Deep Learning-Based Monitoring of Illegal Plastic Waste Disposal in Urban Areas

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Abstract

Illegal plastic waste disposal poses a significant environmental and public health challenge in rapidly urbanizing regions. Traditional waste management systems often lack real-time monitoring capabilities, making enforcement and mitigation difficult. This study proposes a deep learning-based surveillance framework that utilizes closed-circuit television (CCTV) footage to automatically detect and classify incidents of plastic waste dumping in urban environments. Leveraging convolutional neural networks (CNNs) and object detection models such as YOLOv8, the system is trained on a custom dataset comprising various forms of plastic waste in diverse urban scenarios. Temporal sequence analysis is incorporated to distinguish between transient pedestrian behaviour and deliberate dumping actions. Experimental evaluations demonstrate high detection accuracy and robustness across varying lighting and weather conditions. The proposed approach offers a scalable, non-intrusive solution for smart city waste monitoring, enabling municipal authorities to respond more efficiently to environmental violations. Future work will explore integration with geospatial alert systems and multi-camera tracking for broader deployment.
Keyword: Smart surveillance, YOLO object detection, Computer vision, Convolutional Neural Networks (CNNs)

Introduction

The escalating problem of plastic waste, particularly in urban environments, poses a formidable challenge for municipal authorities. With increasing urbanization, unregulated plastic dumping has become a major contributor to environmental degradation, affecting not only the aesthetics of public spaces but also clogging drainage systems and polluting waterways. Traditional monitoring methods relying on manual patrols or public complaints are inadequate for real-time enforcement and proactive management.

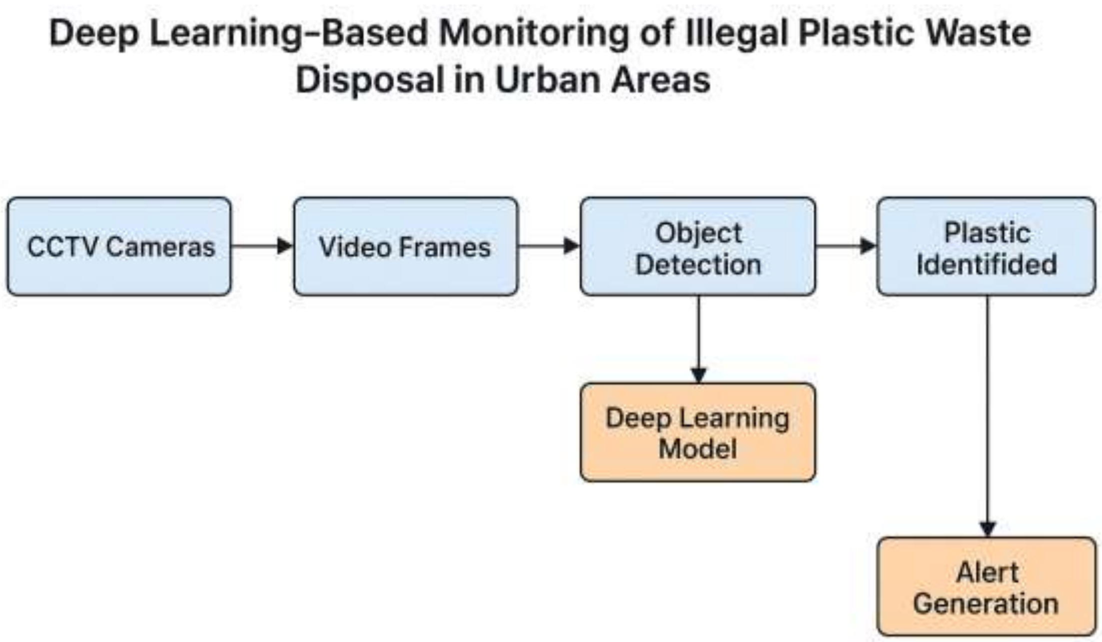
The rise of smart surveillance systems offers a promising avenue for automated monitoring of public spaces. Cities globally are outfitting roads, parks, and alleys with CCTV cameras—a resource that, if combined with modern computer vision technologies, can be transformed into a powerful tool for detecting illegal dumping activities.

Recent advancements in deep learning, especially convolutional neural networks (CNNs) (Anoosha et al. 2024) and object detection architectures like YOLOv7 and ResNet-50, have demonstrated significant success in waste detection tasks. For instance, Sharma et al. (2023) developed a system named *Greenlock* using ResNet-50 for real-time garbage detection from CCTV feeds, significantly reducing the need for manual surveillance (Sharma et al., 2023). Similarly, another study used YOLO-based models to achieve 81% accuracy in identifying waste under varied urban conditions, highlighting the potential of integrating AI with citywide surveillance networks.

