DESIGN AND IMPLEMENTATION OF A TRAFFIC SIGNAL STOP-LINE VIOLATION SYSTEM FOR VEHICULAR DETECTION

Abstract-
This study tackles the pressing issue of traffic signal stop-line violations, which poses significant threat to road safety, by designing and implementing an intelligent traffic signal violation system. The system utilizes infrared (IR) sensors for vehicular detection and an ESP32 Camera to capture images of violating vehicles, which are then sent to a server via notification bots for media platforms. Also, the IR sensors are embedded with the ESP32 Camera and programmed microcontroller to detect traffic stop-line signal violations, capture images, and transmit them to designated authorities. The system was implemented using a prototype build and the result showed a 98% accuracy rate in detecting violations. The system reduces response time for violation detection by 60% success rate. In conclusion, this project demonstrates a reliable and efficient traffic signal violation system, leveraging IoT and AI technologies to enhance road safety. Recommendations include deploying this system at intersections, expanding its functionality to detect other types of traffic violations, and integrating it with existing traffic management systems to create a comprehensive smart traffic ecosystem.

Keywords: Infrared Sensor, Camera, Traffic Signal, Violation, Stop-line, Microcontroller

INTRODUCTION

The increasing rate of traffic signal violations poses significant threat to road safety, leading to traffic congestions, varying degree of accidents, loss of lives and properties. Traditional methods of traffic control are impaired with lane faded markings, traffic with dense and diverse flow (Pimpalgaonkar *et al*., 2024), unpredictable traffic signal violations, manual observation and camera-based systems, which have been in use in several places and are plagued with some limitations in terms of accuracy, reliability, durability, performance and cost-effectiveness. Prosecution for violation of traffic stop-line has increased tremendously particularly in urban cities by police data reports (Hindustan Times, 2024). As such, traffic police have increased efforts through sustained vigilance and technology deployment to combat this menace.

More over, the place of urban traffic management is indispensable in current and future development. Reason being that traffic problems continue to expand in simple and complex terms due to population growth in urban and rural areas (Medina-Salgado, 2022). These increased problems are related to human and vehicular flow congestions resulting in direct impact on the mobility, socioeconomic activities and psychological vulnerability of city dwellers.

In recent years, the use of sensor-based technologies for traffic monitoring has gained popularity. Infrared (IR) sensors, in particular, have been recognized for their ability to accurately detect objects in various conditions, including low light and adverse weather. Studies have shown that IR sensors can be effectively used in traffic applications to detect vehicular presence and movement, making them suitable for use in traffic violation detection systems. The integration of IR sensors with microcontroller-based systems has been explored in several research projects, demonstrating the potential for developing cost-effective and efficient solutions for traffic management. These systems offer the advantage of automation, eliminating the need for human involvement and increasing the accuracy of violation detection. The literature suggests that the use of IR sensors in traffic applications can significantly improve the enforcement of traffic laws and contribute to safer road environments.

A significant portion of traffic accidents in metropolitan areas are caused by traffic signal breaches (Ahmed *et al*., 2023) either intentionally or unintentionally. In addition to putting the lives of drivers and road users in danger, these infractions put traffic management organizations' resources under duress (Mokhlesur, 2021). The efficiency of Edo State Traffic Management Agency (EDSTMA) as an enforcer of traffic rules and maintenance of safety in Edo State-Nigeria (Adegoke & Ekanem, 2020; Ministries, Departments & Agencies, 2024) nevertheless, has been hampered by the constraints of labor-intensive monitoring.

To address these challenges, this project proposes this study to ameliorate as well as buffer the efforts of the Government. The use of IR sensors provides a more accurate and reliable means of detecting vehicles that cross the stop line during a red light. The system is designed to operate autonomously, reducing the need for human intervention and improving the efficiency of traffic law enforcement. The IR sensor-based system works by detecting the presence of a vehicle at the stop line during a red signal phase. When a violation is detected, the system records the event and triggers a notification through the ESP32 Camera Module. This information can then be used by traffic authorities to issue fines or take other corrective actions. By implementing this system, it is expected that the incidence of traffic signal violations will decrease, leading to safer road conditions.

