Traffic Signal Violation Detection and Penalty Application System

Aruna Parameswaran, Debargha Roy, Tarishi Jauhari, S. Aarthi

Abstract: ***This paper explores the use of Radio Frequency (RF) signals to detect vehicles that violate traffic signals. The increasing congestion on the road hinders accurate recognition of traffic intruders and, hence, they are not held accountable. Previous efforts to resolve this issue include the use of Computer Vision (CV) algorithms on traffic surveillance footage to identify vehicle registration numbers, Global Positioning System (GPS) to monitor the movement of the vehicle, and intrusive sensors like magnetometers. Unlike other existing methods, RF signals can be transmitted accurately despite hindrances in line-of-sight, and the cost of construction is relatively less. The proposed methodology involves the transmission of vehicular data through RF signals, picked up by receivers placed on-site. This receiver further filters the intruder data using a detection algorithm, and the necessary action is taken. Additionally, this paper presents a generalized system architecture and examines the implementation of violation detection and penalty notification.***

Index Terms: Intelligent transportation system (ITS), radio frequency (RF) signal detection, red light overrun, traffic signal violation and penalty.

I. INTRODUCTION

According to a report published by the National Crimes Records Bureau of India [1], 4,64,674 road accident cases occurred in 2015, a 3.1% increase from 2014. Approximately 1.5 lakh people were reported dead and almost 5 lakh people were injured. The staggering number of deaths recorded was a direct result of unlawful behaviour, such as over-speeding, careless driving or overtaking, and Driving under Influence (DUI). Over-speeding accounted for a whopping 41.2% of deaths while reckless or dangerous driving caused 32.2% of total deaths. Furthermore, the number of vehicles on road increased by 28.6% over the span of just two years (from 1.41 lakhs in 2011 to 1.82 lakhs in 2013).

The observation to be made is that there is an inverse correlation between traffic congestion and road safety. Hence, it is of grave importance that sufficient measures are introduced to minimise the loss of lives. Consequently, more research is being conducted towards the development of Intelligent Transportation Systems (ITS). The term ITS refers collectively to the suite of applications capable of performing monitoring, communication and control of its connected components. Typically, ITS consists of both wired or wireless communications that connect to its various components. [2] offers a brief history of the ITS and thoroughly documents its various intricacies.

One of the core functions performed by an ITS is vehicle detection, which helps to isolate individual vehicles and hence derive crucial information such as its registration number, or its speed. Different applications (smart parking, traffic management, speed monitoring etc.) perform vehicle detection using an assortment of sensors and technologies. As described in [3], these sensors fall into three broad categories: 1) intrusive, 2) non-intrusive, and 3) off-road. Piezoelectric, magnetic sensors are typically embedded on the road surface. The gradual rupture of the surface poses a significant threat to these intrusive sensors. Traffic surveillance using Computer Vision (CV), RADAR, infrared and ultrasonic detectors are examples of non-intrusive sensors. They are positioned over the road or occasionally integrated into traffic light control systems. Off-road sensors typically use satellites, GPS for instance, to determine the vehicle's position and track its movement.

The issue of red light overrun, while seemingly inconsequential, actually has a significant impact on traffic-related accidents, especially in signal intersections or lane changes. As discussed in [4], one of the factors that causes accidents during lane change is red signal violation. While it may not be as prominent an issue as the consumption of alcohol, for example, it is still considered a ticketable offence in some jurisdictions across the world. Hence, it is imperative to take action imminently. In this paper, we suggest a method of transmitting essential vehicle data through Radio Frequency (RF) signals, which can be used in traffic intersections to identify the intruding vehicles.

The remainder of the paper is organised as follows: Section II reviews the related work done in other similar vehicle intrusion detection systems. Section III presents the system architecture and construction details of the proposed solution. Section IV elaborates extensively on the working of the system, as well as the algorithm used by it and Section V presents the experimental results. Finally, Section V concludes the paper and mentions the scope for future research.

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Aruna Parameswaran, Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India.

Debargha Roy, Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India.

Tarishi Jauhari, Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India.

