Automated High-Speed Traffic Monitoring and Violation Detection Using RFID Technology

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***Abstract*— Traffic monitoring is a wide area in research. Several methods exist for efficient real-time monitoring of the traffic, including RFID-based and CCTV camera-based systems. Several architectures for RFID-based systems have been proposed and utilized for traffic monitoring in some countries. As far as we know, none of the existing implementations utilize the RFID technology for traffic violation detection in high-speed roads. In this paper, a new architecture of using RFID technology in high-speed roads (highways and freeways) is presented; its problems and challenges are analyzed and a number of solutions are proposed. The proposed architecture consists of four hierarchical levels: Vehicle Identification, Row-level Processing, Road-level Processing, and Control Center. Each subsystem processes data of the detected vehicle at a higher level and passes the processed data to the next subsystem in a hierarchical manner. Also in this paper three sample algorithms are proposed in order to show how the architecture works in detecting traffic violations.**

Keywords—Traffic Violation Detection; Traffic Monitoring; Intelligent Transportation System; RFID Application; Road Control

I. Introduction

Traffic monitoring is a wide area in research. It is considered as part of a wider area known as Intelligent Transportation Systems (ITS). Different methods exist for efficient real-time monitoring of the traffic. The most widely used method is to use traffic enforcement Closed-Circuit Television (CCTV) cameras along with Artificial Intelligence (AI) and Computer Vision. In this method, data collected from traffic cameras are transferred to an AI interface to extract traffic parameters from video frames [1, 2]. Alternatively, it is possible to use other methods, such as Bluetooth sensors [3], Wireless Sensor Networks (WSN) [4] and Radio Frequency Identification (RFID) tags [5]. These methods are able to avoid some problems and conflicts that usually arise with using cameras.

The RFID technology is widely used in variety of applications such as product tracing in industrial processes, supply chain management, vehicle control, Electronic Toll Collection (ETC), etc. This technology is one of the industries that are significantly supported all over the world in order to improve in its reliability and performance. The impact of RFID technology on transportation industry cannot be neglected [6,7]. Communications Regulatory Authority (CRA) of The I.R. of Iran officially released the Trial Regulation on 865-868 MHz of the UHF spectrum with ETSI technique for RFID Technology Applications [8]. Legislative barriers are removed by this regulation and RFID market has fully initiated.

Nowadays higher demands for RFID performance for fast moving objects are required; especially with worldwide high-speed transportation. There is a high desire for RFID technology used by high-speed moving objects, especially for high-speed vehicles, ETC systems and railway systems. Fast-moving RFID tags are used in many transportation systems today [9].

Several architectures for RFID-based systems have been proposed and utilized for traffic monitoring in Canada, Azerbaijan, United Kingdom, etc. As far as we know, none of the existing implementations utilize the RFID technology for traffic violation detection in high-speed roads. In this paper, a new architecture of using RFID technology in high-speed roads (highways and freeways) is presented; its problems and challenges are analyzed and a number of solutions are proposed. This paper is organized as follows: section 2 gives an overview of existing methods and their challenges; section 3 introduces our proposed architecture for RFID-base high-speed traffic violation detection system; section 4 presents some model algorithms for violation detection using the proposed system; section 5 discusses challenges of the proposed system; section 6 compares the proposed system with the existing platforms; section 7 discusses about future work to improve the proposed system.

II. Background

One of the earliest methods of traffic monitoring was Inductive Loop Detection (ILD), in which a moving magnet in a loop is facilitated to induce electromotive force in the loop to detect the car and estimate its speed [10,11]. Despite its popularity, the method suffers from fundamental drawbacks. It often generates inaccurate velocity measurements and its high costs make it inefficient.

Newer methods have been developed to remove limitations of ILDs. One such method is to use high-speed cameras along with Automatic License Plate Recognition (LPR). In this method camera captures the vehicle and sends the video stream to Artificial Intelligence platform to process. The AI platform extracts the license plates of the vehicles using Computer Vision techniques; then it identifies and classifies them applying Optical Character Recognition [12-14]. These systems are complicated to install; also the cameras are so expensive that limit their widespread usage.

Another method is to use ultrasonic sensor-based traffic detection. This method is widely used to count or even estimate the speed of vehicles. However, it cannot be used to reliably identify vehicles and its accuracy will be very low [10,11].

We believe that the best way to avoid mentioned problems is to use RFID technology in traffic monitoring. A noteworthy recent work on this area presents design of a Traffic Monitoring System based on RFID [15]. The concept of using RFID is presented in this work and a rudimentary implementation is offered. The concept of using RFID presented in [15] is able to remove early system flaws - such as their cost and complexity, but it could be improved by representing a more sophisticated structure. Actually, their work addresses experimental situations, not actual ones. Nevertheless, in our work we consider more practical environments and will address challenges arose in them.

