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Vehicle Tracking and Traffic Analytics System

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Abstract: Traffic monitoring plays a vital role in improving road safety and transportation management. This paper presents a Vehicle Tracking and Traffic Analytics System that utilizes YOLOv11 for real-time vehicle detection and ByteTrack for multi-object tracking. The system estimates vehicle speed, detects overspeeding vehicles, analyzes traffic movement through predefined regions of interest, and generates traffic density heatmaps. It processes highway surveillance videos to provide accurate vehicle tracking and real-time traffic insights. The proposed system offers an efficient and scalable solution for intelligent transportation systems, traffic surveillance, and highway monitoring.

Keywords: Vehicle Tracking, Traffic Analytics, YOLOv11, ByteTrack, Speed Estimation, Computer Vision

I. INTRODUCTION

The **Vehicle Tracking and Traffic Analytics System** is an AI-based solution designed to monitor and analyze highway traffic using computer vision techniques. With the increasing number of vehicles on roads, efficient traffic surveillance has become essential for improving road safety and traffic management. The proposed system uses **YOLOv11** for vehicle detection and **ByteTrack** for multi-object tracking. It estimates vehicle speed, detects overspeeding vehicles, analyzes traffic movement using predefined Regions of Interest (ROIs), and generates traffic density heatmaps. By integrating these features into a single framework, the system provides real-time traffic analytics for intelligent transportation systems and highway surveillance.

I. SYSTEM WORKFLOW

The workflow of the proposed Vehicle Tracking and Traffic Analytics System consists of the following major stages:

A. Video Acquisition
The system accepts highway surveillance video as input. The video is captured using a fixed camera and processed frame by frame using OpenCV. Each frame is extracted and forwarded to the detection module for further analysis.

B. Vehicle Detection
Each video frame is processed using the **YOLOv11 Nano** object detection model. The model detects multiple vehicle categories, including cars, buses, trucks, and motorcycles. Bounding boxes, confidence scores, and class labels are generated for every detected vehicle

C. Multi-Object Tracking
The detected vehicles are tracked using the **ByteTrack** algorithm. Each vehicle is assigned a unique tracking ID that remains consistent throughout the video sequence, enabling continuous monitoring of vehicle movement.

D. Speed Estimation and Overspeed Detection
The trajectory of every tracked vehicle is analyzed to estimate its speed using the displacement between consecutive frames and a perspective-aware scaling factor. The estimated speed is compared against a predefined speed limit of **80 km/h**. Vehicles exceeding this limit are automatically flagged as overspeeding vehicles, and the violation is recorded.

E. Turn Movement Analysis
Polygon-based Regions of Interest (ROIs) are defined to represent entry and exit zones. Vehicle trajectories are monitored to classify traffic movement into **straight** or **left-turn** categories based on their movement between these predefined regions.

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F. Traffic Heatmap Generation

Vehicle positions are accumulated over time to generate a dynamic traffic heatmap. The heatmap visually represents traffic density, highlighting areas with frequent vehicle movement and potential congestion.

