NETRIK NATIONAL HACK

AI-Powered Traffic Queue Analysis and Rule Violation Detection using Video Analytics

Project: Intelligent Traffic Analysis & Violation Detection System
Domain: Computer Vision & Video Analytics
Problem Area: Intelligent Traffic Management

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1. Introduction

The intersections at urban centers in India are experiencing the growing traffic jams, traffic law breaching behaviors, and unchecked driving habits. The available traffic signal systems are mostly based on the concept of fixed time signaling and manual surveillance that fail to facilitate real time conditions of traffic. These conventional systems tend to cause ineffective traffic circulation and the inability to track the violations because the traffic density changes during the day.

Due to the high number of CCTV cameras in the traffic intersections, much traffic video data is already being gathered but it is not being used. Video analytics and computer vision can offer an efficient method to process this video information and obtain useful traffic data automatically. Due to the ability to identify and trace vehicles on traffic cameras, valuable data can be collected like the length of the queue, the amount of traffic, and violations of traffic laws. The project aims at applying video analytics to transform raw traffic footage into useful and comprehensible traffic intelligence.

2. Problem Statement

This project is aimed at designing a vision-based smart traffic analysis and violation detection system with the help of pre-recorded traffic videotapes. The system is supposed to identify and monitor several vehicles over a duration of time and predict the state of the traffic around the signalized intersections.

In particular, the system is to measure the length and density of queues in front of the traffic lights and detect the violation of traffic rules, including jumping red lights and rushing driving. The project is focused on the accuracy of computer vision, stable multi-object tracking, and explainable analytics instead of true real-time control of signals and hardware integration.

3. System Overview and Objectives

This project aims to develop a modular traffic analysis system, which will take pre-recorded traffic video footage of signalized intersections and will be able to extract major metrics of traffic. The offered system is based on perception and analytics based on computer vision instead of traffic signal control or hardware integration. The system will offer meaningful and explainable insights concerning traffic conditions and violation through vehicle movement patterns in traffic footage.

Objectives
- In order to identify and locate several vehicles using traffic video data.
- To determine the length of queues and queue density around traffic lights.
- In order to identify traffic law offenses including red-light jumping and rash driving.
- To visualize the outputs of the traffic analytics using annotated video and web-based dashboard.

4. Overall System Architecture

The suggested system is based on a pipeline-oriented architecture. The feed into the system is an already recorded CCTV video footage of traffic. A vehicle detection module processes the frames first after the video has been decomposed into them. Vehicles that are detected are further sent to a multi-object tracking module that issues persistent identities to the vehicles across frames.