Another equally related to our work, [5] uses RFID technology in traffic light sequences. In this work, more practical situations are discussed and many experimental problems are addressed. However, in this work RFID is used for car detection only in traffic light intersections. Our work expands the use of RFID to more general situations in traffic for vehicle and violation detection. In this work we also consider variety of situations in which traffic can be faced.

III. The Proposed Architecture

In order for a RFID-based system to work, an RFID tag should be placed on each vehicle. The simplest and most practical type of RFID tag for the application seems to be passive RFID. The passive RFID does not require any power sources; therefore it does not need any modifications to the vehicle electrical system and can be positioned in any convenient place. The most common place for the RFID tag is on the front face of license plate, where it can be seen. With this manner, vehicles without RFID tags are easily detected by law enforcement authorities. A sample of the RFID tag positioned on the license plate is shown in Fig. 1.

Fig. 1. A sample lisence plate with RFID tag positioned on the lower left coner.

The RFID tag of each vehicle should contain the unique identification code of the vehicle. The identification code should also specify the type of vehicle (mid-sized car, bus, trailer, motorcycle, etc.) to simplify later processing. The code should be encrypted in order to prevent forgery of RFID tags.

Our proposed system consists of four hierarchical levels: *Vehicle Identification*, *Row-level Processing*, *Road-level Processing*, and *Control Center*. These subsystems are shown in Fig. 2.

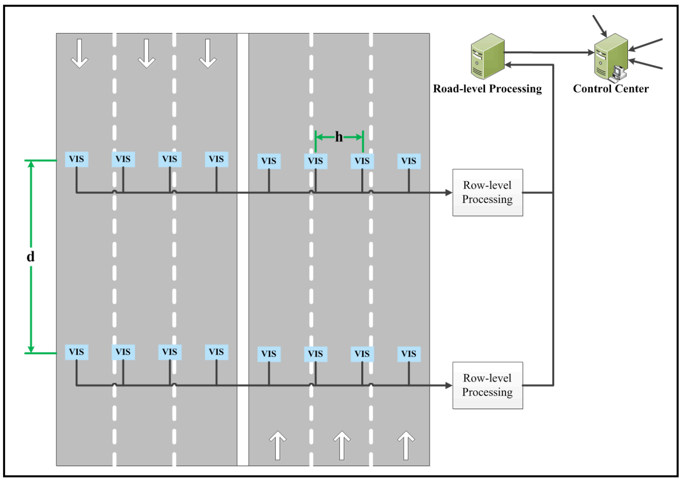

Fig. 2. Subsystems of our proposed architecture for RFID-based traffic violation detection.

A. Vehicle Identification Subsystem

The Vehicle Identification Subsystem (VIS) mainly consists of an RFID reader and a simple (cheap) microprocessor. The microprocessor decrypts the Identification code read by RFID reader, identifies simple errors and tries to correct them. It is also responsible to provide the Row-level Processing Subsystem with the decrypted codes.

The vehicle Identification is mainly done with special RFID readers. The main challenge is to be able to read RFID tags of high-speed vehicles. In [9] such kinds of RFID readers are used for high-speed trains with speeds up to 500 kmph.

Another main challenge is determining the distance h between two adjacent RFID readers in a row. Fortunately, there are RFID readers available with capability of setting their range (such as NXP UCODE7 RFID reader). According to regulations in each country, there is a maximum height h_m for the license plate of vehicles; therefore the range r of each RFID reader should be as in (1).

$$r = \sqrt{{h_m}^2 + \left(\frac{h}{2}\right)^2} \qquad (1)$$

Where r is the range of RFID reader, h_m is the maximum legal height for license plates in vehicles and h is the distance between two adjacent RFID readers, all measured in meters. There is also an obvious constraint that h should be greater than both h_m and r (resulting in $h > 2h_m / \sqrt{3} \simeq 1.15h_m$) in order to decrease interference of two adjacent RFID readers.

B. Row-Level Processing Subsystem

Each row of Vehicle Identification processors are connected to only one Row-level processor. The Row-level Processing Subsystem consists of a cheap microprocessor which receives decrypted identification codes from Vehicle Identification Subsystem. The main job of the processor is removing redundant codes read by single or multiple RFID readers, adding some information (such as timestamp and the lane of the vehicle), encoding the useful information and sending them to the Road-level Processing Subsystem.

