IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

CE-21 Garbage Classification System Using Convolutional Neural Networks and Machine Learning Algorithms for Sustainable Waste Management

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Abstract – *Efficient garbage separation is greatly essential in modern-day waste management systems and has direct implications for the efficiency of recycling, environmental sustainability, and public health. The classical process of manual garbage separation is cumbersome and prone to errors, as well as exposed to harmful materials. With the ever-increasing rate of urbanization and the consequent rise in consumer waste, there is an immense need for intelligent and automated solutions to effectively classify the garbage in a precise and minimally supervised manner. This paper describes Automated Garbage Classification based on Machine Learning (ML) and Deep Learning (DL) techniques to classify images of garbage into pre-defined classes of plastic, paper, metal, battery, and general trash. The project employs multiple techniques of classification like K-Nearest Neighbours (KNN), Support Vector Machine (SVM), and Random Forest Classification, along with a Convolutional Neural Network (CNN) to analyze and compare performance of each technique. Additionally, image processing techniques of resizing, normalizing images, and data augmentation are performed. Results reveal that the CNN approach outperforms classical machine learning techniques in terms of accuracy and reliability, especially in adverse conditions of light and background noise. The system is web-developed and based on Python Flask, enabling users to classify images for real-time results and confidence scores.*

Keywords- *Waste Segregation, Garbage Classification, Convolutional Neural Network (CNN), Machine Learning, Sustainability, Deep Learning, Image Classification.*

INTRODUCTION

There has been rapid growth in urbanization and industrialization, which has led to an increased amount of solid wastes being produced. Due to this factor, proper waste management has become an essential concern. Inadequate separation of wastes has resulted in ineffective recycling processes, overused landfill spaces, and major pollution of the environment. These issues pose threats to nature as well as the health conditions of humans. In current traditional practices of solid waste management, manual garbage separation remains prevalent.

An efficient garbage sorting system plays a crucial role in enhancing garbage recycling. Nevertheless, traditional garbage sorting techniques face difficulties in dealing with the increasing amount of garbage in modern cities. This often leads to mixing of recyclable trash with other non-recyclable garbage, thereby decreasing the rate of recyclable waste recovery. It thereby becomes necessary to introduce a smart garbage sorting system.

In the current context, there have been significant breakthroughs in Artificial Intelligence (AI), specifically in Machine Learning (ML) and Deep Learning (DL), that have shown immense potential for garbage classification. Image sorting of garbage uses computer vision technology that helps recognize garbage types based on certain features like shape, color, and textures. Amongst these methods, Convolutional Neural Networks (CNNs) have shown immense promise. Various studies have also reported that the use of CNNs outperforms other classical machine learning techniques like KNN, SVM, and Random Forest (RF), which rely upon human-designed features. The proposed system aims to develop an automatic waste categorization system based on machine learning and deep learning techniques that classify pictures of waste into several categories including plastic, paper, metal, glass, cardboard, batteries, clothes, shoes, and general trash.

LITERATURE REVIEW

Many researchers have looked into automated garbage classification using machine learning and deep learning techniques to make waste sorting more efficient and boost environmental sustainability.

Table 1. Comparative Analysis of Existing Waste Classification Methods

Authors	Algorithm	Method Summary	Key Results	Limitations
[12] Gulzar Ahmad et al.	ResNet-based CNN	Classified 12 waste types using 15,535 images with augmentation.	98.16% accuracy; strong for multi-category urban waste.	Struggles with similar items under poor lighting; RGB-only.
[13] Faizul Rakib Sayem et al.	Dual-Stream (classif.); GELAN-E (detect.)	Classification and detection on 28 categories (10,406 images).	83.11% classif. acc.; 63% mAP50 detection.	Lower detection acc.; issues with complex items.
[14] Hongwu Qin et al.	CNN + DCGAN	Augmented small domestic dataset with DCGAN for CNN training.	+81.7% data; +7.27% accuracy.	High compute needs; limited real-world variation testing.
[15] Ashok S et al.	Faster R-CNN	Real-time street garbage detection and cleanliness evaluation.	Automated counting/classification for city planning.	Camera/environment dependent; street waste only.
[16] Dr. K. Karuppasamy et al.	CNN	Binary (biodegradable/non-biodegradable) classification via web/mobile uploads.	Real-time feature-based prediction.	Binary only; no multi-class support.
[17] Megha Chhabra et al.	Improved CNN + Dropout	Binary classification with dropout for better generalization.	88.54% accuracy.	Moderate accuracy; binary & image quality sensitive.
[18] Suyash Kunkekar et al.	VGG16 (vs. InceptionV3)	9 recyclable categories from 8,000+ images; web app integration.	VGG16 better in real-world despite ~70% acc.	Limited categories; InceptionV3 overfits real data.
[19] Pratiksha Ambhore et al.	SVM & Random Forest	7 categories (incl. e-waste, medical) using traditional ML.	86.01% accuracy.	Lower acc. than DL; fewer categories/dataset.
[20] Sunardi et al.	CNN + Preprocessing	3 classes (organic/inorganic/hazardous) on Kaggle data.	98.92% accuracy; low loss.	Only 3 classes; dataset-specific; real-world scalability issues.