The tracked vehicle paths are used to estimate the length of the queue and the density of the queue at the stop line. Simultaneously, the violation of the traffic rules is identified through the movement of vehicles. Lastly, the analytics extracted is displayed as annotated video output and a web-based dashboard. This is a modular structure to provide clear separation of components, scalability and explainable data flow among system modules.
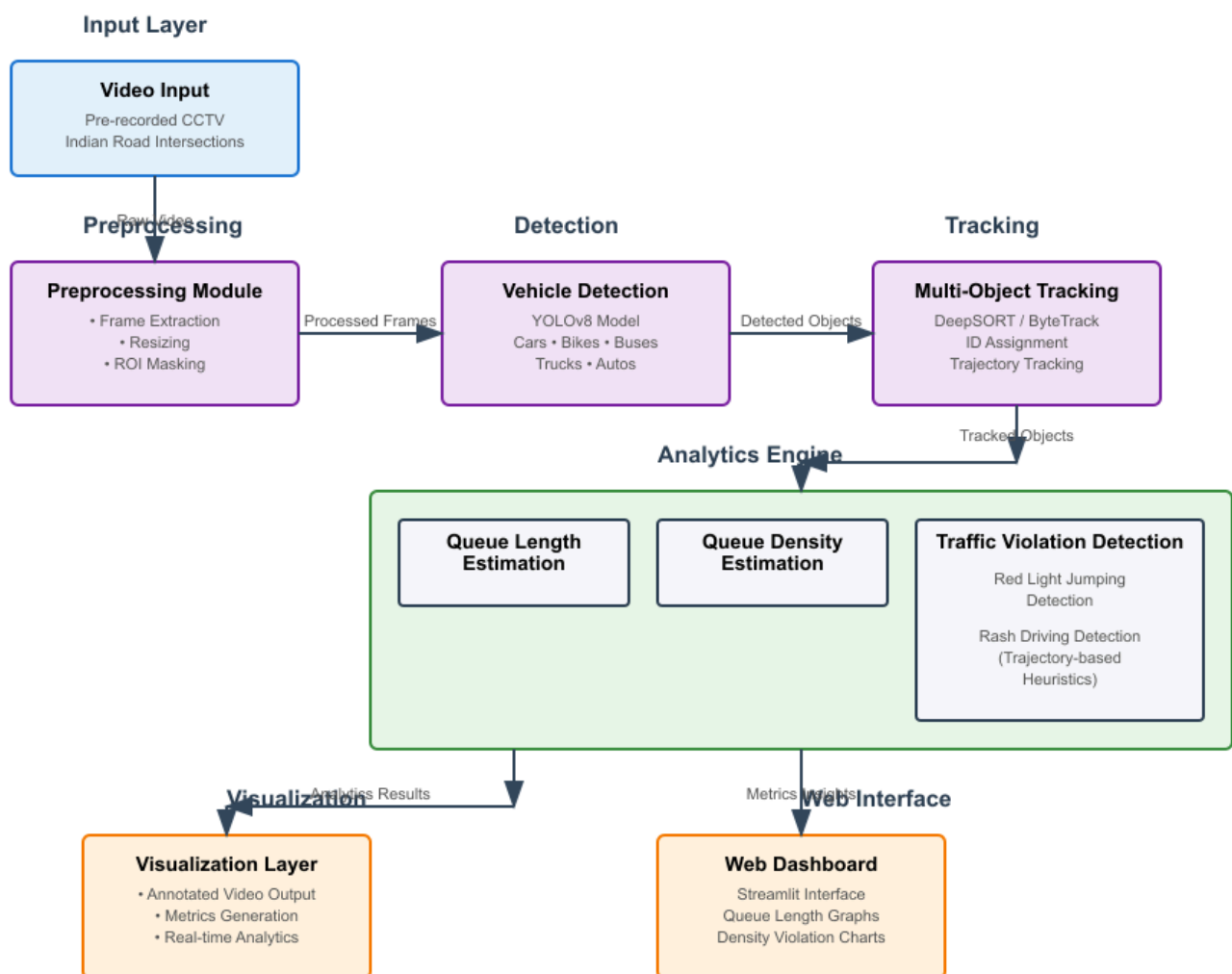
AI Powered Traffic Analysis System Architecture

5. Vehicle Detection Approach

Detecting vehicles is done on separate video frames and it is used to detect the vehicles that are on the intersection. An object detection model that is based on deep learning is applied to identify various types of vehicles that are frequently encountered on an Indian road, such as cars, motorcycles, buses, trucks, and auto-rickshaws.

The detection module gives a bounding box coordinates, vehicle class label and confidence score in each frame. Detection gives spatial data concerning vehicle positions at a moment of time. Detection, however, is not frame-to-frame vehicle identity preserving, which means that it cannot be used alone in traffic analytics.

6. Multi-Object Tracking and State Consistency

In order to preserve vehicle identity across frames, multi-object tracking module is added to the system. The tracker accepts the vehicle detections of the frame under consideration and issues the vehicle with a distinct ID. These IDs are maintained between frames and therefore the system can monitor the movement of a vehicle as the time goes by.

