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Harnessing Machine Learning for Effective Waste Classification and Recycling

Suyash Kunkekar[1], Atharv Sonawane[2], Sarang Kulkarni[3], Suhas Patil[4], Prof. Sarika Aundhakar[5]
[1, 2, 3, 4, 5]*Department of Computer Engineering, Smt. Kashibai Navale College of Engineering, Pune*

Abstract: The world produces nearly 3.5 million tons waste every day so it is important to improve waste management and recycling system. This paper defines how machine learning can classify waste, specifically using VGG16 CNN model to classify 9 types of recyclable materials such as light bulbs, paper, plastic, organic, glass, batteries, clothes, metal and e-waste .We had used nearly 8000+ images from Google Images and Dreamstime.com to test VGG16 model and compare it with another model named as Inceptionv3.

But Inceptionv3 showed higher accuracy (~90%) ,and it did not work well when tested on real data. In contrast, the VGG16 model which initially had lower accuracy of (~70%), performed better when tested on real-world scenarios. We also developed a web application which not only classifies the waste but also provides the valuable information to help people how to minimize waste reduction and maximize recycling. The classified images of the waste and its respective findings will also be shared with local authorities to enhance better recycling efforts. Hence this study focuses on need to select right models for waste classification and suggests looking into another machine learning techniques in future.

Keywords: Waste Classification, Machine Learning, VGG16, Transfer Learning, Recycling, Sustainability.

I. INTRODUCTION

Nowadays, Machine Learning has emerged as powerful tool for tackling environmental problems, specifically in waste management. Waste classification plays an important role in enhancing recycling process by effectively classifying waste materials for disposal. VGG-16 Transfer Learning is utilized in this research to classify 9 recyclable materials such as Light Bulbs, Paper, Plastic, Organic, Glass, Batteries, Clothes, Metal and E-Waste.

A dataset of nearly 8000 images was collected and pre-processed for training model. Initially Inceptionv3 resulted in nearly 90% accuracy, but it was less effective when applied on real-world scenarios. While VGG16 provided lower accuracy of nearly 70% , but the models performance was better in practical tests.

This study stands out for its application of machine learning to waste classification field and developing a user-friendly web application that encourages responsible waste management. Additionally, results of this project, will be shared with local authorities to contribute to take actions towards improved waste management and recycling efforts. Our study highlights effectiveness of machine learning in automating waste classification ,providing scalable and practical solution to global crisis.

II. LITERATURE SURVEY

1) *Burange, R. A., Chakole, P. D., Agre, O. P., & Thakre, U. (2024). Development of E waste management system using machine learning. International journal of advanced research in computer and communication engineering, 13(3), 403-412. Doi:10.17148/ijarcce.2024.13364*

In this study, Prof Burange and his team (2024) highlights the significant advancements in deep learning methods, including Deep Residual Learning and PCA-Net, which had improved accuracy and efficiency for separation of various waste materials. Deep Learning's adaptability extends to various different fields like plant disease, cellular image analysis in which pattern recognition is important. However, in spite of these developments, knowledge gap remains in this field. The lack of specialized datasets, specifically related to waste classification hampers training and validation model. Addition to this robustness of model in environmental conditions like varying light and background scenario had not been studied. To address these gaps, future research of study should focus on creating comprehensive datasets that will accurately represent diversity of waste material, improving model resilience. By targeting these areas, the automated waste classification field could advance significantly, providing efficient solution.

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2) *Adhikari, J., Jumale, A., Pittalwar, L., Joshi, M., Khan, F., & Samund, N. (2023). Automated waste classification via image processing based on deep learning. International research journal of modernization in engineering technology and science, 5(5), 1-9. Doi: 10.5281/zenodo.6375.*

This paper presents the automated waste classification using deep learning techniques, which addresses limitations of traditional waste management method. The paper reviews significant improvements by Convolutional Neural Network (CNN), which includes models like Faster R-CNN and ResNet-50, which had improved classification accuracy and also enabled real-time processing. It also discusses object detection algorithms like YOLO and SSD which improves detection capabilities. Additionally, it also highlights importance of engaging citizen through real-time waste classification system for promoting waste disposal. The study demonstrates transition from the conventional approaches to cutting-edge deep learning methods, indicating future advancements should prioritize mobile-based system to promote public awareness in waste classification.