S. Aarthi, Department of Computer Science and Engineering, SRM Institute of Science and Technology, Chennai, India.

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II. Related Work

This section presents an overview of the previous work done in developing similar vehicle detection systems. Prominent techniques employed include the use of Computer Vision (CV) algorithms to recognise the registration plate, and an assortment of sensors to track the position of the moving automobile. Computer Vision systems generally adopt one of the following approaches for vehicle surveillance; either they employ Optical Character Recognition (OCR) algorithms to detect the registration plate, or the traffic footage is processed to track the motion of the vehicles.

One such system uses Artificial Neural Networks and a plate localisation algorithm to extract the characters present on the number plate [5]. Another innovative approach was the abstraction of higher and lower level modules [6]. While the lower modules were responsible for the frame segmentation and vehicle tracking, the high level module performed rule-based supervision of the system. The system could, hence, be deployed in real time. One vision system developed was capable of license plate detection, triggered by instances of over speeding [7]. The speed of the vehicle was calculated by coordinate estimation and verified using RADAR speed detection and smartphone applications.

Multiple traffic surveillance systems have also been studied and implemented. A blob tracking algorithm was developed to detect vehicles in real-time with the help of CCTV footage [8]. The sole focus of another study was Multi-Vehicle [9]. It proposed a Microscopic Traffic Model algorithm which took into consideration the interactions between automobiles, rather than isolating them. The results indicated that the former method yielded a higher accuracy in estimating the motion, especially during lane changes.

Video surveillance processing and extraction of vehicle blobs, velocities and other features helped to construct a feature based vehicle tracking system [10]. Similarly, CV algorithms were operated on railroad crossing footage to detect 'near-misses' [11]. A line-based shadow algorithm was also implemented on an automated traffic surveillance video sequence to retrieve important traffic parameters [12].

DOCTraMS sought to replace traditional GPS-based detection, especially since GPS systems are particularly well-known for easily draining power in mobile devices [13]. It had a decentralised architecture that did not require any on-board devices or infrastructure connections.

A new sampling rule devised produced two path planning algorithms (circuit patrol and greedy patrol) [14]. Overall, the technique reduced the estimation error from 35% to 10%. A hybrid system for vehicle tracking was conceived by merging RADAR and image processing techniques [15]. Its advantages over conventional RADAR systems were that it could predict the paths of other vehicles, facilitating left and right lane detection, and it could run in real-time. However, RADAR systems tend to fail when multiple vehicles are present in the vicinity [7]. Moreover, the accuracy of transmission also depends upon external weather conditions, like humidity.

Finally, a wireless magnetometer sensor was used on real-time traffic surveillance and performed vehicle detection, counting, classification and speed estimation [3]. The sensor was cheap and produced an accuracy rate of over 97%.

It is worth mentioning that despite several efforts to improve the efficacy of CV systems, the inherent design isn't infallible to deception. For instance, spoofing the registration plate of the vehicle with false data dupes the system, and the driver isn't held accountable.

To conclude, while most of these solutions are reasonably efficient, each poses a different challenge. A system incorporating RF signals, however, can overcome almost all of these hurdles, and will be discussed in the following sections.

III. Proposed System and Construction

The system put forth in this paper incorporates RF signals. Each vehicle transmits immutable information, which is crucial in uniquely identifying it. This data is then picked up by the receiver positioned under the pedestrian pathway. In this section, the details of the aforementioned system are elaborated further, including the system architecture and individual component details.

Fig. 1 illustrates the proposed system architecture. As with any RF system, there is a receiver and transmitter component. The receiver is also connected to the backend server to facilitate communication.

