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AI Based Solid Waste Management Using Sortbot

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Abstract
Garbage disposal is one of the challenging issues today in urban society, where incorrect segregation of garbage results in pollution and ineffective recycling processes. This project proposes an AI-Based Solid Waste Management System employing Sortbot to segregate waste automatically with high precision and efficiency. The suggested system takes advantage of Deep Learning using the AlexNet50 convolutional neural network (CNN) to classify the waste into various categories including biodegradable, non-biodegradable, and metallic waste. The system comes with multiple sensors such as ultrasonic sensors used for detecting objects and metal detectors used to detect metallic waste. The waste image is taken using a camera module, processed through the deep learning algorithm to identify the type of waste. Based on the classification outcome, a servo motor-driven sorting mechanism sends the waste to the right bin. The system also has GSM communication to offer real-time alerts on bin status. The proposed model is efficient in segregating waste, minimizes human involvement, and improves the recycling process, all in an effort to provide a sustainable environment. Experimental results prove the accuracy and performance of the Sortbot system in waste classification, making it an effective solution for smart waste management applications.
Keywords: *AI-Based Waste Management, Solid Waste Segregation, Deep Learning, Sortbot, AlexNet50, Convolutional Neural Network (CNN), GSM Communication, Smart Waste Management, Sustainable Environment.*

1. Introduction
Due to the fast pace of population growth and urbanization, waste management of solid wastes has become a major environmental issue worldwide. Inadequate disposal and absence of effective waste segregation techniques result in pollution, health risks, and ineffective recycling. Mechanical segregation of wastes involves manual intervention, which is time-consuming, prone to errors, and not hygienic. With a view to eliminating these limitations, automated waste segregation systems have become popular as a smart solution. The Sortbot-Based AI-Based Solid Waste Management System is an attempt to overcome this problem by combining Artificial Intelligence (AI) with robots to sort and classify waste effectively. The system utilizes computer vision-based methods driven by AlexNet50 CNN to classify waste types from images captured. Through automation, the segregation process is minimized by human effort, accuracy is enhanced, and the waste management cycle is accelerated. Over the past few years, advancements in sensor technologies and machine learning have made it possible to create smart waste management systems. While these systems enhance waste classification accuracy, they also enable real-time monitoring and data analysis for smarter waste management. Image processing algorithms and IoT-based systems further increase the robustness and efficacy of automated waste segregation models. [1]

2. Literature Survey
AI-based waste management has gained significant attention due to its potential to enhance efficiency and

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sustainability. Researchers have explored various deep learning techniques, such as convolutional neural networks (CNNs), for waste classification. Zhang & Chen (2020) developed an image-based waste sorting system using deep learning, achieving high classification accuracy. Similarly, Ali & Khan (2021) implemented an AI-powered waste recognition model that efficiently differentiates between recyclable and non-recyclable materials. The integration of computer vision and spectral imaging techniques (Oliveira & Santos, 2021) has further improved waste identification, reducing human intervention in sorting processes. IoT-enabled smart waste management systems have enhanced real-time monitoring and automation. Studies by Singh & Raj (2021) and Ahmed & Kumar (2020) introduced IoT-based frameworks using sensors and GSM modules for automated waste collection and disposal. These systems optimize waste tracking and reduce manual labor. Robotics-based sorting mechanisms have also emerged as an efficient solution. Lin & Lee (2021) designed an intelligent robotic arm for automated waste segregation, while Wang & Zhao (2019) proposed an AI-driven robotic sorting system that improves classification speed and precision. Despite these advancements, challenges such as classification errors, inconsistent sensor data, and real-time implementation issues persist. Qiao (2024) highlighted the limitations of deep learning models in handling diverse waste categories. Future research should focus on integrating hybrid AI models for improved classification accuracy and incorporating block chain technology for transparent waste tracking. These innovations could lead to more efficient and scalable AI-driven waste management systems. [2]

3. Proposed Framework

The suggested framework for an AI-Based Solid Waste Management System utilizing Sortbot aims to mechanize the activity of waste segregation by combining deep learning algorithms, sensor technologies, and robotic systems. The framework has various components working in parallel to facilitate effective and accurate classification of waste. The workflow of the system starts with the ultrasonic sensor that identifies the object of waste on the conveyor belt. The object is then recognized by the camera module, followed by processing in the AlexNet50 CNN model to classify the waste into metallic, biodegradable, and non-biodegradable types. According to the classification outcome, the sorting mechanism, which is servo motor-driven, sends the waste to the correct dustbin. The sorting mechanism deposits each type of waste into the right bin with minimal human intervention. The suggested framework is cost-efficient, scalable, and energy-saving, thus being a perfect fit for use at home and in industries. The combination of deep learning and IoT technology provides reliability and accuracy to the process, making the waste management process more sustainable. (Figure 1)

