# BOROSA-2.0

## Bosch Road Safety Hackathon

(Traffic Violation Detection System)

# HUM TEEN

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# ABSTRACT

Traffic signal violations significantly contribute to road accidents and traffic congestion. This project proposes an **intelligent system** to detect **red signal jumps** using an **ESP-32 microcontroller** connected to a **dash camera**. The camera employs a **YOLO model** trained to recognize traffic signals, zebra crossings and continuously monitors them. The system is integrated with the **vehicle's odometer**, which changes colour when a red signal is detected. Additionally, an **audio alert** notifies the driver. A **memory unit** stores the vehicle number and monitors' speed. If the red signal is jumped, the system logs the violation and transmits it to the respective **district police database**. This **real-time detection** aims to enhance road discipline and reduce accidents.

# 2. SYSTEM COMPONENTS

## 2.1 ESP-32 Microcontroller: The Core Processing Unit

Our intelligent traffic signal violation detection system employs the ESP-32 as the central processing unit, coordinating various components such as dash camera, odometer, and memory unit. Here's a breakdown of its functionality and advantages:

**i. Working for ESP-32**

The ESP-32 is a low-power, high-performance microcontroller with built-in Wi-Fi and Bluetooth capabilities. It efficiently processes real-time data from multiple sources, ensuring seamless communication between the dash camera, odometer, and database storage. The ESP-32 receives input from the YOLO-based traffic signal detection model, analyses vehicle speed from the odometer, and determines whether a violation has occurred.

**ii. Advantages of ESP-32 in Traffic Violation Detection**

**Fast Data Processing**: Ensures near-instantaneous response for odometer color changes and audio alerts.

**Connectivity:** Communicates with databases for real-time logging of violations.

**Low Power Consumption**: Efficiently operates in a vehicle without excessive power drain.

**Reliable Performance**: Supports multiple sensors and cameras for robust traffic monitoring.

Hence, ESP-32 plays a critical role in integrating all system components, ensuring real-time signal detection, speed tracking, and law enforcement notification, making it a key enabler for road safety automation.

## 2.2 Dash Camera with YOLO Model: Intelligent Traffic Signal Recognition

Our system integrates a dash camera trained with the YOLO (You Only Look Once) model to accurately detect traffic signals. This module ensures precise identification of red signals and seamless communication with the ESP-32.

### i. Working of YOLO Model

The YOLO model is a deep learning-based object detection algorithm that processes live video footage in real-time. The model has been trained specifically to recognize traffic signals, ensuring accurate differentiation between red, yellow, and green lights. Upon detecting a red signal, the camera sends this information to the ESP-32 for further processing.


Fig. 1. YOLO Model Detecting Traffic Signal

### ii. Advantages of YOLO-Based Signal Recognition

**Real-Time Processing:** Identifies red signals instantly, preventing delays in detection.

**High Accuracy:** Reduces false detections by differentiating between multiple traffic signals.

**Robust Performance:** Functions efficiently in varied lighting and weather conditions.

**Compact and Efficient:** Works within vehicle-mounted cameras without requiring external hardware.

Therefore, the YOLO-based traffic signal detection ensures precise signal recognition, providing accurate data to the ESP-32 for odometer colour changes, audio alerts, and violation tracking.

### 2.3 Vehicle's Odometer: A Visual Indicator for Compliance

The odometer in a vehicle is modified to serve as a visual cue for drivers when a red signal is detected. This enhances driver awareness and ensures timely response to traffic rules.

i. **Working of the Odometer System**

When the YOLO model detects a red signal, the ESP-32 triggers a colour change in the odometer, turning it red. This visual cue alerts the driver and reinforces the need to stop**.**

ii. **Advantages of Odometer Integration**

**Clear Driver Awareness:** Instantly informs the driver of the red signal.
**Non-Intrusive Warning:** Works alongside audio alerts for better compliance.
**Easy to Integrate:** Can be applied to all vehicle types without major modifications.

Therefore, by utilizing the odometer as an alert system, this approach provides an effective, low-distraction method to enforce red signal compliance, reducing accidental violations.

### 2.4 Audio Alert System: Reinforcing Compliance Through Sound

A critical part of the system is the audio alert, which informs drivers through verbal or beep-based notifications when a red signal is detected.

i. **Working of the Audio Alert System**

Upon detecting a red signal, the ESP-32 triggers an audio warning, which states "**Red Signal Detected, Please Stop**". This ensures the driver is fully aware of the need to halt at the intersection.

ii. **Advantages of Audio Alert System**

**Immediate Awareness:** Alerts drivers without requiring visual attention.
**Works in All Conditions:** Effective even in low visibility or night driving.
**Reduces Distractions**: Ensures compliance without requiring constant dashboard monitoring.

