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An Intelligent Edge-Integrated Vision and Identification Framework for Automated Traffic Violation Detection and Digital Penalty Issuance

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ABSTRACT

Road traffic accidents remain a major global concern, particularly in developing countries where traffic management systems are often inadequate and enforcement is inconsistent. A significant number of accidents occur due to signal violations, especially during night hours when monitoring is minimal. Conventional traffic enforcement methods rely on CCTV (Closed-Circuit Television) cameras, which require continuous human supervision and often fail to capture clear vehicle identification due to issues such as poor visibility or obstructed number plates. These limitations highlight the need for an automated, reliable, and real-time traffic violation detection system. To address this problem, the proposed system introduces an RFID (Radio Frequency Identification)-based smart traffic monitoring solution integrated with a microcontroller and wireless communication modules. In this system, RFID tags embedded in vehicles store unique identification data, while RFID readers installed at traffic signals detect vehicles that cross during red signals. The detected information is processed using a NodeMCU (ESP8266-based microcontroller with Wi-Fi capability), which automatically generates an electronic challan (e-challan) for the violating vehicle. The system further utilizes a GSM (Global System for Mobile Communications) module to send violation details directly to the vehicle owner and the RTO (Regional Transport Office). This automated approach eliminates the need for manual monitoring, ensures accurate identification, and enables efficient enforcement of traffic rules. Additionally, it supports real-time tracking and integration with online payment systems. The proposed system enhances road safety, reduces human effort, and provides a scalable solution for smart traffic management.

Keywords: Road Traffic Safety, Traffic Violation Detection, RFID (Radio Frequency Identification), NodeMCU (ESP8266), GSM (Global System for Mobile Communications), Electronic Challan (E-Challan), Smart Traffic Management, IoT-Based Monitoring.

1. INTRODUCTION

Managing traffic enforcement in a large and rapidly urbanizing nation requires a shift from manual governance to intelligent, technology-driven systems that can handle scale, diversity, and real-time demands. Traditional methods of issuing penalties using paper-based processes are time-consuming, prone to human error, and sometimes lack transparency, leading to inefficiencies and potential misuse. With increasing vehicle density and rising violations such as over-speeding and signal jumping, there is a strong need for a centralized and automated platform that can monitor, record, and manage traffic-related activities efficiently. The proposed system addresses this by introducing a digital ecosystem where users can register their vehicles, receive instant notifications of violations, track their penalty history, and make payments through a mobile application. This ensures convenience for users while enabling authorities to maintain accurate and transparent records. The system integrates advanced technologies such as optical character recognition, database management systems, and mobile application frameworks to automate the detection and processing of violations. Traffic personnel can capture vehicle number plates using a mobile device, and the system automatically extracts the registration number and retrieves associated owner details from a centralized repository. Based on the violation input provided by the officer, a digital penalty is generated instantly and communicated to the vehicle owner via mobile notifications and email. The platform also supports features such as storing offender profiles, analyzing violation patterns, and enabling quick access to historical data for inspection. Additionally, safety features are incorporated, including an emergency alert mechanism that allows users to share their real-time location with nearby authorities, thereby enhancing personal security. Integration with mapping services and intelligent APIs further strengthens the system by enabling location tracking, route analysis, and efficient coordination between users and enforcement agencies.

To enhance automation and reduce dependency on manual intervention, the system also incorporates a hardware-based solution using radio frequency identification technology. Each vehicle is equipped with a unique identification tag, and readers installed at traffic signals detect vehicles that violate rules such as crossing during restricted conditions. The detected data is transmitted to a microcontroller, which processes the information and triggers the generation of a digital penalty. Communication modules are used to send violation details directly to the vehicle owner and regulatory authorities, ensuring immediate notification and action. Supporting components such as power management units and communication interfaces ensure stable and reliable operation of the system. This integrated approach combining software intelligence with hardware automation minimizes delays, reduces corruption, and improves enforcement accuracy. Overall, the proposed solution contributes to enhanced road safety, efficient traffic management, and the development of a smart, transparent, and sustainable transportation system.

