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ML-Based Web Application for Sustainable Waste Reuse Suggestions

*Dundi Harini, **Gannoji Chikitha, ***Shaik Fatima, ****Assistant Professor Gnyana Deepa

*(Department of ADCE, Stanley College of Engineering and Technology for Women, Hyderabad.
Email:harini40015@gmail.com)

**(Department of ADCE, Stanley College of Engineering and Technology for Women, Hyderabad.
Email:gannojuchikitha@gmail.com)

***(Department of ADCE, Stanley College of Engineering and Technology for Women, Hyderabad.
Email:shaikfatima2025@gmail.com)

****(Department of ADCE, Stanley College of Engineering and Technology for Women, Hyderabad.
Email:deepayg@gmail.com)

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Abstract:

Effective waste management is crucial for maintaining a clean and healthy environment. Traditional waste disposal methods often result in inefficiencies, leading to pollution and health hazards. This paper presents a Machine Learning-Based Waste Classification and Reuse Suggestion System integrated with Geo-Tagging and Automated Email Notifications. The web application enables users to upload images of waste, which are classified into categories such as plastic, metal, glass, paper, and organic waste using a Convolutional Neural Network (CNN). Based on classification results, the system provides reuse suggestions and relevant external links, promoting sustainable waste practices. Additionally, users can report waste accumulation sites using a Geo-Tagging Module powered by Leaflet.js and the OpenCage API, which captures location coordinates and displays them on an interactive map. A Flask-Mail-based Automated Notification System sends detailed reports to that area's municipal authorities, ensuring immediate action. The model is trained on a public dataset and demonstrates high classification accuracy. By integrating machine learning, geospatial reporting, and real-time communication, this system enhances waste management efficiency.

Keywords — Web Application, Waste Management, Machine Learning, Convolutional Neural Network, Geo-Tagging, Waste Classification, Reuse Suggestions, Automated Email Notification, Sustainable Environment.

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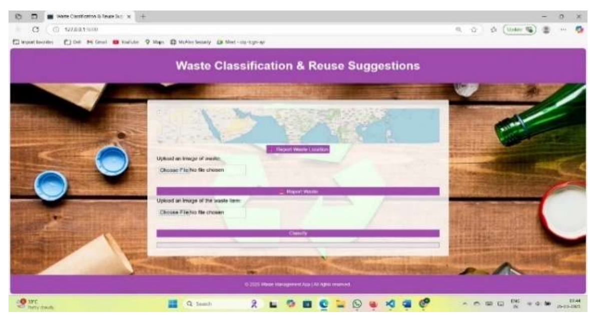
I. INTRODUCTION

Waste management is crucial for maintaining a clean and sustainable environment. It is one of the critical environmental challenges of the modern era. With rapid urbanization and industrial growth, the volume of waste generated has increased significantly and improper disposal of waste leading to landfill pollution, resource depletion, and health hazards affecting human health and ecosystems. Conventional waste management systems primarily rely on manual segregation and fixed collection schedules which is inefficient and labor-intensive, often resulting in inefficient operations, overflowing bins, and delayed municipal responses. Additionally, the lack of awareness regarding proper waste disposal and recycling methods contributes to environmental degradation. Traditional waste management faces multiple challenges, including manual segregation inefficiencies, inadequate monitoring of waste accumulation sites, and lack of real-time communication between citizens and municipal authorities, which contribute to poor sanitation, environmental pollution, and ineffective recycling practices. With the rapid advancements in artificial intelligence (AI) and machine learning (ML), these technologies have emerged as powerful tools to address waste classification challenges. Convolutional Neural Networks (CNNs), in particular, have demonstrated remarkable efficiency in image classification tasks, making them suitable for automated waste identification. There is a need for an automated waste classification system that not only categorizes waste but also suggests sustainable reuse methods. Furthermore, an efficient reporting mechanism is required to enable real-time waste accumulation site tracking and communication with municipal authorities for prompt action. This research aims to develop a Machine Learning-based Waste Classification System that automatically identifies waste types using a Convolutional Neural Network (CNN) trained on a publicly available dataset and demonstrates significant classification accuracy. It also categorizes waste into predefined classes and provides reuse suggestions based on classification results, offering users informative text and external links to promote sustainable waste disposal practices. Additionally, the system integrates Geo-Tagging functionality using Leaflet.js and the OpenCage API, allowing users to report waste accumulation sites and visualize them on an interactive map and it also captures location coordinates through this functionality. This geo-tagged information is then forwarded to municipal authorities via an Automated Email Notification System using Flask-Mail sends detailed waste reports to municipal authorities, ensuring timely intervention, prompt waste management responses and efficient waste management. This project aims to improve waste monitoring and municipal coordination by bridging the gap between citizens and waste management authorities through real-time reporting and data-driven decision-making. By leveraging Machine Learning, Geospatial Mapping, and Automated Reporting, the proposed system enhances waste classification accuracy, facilitates proactive waste management, and encourages sustainable waste disposal practices, contributing to a cleaner and more efficient urban environment.

