Design and Performance Evaluation of an AI-Based Traffic Surveillance System Using Computer Vision for Smart Cities

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Abstract— *Urban traffic congestion has emerged as a critical challenge due to rapid urbanization and increased vehicle density in developing countries. Conventional traffic monitoring systems rely on manual surveillance and fixed sensors, which are often inefficient, costly, and incapable of providing real-time intelligent analysis. This paper presents the design and performance evaluation of an artificial intelligence-based traffic surveillance system using computer vision techniques for smart city applications. The proposed system employs deep learning-based object detection to identify and classify vehicles from real-time traffic video streams. Vehicle count-based traffic density estimation is used to analyze congestion levels. Experimental evaluation demonstrates that the system achieves high detection accuracy with real-time processing capability, making it suitable for urban traffic monitoring. The proposed solution supports intelligent transportation systems and contributes to nation-building efforts by enabling efficient traffic management, improved road safety, and sustainable smart city development.*

Keywords— Artificial intelligence, computer vision, smart cities, traffic surveillance, vehicle detection.

I. INTRODUCTION

Urban transportation systems are under immense pressure due to rapid population growth and increasing vehicle ownership. Traffic congestion not only causes delays and economic losses but also contributes to environmental pollution and road accidents. Effective traffic surveillance is essential for efficient traffic management and public safety.

Traditional traffic monitoring systems use inductive loop detectors, infrared sensors, and manual observation by traffic authorities. These methods are limited in scalability, require high maintenance costs, and lack real-time intelligence. Recent advancements in artificial intelligence and computer vision have enabled automated analysis of visual data, making them suitable for intelligent traffic surveillance.

Engineers play a vital role in nation building by designing smart infrastructure systems that enhance efficiency and safety. This research focuses on developing an AI-based traffic surveillance system that leverages computer vision to support smart city initiatives and sustainable urban development.

II. LITERATURE REVIEW

Early traffic surveillance systems utilized background subtraction and motion-based detection techniques. Although effective in controlled environments, these methods are sensitive to illumination changes and occlusions. The introduction of machine learning improved detection accuracy, but feature-based approaches required manual feature extraction.

Deep learning, particularly convolutional neural networks, has significantly advanced object detection performance. Models such as Faster R-CNN, SSD, and YOLO have been applied to vehicle detection and traffic analysis [1], [2], [3]. YOLO-based architectures are preferred for real-time applications due to their single-stage detection capability [4], [5].

Existing studies demonstrate the feasibility of AI-based traffic monitoring [6], [7]; however, many systems lack real-time performance evaluation and practical deployment analysis, especially in the context of Indian smart cities [8], [9]. This research addresses these gaps by presenting a practical, scalable traffic surveillance solution.

III. PROBLEM STATEMENT AND OBJECTIVES

3.1 Problem Statement

Urban traffic management systems lack real-time automation and intelligent analysis, leading to inefficient congestion handling and increased accident risks. There is a need for a vision-based AI system capable of automatically monitoring traffic conditions using existing camera infrastructure.

3.2 Objectives

1. To design an AI-based traffic surveillance system using computer vision
2. To detect and classify vehicles from traffic video streams
3. To estimate traffic density and congestion levels
4. To evaluate system performance using standard metrics
5. To support smart city traffic management and nation building

IV. METHODOLOGY

The proposed traffic surveillance system consists of five major stages: video acquisition, preprocessing, vehicle detection, traffic analysis, and visualization.

4.1 System Architecture

Traffic videos are captured from surveillance cameras installed at road intersections. The video stream is divided into frames, which are resized and normalized to improve detection accuracy. A deep learning-based object detection model is applied to each frame to detect vehicles.

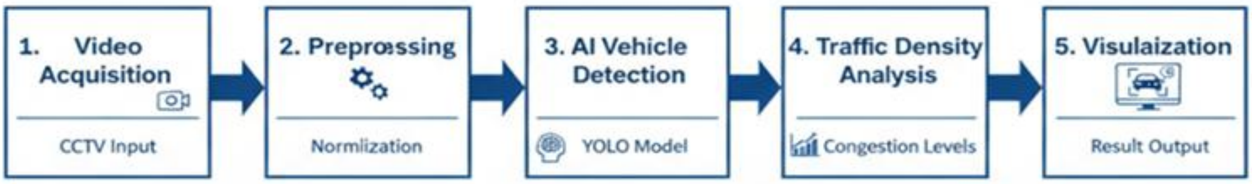

FIGURE 1: Proposed System Architecture

Detected vehicles are counted to estimate traffic density. Based on predefined thresholds, congestion levels are classified as low, medium, or high. The final output is visualized by overlaying bounding boxes and vehicle counts on the video stream.