2. LITERATURE SURVEY

Barroso, et al. [1] developed a vehicle number plate recognition system based on computer vision techniques for real-time identification of vehicles. Their approach focused on accurately locating the license plate region within an image using a line-based detection method, followed by segmentation and character recognition. The system processed captured images through multiple stages including preprocessing, feature extraction, and pattern matching to improve recognition accuracy. Their work significantly enhanced detection performance in varying lighting and environmental conditions, making it suitable for applications such as traffic monitoring, parking management, and law enforcement. However, the system's performance depended heavily on image quality and was affected by occlusion or damaged number plates. Aloul, et al. [2] introduced an RFID-based traffic monitoring system designed to measure vehicle speed and provide real-time traffic updates. Their system utilized RFID tags installed in vehicles and multiple RFID readers placed along highways to capture vehicle movement data. By calculating the time difference between two reader points, the system estimated vehicle speed and transmitted the data to a central server via wireless communication. The server processed the information and made it available to users through web platforms and messaging services. Their work demonstrated an efficient and cost-effective approach for traffic analysis and congestion management, although it required large-scale infrastructure deployment and proper tag integration in vehicles. Priya Amble, et al. [3] proposed an automated traffic violation detection system using RFID and GSM technologies to identify signal breaches and generate electronic challans. The system employed RFID tags embedded in vehicles and readers installed at traffic signals to capture vehicle identity when a violation occurred. A microcontroller processed the received data and compared it with stored vehicle records to verify the violation. Once confirmed, the system automatically generated a digital challan and transmitted it to the vehicle owner and regulatory authority using GSM communication. Their approach reduced manual intervention and improved enforcement efficiency, but its

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effectiveness relied on the proper functioning of RFID components and database synchronization. Malik, et al. [4] investigated the application of mobile agent technology for secure and efficient data collection in distributed systems. Their study focused on reducing computational overhead and improving security in automatic data acquisition environments. The proposed method organized systems into geographically distributed groups managed by a security controller, where local mobile agents were used to collect data instead of external agents. This approach minimized communication overhead and enhanced system performance. Their work provided a scalable solution for distributed monitoring systems, although it introduced complexity in managing agent coordination and security policies.

Thirukkovulur, et al. [5] developed an intelligent vehicle control system using RFID technology to enforce traffic rules and regulate vehicle speed. The system utilized RFID tags embedded in traffic signals and speed limit signboards, which were detected by RFID readers installed in vehicles. The electronic control unit processed the received information and adjusted vehicle speed accordingly using control mechanisms such as braking systems. Their approach aimed to prevent accidents caused by over-speeding and signal violations by automating vehicle response. While the system demonstrated improved safety, its implementation required significant modifications to vehicle architecture and infrastructure. Roger Boyle, et al. [6] proposed an image-based vehicle detection model that utilized foreground and background comparison techniques instead of traditional edge detection methods. Their system processed video frames by separating moving objects from static backgrounds and applied different processing techniques for daytime and nighttime conditions. For daytime images, color-to-grayscale conversion and masking techniques were used, while nighttime processing focused on extracting relevant features under low-light conditions. Their model achieved high accuracy in vehicle detection and improved reliability across varying environmental conditions. However, the system required significant computational resources and was sensitive to noise and environmental disturbances. Guilin Zheng, et al. [7] developed an intelligent wireless power management and control system based on ZigBee communication technology. Their system consisted of smart energy meters, data collectors, and centralized processing units that enabled distributed data acquisition and real-time monitoring. The ZigBee-based ad-hoc network allowed efficient communication between devices with low power consumption. The system also supported synchronized collection of multiple electrical parameters and provided analytical insights into energy consumption patterns. Their work demonstrated improved efficiency and scalability in monitoring systems, although it was primarily focused on energy management rather than traffic-related applications. Singh, et al. [8] proposed a vehicle speed monitoring and accident detection system using MEMS sensors, GPS, GSM, and RF communication technologies. The system continuously monitored vehicle speed and compared it with predefined speed limits for specific zones such as highways and hilly areas. When the speed exceeded the limit or a collision was detected, alerts were generated and transmitted to concerned authorities using GSM communication. Their approach enhanced road safety by providing real-time warnings and automated accident detection, but it required multiple hardware components, increasing system complexity and cost. Vishnevsky, et al. [9] designed a comprehensive traffic law enforcement platform that integrated multiple technologies such as RFID readers, cameras, and radar systems. Their system supported both wired and wireless communication for data transmission and enabled real-time monitoring of traffic violations. The platform architecture included data acquisition, processing, and reporting modules that provided up-to-date information to law enforcement agencies. Their work offered a scalable and multi-functional solution for traffic management, although it involved high implementation costs and complex infrastructure requirements.