Tracking creates the path of vehicles by keeping track of the previous position of each vehicle. This guarantees state consistency of vehicle identities across frames and is anti-duplicate of counts. Queue estimation, violations, and motion-based analytics require tracking.
Computer Vision Flow: Detection and Tracking Pipeline.
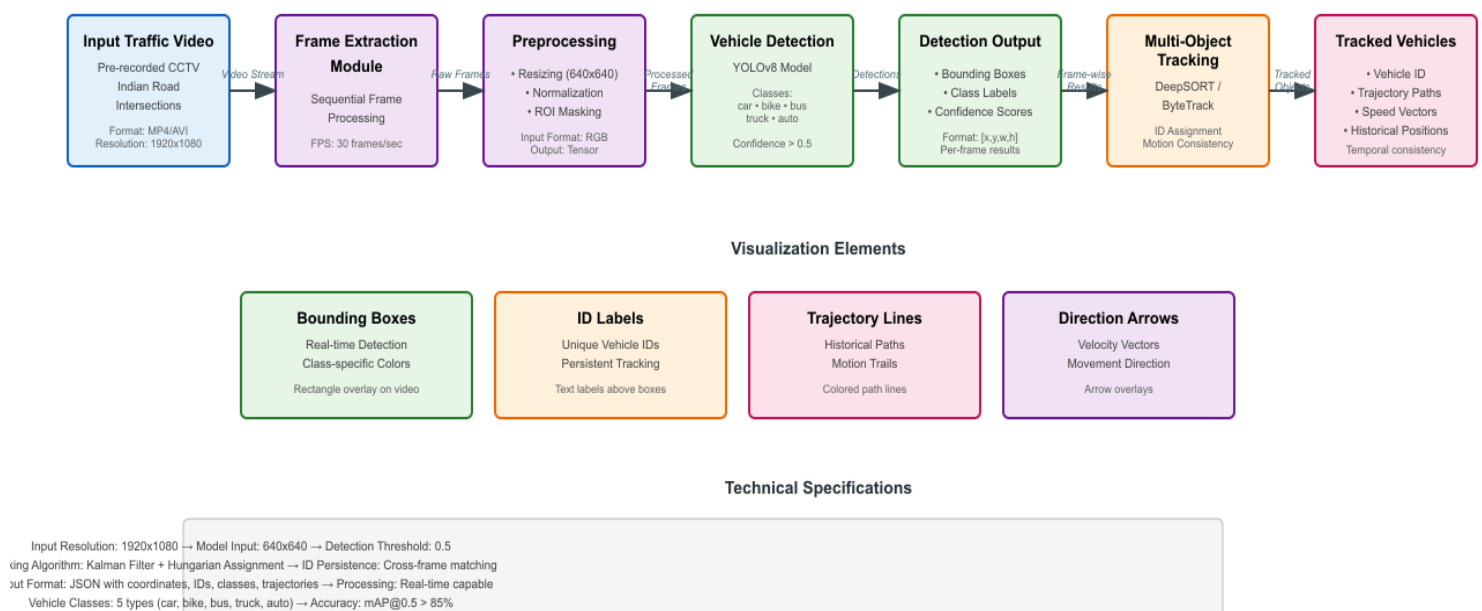
Detection and Tracking Pipeline - Computer Vision Flow

7. Queue Length and Queue Density Estimation

Queue Length Estimation

The length of queues entails the number of vehicles that are behind the stop line whenever there is a red signal. There is a virtu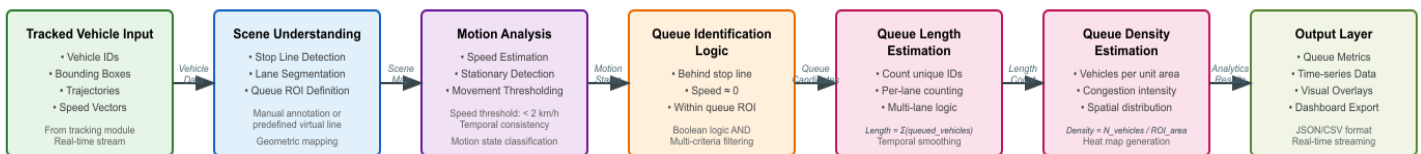al stop line that is defined in the camera view. Based on tracked vehicle data, vehicles that are stationed behind the stop line and have an almost zero speed are detected. IDs of unique vehicles that meet these requirements are enumerated to approximate the queue length.

Queue Density Estimation

Queue density is used to measure the level of congestion and this is calculated by defining a queue area adjacent to the traffic signal. The figure of the vehicles existing in this area is enumerated and normalized against the area of the region to arrive at the queue density.