The audio alert system reinforces traffic rule adherence, reducing violations and improving road safety through immediate verbal warnings.

### 2.5 Memory Unit & Speed Monitoring: Ensuring Accountability

To prevent false violations, our system integrates a memory unit that logs vehicle speed and behavior during red signal detection.

i. **Working of the Memory Unit & Speed Monitoring**

The memory unit continuously records vehicle speed when a red signal is detected. If the speed does not drop below a threshold, the system flags a potential violation and stores the data for further validation.

ii. **Advantages of Speed Monitoring**

**Prevents False Violations**: Ensures drivers attempting to stop aren't penalized.

**Continuous Tracking**: Monitors vehicle behavior throughout the signal period.

**Supports Law Enforcement**: Provides data-backed proof of violations.

Therefore, by tracking vehicle speed during red signals, this system ensures that only genuine violations are reported, making law enforcement more accurate and fairer.

### 2.6 Database Storage: Secure Logging & Violation Tracking

A centralized database stores all vehicle violation data, ensuring efficient tracking of repeat offenders and district-wise monitoring.

#### i. Working of the Database Storage System

The ESP-32 transmits vehicle number, speed data, and violation timestamp to a region-wise database, categorizing violations by vehicle type and location. This allows for law enforcement intervention and tracking of habitual offenders.

#### ii. Advantages of Database Storage

**Scalable Storage**: Stores data for multiple vehicles across regions.

**Automated Violation Reporting**: Reduces manual enforcement effort.

**Law Enforcement Integration**: Directly connects to district police databases.

Therefore, by securely storing violation data, the system ensures seamless law enforcement integration, reducing human error and enhancing traffic law compliance.

# 3. SCENARIOS

## 3.1 Normal Stopping at Red Signal

In this scenario, the intelligent red signal jump detection system ensures that vehicles follow traffic rules efficiently without false violations. The dashcam, integrated with an ESP-32 microcontroller, continuously monitors traffic signals using a **YOLO-trained model**. When the system detects a red signal, it immediately sends a signal to the vehicle's odometer, changing its colour to red. This provides a visual cue to the driver, reinforcing the need to stop.


Fig. 2. Working of Dashcam and colour change in odometer according to traffic signal

Along with this, an **audio alert** is played, stating **"Red signal detected"** to further notify the driver. This multi-sensory approach helps in reducing distractions and ensuring that drivers respond promptly to traffic signals. The ESP-32 processes vehicle speed in real-time, continuously checking whether the driver reacts appropriately. If the vehicle's speed drops below a threshold, the system assumes the driver is intentionally slowing down or stopping at the red light. In such cases, no violation is recorded, and the system resets upon detecting a green light.

This approach prevents false positives, where a driver might take a fraction of a second to react or slow down progressively instead of coming to a sudden halt. The system accounts for real-world conditions, such as braking distance, different driving behaviours, and the need for smooth stops, especially in heavy traffic.

By integrating real-time speed monitoring and signal recognition, the system enhances **traffic discipline** while avoiding unnecessary penalties. This ensures that drivers who genuinely intend to stop at a red signal are not wrongfully flagged for a violation, making the system fair, effective, and practical in improving road safety.

### 3.2 Red Signal Jump Detection

If a driver fails to stop at a red signal, the system identifies a violation using a structured detection process. Once the dashcam detects the red signal, the ESP-32 changes the odometer color to red and triggers an audio alert to remind the driver to stop. The system then monitors the vehicle's speed and movement.

If the driver does not slow down below a threshold speed within a reasonable timeframe, the system considers the possibility of a red signal jump. The dashcam continues tracking the relative position of the traffic signal. If the vehicle crosses the intersection and the dashcam loses sight of the red signal, it confirms that the driver has illegally crossed the stop line.

Once a red signal jump is confirmed, the memory unit logs crucial details, including:

- Vehicle number (for identification)
- Speed and timestamp (to confirm violation time)
- Location (to track region-wise violations)

This information is then sent to the district police database, ensuring automated law enforcement. The police department can review this data and issue penalties, accordingly, making the process efficient and reliable.