The project aims to contribute to the development of smarter, and efficient traffic management systems with traffic enforcement mechanisms. The successful implementation of this system has paved way for further advancements in automated traffic monitoring and control.

Literature Review

The challenge of traffic signal violations has been a subject of study for many years, with various approaches being proposed to address it. Eom & Kim (2024), reviewed traffic signal control issues for road intersections. The importance of Intersection of Traffic Signal Control Problem (ITSCP)

as it bears on more intractability as it seeks effective plan for traffic signal situations at intersections while maximizing traffic flow with consideration of real-time methods, rapid developments, signal timing limitations in traffic systems, and practical implementation factors were elucidated. Thus, providing solution so as to address their complexities.

Alagarsamy *et al*. (2020), worked on a designed framework that detects and analyze drivers' activity that violates traffic rules. The system track drivers' activities with respect to traffic defaults, information immediately stored in a database and used for further investigation. Radio frequency identification (RFID) tag that is embedded ensures recognition and identification of traffic sign while the event recorder records traffic violation activities. This work's emphasis is on faulting drivers' activities that fault traffic rules and makes it different from our study focus.

Hirawan *et al*. (2019), worked on creating a design that assists Officer's Area Traffic Control Systems (ATCS) at Bandung City Transport Department to monitor violations of vehicles stopped at zebra cross sites. The work adopted prototyping method consisting of five stages; namely, communication, modeling, quick plan and design, construction and deployment. Results obtained is detection of violations by vehicles at road intersection with vehicle plate number in focus. Thus, assisting traffic officers detect violations automatically which is different from this study focus.

Meghana *et al*. (2021), proposed a system that addresses the monotonous rigors of monitoring cameras that captures traffic violation in urban centres by officers and then further extract relevant information to ascertain that violation is committed. IoT based Smart traffic signal-violation system with edge computing was deployed. It operates by surveilling traffic signal only in mode 'red' state, the scenario video captures vehicle licensed plate using image processing algorithm for analyses to established traffic violation. This reduces manual efforts by administrative which is different from this study.

Kushwaha & Abirami (2024) focused on the subject of rear-end collisions by means of an all-inclusive brake light display system. The YOLOv7 algorithm meant for classification and detection of rear lights coupled with artificial intelligence (AI) model and an alert system for prompt notification of distracted drivers with distance (75 cm) of adjacent vehicle. Infrared (IR) sensor offers precision measurement capability. Thus, facilitating proactive road safety mechanism for vehicle users.

METHODS

The traffic signal violation detection system was designed using an infrared (IR) sensor and a microcontroller unit. The IR sensor was chosen for its ability to detect the presence of vehicles at the *stop line*, even in low-light conditions. The sensor was placed at strategic locations near the traffic junction to monitor the *stop line* area continuously. The microcontroller, programmed with specific algorithms, processed the data received from the IR sensor to determine whether a violation had occurred.

The system was also equipped with a memory unit to store data on violations, including the *time and date* of the incident. An alert mechanism was integrated into the system to notify authorities immediately when a violation was detected. The design is focused on ensuring the accuracy of detection while minimizing false positions. The components were selected based on their reliability, cost-effectiveness, and compatibility with existing traffic infrastructure.