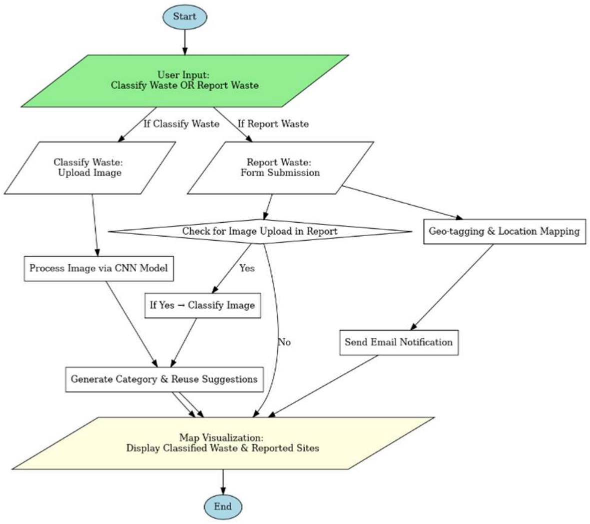


II. LITERATURE REVIEW

The field of waste classification has seen significant advancements through machine learning, computational linguistics, and interdisciplinary methodologies. Early approaches to classification, such as those used in news genre categorization that rely on linguistic and syntactic structures, have demonstrated the potential for automated systems. Within this context, research has explored computer vision approaches to classifying garbage for recycling, focusing on categorizing individual pieces of waste into classes like glass, paper, metal, plastic, cardboard, and trash, often leveraging models such as SVM and CNN. While these methods contribute to the development of automated systems, there's a continued need for effective and scalable solutions to improve recycling processes [1]. An initial breakthrough in waste classification involved using Faster R-CNN to get region proposals and classify objects. Given an image of jumbled waste, research categorizes the different pieces of waste into categories: landfill, recycling, paper. Early progress in waste classification involved using Faster R-CNN to obtain region proposals and classify objects. Research has focused on automating waste sorting using computer vision and deep learning, addressing the challenge of categorizing different pieces of waste within a jumbled image into categories like landfill, recycling, and paper. This involves developing approaches that can categorize waste from images and often utilize models like Faster R-CNN. These efforts aim to provide a foundation for automated waste sorting systems [2]. The computer vision field has made significant strides through the development of deep convolutional neural networks. A breakthrough in the field was AlexNet, which popularized deep convolutional neural networks by winning the ImageNet Challenge: ILSVRC 2012.The document discusses these advancements in computer vision, particularly through the use of deep convolutional neural networks. It highlights AlexNet's role in popularizing these networks after its success in the ImageNet Challenge: ILSVRC 2012. The general trend has been to make deeper and more complicated networks, with research also focusing on efficient models like MobileNets for mobile and embedded vision applications [3]. Deep Learning models can be used for the purpose of classifying recyclable garbage. In this study, DenseNet121, DenseNet169, InceptionResnetV2, MobileNet, Xception architectures were used for the Trashnet dataset. The data augmentation process was applied to increase classification accuracy because of the limited samples of the Trashnet dataset. As a result of the conducted experiments, the best results were found in the DenseNet121 using fine-tuning with a test accuracy rate of 95% [4]. A multilayer hybrid deep-learning system (MHS) can be used to automatically sort waste disposed of by individuals in the urban public area. This system can deploy a high-resolution camera to capture waste images and sensors to detect waste input. The system uses deep learning to classify waste [5]. Visual-based trash detection and classification system for smart trash bin robot is a system that aims to automate the process of trash classification, which is a step towards automatic waste sorting. The robot would inherently need to capture images (or use sensors) to detect and classify waste. The use of a classification system on the robot implies the use of machine learning, and potentially deep learning, for waste classification[6]. There is a growing need for resource preservation and waste reduction thereby introducing a Smart Recycling Bin that employs contemporary methods for waste classification The bin's design prioritizes cost-effective manufacturing and incorporates technologies such as neural networks and the LoRaWAN protocol [7]. The main theme of the work is to develop a smart intelligent garbage alert system for proper garbage management. The smart bin is implemented using IoT as a solution to these problems. The bins are equipped with Raspberry-Pi integrated with ultrasonic sensor for garbage level detection and pi camera which separates garbage by object detection using YOLO algorithm and opens the respective bin lid automatically using servo motor. The intelligent bin is connected with mobile application via cloud for monitoring and clearance of waste which is done using optimized routing [8]. A cloud-based classification algorithm is proposed for automated machines in recycling factories, using machine learning. The study details the training of a MobileNet model to classify five different types of waste, with real-time inference on a cloud server. Techniques such as data augmentation and hyperparameter tuning are employed to enhance classification accuracy. The system uses a cloud-based architecture for classifying waste images captured by embedded devices at waste collection facilities. The experimental results demonstrate the solution's high