Advances in Consumer Research
https://acr-journal.com/
Volume-3 | Issue-2 | Feb 2026

Original Researcher Article

Computer vision based smart waste segregation using YOLO and IOT dashboard integration.

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ABSTRACT
The rapid growth of urban populations has intensified the challenges associated with solid waste management. Improper waste segregation leads to environmental pollution, health hazards, and inefficient recycling processes. Conventional waste management systems rely heavily on manual segregation, which is unhygienic, labor-intensive, and often inaccurate. To overcome these limitations, this paper proposes a computer vision–based smart waste segregation system integrating YOLO deep learning, embedded control, and IoT-enabled real-time monitoring. The proposed system employs a camera to capture waste images, which are processed using a YOLO-based object detection model to classify waste into biodegradable and non-biodegradable categories. Based on the classification result, an Arduino Nano–controlled mechanical unit automatically segregates waste into appropriate bins. Additionally, ultrasonic, flame, and air quality sensors continuously monitor bin fill levels and environmental safety conditions. All sensor data are transmitted to a cloud-based IoT dashboard for real-time visualization and alert generation. The proposed system reduces human intervention, improves segregation accuracy, enhances hygiene, and supports intelligent waste collection strategies. Owing to its low cost, modular design, and scalability, the system is suitable for deployment in smart cities and institutional environments.
Keywords: Smart Waste Management, Computer Vision, Yolo, Iot, Waste Segregation, Arduino Nano...

1. INTRODUCTION:

Efficient waste management is a critical requirement for maintaining environmental sustainability and public health in modern urban environments. With increasing population density and consumption, the volume of solid waste generated daily has risen significantly. Improper disposal and mixing of waste result in contamination of recyclable materials, increased landfill usage, and the release of hazardous gases. Traditional waste management practices largely depend on manual sorting, which exposes workers to harmful substances and often results in inconsistent segregation quality.

Recent advancements in artificial intelligence, computer vision, and the Internet of Things (IoT) have enabled the development of intelligent systems capable of automating complex tasks. Computer vision techniques allow machines to visually recognize and classify objects, while IoT facilitates continuous monitoring and remote access to real-time data. By combining these technologies, waste segregation can be automated at the source, significantly improving efficiency and hygiene.

This paper presents a smart waste segregation system that integrates YOLO-based object detection with embedded control and IoT dashboard monitoring. Unlike conventional smart bins that only monitor waste levels, the proposed system performs intelligent waste classification, automatic physical segregation, and environmental safety monitoring, thereby providing a comprehensive and sustainable waste management solution.

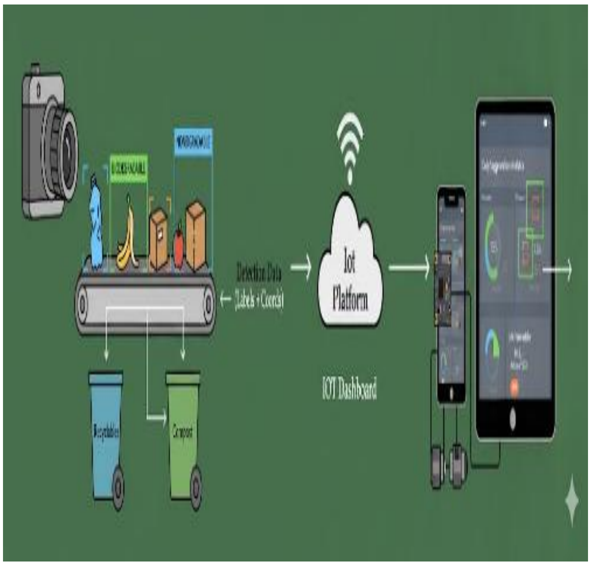

Fig 1 : smart waste segregation

2. RELATED WORK

Waste management has emerged as a critical challenge in urban environments due to rapid population growth, increased consumption, and limited landfill capacity. To address these issues, researchers have proposed various smart waste management solutions by integrating Internet of Things (IoT), sensor networks, and data analytics. Early systems primarily focused on monitoring waste bin fill levels using ultrasonic sensors and transmitting data to cloud platforms for optimized waste collection. While these approaches improved operational efficiency, they did not address the fundamental problem of waste segregation at the source.