Tracked Vehicle Input	Scene Understanding	Motion Analysis	Queue Identification Logic	Queue Length Estimation	Queue Density Estimation	Output Layer
• Vehicle IDs • Bounding Boxes • Trajectories • Speed Vectors From tracking module Real-time stream	• Stop Line Detection • Lane Segmentation • Queue ROI Definition Manual annotation or predefined virtual line Geometric mapping	• Speed Estimation • Stationary Detection • Movement Thresholding Speed threshold: < 2 km/h Temporal consistency Motion state classification	• Behind stop line • Speed ≈ 0 • Within queue ROI Boolean logic AND Multi-criteria filtering	• Count unique IDs • Per-lane counting • Multi-lane logic $Length = \Sigma(queued\_vehicles)$ Temporal smoothing	• Vehicles per unit area • Congestion intensity • Spatial distribution $Density = N\_vehicles / ROI\_area$ Heat map generation	• Queue Metrics • Time-series Data • Visual Overlays • Dashboard Export JSON/CSV format Real-time streaming

Queue Detection Algorithm

Condition 1: Position Check vehicle.y > stop_line.y Behind stop line validation	Condition 2: Speed Check vehicle.speed < threshold Stationary state detection	Condition 3: ROI Check point_in_polygon(ROI) Spatial boundary validation	Logic Gate: AND Operation C1 ∧ C2 ∧ C3 = Queue Boolean combination	Temporal Filter: Consistency Check min_duration = 3 seconds Noise reduction	Queue Update: ID Registration Add to queue_list Increment counter

Visualization Elements

Stop Line	Queue ROI Polygon	Vehicle ID Markers	Density Heat Overlay
Virtual/Physical Line Reference Boundary Red line overlay	Detection Zone Spatial Boundary Transparent overlay	Unique Identifiers Queue Status Color-coded labels	Congestion Intensity Spatial Distribution Heat map visualization

Technical Parameters

Speed Threshold: < 2 km/h • Temporal Window: 3 seconds • ROI Area Calculation: Polygon geometry
Queue Length Formula: Count(unique_IDs) • Density Formula: N_vehicles / ROI_area (vehicles/m²)
Update Frequency: 30 FPS • Smoothing: Moving average (5-frame window) • Export Format: JSON/CSV