performance in waste classification [9]. The research addresses the global issue of waste and the need for effective management, with a focus on mitigating landfill problems and soil toxicity. It emphasizes the importance of waste classification as a crucial first step in the separation of organic and recyclable materials. To achieve this, the study develops a Convolutional Neural Network (CNN) model. The CNN model is trained from scratch to classify waste into organic and recyclable categories. The study utilizes a dataset of 25077 images and examines the model's performance in waste classification [10]. The study explores the application of deep learning techniques to enhance waste classification for improved sustainability. It addresses the critical role of accurate waste disposal in mitigating climate change. The research proposes a mobile application that employs optimized deep learning methods to provide users with instantaneous waste classification. The study experiments with various convolutional neural network architectures for detecting and classifying waste items. The findings demonstrate the potential of deep learning residual neural networks for achieving high precision in waste classification [11]. The research surveys the application of artificial intelligence and machine learning, including deep learning, in smart waste management systems. It explores the use of these technologies to address challenges in solid waste generation and waste disposal. Machine learning techniques are applied to enhance various aspects of waste management, such as predicting waste generation, optimizing waste disposal processes, and improving the efficiency of waste collection in smart cities. The research discusses how machine learning contributes to the development of smart waste management solutions [12]. The research presents a systematic review of smart waste management systems that incorporate machine learning methodologies. It provides an overview of how machine learning techniques are applied within the realm of waste management. The review synthesizes information regarding the utilization of machine learning in various waste management tasks. Furthermore, it examines the role of machine learning in enhancing the efficiency and automation of waste management processes [13]. The research introduces a waste management approach using deep learning models for waste detection, classification, and size quantification. A trained neural network model is integrated into a mobile application, enabling users to geotag waste locations via smartphone images. These images are connected to a cleaner database, facilitating efficient waste management. Experimental results from public datasets demonstrate the method's effectiveness in waste detection and classification. The methodology employs neural network-based object detectors and classifiers and addresses waste volume estimation [14]. The study discusses the importance of classifying waste into biodegradable and non-biodegradable types to aid in energy conversion and proper disposal. It notes that computational approaches like AI and image processing offer solutions for MSW management. The paper utilizes machine learning techniques, including CNNs and transfer learning with ResNet V2 models, for solid waste image classification. The ResNet V2 model is used to train large datasets and improve accuracy. The model aims to identify and classify waste as biodegradable or non-biodegradable for precise collection [15]. The research focuses on employing deep learning models for waste classification through image recognition. It explores the application of these models to categorize waste, aiming to support sustainable development. The research investigates and compares various deep learning neural network models for their effectiveness in waste classification. The study emphasizes the use of image recognition, powered by deep learning, to automate and enhance the accuracy of waste sorting and management processes [16]. The field of waste classification has seen significant advancements through machine learning, computational linguistics, and interdisciplinary methodologies Using an algorithm for automatic garbage detection and instance segmentation in complex settings, using the FCOS algorithm with improvements like a sample-fused feature pyramid network (SF-FPN) and a conditional convolution-based mask branch. The field of computer vision has seen significant progress through deep convolutional neural networks (CNNs), marked by milestones like AlexNet's success in the ImageNet Challenge and the development of more efficient models like MobileNets, leading to advancements in image classification, object detection, and real-time vision applications [17]. The field of computer vision has been revolutionized by deep convolutional neural networks, with AlexNet's success in the ImageNet Challenge: ILSVRC 2012 as a major turning point. Research has since focused on developing deeper and more efficient models, like