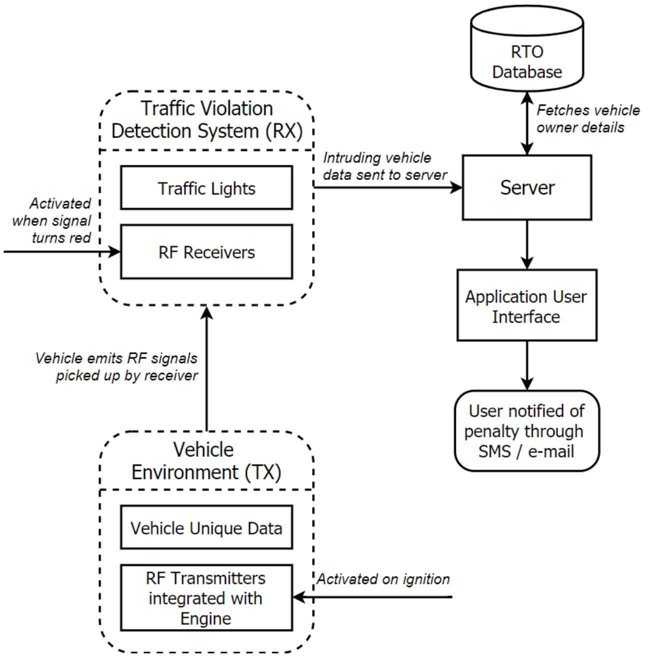

Fig. 1 System Architecture

A. Receiver Component

The transmitter is mounted under the hood and placed away from human vision. A standard 433 MHz transmitter is used, along with encoders for customized encoding of the data.

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The assembly is next fitted to an Arduino or Raspberry Pi board and finally connected to the vehicle's Engine Control Unit (ECU), in the case of cars. For smaller motorcycles, the microcontroller board links to the electric sources that power other components, such as headlamps. The encoded data is the Vehicle Identification Number (VIN), which is unique for each automobile. This data is initially fed to the vehicle at the assembly line production and the secret encoding is also uploaded to the encoder. The entire transmission portion is isolated while the final electrical connections are set up in the manufacturing line.

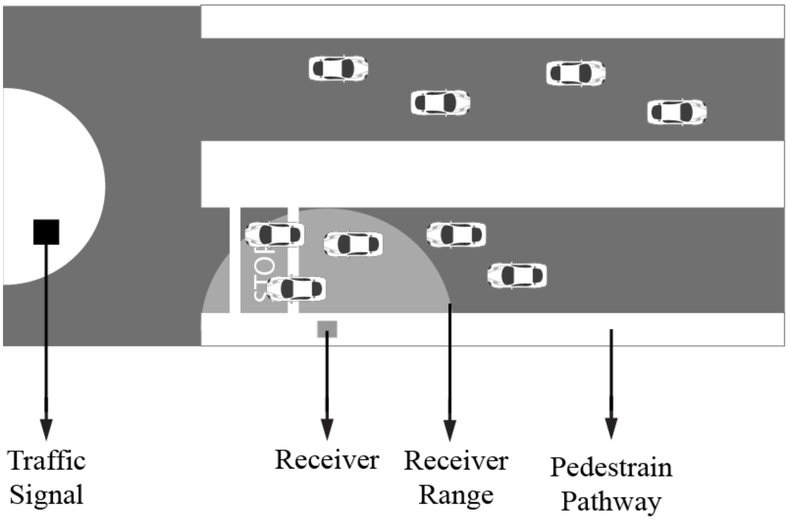

Fig. 2 Environment Setup

B. Transmitter Component

The RF receivers, along with the decoders, are set up on another Arduino or Raspberry board, as depicted in Fig. 2. The microcontroller/microprocessor board also keeps track of the current traffic signal using an LDR sensor that is fitted near the lights to detect when the signal is red. The setup relies on the traffic signal to both receive the transmitted data from the vehicle and subsequently forward the information to the control room for further processing.

C. Backend Component

It consists of a cloud-based server which receives the data for processing and hence takes necessary actions. The server communicates with the RTO database. A web-based application is integrated into the system and also to third-party services for sending SMS messages to notify the driver of penalties.

IV. WORKING OF THE SYSTEM

The working of the system is broadly divided into two separate functional modules; the detection module and the backend module. The working process of the former is illustrated in Fig. 3 and the latter in Fig. 4.

A. Detection Module

The detection module is based on the Detect and Transfer mechanism, the working of which is described here. The LDR sensor is kept facing the red-signal of the traffic light. The LDR is at a high resistance state during the phase in which the red light is turned off. This completely disables the working of the receiver component. When the red light turns on, the resistance of the LDR decreases due to the change in the light intensity, thereby enabling the receiver component.

