.3%) due to distinctive visual characteristics, while shoes demonstrated the lowest accuracy (91.8%) owing to high intra-class variation. The overall classification accuracy of 95.4% represents a significant improvement over existing approaches [11-13].

4.2.System Performance Analysis

The complete end-to-end system demonstrates efficient processing capabilities. Table II summarizes key performance indicators.

Table 2 System Performance Metrics

Metric	Value
Average Classification Time	1.2s
Image Upload Processing	0.4s
Database Query Response	0.08s
Chatbot Response Generation	0.3s
Peak Concurrent Users	150
Model Inference Time (TFLite)	0.6s
Memory Usage (Peak)	512 MB

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The TensorFlow Lite optimized model reduced inference time by approximately 50% compared to the full Keras model while maintaining classification accuracy, making the system suitable for deployment on resource-constrained environments.

4.3.Comparative Analysis

Table III compares our system with existing waste classification solutions across multiple dimensions.

Table 3 Comparative Analysis with Existing Systems

Feature	Yang [11]	Aral [12]	Vo [13]	Chu [15]	Ours
Number of Classes	6	6	7	4	12
Accuracy	63%	87%	91.2 %	89.5 %	95.4 %
Gamification	No	No	No	No	Yes
Chatbot Support	No	No	No	No	Yes
Admin Dashboard	No	Limited	No	No	Yes
Mobile Optimized	No	No	No	Yes	Yes
User Engagement Tools	No	No	No	No	Yes

5. Result

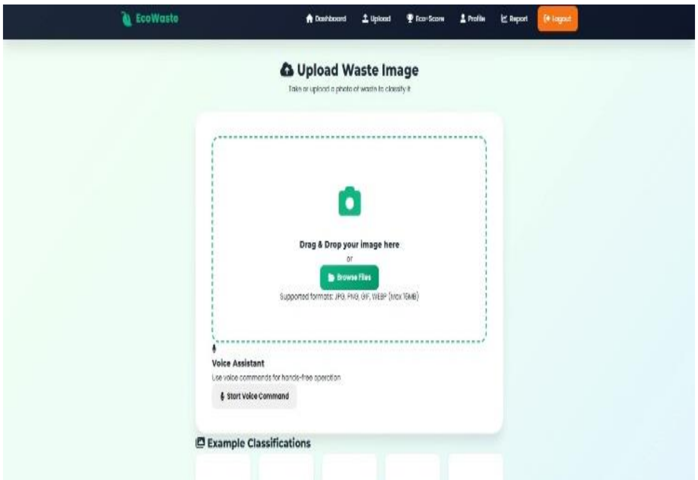

Figure 3 Image Upload Page

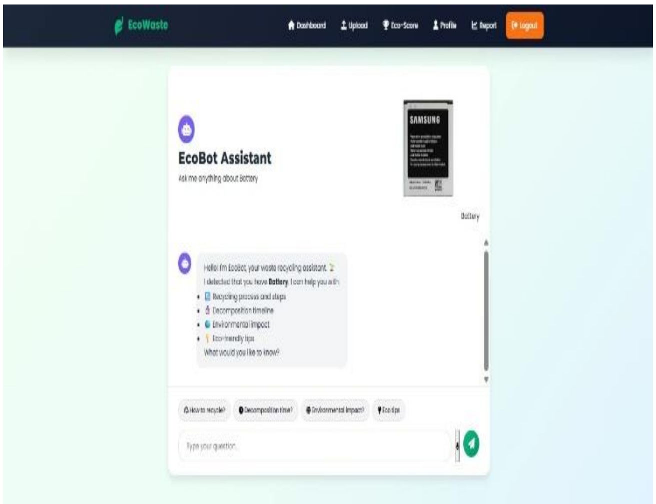

Figure 4 Classification Result and Chatbot Interaction

Conclusion and Future Scope

Expanded Waste Categories and Hazard Detection The waste classification model can be enhanced to recognize hazardous, biomedical, electronic, and industrial waste, improving safety and large-scale usability. Multilingual and Emotion-Aware Chatbot.The voice-enabled chatbot can be extended to support multiple regional languages and emotion-aware responses, increasing accessibility and user engagement across diverse populations The template will number citations consecutively within brackets [1]. The sentence punctuation follows the bracket [2]. Refer simply to the reference number, as in [3]—do not use "Ref. [3]" or "reference [3]" except at the beginning of a sentence: "Reference [3] was the first ..." Number footnotes separately in superscripts. Place the actual footnote at the bottom of the column in which it was cited. Do not put footnotes in the abstract or reference list. Use letters for table footnotes. Unless there are six authors or more give all authors' names; do not use "et al.". Papers that have not been published, even if they have been submitted for publication, should be cited as "unpublished" [4]. Papers that have been accepted for publication should be cited as "in press" [5]. Capitalize only the first word in a paper title, except for proper nouns and element symbols. For papers published in translation journals, please give the English citation first, followed by the original foreign-language citation [6].