MobileNets, enhancing performance for mobile and embedded devices and significantly improving object detection, segmentation, and real-time image analysis. In a specific application of these advancements to environmental sustainability, designed a machine learning and blockchain-oriented system to address municipal solid waste. This system uses a Deep Neural Network (DNN) for object recognition and blockchain to record transactions, promoting reuse and recycling through DIY suggestions [18]. We propose an IoT-based waste management system that automates waste segregation using smart devices such as ultrasonic, rainfall/moisture, and inductive proximity sensors integrated with servo motors and an Arduino controller. This system enhances traditional waste management by enabling real-time garbage tracking, segregation, and collection, improving efficiency and contributing to smart city development. By leveraging sensor-based detection mechanisms, the system optimizes recycling processes, reduces manual intervention, and enhances sustainability. Additionally, the integration of cloud-based data analytics facilitates improved waste tracking, ensuring a more efficient and eco-friendly urban waste management infrastructure [19]. The advancement of deep learning, particularly with models like AlexNet, has significantly improved image recognition and classification in computer vision. To address global waste management challenges, designed a machine learning and blockchain-based system that identifies waste, suggests reuse/recycling ideas, and uses blockchain for transaction verification. propose an algorithm for automatic garbage detection and instance segmentation in complex scenes, using a sample-fused feature pyramid network (SF-FPN) and conditional convolution. developed an IoT-based system for automated waste segregation, utilizing sensors, servo motors, and an Arduino controller to improve waste management efficiency [20]. The Study explores advancements in waste management by integrating machine learning, IoT, and automation to address inefficiencies in traditional disposal methods. It proposes a smart waste classification and tracking system using sensors, machine learning algorithms, and geotagging to optimize segregation, reduce environmental hazards, and enhance municipal coordination. Real-time monitoring and automated notifications ensure efficient waste disposal and sustainability, contributing to smart city development. Additionally, advancements in computer vision, particularly deep convolutional neural networks like AlexNet, have revolutionized automated classification. In waste management, CNNs enable precise classification, while mobile-friendly architectures like MobileNets support real-time identification on embedded devices, promoting sustainable disposal practice [21]. The Research explores advancements in waste management through the integration of machine learning, IoT, and automation to overcome inefficiencies in traditional disposal methods. It proposes a smart waste classification and tracking system utilizing sensors, machine learning algorithms, and geotagging to optimize segregation, minimize environmental hazards, and improve municipal coordination. Real-time monitoring and automated notifications enhance waste disposal efficiency and sustainability, supporting smart city development. Additionally, deep learning techniques, particularly Convolutional Neural Networks (CNNs) such as AlexNet and MobileNets, have revolutionized computer vision by improving image classification accuracy and enabling real-time identification on mobile and embedded platforms, further promoting sustainable waste management practices [22]. This involves employing deep learning models like CNNs for efficient waste classification, developing IoT-based systems for automated waste segregation, and creating mobile applications to assist users in waste identification and sorting. The overarching goal is to create more effective, precise, and sustainable solutions for waste processing, recycling, and disposal, ultimately minimizing environmental impact and fostering improved waste management.[23] The Research explore various technology-driven solutions to address the global issue of waste management. These solutions include employing deep learning models like CNNs for waste classification, developing IoT-based systems for automated waste segregation, creating user-friendly mobile applications for waste identification and sorting, and utilizing blockchain technology to ensure transparent and verifiable waste management processes. Deep learning techniques, particularly Convolutional Neural Networks (CNNs), are highlighted for their effectiveness in image classification and object detection, which are crucial for automated waste recognition. The overarching aim is to develop more efficient, accurate, and sustainable strategies for waste processing, recycling, and disposal, ultimately reducing environmental impact and promoting better waste management practices [24].

