Smart Waste Classification System

I. INTRODUCTION

Rapid urbanization and population growth have significantly increased the volume and complexity of solid waste generated worldwide. Efficient waste segregation is a critical requirement for sustainable waste management systems, as improper segregation leads to environmental pollution, inefficient recycling, and increased operational costs. In recent years, deep learning–based approaches have been widely adopted for automated waste classification due to their superior performance in visual recognition tasks.

An analysis of existing literature on smart waste classification systems reveals notable progress; however, several limitations continue to restrict their real-world applicability. **First**, many existing systems employ single-stage convolutional neural network (CNN)–based classifiers that directly predict waste categories from input images. Such approaches often suffer from reduced accuracy in cluttered environments, particularly when multiple or overlapping waste objects are present, as they lack explicit object localization mechanisms. **Second**, prior studies frequently restrict classification to a limited number of waste categories, typically binary or ternary classes such as biodegradable and non-biodegradable waste. While suitable for controlled environments, this limitation reduces the practicality of these systems for industrial or municipal waste management, where diverse waste types must be identified and processed separately.

Furthermore, many proposed solutions focus either on detection or classification in isolation, resulting in incomplete or loosely coupled pipelines. The absence of an integrated framework limits scalability, modularity, and deployment in real-world smart waste management systems.

To address these gaps, this paper proposes a two-stage deep learning–based waste classification framework that integrates object detection and classification into a unified pipeline. The proposed system first localizes waste objects in complex scenes and subsequently classifies each detected object into multiple waste categories, thereby improving accuracy and robustness in real-world conditions.

II. PROPOSED WORK

A. System Overview

The proposed system adopts a modular two-stage architecture consisting of (i) an object detection module, (ii) a waste classification module, and (iii) a decision logic layer. This design enables accurate localization, fine-grained classification, and practical waste categorization suitable for automated segregation systems.

B. Object Detection Using YOLOv5

In the first stage, YOLOv5 is employed to detect waste objects within input images or video frames. The model generates bounding boxes around individual waste items, enabling precise object localization even in cluttered or overlapping scenarios.

YOLOv5 is selected due to its ability to achieve real-time performance while maintaining high detection accuracy, particularly for small objects and complex backgrounds. Its single-shot detection mechanism makes it suitable for live camera-based waste monitoring systems, where speed and accuracy are both critical.

C. Waste Classification Using Convolutional Neural Network

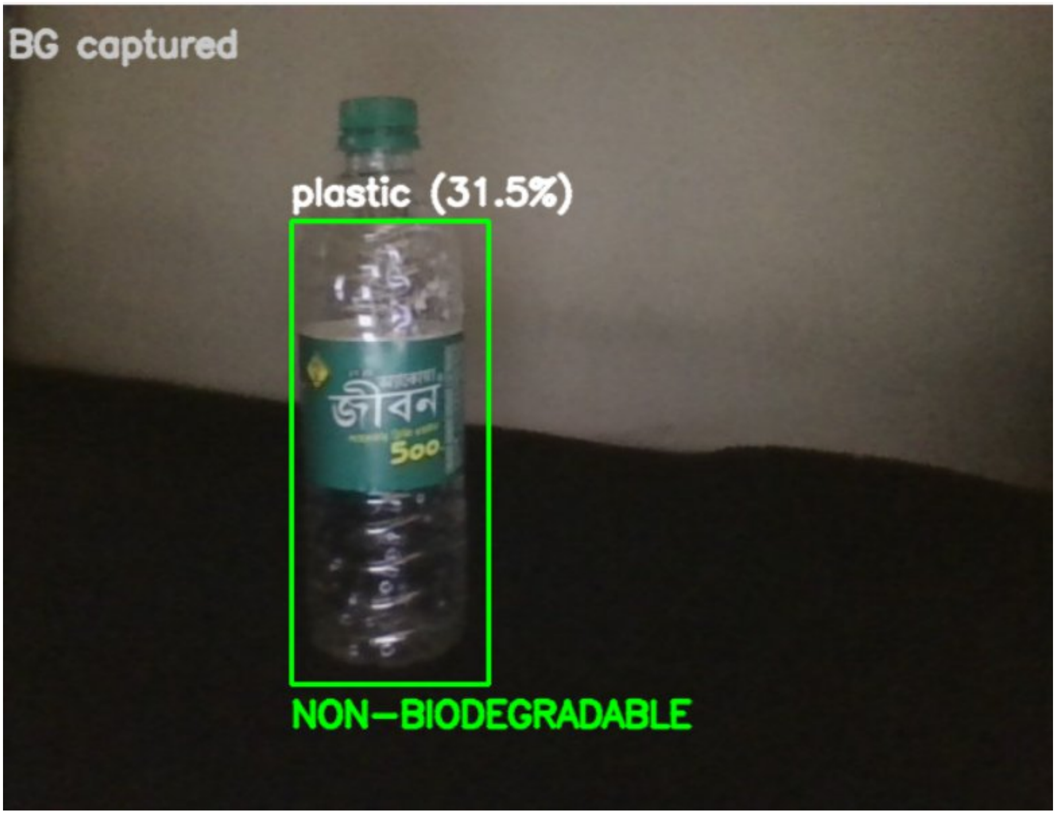
Following detection, each region of interest (ROI) extracted from the bounding boxes is passed to a ResNet-based convolutional neural network for classification. The CNN classifies waste objects into multiple categories such as plastic, paper, metal, glass, and cardboard.