3) *Y. Liu, Z. Zhang, and J. Zhang, "A deep learning approach for solid waste classification and management," Journal of Cleaner Production, vol. 290, p. 125601, 2021. doi: 10.1016/j.jclepro.2020.125601.*

Liu et al. (2021) had presented the deep learning framework for waste classification and management, which addressed challenges of urban waste. The authors deferred traditional sorting methods and insisted for use of Convolutional Neural Network (CNN), to automate waste classification, highlighting the accuracy over conventional methods. By using extensive dataset and various preprocessing methods, the classification accuracy improves a lot with CNN based approach. However, the paper also has limitations like it's reliance on specific dataset that don't fully represent diversity of types of waste in various geographical regions. The results focus on potential for integrating the deep learning technologies into waste management system to improve efficiency and recycling processes, which calls for further research to look into these limitations and explore real-world applicability.

III. METHODOLOGY

This methodology combines data driven machine learning with practical applications to address real-world waste management problem. It highlights effectiveness of transfer learning for classification of waste and provides improvements for future. The following steps were undertaken:

1) *Data Collection:* A dataset of nearly 8000 images was collected from Google Images and Dreamstime.com. The images were manually filtered to ensure that they represent waste of each category.
2) *Data Preprocessing:* The collected images were adjusted in size and format so that they match input requirements of model. To increase diversity of training data, data augmentation methods like rotation, flip, zooms were also applied.
3) *Model Selection:* Two pre-trained convolutional neural networks (CNNs), Inceptionv3 and VGG16 models were selected for transfer learning. Transfer learning enables these models to grasp knowledge from large scale images.
4) *Training Process:* These models were adjusted to specifically recognize 9 types of waste. They were trained for 28 cycles to measure how accurate they were and help them to learn faster. The data was divided in two parts as 80% for training and 20% for testing.
5) *Evaluation:* Models performance was evaluated based on accuracy and real-world application. Inception-v3 achieved high accuracy on validation set but it underperformed during practical testing. While, VGG16 delivered low accuracy but provided more reliable results in real-world use.
6) *Web Application Development:* The web application was developed using combination of Python, HTML, CSS, Bootstrap, JavaScript, NumPy, Matplotlib and TensorFlow. The app allows users to upload images, receives waste classification and provides educational content about recycling and waste management.
7) *Municipality Integration:* The classified waste images and data from system is submitted to local authorities for further waste management and recycling.