III. PROPOSED METHODOLOGY

Building upon the insights gained from the literature review, our research aims to address the limitations of traditional waste management systems by integrating machine learning-based waste classification, reuse suggestions, and geo-tagged reporting with automated notifications. Our proposed methodology consists of multiple interconnected modules that



work together to improve waste classification, encourage sustainable reuse, and facilitate efficient municipal responses. The system workflow follows a structured approach, as depicted in the flowchart, ensuring a efficient waste classification and reporting process.

A. User Interface and System Functionality

The system is designed as a web application where users can interact with two core functionalities: waste classification and waste reporting. A structured and user-friendly interface ensures seamless interaction, allowing users to either upload an image for classification or report waste accumulation sites.

1. ***Waste Classification Module:*** Users can upload images of waste items, which the system processes and categorizes using a machine learning model.

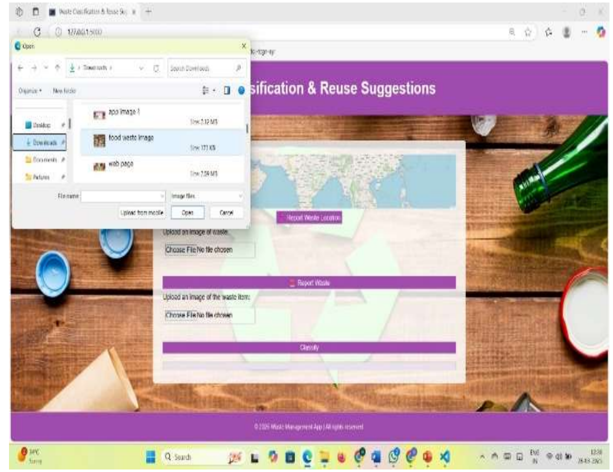
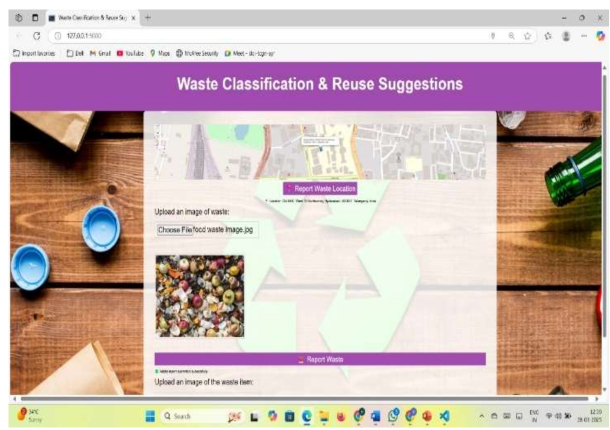


Image Uploading and Preprocessing

2. ***Waste Reporting Module:*** Users can submit waste accumulation reports by providing relevant details, including location information captured using geo-tagging.



B. Image Classification Module

To automate waste identification, a Convolutional Neural Network (CNN) is employed, leveraging Machine learning techniques to classify waste into predefined categories such as plastic, metal, glass, paper, organic waste, etc. where there are around 30 categories of waste.

1. ***Image Preprocessing:***
   - Uploaded images undergo preprocessing steps, including resizing, normalization, and denoising, to ensure consistency and enhance classification accuracy.

2. ***CNN-Based Classification:***
   - A pre-trained CNN model, fine-tuned on a publicly available waste classification dataset, predicts the waste category.
   - The model extracts key features from the input image and assigns it to the most probable waste category.

3. ***Classification Output:***
   - If an image is uploaded for classification, the system processes it via the CNN model and outputs the identified waste category along with a confidence score.
   - Additionally, reuse suggestions and recycling guidelines are provided based on the classification results through text as well as through external links.

C. Geo-Tagging & Reporting System

To facilitate efficient waste monitoring, the system integrates a geo-tagging module that allows users to report waste accumulation sites.

1. ***Location Data Acquisition:***
   - When a user reports waste, the system checks if an image is uploaded. If an image is included, it undergoes classification before further processing.
   - The OpenCage API fetches real-time geolocation data when users report a waste accumulation site.
   - Location details, including latitude and longitude, are extracted and stored.

2. ***Interactive Mapping:***
   - The system employs Leaflet.js and OpenStreetMap to visualize reported waste sites.
   - Users can interact with the map to view the reported waste locations and also ensure that the reported waste location is correctly visible to the users.

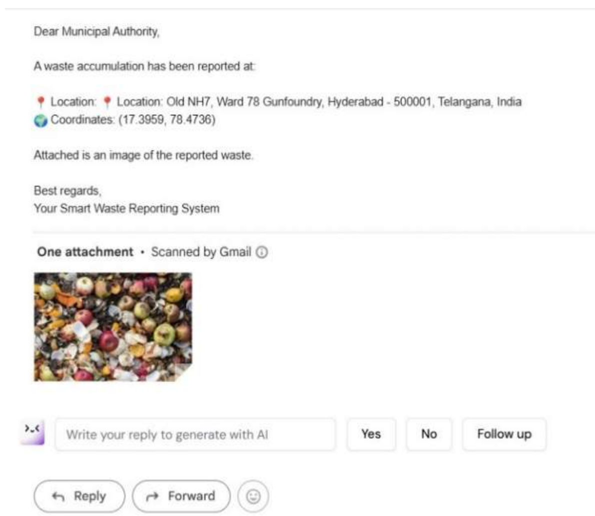
3. ***User Submission:***
   - Users submit reports detailing waste accumulation sites, along with any additional notes for municipal authorities.