Deep CNN architectures are well-suited for learning hierarchical visual features, enabling robust discrimination between visually similar waste types. The use of a ResNet architecture mitigates the vanishing gradient problem and allows deeper networks to be trained effectively, resulting in improved classification accuracy. By operating on localized ROIs rather than full images, the proposed approach outperforms traditional single-stage classifiers.

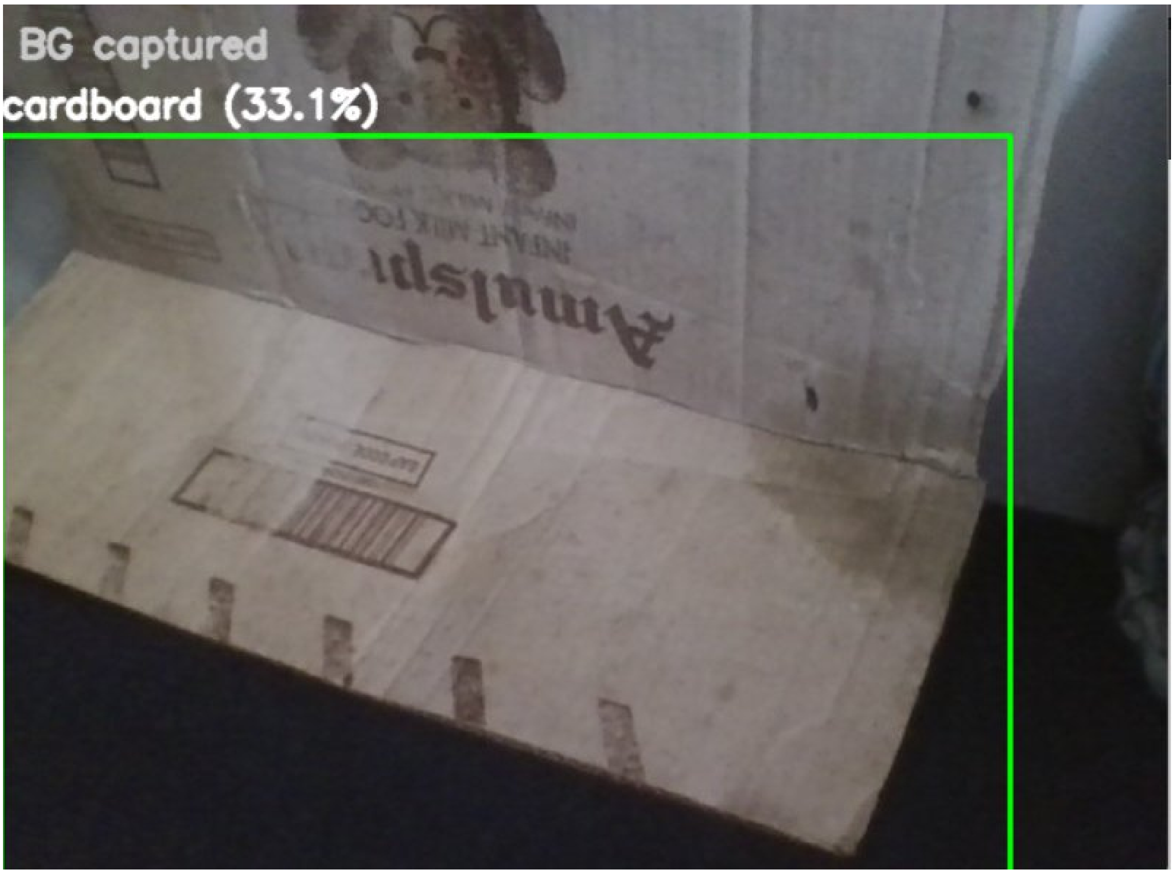
D. Decision Logic Layer

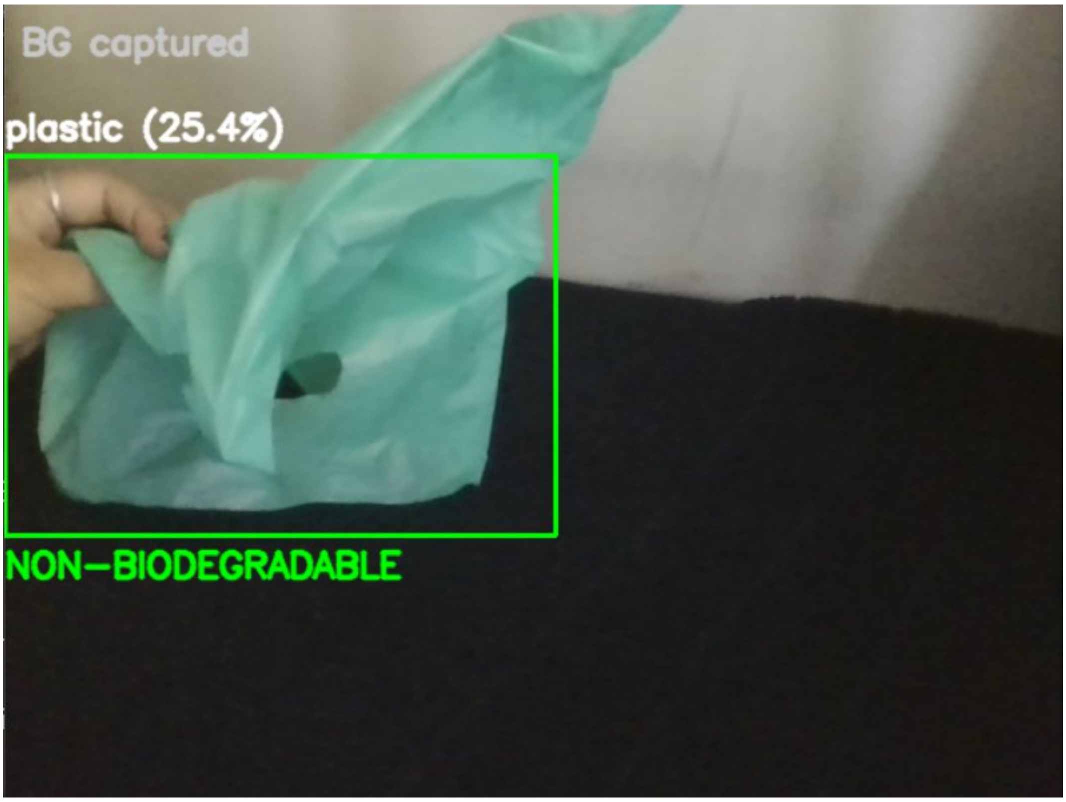
In the final stage, the classified waste categories are mapped into biodegradable and non-biodegradable classes using a rule-based decision logic layer. This abstraction enables practical waste segregation while maintaining flexibility for future expansion into additional waste categories or recycling streams.