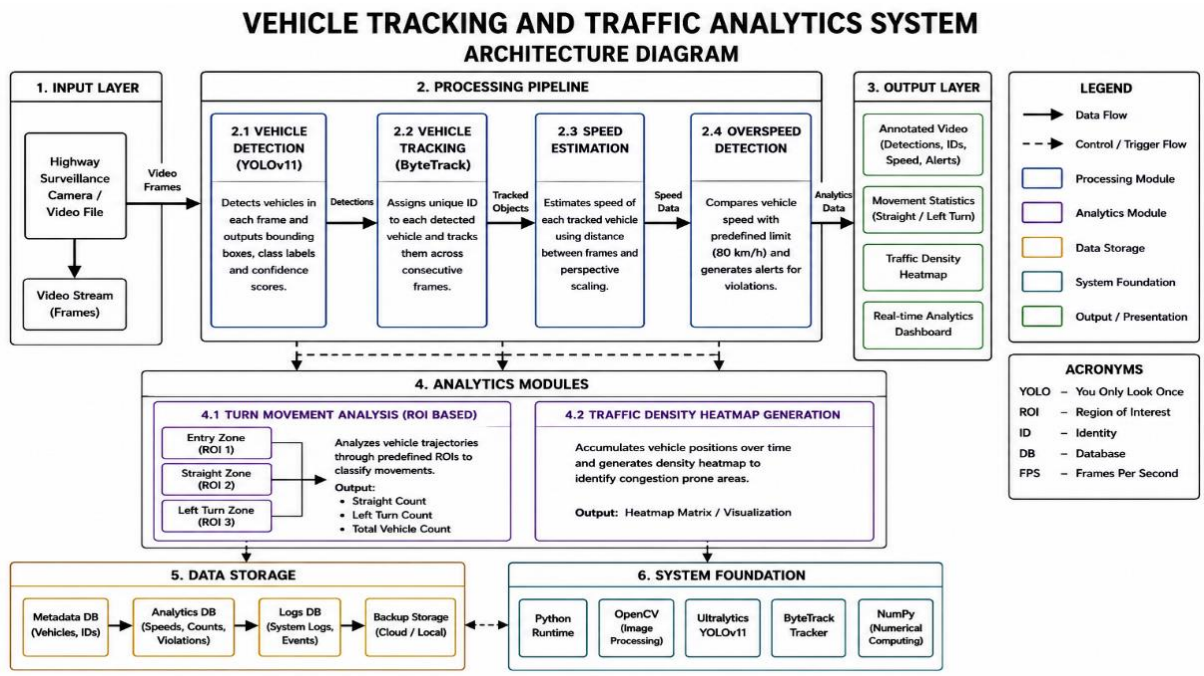
G. Real-Time Visualization

The processed video is displayed with bounding boxes, tracking IDs, estimated speeds, overspeed alerts, movement statistics, ROI boundaries, and heatmap overlays, providing comprehensive real-time traffic analytics.

II. FEATURES

1. **Vehicle Detection:** Detects cars, buses, trucks, and motorcycles using the YOLOv11 object detection model.
2. **Multi-Object Tracking:** Assigns a unique ID to each detected vehicle using ByteTrack and tracks its movement across video frames.
3. **Speed Estimation:** Calculates vehicle speed using frame-to-frame displacement and perspective-aware scaling.
4. **Overspeed Detection:** Automatically detects vehicles exceeding the predefined speed limit and generates violation alerts.
5. **Turn Movement Analysis:** Classifies vehicle movement into straight or left-turn categories using predefined ROI zones.
6. **Traffic Heatmap Generation:** Produces a dynamic heatmap indicating vehicle density and frequently traveled regions.
7. **Real-Time Visualization:** Displays annotated video containing vehicle IDs, speeds, alerts, movement counts, and traffic statistics.
8. **Traffic Analytics:** Provides continuous monitoring of vehicle movement and traffic flow for highway surveillance applications.
9. **Modular Architecture:** Implements separate modules for detection, tracking, speed estimation, movement analysis, and visualization, making the system scalable and easy to maintain.
10. **Edge AI Ready:** Utilizes the lightweight YOLOv11 Nano model for efficient real-time deployment on resource-constrained systems.

III. ARCHITECTURE DIAGRAM



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IV. TECH STACK

Category	Technology Used	Description
Programming Language	Python	Core programming language used for system development.
Computer Vision	OpenCV	Processes video frames, image operations, ROI creation, and visualization.
Object Detection	YOLOv11 Nano	Detects vehicles such as cars, buses, trucks, and motorcycles in real time.
Object Tracking	ByteTrack	Assigns unique IDs and tracks vehicles across consecutive frames.
Numerical Computing	NumPy	Performs mathematical calculations for speed estimation and image processing.
AI Framework	Ultralytics YOLO	Provides implementation and inference of the YOLOv11 model.
Model Deployment	ONNX	Exports the trained YOLO model for optimized deployment.
Development Environment	Visual Studio Code	Used for coding, debugging, and testing the application.
Input Source	Highway Surveillance Video	Input video used for vehicle detection and traffic analysis.
Output	Real-Time Traffic Analytics	Displays detected vehicles, tracking IDs, speed estimation, overspeed alerts, turn analysis, and traffic heatmaps.

V. CONCLUSION

The **Vehicle Tracking and Traffic Analytics System** provides an effective and intelligent solution for real-time highway traffic monitoring. By integrating **YOLOv11** for vehicle detection and **ByteTrack** for multi-object tracking, the system accurately detects and tracks multiple vehicles while estimating their speed. It also identifies overspeeding vehicles, analyzes traffic movements using predefined Regions of Interest (ROIs), and generates traffic density heatmaps for better visualization of traffic patterns. The proposed system demonstrates the potential of computer vision and deep learning in improving traffic surveillance, enhancing road safety, and supporting intelligent transportation systems. Its modular architecture also allows future enhancements such as lane detection, number plate recognition, and accident detection.

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