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References

[1]. Kaza, S., Yao, L., Bhada-Tata, P., & Van Woerden, F., "What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050," World Bank Publications, 2018.

[2]. Hoornweg, D., & Bhada-Tata, P., "What a Waste: A Global Review of Solid Waste Management," Urban Development Series Knowledge Papers, vol. 15, pp. 1-98, 2012.

[3]. Wilson, D. C., Rodic, L., Scheinberg, A., Velis, C. A., & Alabaster, G., "Comparative Analysis of Solid Waste Management in 20 Cities," Waste Management & Research, vol. 30, no. 3, pp. 237-254, 2012.

[4]. Bernstad, A., "Household Food Waste Separation Behavior and the Importance of Convenience," Waste Management, vol. 34, no. 7, pp. 1317-1323, 2014.

[5]. Nowakowski, P., & Pamuła, T., "Application of Deep Learning Object Classifier to Improve E-Waste Collection Planning," Waste Management, vol. 109, pp. 1-9, 2020.

[6]. Lu, W., & Chen, J., "Computer Vision for Solid Waste Sorting: A Critical Review of Academic Research," Waste Management, vol. 142, pp. 29-43, 2022.

[7]. Krizhevsky, A., Sutskever, I., & Hinton, G. E., "ImageNet Classification with Deep Convolutional Neural Networks," Communications of the ACM, vol. 60, no. 6, pp. 84-90, 2017.

[8]. Pan, S. J., & Yang, Q., "A Survey on Transfer Learning," IEEE Transactions on Knowledge and Data Engineering, vol. 22, no. 10, pp. 1345-1359, 2010.

[9]. Deterding, S., Dixon, D., Khaled, R., & Nacke, L., "From Game Design Elements to Gamefulness: Defining Gamification," in Proc. 15th International Academic MindTrek Conference, 2011, pp. 9-15.

[10]. Hamari, J., Koivisto, J., & Sarsa, H., "Does Gamification Work? A Literature Review of Empirical Studies on Gamification," in Proc. 47th Hawaii International Conference on System Sciences, 2014, pp. 3025-3034.

[11]. Yang, M., & Thung, G., "Classification of Trash for Recyclability Status," Stanford University, CS229 Project Report, 2016.

[12]. Aral, R. A., Keskin, Ş. R., Kaya, M., & Hacıömeroğlu, M., "Classification of TrashNet Dataset Based on Deep Learning Models," in Proc. IEEE International Conference on Big Data, 2018, pp. 2058-2062.

[13]. Vo, A. H., Hoang Son, L., Vo, M. T., & Le, T., "A Novel Framework for Trash Classification Using Deep Transfer Learning," IEEE Access, vol. 7, pp. 178631-178639, 2019.

[14]. Howard, A. G., et al., "MobileNets: Efficient Convolutional Neural Networks for Mobile Vision Applications," arXiv preprint arXiv:1704.04861, 2017.

[15]. [Chu, Y., Huang, C., Xie, X., Tan, B., Kamal, S., & Xiong, X., "Multilayer Hybrid Deep-Learning Method for Waste Classification and Recycling," Computational Intelligence and Neuroscience, vol. 2018, Article ID 5060857, 2018.

[16]. Cechanowicz, J., Gutwin, C., Brownell, B., & Goodfellow, L., "Effects of Gamification on Participation and Data Quality in a Real-World Market Research Domain," in Proc. First International Conference on Gameful Design, Research, and Applications, 2013, pp. 58-65.

[17]. Rodrigues, L. F., Oliveira, A., & Costa, C. J., "Does Ease-of-Use Contributes to the Perception of Enjoyment? A Case of Gamification in E-Banking," Computers in Human Behavior, vol. 61, pp. 114-126, 2016.

[18]. RecycleBank, "2019 Impact Report: Transforming Recycling Through Rewards and Education," RecycleBank Annual Report,

[19]. Sandler, M., Howard, A., Zhu, M., Zhmoginov, A., & Chen, L. C., "MobileNetV2: Inverted Residuals and Linear Bottlenecks," in Proc. IEEE Conference on Computer Vision and Pattern Recognition, 2018, pp. 4510-4520.

[20]. EPA, "Environmental Benefits of Recycling and Waste Reduction," U.S. Environmental Protection Agency, Technical Report EPA530-F-03-023, 2003.