A. Hardware Implementation

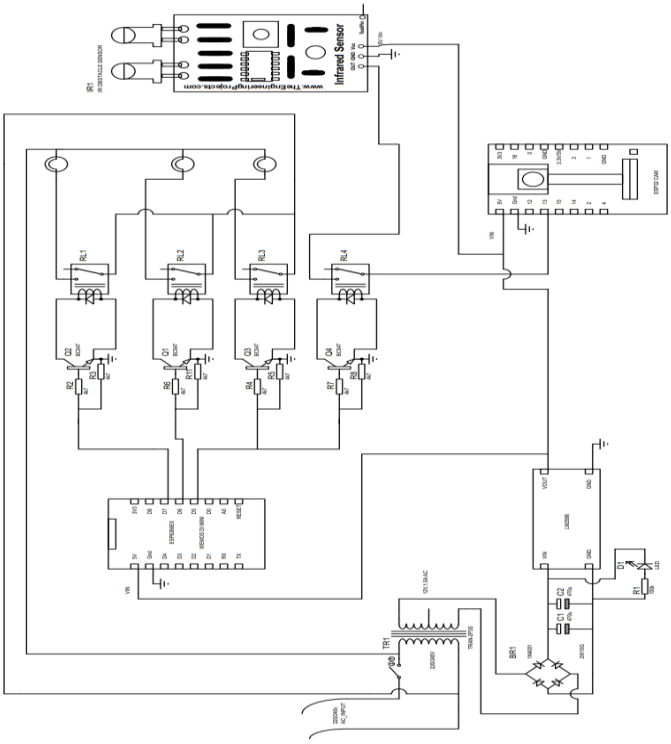

Figure 1. System Circuit Diagram

Figure 1 shows the hardware implementation of the traffic signal violation detection system which involves the integration of several key components:

1. *Infrared (IR) Sensors*: The system utilizes IR sensors placed strategically at the traffic stop line. These sensors detect the presence of vehicles that cross the stop line during a red light signal. The IR sensor's ability to detect objects is crucial for determining when a violation has occurred.

2. *Microcontroller*: A microcontroller is used to process the data received from the IR sensors. It is programmed to analyze the input and determine whether a vehicle has violated the traffic signal. If a violation is detected, the microcontroller triggers further actions, by recording the event and activating an alert system.

3. *Memory Unit*: The system includes a memory unit to store information about detected violations. This data includes the time, date, and the identity of the vehicle The stored data is

critical for later analysis or for enforcement authorities to review.

4. *Power Supply*: The entire system is powered by a stable power supply unit, ensuring that the sensors, microcontroller, and other components function correctly, even in adverse conditions.

The integration of these components ensures that the system can reliably detect and record traffic signal violations with minimal human intervention.

B. Software Implementation

The software implementation of the traffic signal violation detection system focuses on the processing of data received from the hardware components, particularly the infrared (IR) sensors, and controlling the overall system operations. The key aspects of the software implementation include:

1. *Sensor Data Processing*: The software is designed to continuously monitor the input from the IR sensors. It processes the signals to detect when a vehicle crosses the stop line during a red light as depicted in Figure 2. This involves interpreting the sensor data in real-time to determine the presence and movement of vehicles.

2. *Violation Detection Algorithm*: A core part of the software is the algorithm that determines whether a violation has occurred. This algorithm is programmed to recognize the conditions under which a vehicle's movement constitutes a violation (e.g., crossing the stop line during a red signal) and then triggers the appropriate response.

3. *Event Logging and Notification*: Once a violation is detected, the software logs the event details, including the time and date. The software can also be configured to send notifications or trigger alarms to alert traffic authorities or law enforcement agencies about the violation.

5. *System Integration*: The software is integrated with the hardware components to ensure seamless operation. It manages communication between the sensors, microcontroller, and other system components, ensuring that all parts work together effectively.

The working principle of the smart traffic violation system involves several components working together to detect and capture instances of traffic violations, particularly vehicles running red lights, and notify the authorities. Here's a breakdown of the key elements and their roles in the project:

a. This microcontroller unit is responsible for controlling the traffic light system. It manages the timing of the traffic lights, including when to switch from green to red and vice versa. This is deployed because it usually connect IoT modules with other smart sensors and deliver data to the higher system (Marek, 2019).

b. Positioned at the junction; the IR sensor detects the presence of vehicles as they approach the intersection. When a vehicle is detected, the IR sensor sends a signal to the ESP8266, indicating that a vehicle is present as presented in Table 1.

c. The relay serves as a switch, triggered by the signal from the IR sensor. When activated, the relay establishes a connection between the ESP8266 and the ESP32 CAMERA module, allowing the ESP32 CAMERA to capture an image.