Research Gap and Motivation

The literature reveals that most current systems either focus only on deep learning models or are limited to specific types of waste. Additionally, there are fewer studies that combine traditional machine learning algorithms (KNN, SVM, RF) with CNNs while offering an interactive learning platform for users. The proposed system fills this gap by merging CNNs with classical machine learning models and implementing them in a web-based educational waste segregation system. This combination improves classification performance and raises public awareness.

DATASET DETAILS

The dataset contains images of nine waste categories including plastic, paper, cardboard, metal, battery, glass, clothes, shoes, and general trash. The images were collected from the Kaggle Garbage Classification Dataset and include variations in lighting, background, angles, and backgrounds, ensuring that the image classification environment for the model is diverse.

Table 2. Dataset Details (Adapted from [21])

Class	Types of Waste Included	Count of Images
Plastic	Bottles, wrappers, containers	2753
Paper	Newspapers, notebooks, pamphlets	3253
Cardboard	Carton boxes, packaging boxes, corrugated sheets	2350
Metal	Beverage cans, foil, tins	2803
Battery	Mobile batteries, power cells, damaged or leaked batteries	945
Trash	Cups, tissues, non-recyclable waste	900
Glass	Bottles, jars, broken glass items	4727
Clothes	Shirts, jeans, fabric scraps	5325
Shoes	Sneakers, sandals, slippers	1977

METHODOLOGY

The proposed garbage categorization system adopts a systematic approach that entails dataset preparation, preprocessing of images, feature extraction, training of the model, model evaluation, and integration of the system. The method is informed by the existing garbage classification and recycling technology that uses deep learning techniques proposed in the literature.

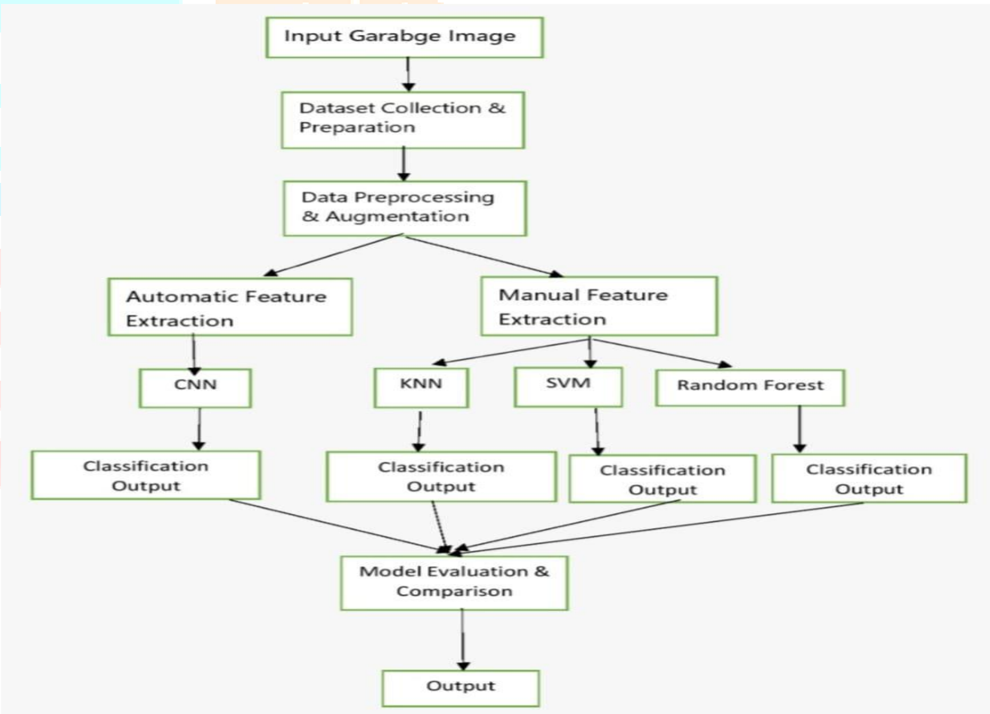

Fig. 1. System Workflow

A. User Upload Image

In this step, the user provides an input image of a discarded waste item through the system interface. These images reflect real-world conditions, as they may be captured under varying lighting environments, object orientations, and background scenes. By allowing user-uploaded images with such variations, the system ensures that the trained classification model is evaluated under practical conditions consistent with the dataset used during training and validation, thereby enhancing the robustness and real-world applicability of the proposed garbage classification approach.