Once activated, the receiver continuously scans the area and records the data that are transmitted by the vehicles in its

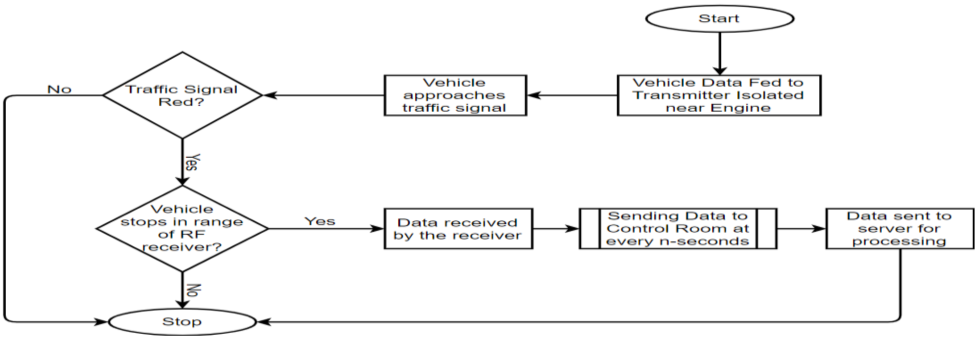

Fig. 3 Vehicle Detection module working

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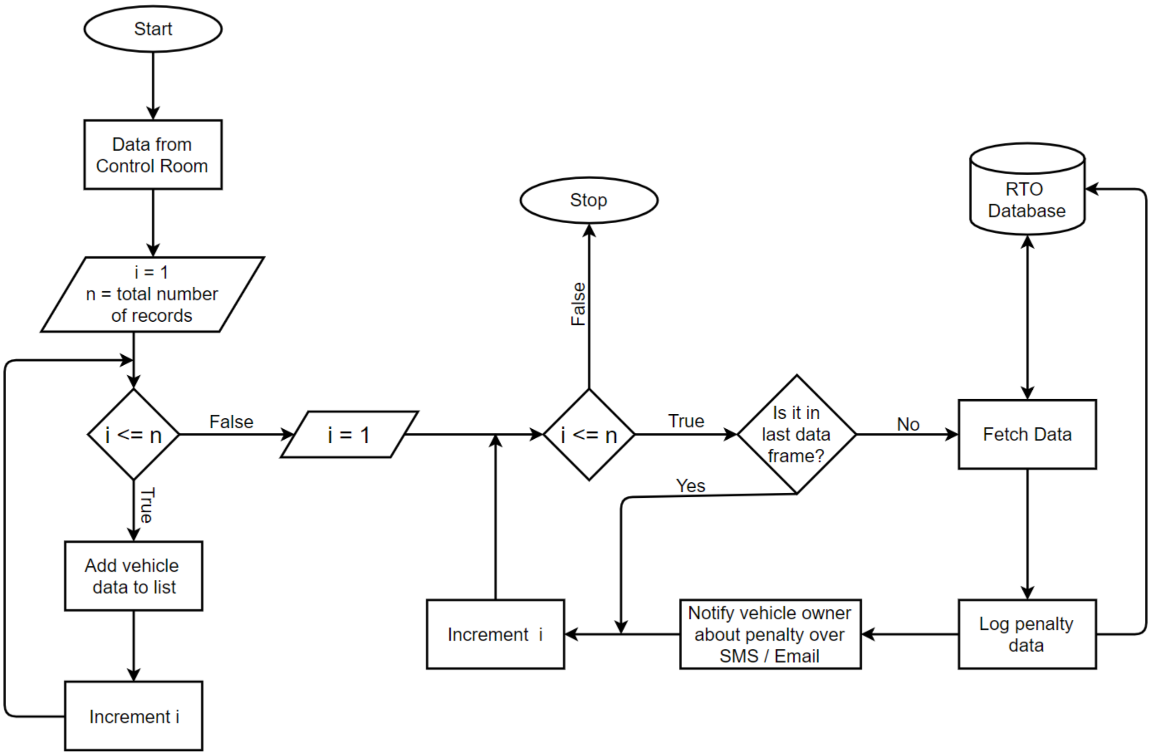

Fig. 4 Backend module working

vicinity. Although data is received continuously, it gets transmitted to the control room only once every five seconds. The very same channel is used for data transmission and traffic signal control. The data, once received, is finally transmitted to the server for further processing.

B. Backend Module

The server maintains separate lists for each traffic signal. After receiving the information, it is listed against the respective signal to facilitate processing. The steps undertaken to identify the intruders' data is described below in Algorithm 1 and explained further with the help of an example.

Assume that the traffic light turns red at *time = 0 sec* and the traffic light turns green at *time = t sec*. Let there be *n* vehicles that stop at the signal between time *0* and *t* seconds. Frames, or transmission records, are data structures that contain the information being transmitted, and utilise delimiters at the beginning and ending.