To prevent false violations, the system only logs data if:

1. A red signal was detected.
2. The vehicle did not slow down within the allowed threshold.

3. The dashcam lost sight of the red signal, confirming the jump.

This ensures that drivers who mistakenly inch forward but ultimately stop are not penalized unfairly. The system also provides a fair reaction time window, preventing abrupt breakthroughs that could be hazardous.

By integrating real-time signal detection, vehicle monitoring, and automated reporting, this system significantly reduces manual enforcement efforts while promoting responsible driving behavior.

### 3.3 Normal Stopping at Zebra Crossing

When the dashcam detects a zebra crossing using a YOLO-trained model, the ESP-32 triggers an audio alert stating, **"Zebra crossing detected."** The system then monitors vehicle speed in real-time. If the driver slows down below a safe threshold and stops before the crossing when pedestrians are present, no violation is recorded. The system resets once the road is clear. This ensures drivers are alerted in time, encouraging responsible stopping behavior without unnecessary penalties, ultimately improving pedestrian safety and adherence to traffic rules.

### 3.4 Zebra Crossing Jump Detection

If the driver fails to stop at a zebra crossing when pedestrians are present, the system identifies a violation. Upon detection, the ESP-32 triggers an alert and continuously tracks vehicle movement. If the driver does not slow down within a reasonable timeframe and crosses the marked area, the system confirms a zebra crossing jump. The vehicle number, timestamp, and location are logged and sent to the authorities for enforcement. This structured process prevents false violations while ensuring that pedestrian rights are safeguarded, promoting safer road practices.

# 4. ASSUMPTIONS

To ensure the effectiveness and reliability of our **Intelligent Red Signal Jump Detection System**, we have made several key assumptions regarding its operation, deployment, and accuracy. These assumptions help define the system's expected working conditions and outline areas where improvements or additional measures may be required in future versions.

## 4.1 Dashcam Has Clear Visibility of Traffic Signals

One of the fundamental requirements for this system to function accurately is that the dashcam has an unobstructed view of traffic signals. The YOLO-based deep learning model used for signal recognition relies on clear and well-lit input images to differentiate between **red, yellow, and green signals**. Any obstructions such as dirt on the windshield, other vehicles blocking the view, extreme weather conditions, or poorly positioned signals—could compromise detection accuracy.

To ensure visibility, it is assumed that:

- Traffic signals are placed at standardized, easily detectable positions.
- Dashcams are installed correctly within the vehicle, minimizing blind spots.
- Regular maintenance and cleaning of dashcams will be performed to prevent obstructions due to dirt or damage.
- The system is tested under different lighting conditions, ensuring that night-time driving and varying weather conditions do not cause false detections.

In the future, adaptive brightness correction and thermal imaging cameras could be integrated to improve detection in extreme weather conditions such as fog, heavy rain, or snowfall.

### 4.2 Vehicles Are Fitted with ESP-32 and Cannot Be Tampered with ease

For the system to function effectively, it is assumed that every vehicle participating in the system is fitted with an ESP-32 microcontroller that remains **active throughout the vehicle's operation**. The ESP-32 serves as the **central processing unit**, linking the dashcam, odometer, audio alert system, and memory unit while ensuring real-time data processing and storage.

To prevent tampering, the following assumptions are made:

- **ESP-32 activates automatically when the vehicle starts** and shuts down only when the vehicle is properly turned off.
- The system is securely embedded within the vehicle, preventing unauthorized removal or modification.
- Any attempt to disconnect or manipulate the ESP-32 while the vehicle is running triggers a tampering alert, which is logged into the system database.
- Future iterations may include encryption-based security and tamper-proof enclosures to enhance protection against unauthorized modifications.

By ensuring that all vehicles in the system remain **consistently monitored**, the risk of circumvention is minimized, leading to more accurate enforcement of traffic laws.

### 4.3 A Grace Period is Given if the Vehicle Reduces Speed Below 10 km/h

Understanding that **drivers require a reasonable reaction time** to slow down at a red signal, the system incorporates a grace period that allows vehicles to gradually decrease speed below 10 km/h before being flagged for a violation. This assumption prevents unnecessary penalties for vehicles that are in the process of stopping.

To ensure fairness, the following parameters are set:

- If a vehicle's speed drops below 10 km/h after detecting a red signal, no violation is recorded.

- The system continuously monitors the vehicle's speed trend to differentiate between drivers intentionally stopping versus those attempting to bypass the signal at a lower speed.
- A reaction time window (e.g., 2-3 seconds) is allowed before finalizing a violation, preventing unfair penalties for drivers who slow down properly.

By incorporating realistic traffic behaviors into the system, the likelihood of false violations is minimized, ensuring that only intentional red signal jumpers are penalized.

