ABSTRACT

Traffic signal violations significantly contribute to road accidents, traffic congestion, and overall road safety concerns. Traditional enforcement methods, such as manual monitoring and traffic cameras, are often inefficient due to human limitations and resource constraints. This project proposes an **intelligent real-time traffic signal violation detection system** leveraging an **ESP-32 microcontroller**, a **dash camera**, and an advanced **YOLO-based object detection model**. The system is designed to continuously monitor **traffic signals, zebra crossings, and vehicle movement** to identify red light violations accurately.

To enhance detection accuracy, the system is integrated with the **vehicle's odometer**, allowing it to track real-time speed. When a red signal is detected, the system initiates a **visual alert** by changing the odometer's color and an **audio notification** to warn the driver. If the vehicle fails to stop and crosses the zebra line while the signal is red, the system logs critical details such as the **vehicle number, speed, and violation timestamp**. This data is then securely transmitted to the **respective district police database** for further processing and penalty enforcement.

The proposed system aims to enhance **road discipline, reduce traffic signal violations, and minimize accident rates** through real-time monitoring and automated enforcement. By leveraging **IoT, computer vision, and AI-driven automation**, this solution provides an efficient, scalable, and cost-effective method for traffic law enforcement, ultimately improving urban road safety.

SYSTEM COMPONENTS

- **ESP-32 Microcontroller: The Core Processing Unit**
- **Dash Camera with YOLO Model: Intelligent Traffic Signal Recognition**

Fig. 1. YOLO Model Detecting Traffic Signal

- **Audio Alert System: Reinforcing Compliance Through Sound**
- **Memory Unit & Speed Monitoring: Ensuring Accountability**
- **Database Storage: Secure Logging & Violation Tracking**

SCENARIOS

- **Normal Stopping at Red Signal**

The intelligent red signal jump detection system ensures compliance with traffic rules while preventing false violations. The **ESP-32 microcontroller** and **dashcam** continuously monitor traffic signals using a **YOLO-trained model**. When a red signal is detected, the system changes the **odometer color to red** and plays an **audio alert** ("Red signal detected"), prompting the driver to stop.

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

- **Red Signal Jump Detection**

If a vehicle fails to stop at a red signal, the system confirms a violation through a structured process. The **ESP-32 detects the red signal**, changes the **odometer color**, and plays an **audio alert**. If the driver does not slow down within a set threshold, the system checks whether the vehicle **crosses the intersection**.

Once confirmed, the system logs:

1. **Vehicle number** (for identification)
2. **Speed & timestamp** (to validate violation)
3. **Location** (to track violations regionally)

- **Normal Stopping at Zebra Crossing**

When a **zebra crossing** is detected, the system triggers an **audio alert** ("Zebra crossing detected"). If the driver slows down and stops **before the crossing** when pedestrians are present, no violation is recorded. The system resets once the road is clear, encouraging responsible driving and improving pedestrian safety

- **Zebra Crossing Jump Detection**

If a driver **fails to stop at a zebra crossing** with pedestrians present, the system detects a violation. The ESP-32 monitors vehicle movement, and if the vehicle crosses the **marked area** without slowing, it logs:

- **Vehicle number**
- **Timestamp**
- **Location**

The data is sent to authorities for enforcement, ensuring pedestrian rights and promoting safer road practices.

ASSUMPTIONS

- **Dashcam Has Clear Visibility of Traffic Signals**

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.

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

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.

- **A Grace Period is Given if the Vehicle Reduces Speed Below 10 km/h**

  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.

  - A reaction time window (e.g., 2-3 seconds) is allowed before finalizing a violation, preventing unfair penalties for drivers who slow down properly.

SOLUTION

- **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.

- **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.

- **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.

- **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.

- **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.

DESIGN

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

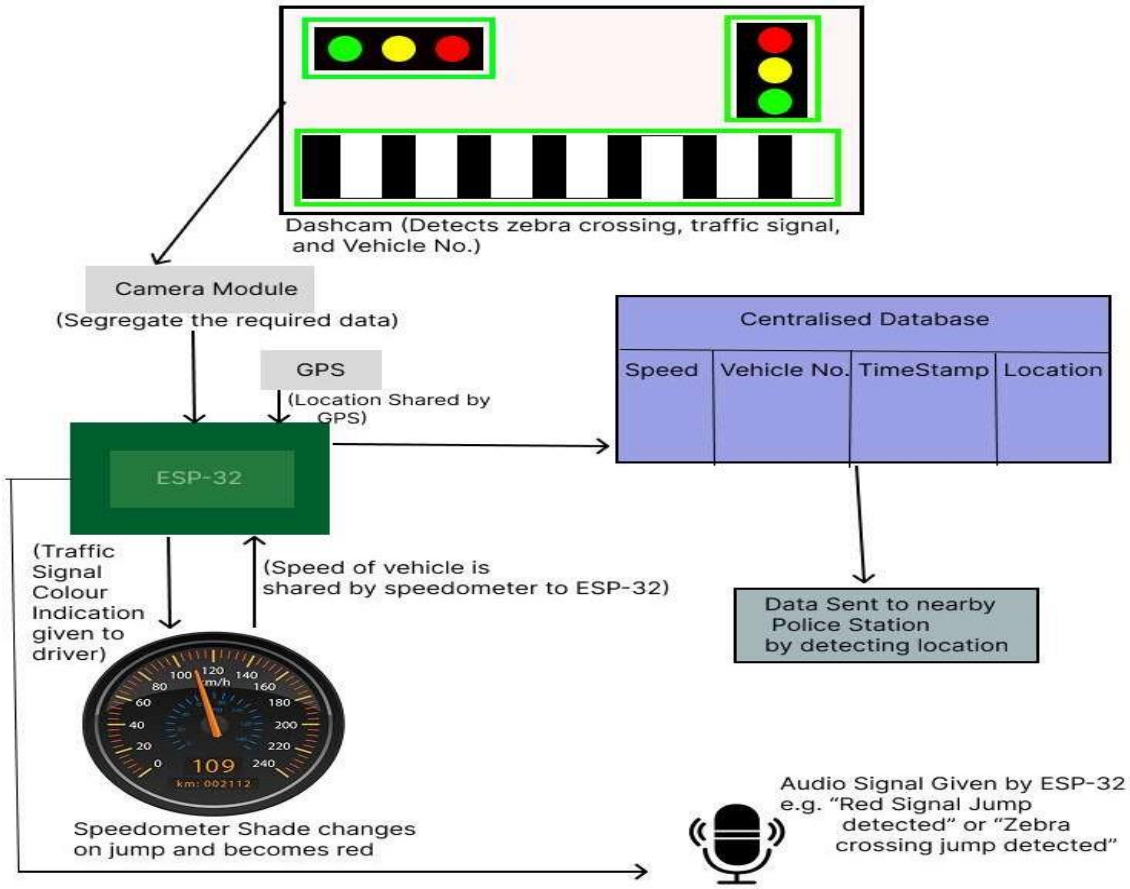

Fig. 3. Design Architecture of proposed model

- **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.

- **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.

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.

- **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.

- **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