C. Road-Level Processing Subsystem

All the Row-level microprocessors along a road are connected to a server which serves as the Road-level Processing Subsystem (RPS). RPS processes all the data received from each Row-level microprocessor (consisting of the identification number of the vehicle, timestamp and the lane of the vehicle), and detects traffic violations occurred using the algorithms proposed in the next section.

The RPS server should be a rather powerful computer. The software should have a friendly user interface to bring the capability of controlling road parameters (such as speed limits in each section of the road, etc.).

RPS can be used for monitoring the traffic in different sections of the road. All the data, including statistics about traffic density in different sections and detected violations are sent to the Control Center.

D. Control Center

All Road-level servers are connected to a very powerful server called Control Center. The Control Center receives and manages all the data. It does high-level processing associated with the traffic violations and also calculates the traffic violation fines. High-level monitoring of traffic in roads is done in the Control Center.

IV. Algorithms for Traffic Violation Detection

In this section we discuss some algorithms to illustrate how our proposed system works. This set of algorithms is not complete in any way and is used for illustration purposes only. In the final implementation there should be many similar algorithms in order to detect as much violations as possible.

Traffic violation detection algorithms are executed on Road-level Processing Subsystem. We suppose violation detection run on T second intervals. Two preprocessing steps should be done on iterations to decrease the processing overhead:

- All data with the timestamp older than a certain threshold are completely removed.
- All data with unique identification numbers should be saved for the next iteration and removed from current iteration.

To justify the first step, we claim that it is almost impossible to use the old data to detect the new violations. Any violation is most likely detected by the current time. Therefore, the data older than a certain time (e.g. 15 minutes) can be completely removed from the system.

The second step supposes that detecting any violation requires at least two different positions of a vehicle along with the timestamps. Therefore, violation detection algorithms have no use of the single positions of vehicles. The iteration keeps these data for next iteration and passes remaining data to violation detection algorithms.

At the end of iteration (after running all violation detection algorithms), we keep only the latest data for each vehicle and remove everything else. All the proposed algorithms only need two positions of a vehicle; therefore it is safe to keep only the latest data. This way we also make sure that no traffic violation is detected more than once.

Three violation detection algorithms are discussed in this section. The algorithms are straightforward, so rather than writing pseudocodes we preferred to simply describe them.

A. Algorithm for Speed Limit Violation Detection

The speed of a vehicle using the timestamp of its two different positions (read by different rows of RFIDs) is calculated using (2).

$$V = \frac{t_2 - t_1}{d} \tag{2}$$

Where V is the estimated speed in m/s, t_1 and t_2 are timestamps in seconds, and d is the distance between the two positions in meters. The Road-level Processing server knows the distances of all pairs of RFID rows beforehand.

The calculated speed can then be compared with the maximum and minimum speed limits set for that section of the road in order to detect speed limit violations. In this comparison the vehicle type (extracted from vehicle identification number) should be considered in order to use correct speed limits. For example, a speed limit of 100 kmph for busses and 120 kmph for regular cars can be used.

It is possible to enhance the speed limit violation detection algorithm using the lane data included along with the timestamp and identification. Different speed limits can be assigned to different lanes. In this way it is even easy to prohibit some certain types of vehicles to enter certain lanes. For example, by setting maximum speed limit of busses in speed lane to zero, illegal intrusion of a bus into the speed lane can be detected.

In general, the speed limits will be the function of vehicle type and lane, as in (3).

$$V_{\min},\ V_{\max} = f\ (lane,\ type) \tag{3}$$

B. Algorithm for Detection of Illegal Reverse Move

Most of the traffic laws prohibit reverse move of the vehicles in highways and other roads. Detecting this violation is also very easy: if the two consecutive positions are in backward order, then the vehicle moved against the road direction.

C. Algorithm for Detection of Illegal Entries from Exits

There are many cases when the drivers try to enter the road from road exits (driving against the exit direction). This causes many accidents and should be detected. Adding a Vehicle Identification row in exits (or U-turns) makes the detection possible. If the vehicle enters the road from any exit, one of its positions will be in the exit and the next in the road.

V. Challenges of the Proposed System

Any RFID-based system implemented for high-speed traffic violation detection applications may face challenges that should be taken care of. Some of the main challenges are listed below.

A. RFID Collision

In situations where several high-speed vehicles (RFID tag) simultaneously pass in a single RFID reader's range, it is possible for the reader to fail in identifying all RFID tags. Our proposed architecture uses a number of RFID readers in a row and is capable of reading all of the tags in most of the situations.

B. Security Issues

Using RFID technology without some sort of encryption may lead to several security problems. Fortunately there are many security protocols which are able to prevent security attacks to the system. By assigning a few more bits to RFID tags and using state-of-the-art encryption/decryption protocols, it is possible to prevent forgery of RFID tags.