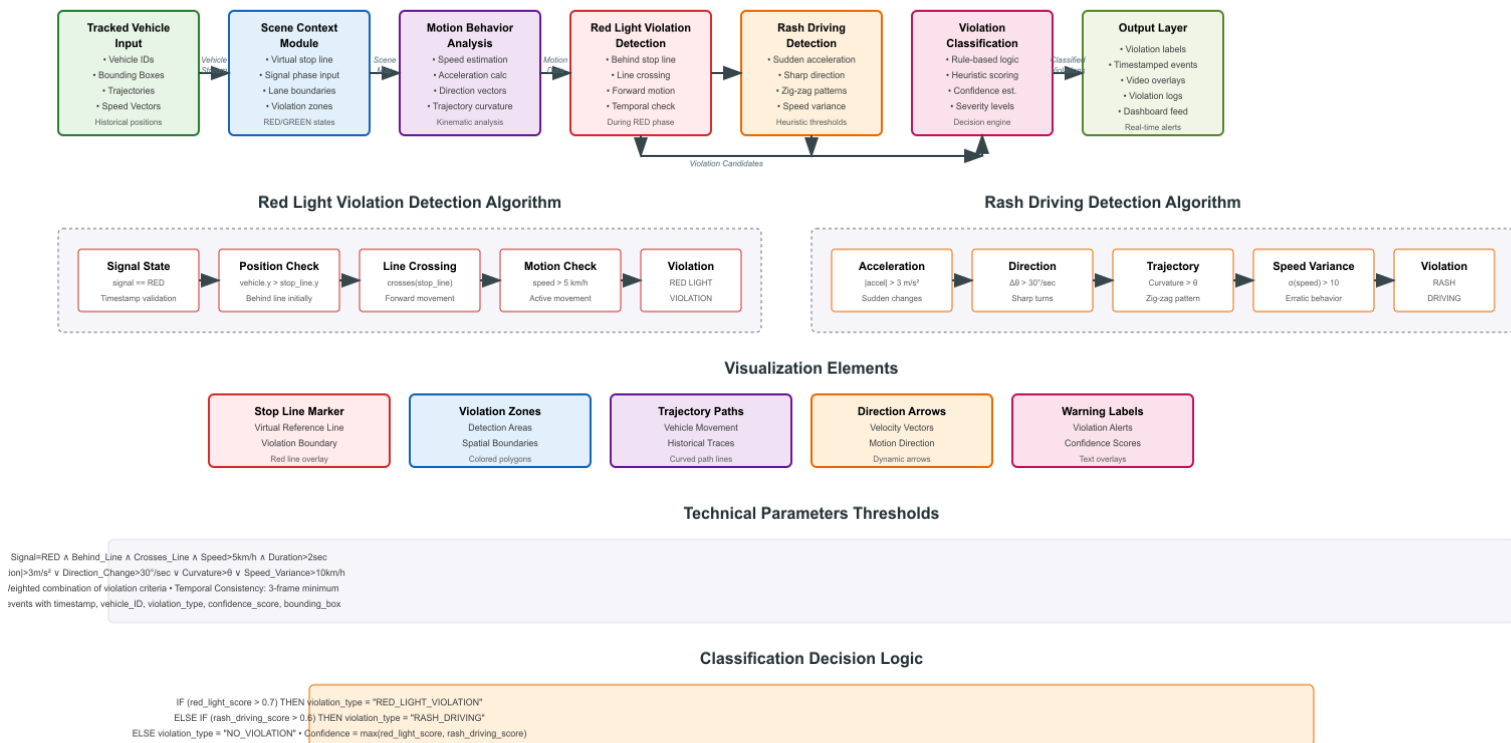**Queue Estimation Analytics Pipeline**

8. Traffic Rule Violation Detection

Red-Light Jump Detection

Red-light jumping is ensured by observing vehicle routes when it is red light. A virtual stop line is taken as a reference. It is reported as a violation when a tracked vehicle crosses the stop line when the signal is red. Stable vehicle ID will give proper identification of violators.

Rash Driving Detection

Motion-based heuristics based on the trajectory of the vehicles are used to detect rash driving behavior. Unsafe driving behavior is defined by indicators of sudden acceleration, sharp directional control and abnormal speed variations. The explanatory and interpretable violation detection is guaranteed by the heuristic-based approach.

Traffic Violation Detection Analytics Pipeline

9. Assumptions, Limitations, and Edge Cases

Assumptions

- The traffic camera is fixed and stable throughout the video recording, ensuring a consistent field of view for detection and tracking.

- The stop line at the signalized intersection is clearly visible in the camera frame, allowing accurate spatial reference for queue estimation and violation detection.

- Traffic signal phases such as red and green are known beforehand or can be reasonably approximated based on timestamps or external information.

- Video footage is recorded under adequate lighting conditions, such as daytime or well-lit environments, to support reliable vehicle detection and tracking.

Limitations

- In extremely congested traffic conditions, vehicles can even be obscured, which results in missed detections or a loss of the track at some point.

- The visibility can be impaired either through poor weather conditions like rain or fog or during the night time leading to deterioration of system performance.

- Abnormal lane discipline and non-lane based movement that is prevalent in Indian traffic can impact tracking consistency and path analysis.

- Small, fast-moving objects or partially seen may not be properly detected in every frame, particularly when there are a great number of objects in the frame.

Edge Cases

- Two-wheelers weaving between larger vehicles, causing frequent occlusions and abrupt trajectory changes.

- Vehicles stopping beyond the stop line during congestion, making queue and violation interpretation challenging.

- Emergency vehicles moving against normal traffic rules, which may be incorrectly flagged as violations without contextual information.

10. Visualization and Dashboard

The system generates annotated video outputs displaying detected vehicles, tracking IDs, and traffic violations. A web-based dashboard presents traffic metrics such as queue length, queue density, and violation counts in real-time or near real-time.

Clear visualization of analytics improves interpretability and supports effective traffic monitoring and decision-making.

11. Conclusion

This project proposes a vision-based traffic analysis and violation detection system that leverages computer vision and multi-object tracking to extract actionable traffic intelligence from CCTV footage. By focusing on modular system design, tracking consistency, explainable analytics, and clear visualization, the system effectively addresses real-world traffic monitoring challenges. The proposed approach demonstrates how video analytics can support data-driven traffic management and enforcement.