Several studies have explored IoT-based waste monitoring systems using microcontrollers such as Arduino and NodeMCU combined with ultrasonic and gas sensors. These systems enabled real-time monitoring of bin status and environmental conditions, along with alert mechanisms using GSM or cloud-based dashboards. Although effective in reducing overflow and improving safety, such systems relied heavily on manual waste segregation, which limited their overall impact on recycling efficiency and hygiene.

To overcome the limitations of sensor-only approaches, recent research has shifted toward incorporating machine learning and image processing techniques for automated waste classification. Traditional computer vision methods employed hand-crafted features and classical classifiers such as Support Vector Machines (SVM) and k-Nearest Neighbors (k-NN). However, these techniques demonstrated limited accuracy under varying lighting conditions and complex backgrounds, making them unsuitable for real-world deployment.

With advancements in deep learning, Convolutional Neural Networks (CNNs) have gained popularity for waste classification tasks. Researchers have proposed CNN-based models capable of classifying waste images into multiple categories with improved accuracy. While these models achieved promising results in controlled datasets, their high computational complexity and slower inference speeds posed challenges for real-time applications, particularly in embedded and edge environments.

To address real-time performance constraints, object detection frameworks such as YOLO (You Only Look Once) have been increasingly adopted in smart waste management systems. YOLO-based models offer fast inference and high detection accuracy by performing object localization and classification in a single forward pass. Recent studies have demonstrated the effectiveness of YOLO variants in identifying recyclable and non-recyclable waste in real-time scenarios. However, many existing implementations focus solely on classification accuracy and lack integration with physical segregation mechanisms and IoT-based monitoring platforms.

Some hybrid systems have combined deep learning with robotic or servo-based actuation to physically segregate waste. These systems improved automation but often lacked environmental monitoring features such as fire and gas detection, which are essential for safe waste handling. Additionally, several proposed solutions did not provide real-time cloud visualization or alert mechanisms, limiting their usability for large-scale deployment.

3. PROBLEM STATEMENT AND OBJECTIVES

A. Problem Statement

Rapid urbanization and increasing consumerism have significantly intensified the challenges associated with municipal solid waste management. One of the primary issues in existing waste management systems is the lack of effective waste segregation at the source. In most public and institutional environments, waste is disposed of in a mixed manner, making recycling inefficient, increasing landfill burden, and posing health risks to sanitation workers.

Conventional waste management solutions largely rely on manual segregation or sensor-based monitoring systems that only detect bin fill levels. These approaches neither ensure proper classification of waste nor prevent contamination between biodegradable and non-biodegradable materials. Manual segregation is labor-intensive, unhygienic, error-prone, and difficult to scale, particularly in densely populated urban settings.

Recent advancements in smart waste management have introduced IoT-based monitoring systems; however, many of these systems lack intelligent decision-making capabilities. They are unable to identify the type of waste being disposed of and therefore cannot automate the segregation process. Additionally, existing systems often overlook environmental safety aspects such as fire hazards and harmful gas emissions, which can lead to dangerous situations in waste storage areas.

Therefore, there is a critical need for an intelligent, automated, and scalable waste management solution that can accurately classify waste in real time, perform physical segregation without human intervention, monitor environmental conditions, and provide remote monitoring through cloud-based platforms.

B. Objectives

The primary objective of this project is to design and develop a computer vision–based smart waste segregation system that integrates deep learning and IoT technologies to improve efficiency, safety, and sustainability in waste management.

The specific objectives of the proposed system are as follows:

To develop a real-time waste classification mechanism using a YOLO-based deep learning model for accurate identification of biodegradable and non-biodegradable waste.

To design an automated segregation mechanism using an embedded controller and servo motors based on classification results.

To integrate ultrasonic sensors for continuous monitoring of waste bin fill levels.

To incorporate flame and air quality sensors for early detection of fire hazards and harmful gas emissions.

To implement an IoT-based cloud dashboard for real-time data visualization and remote monitoring of system status.