B. Data Preprocessing and Augmentation

Images have been resized to a constant resolution to provide a uniform input size, reducing complexity in the training phase of the model. Pixel normalization is applied to ensure a stable learning phase and the convergence of the deep learning model. To improve the diversity of the image data and tackle variations, image rotation, flip, zoom, and brightness adjustments are conducted as data augmentation strategies. Such strategies have been demonstrated to optimize the classification efficiency in garbage segregation algorithms.

C. Feature Extraction

In the case of conventional machine learning models, manual feature extraction techniques were carried out by employing the Histogram of Oriented Gradients (HOG) method. HOG features focus on edge and shape characteristics and have been successfully employed in waste classification problems with conventional classifiers like SVM and Random Forest classifiers. On the other hand, the Convolutional Neural Network (CNN) automatically identifies the spatial and textural features from the raw image data without the need for the manual design of the aforementioned features.

D. Model Architectures & Training

This section provides an overview of the models used for garbage classification and the training strategy adopted in this work. Different machine learning and deep learning algorithms are employed to analyze waste images and learn discriminative features, which are then used to classify garbage into multiple categories.

1. Convolutional Neural Network (CNN)

Convolutional Neural Networks (CNNs) are effective for image classification tasks because they automatically learn spatial features from images. In garbage classification, CNN extracts important visual features such as edges, textures, and shapes to accurately classify waste images into different categories. The proposed CNN model consists of convolutional layers, pooling layers, and fully connected layers. Convolutional layers apply learnable filters to the input image X to generate feature maps, defined as:

$Z[i,j] = (X * W)[i,j] + b$

where W is the convolutional kernel and b is the bias. A non-linear activation function g(·), such as ReLU, is applied:

$A[i,j] = g(Z[i,j])$

Pooling layers are used to reduce the spatial dimensions of feature maps and improve computational efficiency. The output feature maps are then flattened:

$F = flatten(A)$

Fully connected layers perform classification using:

$Z = F \cdot W + b,\ \ A = g(Z)$

The final layer uses the softmax activation function to predict the probability of each garbage class. This CNN architecture enables accurate and robust garbage image classification.

2. K-Nearest Neighbors (KNN)

KNN is a simple and distance-based machine learning algorithm that classifies data by comparing a new sample with previously stored samples. In this project, KNN is used to classify garbage images based on extracted visual features such as color and texture. When a new waste image is provided, the algorithm identifies the nearest images in the training dataset and assigns the waste category based on majority voting. KNN helps in understanding similarity-based classification performance and serves as a baseline model for evaluating the effectiveness of more advanced techniques.

3. Support Vector Machine (SVM)

SVM is a supervised learning algorithm that classifies data by constructing an optimal decision boundary between different classes. In the proposed garbage classification system, SVM is applied to image features to separate waste categories such as plastic, paper, metal, battery, and trash. Its ability to handle high-dimensional data and complex class boundaries makes it suitable for image-based classification tasks. SVM is used in this project to achieve reliable classification results and to compare traditional machine learning performance with deep learning models.

4. Random Forest (RF)

Random Forest is an ensemble learning algorithm that combines multiple decision trees to improve prediction accuracy and robustness. In this project, Random Forest processes extracted image features by aggregating decisions from several trees trained on different subsets of data. This approach reduces overfitting and improves stability when dealing with noisy or complex waste images. Random Forest plays an important role in validating ensemble-based learning techniques and provides a strong traditional model for comparison against CNN-based automatic feature learning.

E. Final Output

In the final stage of the workflow, the system presents the classification result obtained from the trained model to the user. Based on the prediction, the output clearly indicates the identified waste category, such as plastic, paper, cardboard, metal, glass, battery, clothes, shoes, or general trash. This result is displayed through the application interface in a user-friendly manner, enabling users to easily interpret the classification outcome. By providing an accurate and clear final output, the system supports proper waste segregation and contributes to improved recycling efficiency and effective waste management practices.