**Conclusion**

These assumptions **define the expected working conditions** of the Intelligent Red Signal Jump Detection System. While they **help standardize its functionality**, future advancements—such as AI-driven visibility adjustments, tamper-proof hardware, adaptive speed detection, and enhanced GPS mapping—can further improve the system's reliability and effectiveness in reducing traffic violations.

# 5. SOLUTION

To effectively detect and report red signal jump violations, the **Intelligent Red Signal Jump Detection System** utilizes a combination of **c**omputer vision, microcontroller processing, real-time alerts, and cloud-based violation reporting. The system is designed to function **autonomously** within a vehicle, ensuring accurate monitoring and minimal driver intervention. Below is a detailed explanation of how each component contributes to the overall solution.

### 5.1 Dashcam Continuously Scans for Traffic Signals Using YOLO

The system employs a **vehicle-mounted dashcam** integrated with a **YOLO (You Only Look Once) deep learning model**, specifically trained to detect **traffic signals** in real time. The YOLO model has been pre-trained on datasets containing various types of traffic lights, ensuring high accuracy in recognizing red, yellow, and green signals.

The dashcam continuously scans the road ahead and identifies traffic signals in its field of view. Upon detection, it classifies the signal colour and transmits this data to the ESP-32 microcontroller.

To ensure accuracy, the system considers:

- Different lighting conditions, including nighttime and adverse weather**.**
- Occlusions, where another vehicle or an object partially blocks the signal.
- Multiple traffic signals, ensuring it tracks the relevant one for the vehicle's lane.

By leveraging real-time object detection, the system guarantees precise identification of red signals, allowing for accurate violation detection.

### 5.2 ESP-32 Processes Signal Data & Links with Odometer

The ESP-32 microcontroller serves as the central processing unit, receiving real-time input from the dashcam regarding traffic signal status. Once a **red signal is detected**, the ESP-32:

1. Confirms that the signal is valid and within the vehicle's relevant lane.
2. Links the information with the vehicle's odometer.
3. Monitors vehicle speed to determine if the driver is attempting to stop.

The ESP-32 ensures **immediate processing** of the detected red signal, triggering **both visual and audio alerts** to the driver.

### 5.3 Odometer Turns Red & Audio Alert is Triggered

To provide an immediate visual cue, the odometer colour changes to red when a red traffic signal is detected. This serves as a **non-intrusive** yet highly visible indication that the vehicle must stop.

In addition, an audio alert (such as "Red signal detected, please stop") is played through the vehicle's built-in speaker system. This reinforcement helps in cases where the driver may not immediately notice the red signal or is distracted.

This dual-alert mechanism (visual + audio) ensures that the driver is:

- Clearly informed of the red signal without taking their eyes off the road.
- Prompted to react quickly, reducing the risk of accidental signal jumps.
- Not overwhelmed, as the alerts are designed to be simple and effective.

The system monitors driver behaviours after the alert, tracking whether the vehicle slows down or continues moving.

### 5.4 Memory Unit Logs Vehicle Number & Tracks Speed

The memory unit plays a crucial role in ensuring accurate violation detection. Upon detecting a red signal, it starts tracking the vehicle's speed in real-time.

Key functions include:

1. Recording the vehicle number, ensuring identification of potential violators.
2. Logging speed data, checking if the driver slows below 10 km/h.
3. Time-stamping the event, ensuring precise violation records.

This step is critical in differentiating genuine violations from false alarms. If the system detects that the driver has intended to stop (e.g., slowing down within an allowed reaction time), no violation is recorded.

However, if the vehicle maintains a high speed or fails to stop within a reasonable timeframe, it moves to the final stage: violation reporting.

### 5.5 Violation Detection & Reporting to District Police Station

If a vehicle fails to stop at the red signal and crosses the intersection, the system confirms a red signal jump violation. This is determined when:

- The dashcam loses sight of the red signal, meaning the vehicle has crossed illegally.
- The odometer remained red, proving the driver was alerted but ignored the warning.
- The speed remained above the allowed threshold, confirming no effort was made to stop.

Once the violation is confirmed, the system automatically logs the following details:

- Vehicle number (for identification).
- Date, time, and location of the violation.

- Speed at the time of the signal jump.
- Odometer & alert data, proving that the driver was warned.

This data is then transmitted to the district police station's database, where authorities can review and enforce penalties as per local traffic laws.