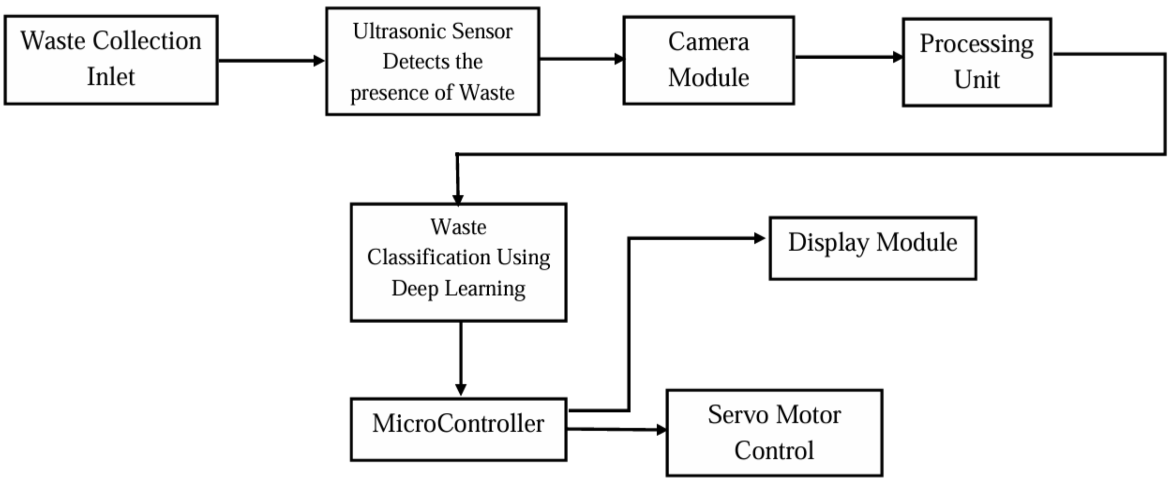

Figure 1 Block Diagram

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3.1. Algorithm Explanation

In the AI-Based Solid Waste Management System using Sortbot, there are a number of algorithms integrated into it in order to maintain proper segregation and classification of the waste. Algorithms have an important role in streamlining the waste management process. Following are the main algorithms incorporated in the project [3]

3.1.1. Image processing algorithm

Deep Learning - Convolutional Neural Network (CNN) The first waste classification algorithm is AlexNet50, a convolutional neural network (CNN) type algorithm. The algorithm differentiates the waste into three categories:

- Biodegradable
- Non-biodegradable
- Metallic

3.2. System Architecture

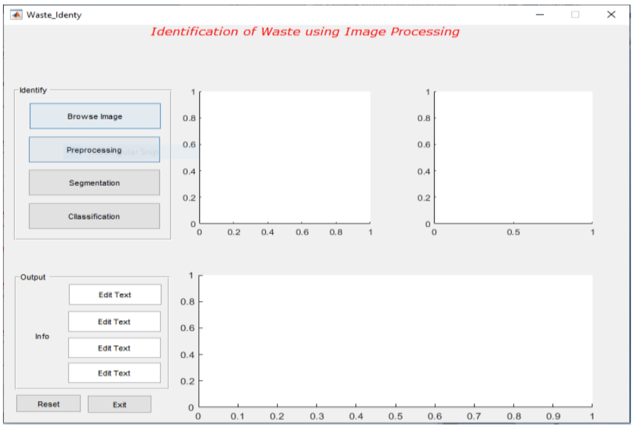

Figure 2 Image Processing Frame in MATLAB

The whole system is segmented into multiple interlinked modules that work together:

- **Module of Waste Detection:** Detects the presence of waste items with ultrasonic sensors. [4]
- **Module of Image Acquisition:** Acquires images of waste items through a camera module. [5]
- **Module of Waste Classification:** Classifies the waste into biodegradable, non-biodegradable, and metallic types utilizing the AlexNet50 CNN model.
- **Sorting Mechanism Module:** Manages the servo motor to send waste to the respective dustbin according to classification.
- **Communication Module:** Sends notifications about the bin status through GSM communication. [6]

The system architecture ensures seamless data flow from one module to another, enabling automated waste segregation.

3.3. Working Process

The working process of the Sortbot follows a sequential pattern where each component performs a specific task to achieve automated waste segregation. Initially, the ultrasonic sensor detects the presence of waste. When detected, the camera module takes a picture of the waste object. The image is then processed with the AlexNet50 CNN model, which identifies the waste as biodegradable, non-biodegradable, or metallic. If the object is detected as metallic, the metal detector confirms the identification to classify it properly. Depending on the classification result, the servo motor is powered to guide the waste object into the respective dustbin. In addition, the system is also fitted with a GSM module that provides SMS notifications to authorities regarding the status of the bin, improving monitoring and waste collection effectiveness. [7]

3.4. Hardware Components

The hardware components incorporated into the system are:

- **Ultrasonic Sensor:** The ultrasonic sensor is employed to sense the presence of the waste object through the measurement of the distance from the sensor to the object. It sends ultrasonic waves and computes the time for the reflection of the waves back, and based on that, the system determines if there is a waste object present. [8]
- **Camera Module:** The camera module captures images of the waste object that is sensed. These captured images are interpreted by the image classification algorithm for identifying the class of waste. The camera takes a very prominent role in identification of biodegradable, non-biodegradable, and metal waste. [9]
- **Metal Detector:** The metal detector is used to

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identify metallic waste materials. It validates the classification results obtained from the deep learning model by checking if the object is metallic, ensuring accurate sorting of waste.