RESULT AND DISCUSSION

The proposed garbage classification system was tested using a multi-class image dataset that included plastic, paper, cardboard, metal, glass, battery, clothes, shoes, and general waste. Before training, all images were processed through resizing, normalization, and data augmentation to improve learning and consistency. The results clearly show that the Convolutional Neural Network (CNN) performs better than traditional machine learning models such as KNN, SVM, and Random Forest. CNN produced consistent and reliable results across most waste categories, especially for visually clear items like glass, plastic, and clothes. Some classification errors were noticed between similar-looking categories, mainly paper and cardboard, because of their close resemblance in texture and color. Lower performance in a few classes was also affected by an unequal number of images, indicating the impact of dataset imbalance on accuracy.

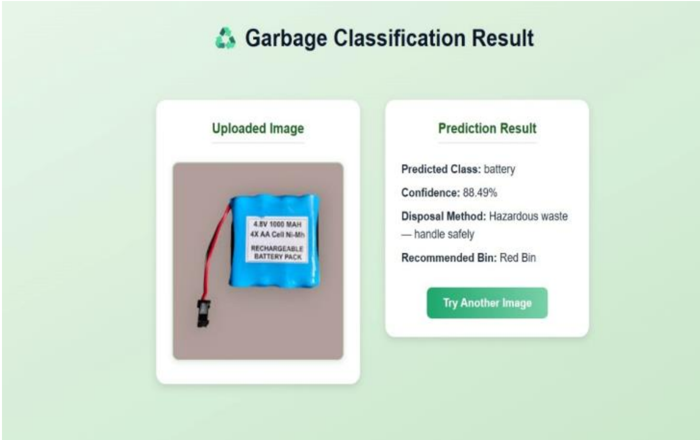

Fig. 2. Final Output of Garbage Classification System

A. CNN vs Traditional Machine Learning Models

A performance comparison was carried out between CNN and conventional machine learning classifiers. The comparison confirms that CNN achieves much higher accuracy and better robustness than KNN, SVM, and Random Forest. Traditional models depend on manually extracted features such as edges and texture patterns, which limits their ability to handle variations in lighting, background, and object orientation. In contrast, CNN automatically learns meaningful features from images through convolutional layers, allowing it to generalize better and deliver improved classification results.

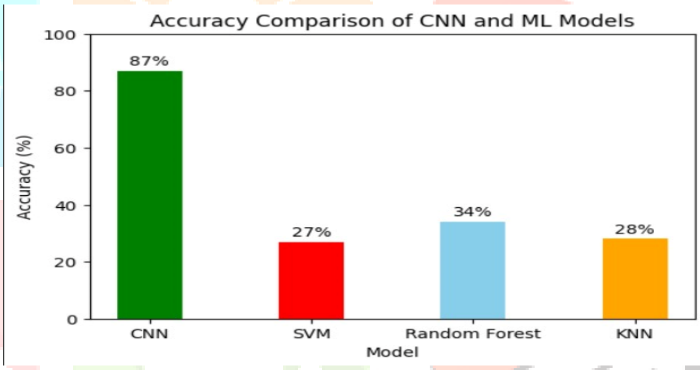

Fig. 3. Accuracy Comparison of Different Classification Models

B. Discussion

CNN shows the best performance among all models due to its ability to automatically learn hierarchical features from garbage images. The initial layers extract simple features such as edges and textures, while deeper layers capture high-level features like object shape. This enables accurate differentiation between waste categories. CNN is also robust to variations in lighting, background, and object orientation. Although computationally intensive, its high accuracy makes it suitable for real-world garbage classification.

CONCLUSION

The garbage classification system that is proposed is a good example of how machine learning and deep learning concepts can be used effectively to improve the garbage classification process. In the proposed garbage classification system, various machine learning and deep learning concepts such as CNN, KNN, SVM, and Random Forest are used to classify images of garbage into various classes. The CNN model is identified as the most accurate classification model due to its ability to learn and extract key features from images. The proposed model is also integrated into a Flask-based application to classify garbage images. Using this application, users can upload their garbage images and get instant classification results. The proposed system is effective in reducing manual work and encouraging environmentally friendly practices.

The garbage sorting system can be further improved by integrating it with smart bins equipped with cameras and sensors to detect and sort waste automatically. These bins can also communicate with waste collection services for efficient scheduling. The system can be enhanced by adding more waste categories such as food waste and medical waste, and by capturing images under diverse lighting and weather conditions for improved real-world performance.

ACKNOWLEDGMENT

The authors would like to thank the Department of Artificial Intelligence & Data Science, Government College of Engineering, Kolhapur, for providing the necessary resources and support for this research work.

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