**Conclusion**

By integrating real-time traffic signal detection, vehicle monitoring, and automated violation reporting, this system ensures efficient traffic law enforcement. It removes the need for manual policing, reduces human error, and ensures that only genuine violations are flagged. Future improvements could include V2X communication, allowing traffic signals to directly transmit their status to vehicles for even greater accuracy.

# 6. DESIGN

The Intelligent Signal Jump Detection System is designed for seamless integration into vehicles, ensuring accurate traffic rule enforcement with minimal driver intervention.

## 6.1 ESP-32 Microcontroller as the Central Unit

The ESP-32 microcontroller serves as the central processing unit, efficiently managing all system operations. It processes real-time input from the dashcam, and speedometer, ensuring accurate violation detection. The ESP-32 continuously evaluates traffic signals, vehicle speed, and road conditions, making decisions in real-time to improve road safety.

Additionally, the ESP-32 ensures secure data transmission by encrypting and relaying information to a centralized database. Its low-power consumption and wireless communication capabilities enable seamless integration with cloud-based monitoring systems. By handling data processing locally before transmitting essential information, the ESP-32 optimizes efficiency, reducing latency in violation detection.

## 6.2 Dashcam for Traffic Signal Detection

The dashcam, equipped with a YOLO-trained model, ensures high-precision traffic signal detection. Positioned at an optimal angle to minimize obstructions from other vehicles, it captures real-time video frames to identify traffic signals accurately. The system is designed to function effectively under varying lighting conditions, adverse weather, and heavy traffic, ensuring consistent performance.

The YOLO model runs on-device inference through the ESP-32, enabling low-latency detection of red signals. When a red light is detected, the system immediately assesses the vehicle's speed and movement to determine if a violation has occurred. To further enhance detection accuracy, the dashcam employs frame-by-frame analysis and integrates motion tracking to verify whether a vehicle has crossed the stop line.

The dashcam is strategically positioned to provide a clear and unobstructed view of traffic signals. Its placement is optimized to reduce issues like reflections, obstructions from other

vehicles, and varying lighting conditions. The dashcam continuously captures video frames, allowing the YOLO-based model to accurately detect red signals and ensure reliable violation detection.

### 6.3 Odometer Integration for Driver Alerts

To provide immediate and intuitive feedback to the driver, the system integrates with the vehicle's odometer. When the dashcam detects a red signal, the ESP-32 synchronizes with the speedometer to assess the vehicle's response. If a violation is detected (e.g., the driver fails to slow down), an audio warning is triggered, ensuring instant notification.

The integration with the odometer also helps analyze gradual stopping behavior, preventing false violations. If the system detects that the driver is progressively slowing down rather than abruptly stopping, it accounts for real-world driving conditions, such as braking distance and vehicle momentum, ensuring fair rule enforcement.

### 6.4 Storage for Violation Logging

To maintain a structured and tamper-proof record of traffic violations, the system securely logs violation data into a centralized database. The stored information includes:

- Vehicle Number – for precise offender identification
- Speed and Timestamp – to verify the exact moment of violation
- Location Data – to track region-specific traffic rule compliance

By systematically organizing data region-wise, traffic authorities can analyze trends, identify high-risk areas, and implement better enforcement strategies. The system ensures automatic data retention, enabling law enforcement to review past violations if needed. Additionally, cloud-based storage enhances accessibility, allowing authorities to retrieve records in real time.

### 6.5 Seamless System Connectivity

A key aspect of the intelligent signal jump detection system is its ability to establish seamless connectivity among all components. The ESP-32 acts as a hub, ensuring efficient data exchange between the dashcam, odometer and centralized database.

The system supports real-time data synchronization, ensuring minimal delay in violation detection and reporting. Wireless connectivity (Wi-Fi/Bluetooth) allows the ESP-32 to transmit violation details to enforcement agencies, enabling automated fine processing and real-time monitoring.

Additionally, the modular architecture allows for future upgrades, such as AI-powered predictive analytics, which could help authorities proactively manage traffic congestion and optimize law enforcement strategies.