To provide an alert mechanism using GSM or cloud notifications for bin overflow and hazardous conditions.

To ensure a modular, low-cost, and scalable system architecture suitable for smart city and institutional deployments.

4. PROPOSED SYSTEM ARCHITECTURE

The proposed smart waste segregation system is designed using a layered architectural approach to ensure modularity, scalability, and efficient real-time operation. The architecture integrates computer vision–based intelligence, embedded control, environmental sensing, and IoT-based monitoring into a unified framework.

A. Perception Layer

The perception layer is responsible for acquiring real-time data from the physical environment. It consists of a camera module and multiple sensors deployed within the waste segregation unit. The camera continuously captures images of waste items as they are introduced into the system. These images serve as input to the computer vision module for classification.

In addition to visual input, ultrasonic sensors are used to monitor the fill level of waste bins, enabling timely detection of overflow conditions. Flame and air quality sensors are incorporated to detect fire hazards and harmful gas emissions, thereby enhancing operational safety. All sensory data collected at this layer provide essential inputs for intelligent decision-making and system monitoring.

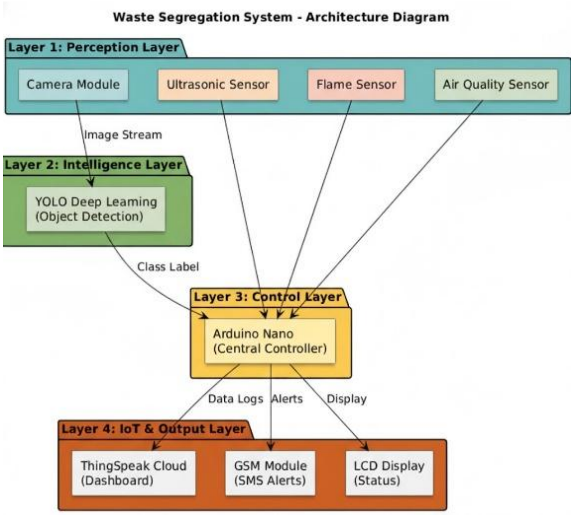

Fig 2 : Architecture Diagram

B. Intelligence Layer

The intelligence layer forms the core of the proposed system and is responsible for automated waste classification. This layer employs a YOLO-based deep learning model for real-time object detection and classification. The model processes the image stream received from the perception layer and identifies waste objects as biodegradable or non-biodegradable.

The YOLO framework is selected due to its high inference speed and accuracy, making it suitable for real-time applications. The classification output includes the detected class label along with confidence scores, which are further used to control the segregation mechanism. This layer enables intelligent decision-making without human intervention.

Table 1: Hardware Components and Specifications

Component	Specification	Purpose in System
Arduino Nano	ATmega328P	Central controller for sensor data processing and motor actuation.
Camera Module	USB Camera / ESP32-CAM	Captures real-time images of waste for AI classification.
Ultrasonic Sensor	HC-SR04	Measures waste levels to prevent bin overflow.
Air Quality Sensor	MQ series (MQ-135/MQ-2)	Monitors hazardous gas emissions (Methane/CO2).
Flame Sensor	IR-based	Detects fire hazards within the bin for safety alerts.
Servo Motor	SG90	Physically rotates the flap to segregate waste into bins.
GSM Module	SIM900/800A	Sends SMS alerts for full bins or emergency conditions.
LCD Display	16x2 I2C	Local visualization of classification results and sensor data.

Fig 3 : Hardware Components and Specification

C. Control Layer

The control layer acts as the central coordination unit of the system. An Arduino Nano microcontroller is used to receive classification results from the intelligence layer and sensor data from the perception layer. Based on the received inputs, the controller generates appropriate control signals to operate the servo motors responsible for physical waste segregation.