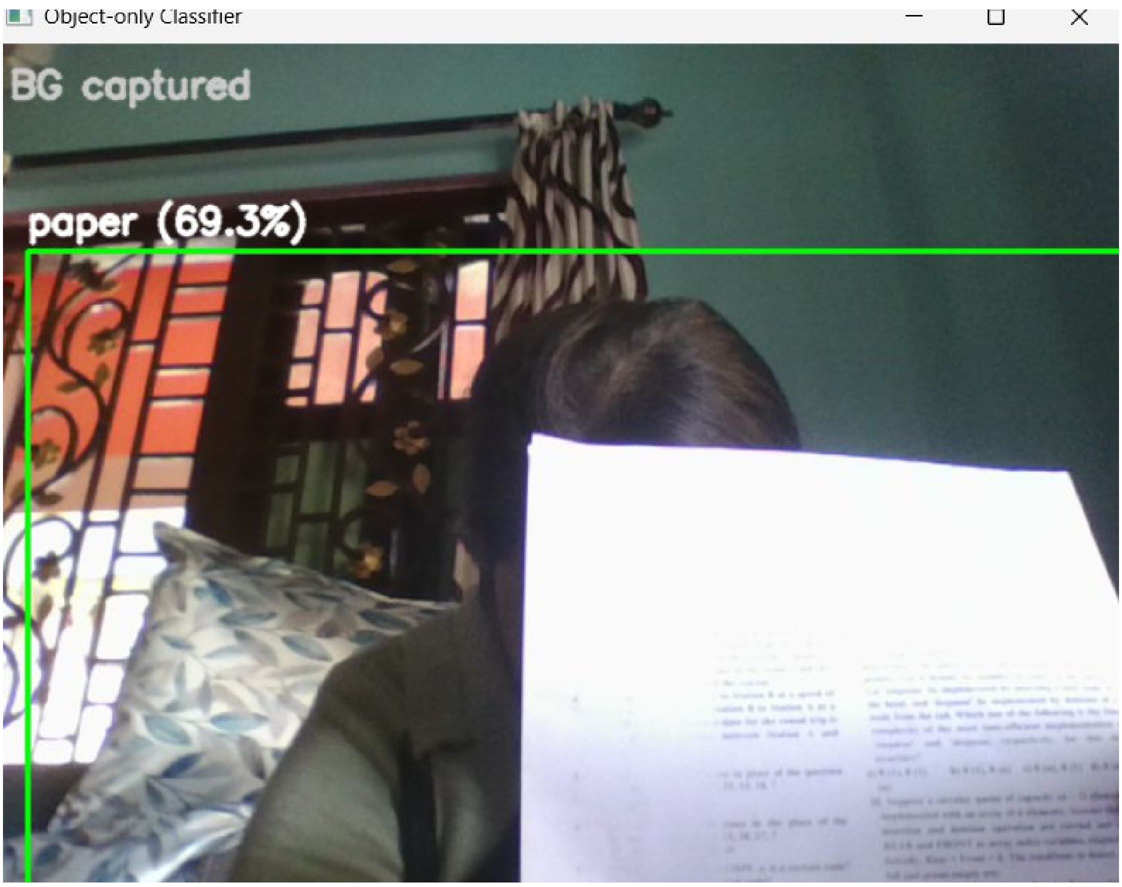

metal (59.6%)
NON-BIODEGRADABLE


BG captured
plastic (31.5%)
জীবন
500
NON-BIODEGRADABLE

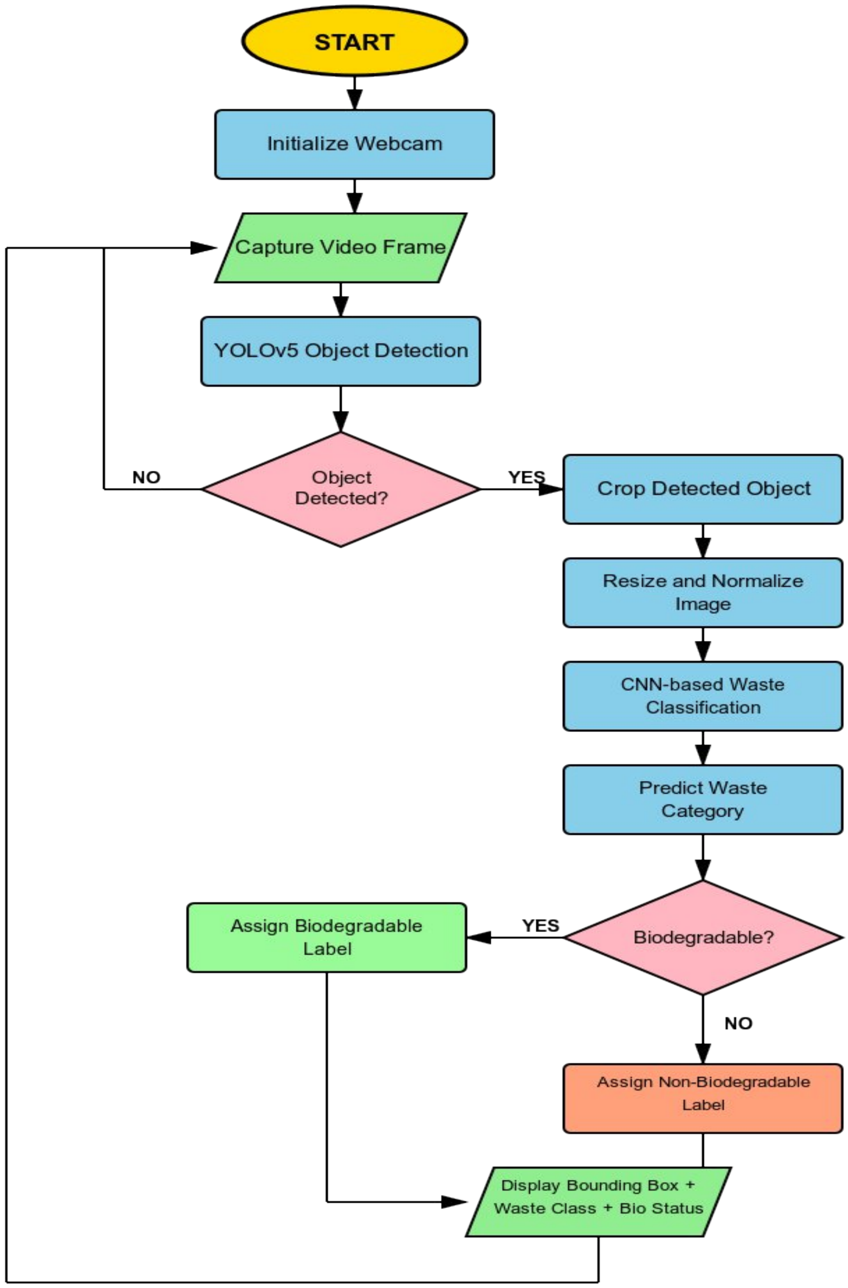

BG captured
glass (26.1%)
NON-BIODEGRADABLE


BG captured
cardboard (33.1%)


BG captured
plastic (25.4%)
NON-BIODEGRADABLE


Object-only Classifier
BG captured
paper (69.3%)

FLOWCHART


START
Initialize Webcam
Capture Video Frame
YOLOv5 Object Detection
Object Detected?
NO
YES
Crop Detected Object
Resize and Normalize Image
CNN-based Waste Classification
Predict Waste Category
Biodegradable?
YES
Assign Biodegradable Label
NO
Assign Non-Biodegradable Label
Display Bounding Box + Waste Class + Bio Status