Fig 1. Waste Types

IV. SYSTEM ARCHITECTURE

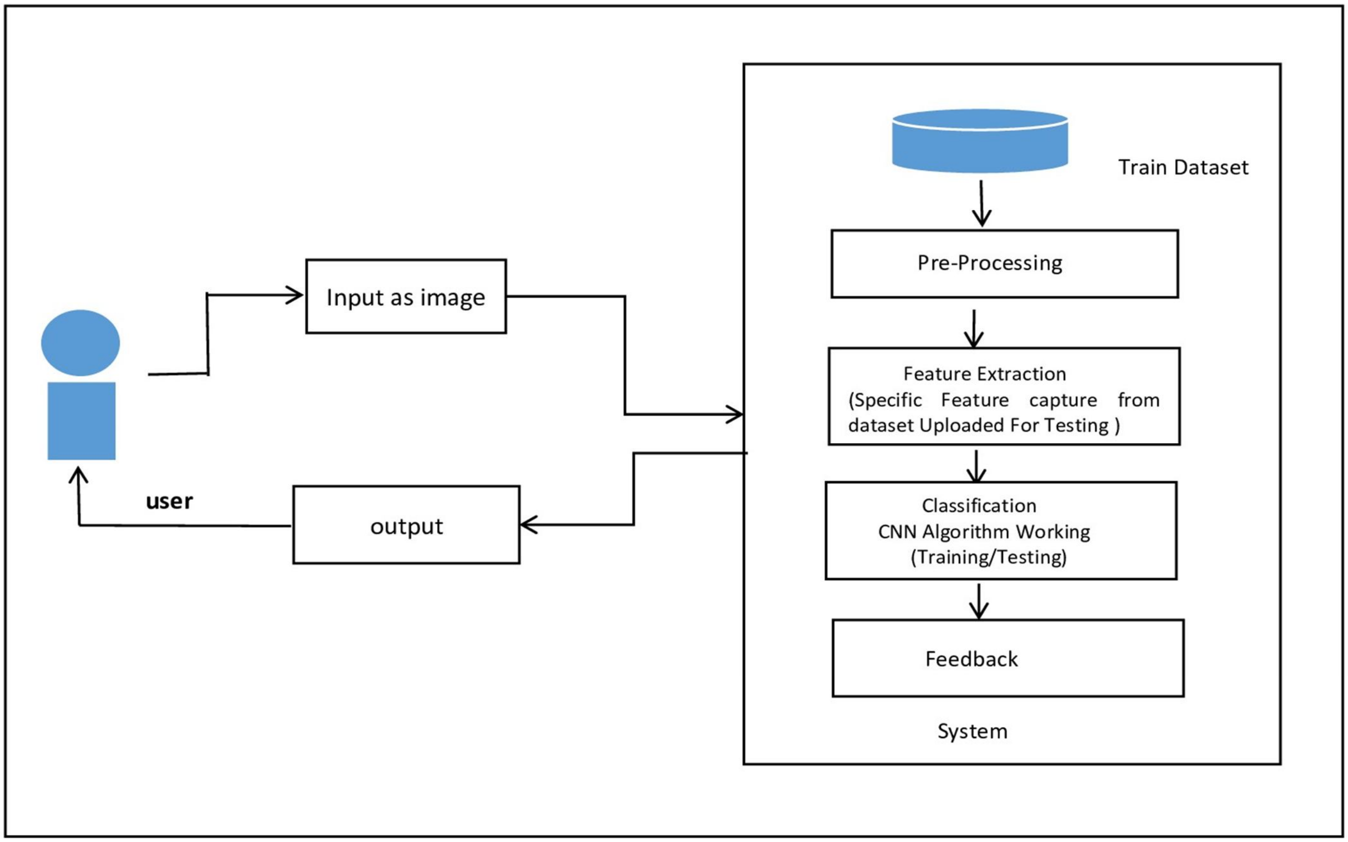

Fig 2. System Architecture

1) *Input as Image (User Input):* The user must provide an image as input to the system. The image which is intended to be classified, must likely represent waste material.
2) *Pre-Processing (Train Dataset):* The system will first apply pre-processing techniques to both user input image and training dataset. This step can involve tasks such as resizing, normalization, and removing noise to prepare data for feature extraction.
3) *Feature Extraction:* In this step specific features are extracted from both user input and dataset. After that the system identifies and captures similar characteristics (shape, colour, texture) from image.
4) *Classification (CNN Algorithm):* The extracted features are transferred to Convolutional Neural Network (CNN) for classification. The system then utilizes trained CNN model for classifying input image into specific category. During this process, the system can be either in training mode or testing mode.
5) *Feedback (System):* The system processes result of classification and provides feedback to the user as output. This maybe an identifying type of waste material & giving its harmful effects on environment also providing recycling steps.

V. FUTURE WORK

1) *Model Enhancement:* Working on improving the classification accuracy by testing different deep learning architectures and larger datasets.
2) *Expand Waste Categories:* Extend model to handle more than 9 categories of waste, including E-waste component.
3) *Mobile Application:* Developing mobile app version for easy user access and contributing to waste classification.
4) *Public Integration:* Partnering with municipal authorities for directly integrating app into local waste collection systems for smooth processes.

VI. CONCLUSION

In conclusion, this study focuses on importance of effective waste classification using machine learning techniques, specifically VGG16 model. Our findings reveal that Inceptionv3 showed high accuracy during training, VGG-16 performed better in real-world scenarios. By developing this user-friendly web application ,we aim to increase the awareness of waste classification and recycling .

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