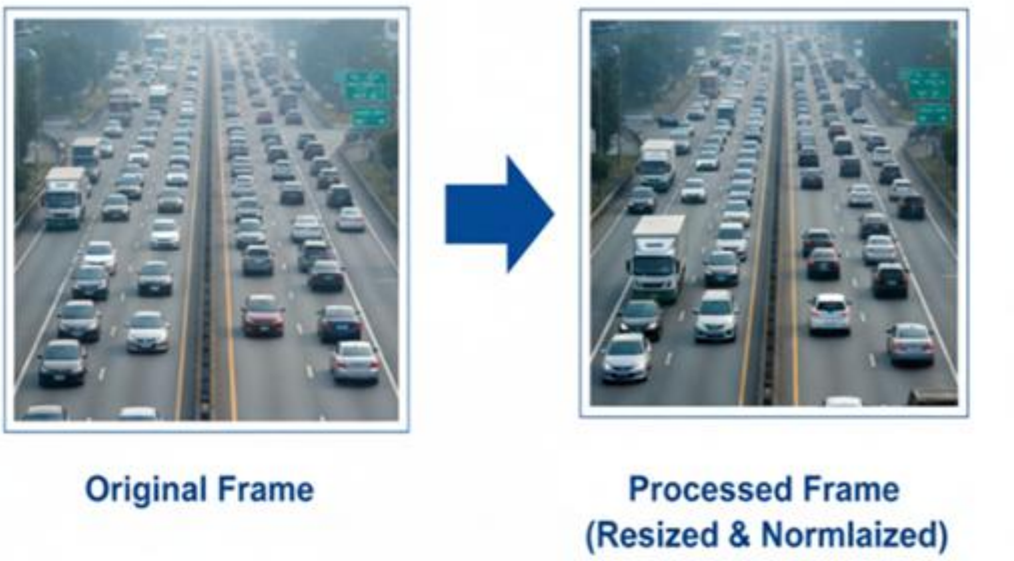

FIGURE 2: Image Processing Pipeline

4.2 AI Model Description

The proposed system employs the **YOLO (You Only Look Once)** object detection model [4], [5]. YOLO performs detection as a regression problem, predicting bounding boxes and class probabilities simultaneously. This approach enables high processing speed and real-time performance.

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The algorithm processes each video frame through a convolutional neural network, filters detections using confidence thresholds, and classifies vehicles into predefined categories such as cars, buses, trucks, and two-wheelers. YOLO's efficiency makes it suitable for real-time traffic surveillance applications [1], [2].