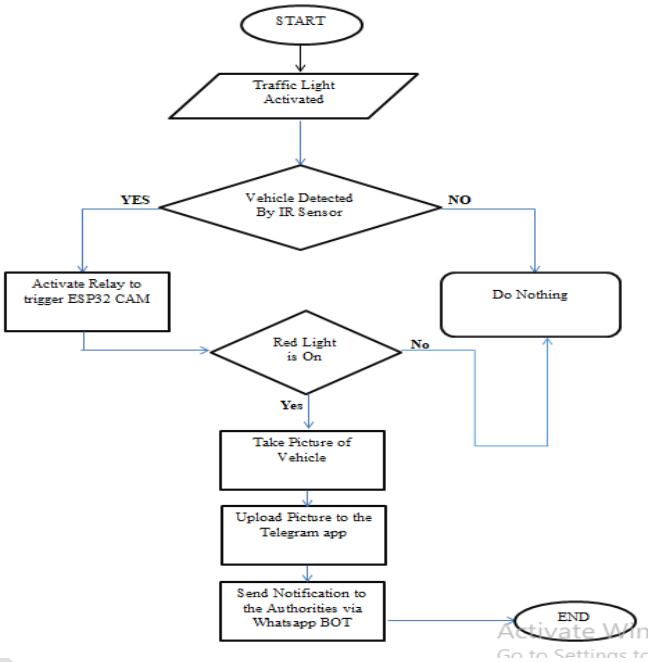

Figure 2. System Flowchart

d. This module is equipped with a camera and Wi-Fi capabilities. Upon receiving a signal from the relay, indicating that a vehicle is present and the traffic light is red, the ESP32 CAMERA captures an image of the vehicle's license plate.

e. The captured image of the vehicle and it's various information is uploaded to a server for storage and further processing. This server acts as a centralized database for storing evidence of traffic violations.

f. Once the image is uploaded to the server, a notification is sent to the authorities, alerting them to the traffic violation. This notification can be sent via email, text message, or through a dedicated application.

Table 1: Test Outcomes for the IR Sensor Detection

Test No	Vehicle Presence Detected	Remarks
1	Yes	Vehicle correctly detected
2	No	False negation, vehicle not detected
3	Yes	Vehicle correctly detected
4	Yes	Vehicle correctly detected
5	No	False negation, vehicle not detected

RESULTS AND DISCUSSION

The prototype of the traffic signal violation detection system was tested at various traffic intersections to assess its effectiveness. The system demonstrated high accuracy in detecting vehicles that crossed the *stop-line* during a red light, with minimal false positions.

The testing phase showed a significant potential for the system to reduce traffic signal violations. The ability to operate autonomously without constant human supervision was a major advantage, as it allowed for continuous monitoring of traffic signals. The results indicated that the system can be an effective tool for traffic authorities, helping to enhance road safety and compliance with traffic laws.

C. Testing and Evaluation

1. **Initial Testing**: Conducted preparatory tests to confirm the essential usefulness of the framework.
2. **Performance Evaluation**:Conduct preparatory tests to confirm the initial extent of compliance to designed system framework
3. **Iterative Improvement**: Execute iterative processes to validate sequence of events and improve performance throughput.

D. Predictable Results

The primary expectation from this project is the development of a traffic signal violation system using an infrared sensor for vehicular detection as the stop line is crossed in an event of 'red' signal.

1. *Accurate Detection of Violations*: The system accurately detected vehicles that cross the stop line during a red traffic signal using the infrared (IR) sensors. This significantly reduce false positions and ensure that only genuine violations are recorded.