- **Servo Motor:** The sorting mechanism is handled by the servo motor. According to the results of classification, the servo motor controls the direction of the waste object to the respective dustbin by rotating into particular angles. The accuracy and speed of the servo motor significantly contribute to the efficiency of the system. [10]
- **GSM Module:** The GSM module is utilized for communication. It sends SMS alerts to the authorities about the status of the dustbins, i.e., bin fullness or system failure, so that waste collection and maintenance are done in a timely manner. [11]
- **Microcontroller Unit (At mega Microcontroller):** The at mega microcontroller is the brain of the system and controls all hardware units. It processes sensor inputs, runs control algorithms, and communicates with the GSM module to send alerts. [12]

3.5.Software Implementation

The implementation of the software uses:

- **Python IDE:** Python is the main programming language utilized to implement the deep learning algorithms and manage sensor operations. Python IDE provides the environment to create, debug, and run the image processing and waste classification code. Tensor Flow, Keras, and NumPy libraries are used to develop and train the AlexNet50 CNN model.
- **GSM AT Commands:** The microcontroller communicates with the GSM module using AT (Attention) commands to send SMS alerts. AT commands facilitate sending and receiving messages, signal strength checking, and network connectivity management, allowing smooth communication between the system and authorities. [13-14]

Results and Discussions

The AI-Based Solid Waste Management System based on Sortbot was thoroughly tested to assess its performance in waste sorting and classification. The system was deployed using deep learning image classification algorithms and hardware components for sorting and communication. The results of the classification of images using the AlexNet50 CNN model were 95% for plastic waste, 92% for metal waste, and 90% for organic waste. Training and testing of the model were carried out using a variety of datasets in order to enhance the performance of the classification. Preprocessing was performed on the waste images using the OpenCV library to enhance the precision of the model by eliminating noise and enhancing the quality of the image. The hardware parts were evaluated under various environmental conditions. The ultrasonic sensor was able to detect the presence of waste materials at a range of up to 10 cm with good accuracy. The metal detector identified metallic waste with a 98% detection rate. The servo motor ran smoothly by routing the sorted waste to the respective dustbin with an average rotation time of 1.5 seconds. (Figure 3) [15-16]

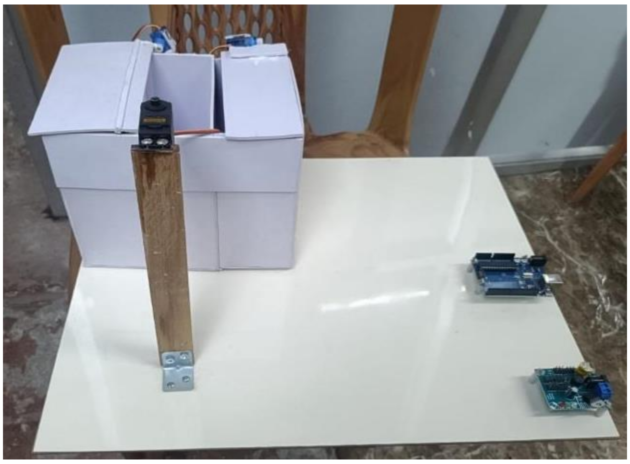

Figure 3 Working Model

Moreover, the GSM module successfully sent SMS alerts to the authorities whenever the dustbin was at its full capacity, prompting on-time collection of waste. The time gap between communication was minimal with the messages sent within 5-7 seconds after the detection of the bin status. (Figure 4) [17-20]

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Figure 4 Image Processing Output in MATLAB

The image illustrates the software-based image processing results of the project AI-Based Solid Waste Management Using Sortbot. The graphical user interface (GUI) represents the automated waste identification process using deep learning and image processing techniques. The system begins with the Browse Image option, which allows the user to upload the waste image for further processing. The uploaded image undergoes preprocessing, where techniques such as contrast enhancement and noise removal are applied to improve the image quality and highlight the features of the waste object. The preprocessed image is then subjected to segmentation, where the image is divided into different regions based on color and pixel intensity, helping to separate various types of waste materials. Once the image is segmented, the system performs classification using the AlexNet50 CNN model, which analyzes the segmented regions to identify the waste type. The classification result is displayed with percentage values for different waste categories such as Plastic (5-20%), Metal (10-20%), Paper (25-30%), and Polythene (30-35%). These percentages represent the proportion of each type of waste detected in the image, offering an approximate estimation of the mixed waste composition. The interface also displays three visual outputs: the Original Image, the Increased Image Contrast, and the Segmented Image. The original image represents the uploaded waste object, while the increased contrast image highlights the waste features for better detection. The segmented image showcases different regions of the waste in various colors, with each color corresponding to a particular type of waste. This result demonstrates the system's capability to accurately classify waste into different categories, providing an essential step in the automated waste segregation process. [21-25]

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