C. RF Interference

In the presence of more than one RFID readers, the RF interference can cause failure in reading RFID tags. The solution to this problem in our proposed architecture is fine-tuning and calibration of RFID readers. The distance of the readers and the range of each reader should be tuned to prevent interference of the adjacent readers. The final range depends on the type of the RFID reader, input power, maximum legal height of license plates in the target country and other factors.

VI. Advantages and Drawbacks

As it is mentioned in the previous sections, there are several common technologies in use for the purpose of traffic monitoring. The most widely used are Inductive Loop Detection (ILD) and high-speed CCTV cameras. ILD is mainly used for not so reliable vehicle detection and speed estimation. It is incapable of uniquely identifying the vehicle in order to record vehicles violating the traffic rules.

The only true competitor for RFID-based traffic violation detector systems is CCTV system, which suffers from these issues compared to RFID-based solution:

- High-speed cameras used for the purpose of traffic monitoring are extremely expensive, which limits their use. On the other hand, RFID-based solutions need only one central powerful server for Control Center, a server for each road (that can be of more than 200 kms long), RFID readers and microprocessors. Each microprocessor is very cheap and can be mass produced. In overall, with a simple calculation it can be concluded that the average cost per road for RFID-based solutions is much less than the camera-based solution.
- High-speed cameras need continuous maintenance in order to work well. Components of our proposed architecture are much simpler and require less attention; thus reducing the maintenance costs.
- There are ways to remain unidentified by CCTV cameras, such as using special sprays on license plates, covering plates with mud, moving behind another vehicle, tilting the license plate, etc. Also, common cameras still suffer from motion blurring when the vehicle speed is more than a certain threshold (e.g. 180 kmph or more). These strategies are not efficient for RFID-based systems and high-speed RFID readers are able to read the tags in all the above situations.
- CCTV cameras are mostly tuned to capture license plates of cars; thus capturing license plates of other types of vehicles (e.g. motorcycles) by CCTV cameras is hard. Identification number of all types of vehicles with RFID tags is captured and processed by RFID readers.
- Many of the current camera-based systems are not completely unsupervised and require some level of human supervision to detect traffic violations. Our proposed system can be enhanced to require minimum possible supervision.

On the other hand, our system has some disadvantages in comparison to CCTV cameras: installation of the system is harder and more expensive than installation of the cameras. However, we believe the total cost is still less and also in long run the maintenance costs and accuracy of the proposed system compensates the initial costs.

VII. Future Work

Our proposed architecture is still in its infancy stages. From the hardware point of view it can be complemented with many existing and novel technologies. On the other hand, from the software point of view, other traffic violation detection algorithms can replace the current algorithms. These algorithms may improve the proposed algorithms or monitor the other traffic violations not covered in this paper.

Possible additions to the current system are:

- Implementing more traffic violation algorithms not covered in this paper
- Improving proposed basic algorithms with faster algorithms
- Using Wireless Sensor Networks with the proposed architecture
- Integration of the current architecture with the existing platforms in the target road
- Implementing adaptive algorithms capable of changing parameters with the instantaneous traffic density
- Adding other applications to the system, such as automated toll-payment, etc.

The dominant traffic monitoring and violation detection system in Iran is based on high-speed cameras. For immediate implementation of our RFID-based system in Iran, it would be useful to integrate it with the current camera-based system, decreasing costs of completely replacing the system and making use of the existing platform.

It is also possible to use this system in urban streets with some minor hardware modifications. For example, the integration of this architecture with traffic lights to detect right-turn violations on red lights at the intersections (which is a common violation in Iran) is considered a fairly easy problem. As another potential application, detecting vehicles violating limited traffic zones could be implemented by connecting the Control Center to the database of permitted vehicles. In this manner more violating vehicles are detected, discouraging drivers from illegally entering the zone; thus reducing the traffic problems in cities like Tehran.

Since the proposed system tries to capture all vehicles travelling in the road, another equally important potential application is finding the location of a vehicle in the country. It is not very hard to modify the system such that the system notifies the Control Center with the exact position of the specified vehicle as soon as the vehicle is seen in a RFID-equipped road. This feature can be used for finding stolen cars. However, it may raise some privacy issues.

VIII. CONCLUSION

In this paper a new RFID-based architecture for traffic monitoring and violation detection is presented. The proposed architecture was compared to the existing technologies and the challenges were discussed. Also some algorithms that work well in this architecture are discussed. However, the proposed system is new and many improvements can be done on the system to decrease the costs and ease the use. Some of the improvements are studied and some of the basic ideas are discussed to start working on them.

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