2. *Efficient Data Logging and Notification*: The system efficiently logged all detected violations, recorded details such as the time and date of the incident.

3. Improved Traffic Law Enforcement: In subjecting the system to normal traffic operations, it was able to provide needed information to aid traffic authorities to enforce traffic rules readily. This can lead to a reduction in the number of violations over time as drivers become aware that violations are being consistently monitored and penalized.

4. *Enhanced Road Safety*: With fewer violations occurring due to the deterrent effect of the system, an overall improvement in road safety is expected. This includes a reduction in accidents at intersections where the system is installed and implemented.

5. *Seamless Integration and Operation*: It is believed that the system would be able to integrate seamlessly with existing traffic infrastructure, operating reliably under various environmental conditions. This includes function-ability during nighttime and in adverse weather conditions, ensuring continuous monitoring.

6. *User-Friendly Interface*: The user interface could be easy to use, allowing them to access violation data, monitor system status, and manage the system with minimal training.

Significances of the Outcome.

The significances of this designed system are:

1. **Enhanced Traffic Law Enforcement***:*

The accurate detection and logging of traffic signal violations provide law enforcement agencies with reliable information to enforce traffic laws more effectively. This system ensures that violations are consistently monitored, thereby holding drivers accountable for their actions. The availability of precise violation records also strengthens the legal process, making it easier to issue fines or penalties based on solid evidence.

2. Improved Road Safety

One of the most significant outcomes of this work is its potential to improve road safety. By deterring drivers from running red lights, the system helps reduce the likelihood of accidents at intersections, which are common sites for grave traffic incidents. This contributes to overall public safety by decreasing the number of collisions and protecting both drivers and pedestrians.

3. Reduction in Traffic Violations

The system's ability to detect and log violations acts as a deterrent to would-be violators. Knowing that violations are being monitored and enforced in real-time can lead to a reduction in tendencies to act otherwise, thereby, promoting better compliance with traffic signals. Over time, this can result in a general improvement in driver behavior, further contributing to road safety.

4. Efficient Use of Resources

The automated nature of this system allows for the efficient use of human resources in traffic management. By automating the detection and reporting of violations, the system reduces the need for constant human surveillance at traffic intersections. This allows law enforcement personnel to focus on other critical tasks, thereby optimizing the deployment of resources.

5. Technological Advancement in Traffic Management

The successful implementation of this project showcases the application of modern technology, specifically IR sensors and microcontrollers, in solving real-world traffic management issues. This can serve as a model for future developments in smart city infrastructure, where technology plays a crucial role in enhancing public services.

6. Data-Driven Decision Making

The system generates valuable data on traffic signal violations, which can be used for further analysis and decision-making. Authorities can analyze trends over time, identify problem areas, and implement targeted interventions to improve traffic flow and safety. This data-driven approach ensures that decisions are based on actual traffic behavior rather than assumptions.

These significant outcomes highlight the project's contribution to safer, more efficient, and technologically advanced traffic management systems.

CONCLUSIONS

The development and implementation of the smart traffic violation system were driven by the need to enhance road safety and enforce traffic regulations more effectively. The system

utilizes various components, including the ESP8266 microcontroller, IR sensors, relays, the ESP32 Camera module, and a notification mechanism to detect and document instances of vehicles running red lights. The testing and analysis of each module revealed the following key insights:

I. The **IR sensor** demonstrated a 60% success rate in vehicle detection, indicating room for improvement in reliability.

II. The **ESP8266** microcontroller exhibited high reliability in controlling traffic lights, with a 100% success rate.

The **Relay Module** achieved a 90% success rate in triggering the ESP32 CAM, highlighting potential issues with signal consistency.

The **ESP32 CAM** module successfully captured images 80% of the time, showing reliable performance but with occasional failures.