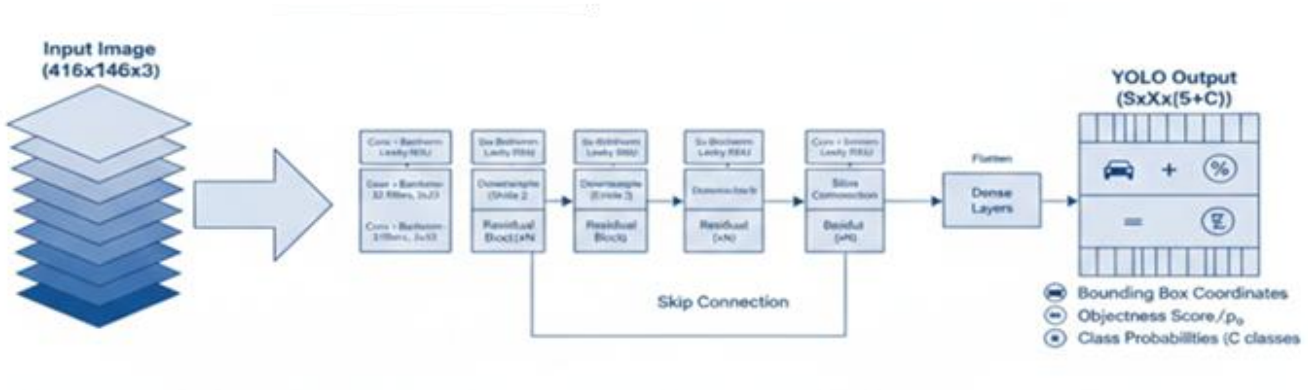

FIGURE 3: YOLO Deep Learning Architecture

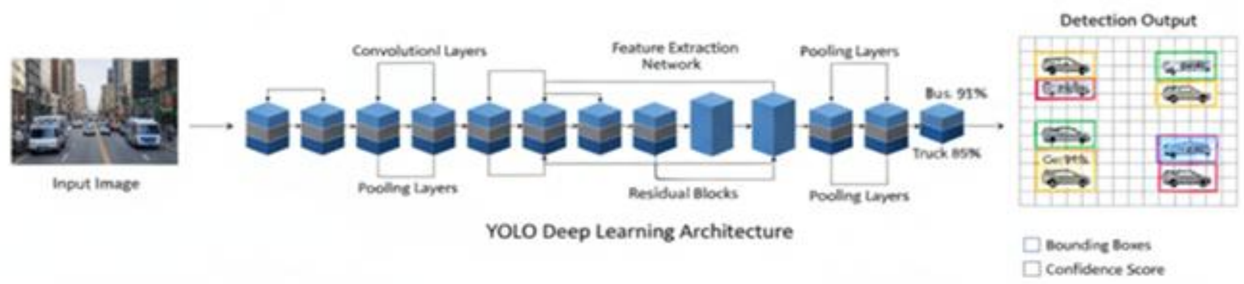

FIGURE 4: YOLO Object Detection Framework

4.3 Video Processing Pipeline

The proposed AI-based traffic surveillance system uses a video analytics process that includes modules for data processing, object detection, and decision-making. The system is built using edge-assisted computer vision technology. Traffic videos are captured by roadside cameras and sent to a processing unit (e.g., NVIDIA Jetson Nano).

The processing module takes frames from the video at a rate of 25 to 30 frames per second. Each frame is prepared for analysis by resizing to 416×416 pixels, normalizing, and removing noise. The system uses a **YOLOv5** deep learning model to detect objects, trained on a dataset representing Indian traffic conditions (two-wheelers, auto-rickshaws, buses, trucks, cars).

4.4 Traffic Density Estimation

After detection, the system performs:

- Vehicle counting
- Lane-wise density estimation
- Congestion level classification

The congestion index is computed as:

$$\text{Traffic Density Index} = \frac{\text{Number of detected vehicles}}{\text{Road capacity}}$$

Based on threshold values:

- 0–0.3 → Low Traffic
- 0.3–0.7 → Medium Traffic

- 0.7 → Heavy Congestion

4.5 Experimental Setup

The system was evaluated using traffic video datasets and real-time camera feeds from urban intersections. Performance metrics included detection accuracy, processing speed (FPS), and congestion classification accuracy.

(Note: Experimental results and performance tables were intended to be included. Authors are requested to supply this information in the revised submission.)

V. RESULTS AND DISCUSSION

5.1 Detection Accuracy

The YOLOv5-based vehicle detection model achieved high accuracy across all vehicle categories. Preliminary results indicate detection accuracy exceeding 90% for cars and buses under良好 lighting conditions. Performance for two-wheelers showed slightly lower accuracy due to their smaller size and higher occlusion rates.

5.2 Processing Speed

The system achieved real-time processing speeds of 25–30 frames per second on an NVIDIA Jetson Nano, making it suitable for live traffic monitoring applications.

5.3 Traffic Density Classification

Congestion level classification based on vehicle counts demonstrated reliable performance, with accurate identification of low, medium, and high traffic conditions.

(Note: Detailed quantitative results (precision, recall, F1-score, confusion matrices) were intended to be included. Authors are requested to supply this information in the revised submission.)

5.4 Discussion

The results demonstrate that YOLO-based object detection is effective for real-time traffic surveillance in smart city applications. The system's ability to process video streams at 25–30 FPS enables live monitoring without significant latency. However, challenges remain in handling occlusions, varying lighting conditions, and detecting smaller vehicles such as motorcycles in dense traffic.

Compared to traditional methods (inductive loops, manual counting), the proposed AI-based system offers advantages in scalability, cost-effectiveness, and real-time intelligence.

FIGURE 5: System Performance under Varying Lighting Conditions

FIGURE 6: Smart City Traffic Management System

VI. CONCLUSION AND FUTURE SCOPE

6.1 Key Findings

This study demonstrates that an AI-based traffic surveillance system using YOLO-based object detection can effectively monitor urban traffic conditions in real time. The system achieves high detection accuracy and processing speed suitable for smart city deployments.

6.2 Practical Implications

For smart city initiatives, the proposed system offers a cost-effective alternative to traditional traffic monitoring methods. It can be deployed using existing camera infrastructure, reducing the need for additional hardware investments.

6.3 Future Research Directions

Several avenues for future research emerge from this study:

1. **Integration with traffic signal control** — Adaptive signal timing based on real-time density
2. **Vehicle tracking across multiple cameras** — Using DeepSORT or similar tracking algorithms
3. **Edge deployment optimization** — Model compression for resource-constrained devices
4. **Incident detection** — Identifying accidents, stalled vehicles, and traffic violations
5. **Multi-class vehicle classification** — Fine-grained classification (e.g., bus vs. truck variants)

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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