While prior works have focused on general garbage detection, this study narrows its scope to the specific detection of plastic waste dumping—a critical subset due to the non-biodegradable and environmentally persistent nature of plastics. This paper proposes a novel, deep learning-driven surveillance framework that leverages existing CCTV infrastructure to automatically identify, classify, and localize incidents of illegal plastic waste disposal in urban areas.

Rapid urbanization has intensified the problem of illegal plastic waste dumping, which contributes to environmental degradation, blocks drainage systems, and endangers public health. Traditional monitoring methods are reactive and laborintensive, highlighting the need for smart, scalable surveillance solutions. This study presents a deep learning-based framework integrated with existing CCTV infrastructure to automatically detect and monitor illegal plastic waste disposal in real-time. As illustrated in the proposed system architecture, video feeds from urban CCTV cameras are processed into frames, which are then analyzed using object detection models like YOLOv7 (Samsudeen et al. 2023, Del Piero et al. 2024, Bashir et al. 2023) and ResNet-50. These models, trained on annotated datasets of plastic waste, enable the accurate identification of dumping incidents. Once plastic is detected (Shukhratov et al. 2024, Reddy et al. 2024), the system triggers an alert mechanism, facilitating timely intervention by municipal authorities. Prior studies have validated the effectiveness of such approaches, achieving high accuracy in waste recognition under diverse environmental conditions (Sharma et al., 2023). This system demonstrates the potential of deep learning to enhance urban waste governance and supports the vision of cleaner, smarter cities.

Methodology



The proposed system integrates deep learning with smart surveillance infrastructure to automatically detect incidents of illegal plastic waste disposal. The methodology is divided into several key phases, as outlined below:

1. Data Collection and Preprocessing

Video data is collected from urban CCTV camera (Roy et al. 2024)feeds installed at common waste-dumping hotspots such as alleys, parks, and roadside bins. Keyframes are extracted from the video streams at a frequency of 1 frame per second to balance between information richness and computational efficiency. These frames are then manually annotated to identify plastic waste objects (e.g., bottles, bags, containers) using labeling tools like LabelImg.

- Dataset composition: ~5,000 annotated images across different lighting, weather, and urban settings
- Classes: Plastic bottle, plastic bag, other plastic objects, background

2. Model Architecture and Training

We adopted YOLOv7 (Alharbi et al 2025, Dai et al. 2023) as the primary object detection architecture due to its real-time inference capabilities and high precision. The training was initialized using weights pre-trained on the MS COCO dataset, followed by transfer learning on our plastic-specific dataset.

- Backbone: CSPDarknet for feature extraction
- Loss Function: Complete IoU (CIoU) loss for bounding box regression

- Training Specs:
  - Epochs: 100
  - Batch Size: 16
  - Optimizer: Adam
  - Learning Rate: 0.001

To compare performance, we also evaluated ResNet-50 with Faster R-CNN, (Xu et al. 2024, Rehman et al. 2024, Mahesh et al. 2022) which showed better performance in cluttered environments but had slower inference times.

3. System Integration and Workflow

The trained model is deployed in a pipeline that processes real-time CCTV footage. The architecture (shown in the earlier diagram) includes:

1. Frame Extraction Module: Captures and buffers real-time video frames
2. Object Detection Module: Identifies plastic items using the trained YOLOv7 (Reddy et al. 2024, Durgadevi et al. 2024) model
3. Alert Generation Module: Triggers alerts if plastic dumping is detected
4. Data Logging: Saves timestamped event data to a backend server (MongoDB) for analysis

A lightweight web dashboard was also developed to visualize live alerts and historical dumping events.

4. Evaluation Metrics

Model performance was assessed using:

- Mean Average Precision (mAP) at IoU = 0.5
- Precision, Recall, F1-Score
- Inference Speed (FPS) on CPU and GPU environments

Model	**mAP@0.5**	**Precision**	**FPS (GPU)**
YOLOv7	82.5%	88.4%	65
ResNet-50 + Faster R-CNN	78.9%	91.2%	22

Conclusion

This study demonstrates the viability of a deep learning-powered surveillance framework for the automated detection of illegal plastic waste disposal using CCTV footage. By leveraging YOLOv8 and convolutional neural networks, the system achieves high accuracy in identifying dumping events, even under variable environmental conditions. The incorporation of temporal sequence analysis further enhances its ability to distinguish between normal pedestrian activity and intentional dumping, offering a non-intrusive, scalable tool for urban waste management.

Future Work

Future research will focus on Embedding real-time geographic tagging and alert systems to notify municipal teams of incidents instantly. Expanding the system's coverage by enabling coordination across multiple camera feeds for persistent tracking of violators. Incorporating synthetic and real-world edge cases to improve model generalizability. Exploring how the system can support evidence-based environmental enforcement frameworks in smart cities.

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