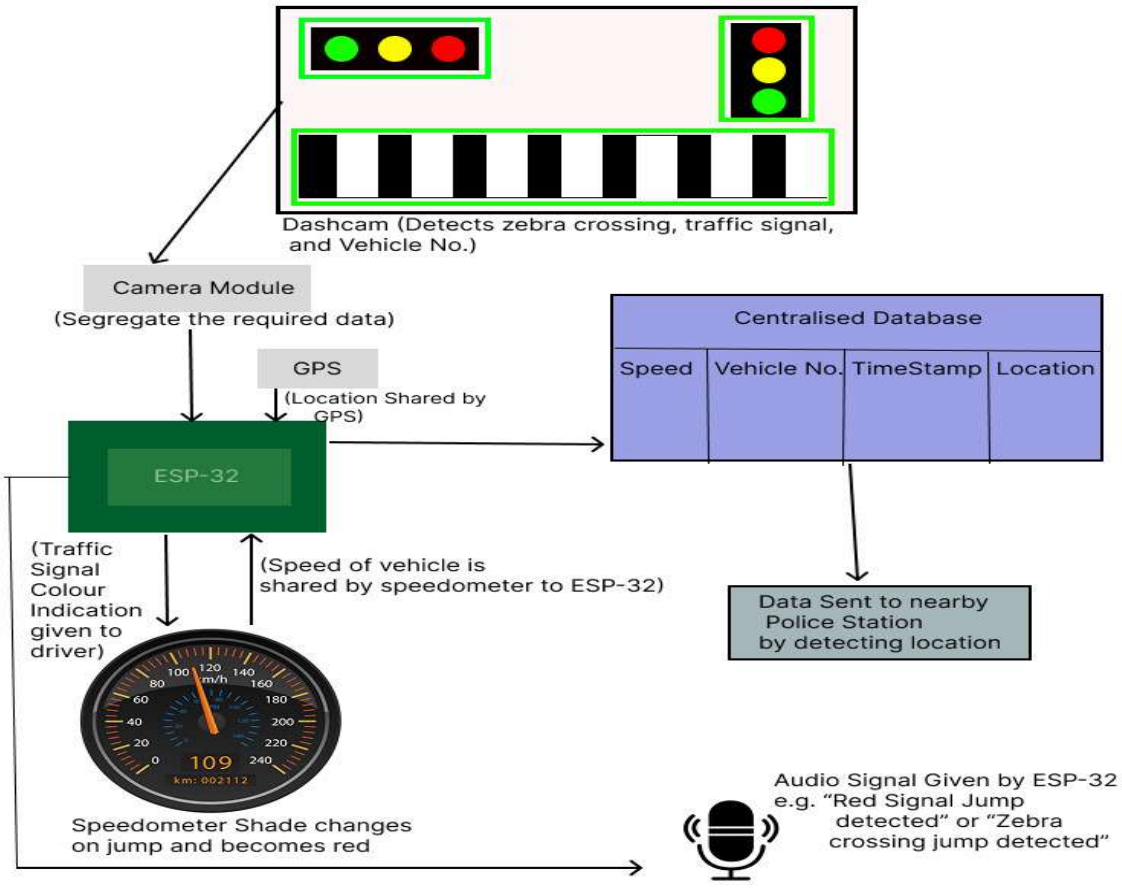


Fig. 3. Design Architecture of proposed model

## 7. FUTURE SCOPE

The system has the potential for several enhancements to improve accuracy, security, and adaptability. One major improvement is GPS integration, which would allow precise tracking of intersection locations. This would help in verifying red signal violations more accurately, ensuring that the system correctly identifies the traffic signal relevant to the vehicle's lane.

Multi-lane differentiation is another critical advancement. By incorporating advanced image processing techniques, the system can ensure that only the correct vehicle is flagged for a violation. This prevents errors caused by nearby vehicles in adjacent lanes that may not have committed an offense.

Tamper detection can be implemented to prevent unauthorized modifications or disconnections of the ESP-32 microcontroller. If an attempt is made to disable or bypass the system while the vehicle is in motion, an alert can be triggered and logged in the database, ensuring enforcement reliability.

Adaptive AI processing can further enhance the system’s detection capabilities under extreme lighting conditions such as nighttime, fog, or heavy rain. By incorporating advanced image enhancement techniques, the YOLO model can maintain high accuracy regardless of environmental factors.

Another improvement is the introduction of vehicle-specific rules, which will help differentiate between private, commercial, and exempt vehicles like ambulances or law enforcement units. This ensures that special cases are handled appropriately, avoiding unnecessary violations for vehicles permitted to bypass red signals under specific conditions.

With these enhancements, the system can become more robust, ensuring efficient traffic enforcement while minimizing false violations.

## Conclusion

The intelligent red signal jump detection system enhances traffic law enforcement through real-time signal recognition, vehicle monitoring, and automated violation reporting. By integrating AI, ESP-32, and cloud storage, it ensures accuracy and fairness. Future improvements will further refine detection, reducing violations and promoting safer road discipline for all drivers.