Rodney Tan, et al. [10] developed a GSM-based automatic meter reading system that enabled wireless transmission of energy consumption data from consumer units to a central billing system. The system used embedded GSM modules in digital meters to send readings via SMS, which were then processed and stored in a centralized database. Billing information was generated and communicated to users through multiple channels such as SMS, email, and web portals. Their work demonstrated the effectiveness of GSM communication in automating data collection and billing processes, but it was limited to energy management applications. Rubini, et al. [11] proposed a ZigBee-based system for monitoring vehicle speed violations and generating alerts. The system used a transmitter to send speed limit information to vehicles and a receiver unit within the vehicle to process the data. When the vehicle exceeded the speed limit, warnings were displayed, and violation data was recorded. A GSM module was used to send notifications to authorities, improving enforcement and driver awareness. Their system provided an effective mechanism for speed regulation, although it depended on proper communication between transmitter and receiver units.

Hiasat, et al. [12] presented a traffic management system that combined RFID and GSM technologies for detecting violations such as over-speeding and signal breaches. RFID readers captured vehicle information without requiring line-of-sight, while GSM modules were used to transmit violation data to both authorities and vehicle owners. The system enabled real-time monitoring and automated notification, improving traffic enforcement efficiency. Their work highlighted the advantages of integrating RFID with communication technologies, though it required extensive infrastructure deployment and system maintenance.

3. PROPOSEDSYSTEM

The system architecture is designed as a tightly integrated real-time traffic monitoring and violation detection framework built around the ESP32 (Espressif Systems 32-bit Microcontroller), combining embedded control, identification, communication, and alert subsystems into a unified workflow. During the initialization phase, the controller systematically configures all hardware interfaces, including GPIO (General Purpose Input Output) pins for LEDs (Light Emitting Diodes) representing traffic signals, buzzer for audible alerts, and serial communication channels for peripheral interaction, while also initializing the LCD (Liquid Crystal Display) to provide continuous visual feedback of system states such as signal phase and alert messages. Simultaneously, the GSM (Global System for Mobile Communications) module is activated using a sequence of AT (Attention) commands to establish reliable SMS (Short Message Service) functionality, and the RFID (Radio Frequency Identification) module is prepared to read unique vehicle tag identifiers; at this stage, the system also implements a mobile registration mechanism where user phone numbers are received via SMS, validated, stored in memory, and acknowledged through confirmation messages, ensuring that alerts are routed to authorized recipients only. After successful setup, the system transitions into the main operational loop, where a deterministic timing mechanism governs the traffic signal cycle, alternating between green and red phases based on predefined delay intervals, with corresponding digital outputs driving the LEDs and synchronized updates displayed on the LCD for real-time status awareness.