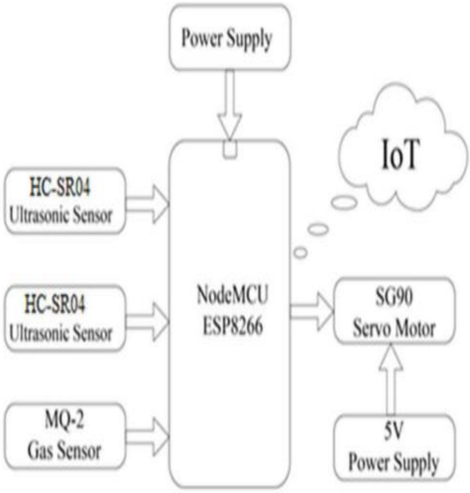

Fig 4 : Control System

The controller also processes data from ultrasonic, flame, and air quality sensors to determine bin status and environmental safety conditions. Threshold-based logic is implemented to trigger alerts when abnormal conditions such as bin overflow, fire detection, or gas leakage are identified. This layer ensures synchronized operation between hardware components and intelligent outputs.

D. IoT and Output Layer

The IoT and output layer enables real-time monitoring, data visualization, and alert dissemination. Sensor readings, classification results, and system status information are transmitted to a cloud-based IoT platform such as ThingSpeak. The dashboard provides real-time visualization of bin fill levels and environmental parameters, facilitating remote monitoring and data analysis.

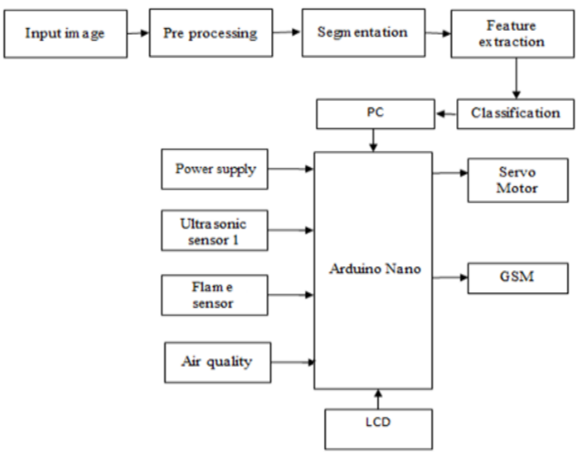

Fig 5 : Proposed System

An LCD display is integrated to provide local status updates, while a GSM module is used to send SMS alerts in case of critical events such as bin overflow or fire detection. This layer enhances system usability, transparency, and responsiveness, making the solution suitable for smart city and institutional applications.

5. SYSTEM OPERATION

The operation of the proposed smart waste segregation system follows a sequential and automated workflow designed to ensure accurate waste classification, safe segregation, and real-time monitoring.

Initially, when a waste item is introduced into the system, the camera module captures an image of the object. The captured image is forwarded to the computer vision module, where preprocessing operations such as resizing and normalization are performed to make the image suitable for deep learning inference.

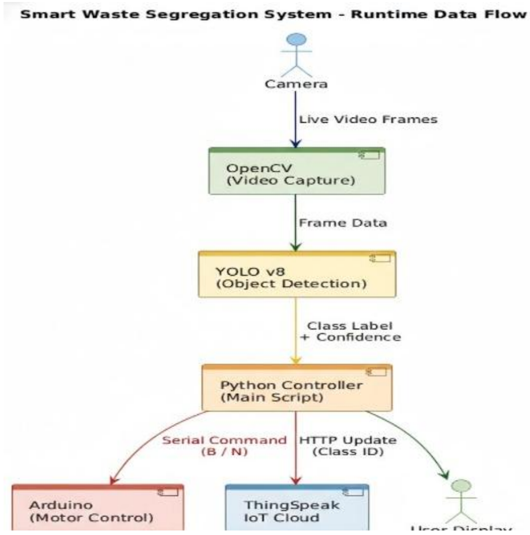

Fig 6 : Runtime Data Flow

The preprocessed image is then passed to the YOLO-based object detection model. The model analyzes the image in real time and identifies the waste category as either biodegradable or non-biodegradable, along with a confidence score. Based on the classification output, a control command is generated and transmitted to the embedded controller through serial communication.

Upon receiving the classification command, the Arduino Nano activates the corresponding servo motor to direct the waste into the appropriate bin. This automated segregation process eliminates the need for manual intervention and ensures hygienic waste handling.