D. Automated Email Notification System

To ensure timely intervention by waste management authorities, the system includes an automated email notification module.

1. ***Report Generation:***
   - Upon submission, the system generates a structured waste report containing details such as uploaded waste image attachment, location coordinates, and also proper location where waste accumulation is reported with some message to the municipal authorities.

2. ***Email Dispatch:***
   - Using Flask-Mail, an automated email is sent to the designated municipal authority or relevant recycling center.
   - The email contains waste location details and an accumulated waste image attachment for easy reference.



3. Municipal Response:
   - Authorities can take necessary action based on the received report, ensuring prompt waste collection and site cleanup.

E. Map Visualization

A centralized dashboard visualizes classified waste and reported accumulation areas to facilitate informed decision-making.

1. ***Interactive Map Display:***
   - The interactive map display helps in viewing the location by zooming in and out and is also useful for users to confirm the location allowing real-time tracking of waste accumulated areas.
2. ***Waste Accumulation Sites:***
   - Reported waste accumulation areas are marked on the map, enabling users to check if the location is proper so that it helps authorities to prioritize cleanup efforts.
3. ***User Interaction:***
   - Users can filter waste data based on type, location, and submission date for better analysis.

F. System Workflow Integration

The proposed methodology follows a structured workflow, aligning with the flowchart presented:

1. Users access the web application and choose either waste classification or waste reporting.
2. For classification, users upload an image, which undergoes preprocessing and CNN-based classification, and the system provides category predictions along with reuse suggestions.
3. For reporting, users submit site details, which are geo-tagged and visualized on an interactive map.
4. If an image is uploaded in the classification report, it is classified before submission, adding categorized information to the report.
5. An automated email notification system sends reports to municipal authorities for action.
6. The interactive map allows users to confirm and monitor classified waste and reported waste accumulation areas in real time.

G. Expected Outcomes

By integrating machine learning, geospatial reporting, and automated communication, the proposed system aims to:

- Improve the accuracy of waste classification through Machine learning.
- Encourage sustainable waste disposal practices via reuse suggestions.
- Enhance real-time waste monitoring using geo-tagging and mapping.
- Facilitate swift municipal responses through automated reporting.
- Bridge the gap between citizens and authorities, leading to a cleaner and more sustainable environment.

Our methodology effectively combines ML-driven classification with real-time waste tracking and automated municipal notifications, presenting an innovative solution to modern waste management challenges. The flowchart provided illustrates the step-by-step process of waste classification and reporting, ensuring clarity in system execution and demonstrating the seamless interaction between machine learning, geo-tagging, and notification components.

IV. CONCLUSIONS

Building upon the insights gained from the literature review, this research presents an innovative Machine Learning-Based Waste Classification and Reuse Suggestion System that integrates automated waste classification, geo-tagged reporting, and real-time notifications to enhance waste management efficiency. By leveraging a CNN-based classification model, the system accurately categorizes waste into 30 predefined categories, providing users with reuse suggestions and recycling guidelines to promote sustainable waste disposal practices. The integration of geo-tagging allows users to report waste accumulation sites with real-time location tracking using Leaflet.js and the OpenCage API. These reports are displayed on an interactive map, enabling users and municipal authorities to monitor waste disposal sites and take appropriate action. To ensure prompt municipal response, an automated email notification system powered by Flask-Mail sends detailed reports, including images and precise location coordinates, to relevant authorities.

The system is designed as a user-friendly web application, offering an intuitive interface where users can classify waste, report accumulation sites, and track waste locations seamlessly. By integrating machine learning, geospatial technologies, and automated notifications, the proposed system bridges the gap between citizens and municipal authorities, fostering active community participation in waste management.

The structured workflow ensures a seamless interaction between the waste classification, reporting, and notification modules, contributing to a more efficient and sustainable waste management framework. Future enhancements may include expanding the waste classification categories, integrating AI-driven route optimization for waste collection, and incorporating community-driven recycling initiatives to further improve sustainability efforts. This project demonstrates the potential of technology-driven waste management solutions, paving the way for a cleaner and more environmentally responsible future.

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