Data gets transmitted once in every five seconds. That is, each frame contains 5 seconds of vehicular data. The assumption being made is that the number of vehicles is uniform from the first frame to the last frame. Now, the data received at the server end after *t* seconds are:

Number of vehicles in each frame = *n*,

Total time = *t* sec,

Time slot = 5 sec each,

Total number of frames = *t / 5*, and

Total number of records = *(t / 5) * n = nk*.

Now for all the records Algorithm 1 is followed to identify all the vehicles that were in its vicinity. The algorithm described initially accepts the list of all the records vehicles that were in the vicinity of the receiver. The final frame is checked to see which vehicles are still available by the end of the red light duration.

Algorithm 1 Intrusion Detection

```
function SIGNALBREAK(records[k, n])
    // Input: n records from all k frames
    Initialise list_of_vehicles_stopped
    // Add distinct vehicles to the list
    for x in records[1 ... k, 1 ... n] do
        if x not in list_of_vehicles_stopped then
            Add x to list_of_vehicles_stopped
        end if
    end for
    // Check which vehicles not present in final frame k
    for x in list_of_vehicles_stopped[1 ... n] do
        if x not in records[k, 1 ... n] then
            report_signal_violation(x)
        end if
    end for
end function
```

Let *t* = 60 seconds and *A* be a car, that halted at time *t* = 17 seconds. So, the first part of the algorithm adds *A* to the *list_of_vehicles_stopped*.

The second part of the algorithm checks for the presence of *A* in the last frame. If the vehicle is still present just before the signal turns green, the implication is that it hasn't moved during the red light duration, and hence hasn't violated the signal. Otherwise, it means that the vehicle moved out of the range of the receiver and overran the red light.

It should be noted that the

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vehicle is only checked in the last frame simply because it is likely that the engine may be turned off any time during the stop light waiting duration, automatically turning the transmitter off as well.

The data of the vehicle that violates the signal is then sent to the Penalty module. The Penalty module uses the unique Vehicle Identification Number (VIN) to query the RTO database and obtain information about the vehicle owner. The query also ensures that the vehicle does not belong to the special category. Special category vehicles include Ambulances, Police Cars and Fire Trucks, and the drivers of these vehicles are not penalised. Otherwise, the VIN and owner details are recorded in the RTO's penalty database and the owner is notified over SMS and Email services about the incident. The sample MySQL query is given below.

*Select * from RTO_vehicles where 'vin' ==* curr_record *AND 'category' != 'special'*

V. RESULTS & DISCUSSION

The above described system was found to be effective in detecting vehicles with a latency of around 1.5 seconds. The system was implemented with RF transmitter and receivers available on retail sale that come as a receiver-transmitter pair, thereby enabling the system to detect only those vehicles whose respective transmitter were used in the test vehicles. When deployed commercially, the system will be able to detect distinct signals from multiple transmitters, as is the case of cellular signals, hence allowing it to detect a significantly large number of vehicles.

When compared with the other existing technologies being used today, RF signal systems have certain advantages that make it more appropriate for this specific use case of detecting traffic intruders. Firstly, it does not depend on line-of-sight transmission, and is hence a better alternative to infrared and laser systems. While the use of video surveillance processing and CV algorithms may be feasible, and even more accurate at times, it may also be extremely complex to deploy in real-time, hence requiring more sophisticated equipment in terms of computational power. Additionally, the overall cost of implementing the RF system is quite minimal due to the easy availability of good sensors.

VI. CONCLUSION

This paper elaborated on the design and construction of a RF-based traffic signal violation detection system. In the proposed architecture design, the vital information associated with the vehicle is transmitted in the form of RF signals, which gets detected when the vehicle intrudes the traffic signal. This triggers a penalty to the driver, the working of which has been discussed extensively. Unlike a few other intrusive systems, RF signals are not disturbed by hindrances in line-of-sight. The system can be easily implemented, is cheap and not complex. Therefore, this paper concludes that the use of RF signals can be recommended for the purpose of traffic signal violation detection.

Future work will look into the wide-scale implementation of this system, testing within a real-time traffic environment and analysing the results. A detailed study should also be conducted comparing the efficacy of the RF system with other existing ones.

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