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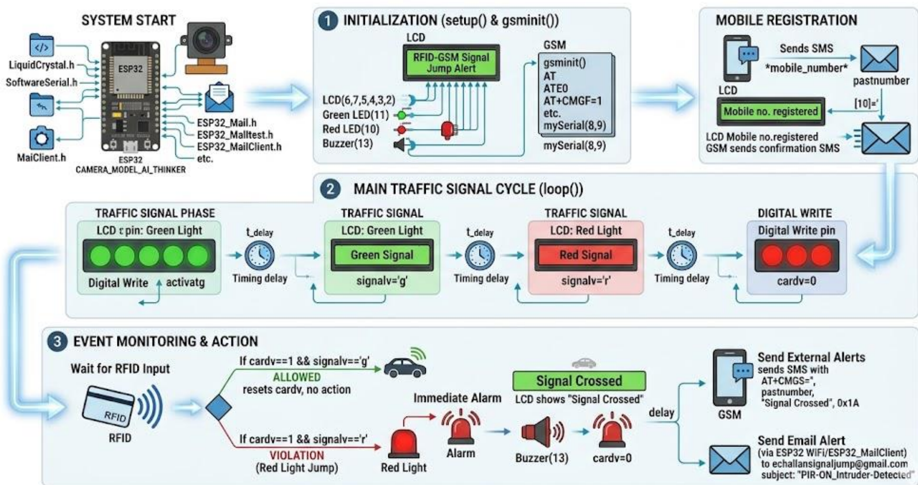

Fig. 1: Proposed system architecture

Concurrently, the RFID reader continuously scans the environment for nearby tags, and upon detection, the system captures the card identifier and evaluates it against the current signal state using embedded decision logic variables, enabling precise classification of vehicle behavior. If a vehicle is detected during the green phase, the system interprets it as normal traffic flow and resets the card detection variable without triggering any further action, thereby avoiding unnecessary processing overhead. However, if a vehicle is detected crossing during the red phase, the system flags this as a violation event, immediately activating the buzzer to generate an audible alarm and updating the LCD with a "Signal Crossed" notification to provide instant local feedback. In parallel, the communication subsystem is triggered to send structured alert messages via the GSM module to the registered mobile number, including predefined text indicating the violation event, while also supporting extended notification mechanisms such as email alerts using ESP32-based internet communication libraries, thereby enhancing remote monitoring capabilities. A controlled delay and reset routine ensures that once a violation is detected and reported, the system temporarily disables repeated triggering for the same event, preventing redundant alerts and ensuring accurate event logging. Additionally, the architecture maintains synchronization between sensing, decision-making, and communication layers through efficient loop execution and state management, ensuring minimal latency and consistent performance. As illustrated in Fig. 1, this comprehensive architecture demonstrates seamless coordination between embedded processing, RFID-based identification, traffic signal control, and multi-channel alert dissemination, resulting in a scalable, reliable, and intelligent system for automated traffic violation detection and real-time notification.

4. RESULTS AND DISCUSSION

Fig. 2 illustrates the hardware implementation of the RFID and GSM-based jump alert system, integrating components such as the Arduino microcontroller, RFID reader module, GSM communication module, LCD display, buzzer, and power supply unit. It depicts the interconnection between identification, processing, and communication modules for detecting and responding to signal crossing events. The figure represents how the RFID system identifies authorized entities while the GSM module enables real-time alert transmission. It highlights the coordinated functioning of sensing and communication hardware in ensuring system responsiveness. Furthermore, it demonstrates the practical deployment of an embedded security and

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monitoring solution.