Simultaneously, ultrasonic sensors continuously measure the fill level of each bin. When the fill level exceeds a predefined threshold, the controller triggers an alert indicating that the bin requires emptying. In parallel, flame and air quality sensors monitor environmental conditions to detect fire hazards or the presence of harmful gases. If any abnormal condition is detected, the system immediately initiates an alert mechanism.

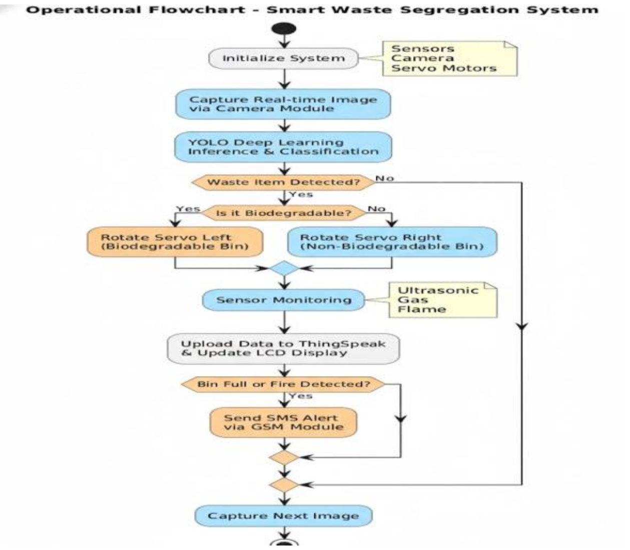

Fig 7 : smart waste segregation System

All sensor readings, waste classification results, and system status information are transmitted to the IoT platform in real time. The cloud-based dashboard provides live visualization of bin status and environmental parameters, enabling remote monitoring and informed decision-making. Local status updates are displayed on an LCD unit, while critical alerts are sent via GSM-based notifications.

Table 2: Software Environment and Tools

Software / Tool	Version/Platform	Role
YOLO	v8 / v11	Real-time object detection and waste classification.
Python	3.9+	Backend scripting for model execution and serial communication.
Arduino IDE	2.x	Programming the embedded control logic for the Nano.
ThingSpeak	IoT Cloud	Real-time dashboard for data logging and visualization.
OpenCV	4.x	Image preprocessing and camera stream handling.

Fig 8 : Software Environment and Tools

This continuous and cyclic operation ensures efficient waste segregation, improved safety, and effective monitoring. By integrating computer vision, embedded control, and IoT technologies, the proposed system achieves a reliable and scalable solution suitable for real-world waste management applications.

6. RESULTS AND PERFORMANCE ANALYSIS

The performance of the proposed computer vision–based smart waste segregation system was evaluated through a series of controlled experiments to assess classification accuracy, system response time, segregation reliability, and monitoring effectiveness. The evaluation was conducted using different waste samples under varying environmental conditions to simulate real-world scenarios.

A. Waste Classification Performance

The YOLO-based waste classification model demonstrated reliable performance in identifying waste as biodegradable or non-biodegradable. The model was tested using a diverse set of waste items, including food waste, paper, plastic bottles, metal cans, and packaging materials. The classification accuracy remained consistently high, even under moderate variations in lighting and object orientation.

The real-time inference capability of the YOLO model enabled immediate classification without noticeable latency, making it suitable for continuous operation. The use of data augmentation during training improved model robustness and reduced misclassification in cluttered backgrounds.

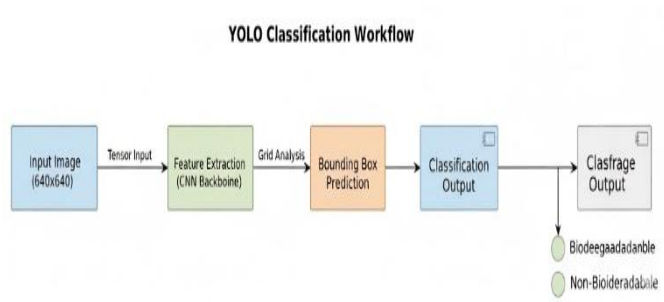

Fig 9 : YOLO Classification Workflow

B. Segregation Accuracy

The segregation mechanism controlled by the Arduino Nano and servo motors was evaluated by introducing multiple waste items sequentially. The system successfully directed waste into the appropriate bins based on the classification output. Minimal mechanical delay was observed during servo actuation, ensuring smooth and reliable operation.