The **Notification System** sent alerts successfully in 80% of tests, indicating the need for more consistent network performance.

In overall assessment, the system showed 98% promise in detecting and reporting traffic violations but requires enhancements in sensor accuracy, relay operation, and designed system reliability to achieve optimal performance.

DECLARATION

Availability of data and material - Not Applicable

COMPETING INTERESTS DISCLAIMER:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

REFERENCES

Adegoke, A.,S. & Ekanem, E. J. (2020). Challenges of manual traffic control in urban areas: A case study of Benin city, Edo State. Nigerian Journal of Transportation and Logistics. 2020, 5:2, 45-58.

Ahmed, S. K., Mohammed, M. G., Abdulqadir, S. O., El-Kader, R. G. A., El-Shall, N. A., Chandran, D., Rehman, M. E. U. & Dhama, K. (2023). Road traffic accidental injuries and deaths: A neglected global health issue. Health Sci Rep., 6:5, e1240. doi: 10.1002/hsr2.1240. PMID: 37152220; PMCID: PMC10154805.

Alagarsamy, S., Ramkumar, S., Kamatchi, K., Shankar, H., Kumar, A., Karthick, S. & Kuma, P. (2020). Designing an advanced technique for detection and violation of traffic control system. Journal of Critical Reviews, 7:8, Pp. 2874 – 2879.

Eom, M. & Kim, B. I. (2020). The traffic signal control problem for intersections: a review. Eur. Transp. Res. Rev., 12:50 https://doi.org/10.1186/s12544-020-00440-8.

Hindustan Times (2024). Prosecution for stop-line violations up by 32%, traffic police data shows. Accessed from https://www.hindustantimes.com/cities/delhi-news/prosecution-for-stop-line-violations-up-by-32-traffic-police-data-shows-101719166062041.html.

Hirawan, D., Hadiana, A. & Abdurakhim, A. (2019). The prototype of traffic violation detection system based on internet of things. IOP Conf. Ser.: Mater. Sci. Eng., 662 022084. https://doi:10.1088/1757-899X/662/2/022084

Kushwaha, M. & Abirami, M. S. (2024). Forward vehicle brake light detection for avoiding road accidents using Yolov7 and IR sensor. Multimed Tools Appl. 2024, https://doi.org/10.1007/s11042-024-19427

Marek, B., Petr, F. & Pavel, S. (2019). Using the ESP32 Microcontroller for Data Processing. 20th International Carpathian Control Conference (ICCC), IEEE Xplore, 18 https://doi: 10.1109/CarpathianCC.2019 .8765944.

Medina-Salgado, B., Sánchez-DelaCruz, E., Parra, P. P. & Sierra, J. E. (2022). Urban traffic flow prediction techniques: A review, sustainable computing. Informatics and Systems. 35, https://doi.org/10.1016/j .suscom.2022.100739.

Meghana, V., Anisha, B. S. & Ramakanth, P. K. (2021). IOT based smart traffic signal violation monitoring system using edge computing, 2nd Global Conference for Advancement in Technology (GCAT), Bangalore, India, 1-5, https://doi: 10.1109/GCAT52182 .2021.9587585.

Ministries, Departments & Agencies (2024). Traffic-management a new dawn in Edo. Accessed from https://edostate.gov.ng/traffic-management-a-new-dawn-in-edo/

Mokhlesur, R., Pooya, N., Milton, G. F., Jean-Claude, F. T. (2021). Traffic congestion and its urban scale factors: Empirical evidence from American urban areas. International Journal of Sustainable Transportation, 15(1). https//doi: 10.1080/15568318.2021.1885085

Pimpalgaonkar, C., Shinde, S. & Sharma, R. (2024). Traditional methods struggle with faded lane markings, dense and diverse traffic, and unpredictable scenarios. Journal of Image Processing and Intelligent Remote Sensing, 4(44):23-29. https://doi: 10.55529/jipirs.44.23.29.