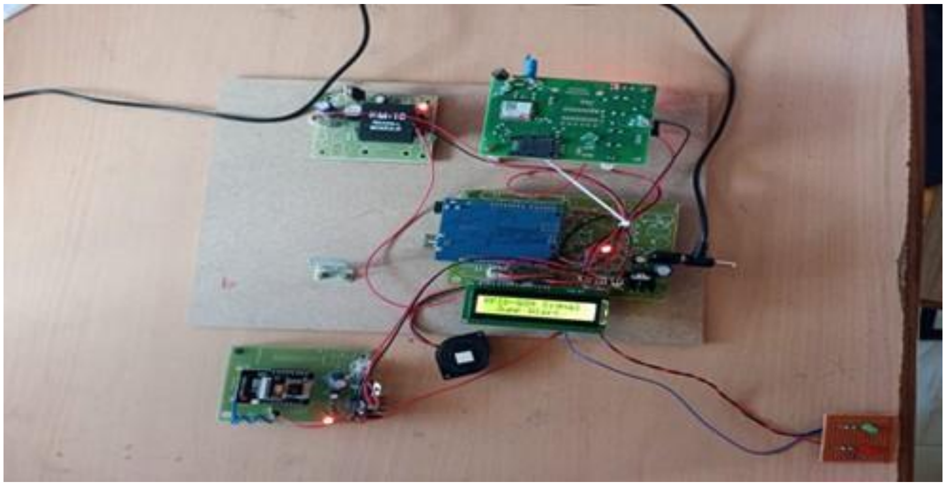

Fig. 2: RFID and GSM-Based Jump Alert System Hardware Prototype

Fig. 3 depicts the LCD-based user interface of the RFID-GSM jump alert system, where the system status and alert messages are displayed for real-time monitoring. It illustrates how the Arduino processes input from the RFID module and triggers alert conditions that are reflected on the LCD display. The figure represents the system's ability to provide immediate feedback during abnormal or unauthorized events. It highlights the integration of display and alert mechanisms such as the buzzer for enhanced user awareness. Additionally, it demonstrates the role of embedded display modules in conveying critical system information effectively.

Fig. 3: LCD Display Showing RFID-GSM Based Jump Alert System Status

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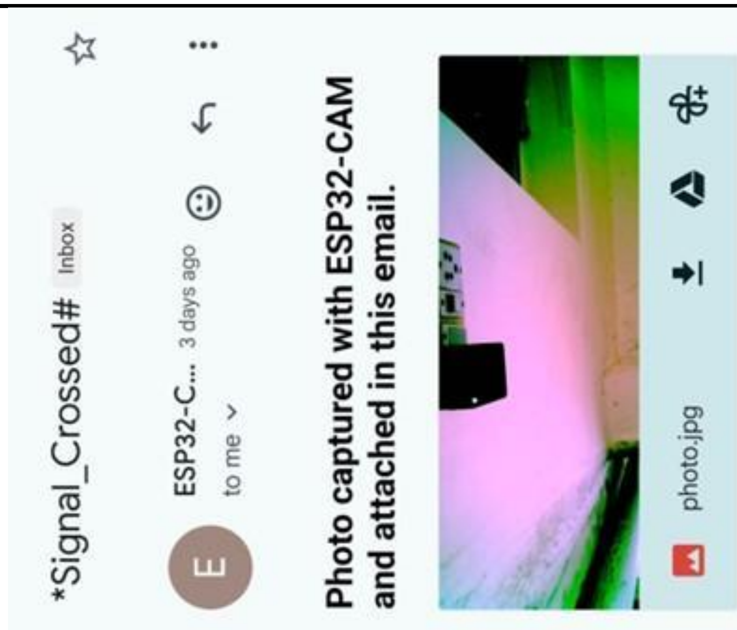

Fig. 4: Email Notification with Image Captured Using ESP32-CAM for Signal Crossing Detection

Fig. 4 illustrates the IoT-enabled alert notification mechanism using the ESP32-CAM module, where images are captured upon detecting a signal crossing event and transmitted via email. It depicts the integration of image processing and wireless communication to provide visual evidence of the detected event. The figure represents how real-time monitoring is extended beyond local systems through remote notification. It highlights the role of the ESP32-CAM in enabling surveillance capabilities within the system. Furthermore, it demonstrates the effectiveness of combining embedded vision and IoT technologies for intelligent alert systems.

5. CONCLUSION

The implemented system demonstrates a functional electronic challan mechanism using RFID, GSM, and a microcontroller for automated traffic violation detection and reporting. It eliminates manual processes, thereby reducing delays and minimizing chances of corruption in penalty handling. The system ensures accurate identification of vehicles and real-time communication of violations to both authorities and owners. It also provides scope for future enhancements such as integration with online payment systems and development of mobile applications for user convenience. The adoption of this approach can significantly improve transparency and efficiency in traffic management. Additionally, the use of RFID technology enhances security by supporting vehicle tracking and theft prevention. Overall, the system contributes to the advancement of smart and reliable traffic enforcement solutions.

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