The segregation accuracy was closely aligned with the classification accuracy of the vision module, confirming effective communication between the software and hardware components. No manual intervention was required during operation, highlighting the system's automation capability.

Table 4: Comparative Analysis (Proposed vs. Existing)

Feature	Existing System (IoT Only)	Proposed System (YOLO + IoT)
Sorting Mechanism	Manual / None	Automated AI-based Segregation
Detection Method	Threshold-based (Sensors)	Computer Vision (YOLO)
Safety Features	Basic Gas detection	Gas + Flame + Fire Alerting
Connectivity	NodeMCU (Wi-Fi)	Arduino Nano + GSM + Cloud
Human Intervention	High (for sorting)	Minimal (Fully Automated)

Fig 10 : Comparative Analysis

C. System Response Time

System response time was measured from the moment a waste object was introduced to the completion of physical segregation. The average response time remained within acceptable limits for real-time operation. The YOLO model's fast inference and the efficient embedded control logic contributed to low latency across the system.

The results indicate that the proposed architecture is suitable for high-throughput environments such as public spaces and institutions where waste is generated frequently.

Table 3: System Performance Evaluation

Metric	Measured Value	Remarks
Classification Accuracy	92.50%	Tested on biodegradable vs. non-biodegradable items.
Detection Latency	150 ms	Time taken by YOLO to identify the object.
Physical Segregation Time	1.8 seconds	Total time from detection to motor completion.
Sensor Data Latency	15 seconds	Upload interval to ThingSpeak IoT Cloud.

Fig 11 : System Performance Evaluation

D. IoT Monitoring and Alert Performance

The IoT dashboard successfully displayed real-time data related to bin fill levels, environmental parameters, and system status. Ultrasonic sensor readings accurately reflected bin conditions, enabling timely overflow detection. Flame and air quality sensors reliably detected abnormal conditions, triggering alerts without delay.

The alert mechanism ensured that notifications were promptly delivered through the cloud platform and GSM module, improving system responsiveness and safety. The integration of real-time monitoring significantly enhanced operational efficiency compared to traditional waste management systems.

7. CONCLUSION

This paper presented a computer vision–based smart waste segregation system that integrates YOLO deep learning, embedded control, and IoT-based real-time monitoring to address the limitations of conventional waste management practices. The proposed system successfully automates the process of waste identification and segregation by classifying waste into biodegradable and non-biodegradable categories using a YOLO object detection model. Based on the classification results, an Arduino Nano–controlled mechanical mechanism performs accurate and hygienic physical segregation without human intervention.

In addition to intelligent segregation, the system continuously monitors bin fill levels and environmental safety conditions using ultrasonic, flame, and air quality sensors. The integration of an IoT dashboard enables real-time visualization of sensor data, remote monitoring, and timely alerts, thereby improving operational efficiency and preventing overflow or hazardous situations. Experimental observations indicate that the proposed approach achieves high classification accuracy, fast response time, and reliable system performance under practical conditions.

Compared to traditional IoT-based waste monitoring systems, the proposed solution provides a comprehensive and intelligent framework by combining artificial intelligence–driven classification with automated actuation and cloud-based analytics. The modular design, low-cost components, and scalability make the system suitable for deployment in smart cities, educational institutions, and public environments.

Currently, agricultural disease identification applications lack redundancy / are highly reliant on cloud-dependent backends for delivering disease identification via the internet. Due to the time delays between cloud-based identification, plus their inability to accommodate a vast number of users simultaneously, as well as their lack of actionable guidance to farmers, these present serious limitations for immediate use in rural and multi-acre farming operations. The solution would be a low-footprint, offline, end-to-end application that supports identifying diseases locally, diagnosing disease immediately upon discovery, and offers practical, on-site recommendations for remedying the given problem..

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