6th International Conference on Electrical and Computer Engineering
ICECE 2010, 18-20 December 2010, Dhaka, Bangladesh

A Design for Low Cost Electronic Toll Collection System with Secured Data Communication

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***Abstract*— Electronic toll collection (ETC) with combined information and communication technology has become a major concern in the intelligent transportation systems. In this paper, an efficient design of ETC system is proposed, which incorporates automatic vehicle classification, identification, and violation enforcement. In the proposed design, to enhance the level of security in data communication, a two stage protocols based on digital watermarking and encryption algorithms are introduced. Moreover, a short message service (SMS) based notification system is proposed to facilitate user convenience. A prototype of the proposed system is developed and found to meet the desired specifications. Here use of simple infrared technology minimizes both overall cost and complexity. In the design of the prototype, aspects related to the real life implementation have been taken into consideration. From a comparative performance analysis, it is found that the proposed scheme is superior to some of the existing methods in terms of advanced technological features, security, overall cost, and ease of implementation.**

***Keywords*— electronic toll collection, intelligent transportation system, vehicle identification, vehicle classification, prepaid vehicle, security, violation enforcement, SMS based notification.**

I. INTRODUCTION

Electronic toll collection (ETC) system is basically designed for an uninterrupted toll collection, which has become an important part of intelligent transportation system. Numerous advanced technologies, such as global satellite navigation, automated number plate recognition, and dedicated short range communication (DSRC) are being used in ETC system implemented in different developed countries [1]-[6]. However, the third world developing countries are still deprived of these technologies due to high cost and technological complexity. Recent research on ETC system is mainly concerned with combining the information and communication technology with transport infrastructure [3]. The overall ETC system is expected to provide high operating efficiency, low travel time, improved highway safety, and low level of pollution. An ETC system with all these desirable features is still in great demand.

In this paper, an efficient ETC system is designed incorporating information and communication technology. The main idea behind the proposed design is to offer a very low cost and ease of implementation while providing several advanced features with high level of security. Three major intelligent aspects are incorporated in the proposed ETC system to make it compatible with a standard intelligent transportation system. In the proposed AVI and AVE systems, a central server based data communication scheme is employed, where unlike conventional technologies a two stage security system is proposed. The uniqueness in the proposed design lies in introducing a robust encryption algorithm along with a short message service (SMS) based notification system. A prototype of the proposed ETC system is also implemented incorporating all the features mentioned above. Moreover, a comparative performance analysis along with a real-life cost estimate is also provided.

II. PROPOSED ETC SYSTEM

The vehicle entered near the tollbooth is passed through the AVC, AVI, and AVE blocks of the proposed ETC system as shown in Fig. 1 with a simple flow diagram. Fig. 2 depicts a real life situation via a schematic diagram, where some major components are shown. The AVC system is incorporated to determine an appropriate amount of toll to be paid by a vehicle depending on its load on the road, such as length, height, and speed. The AVI system is designed to perform the task of vehicle verification or identification, in particular for prepaid tolling system. Use of an AVE system helps identifying vehicles those are violating the rules and it provides better traffic control and criminal detection. In what follows we describe the detailed design of all these blocks.

A. Automatic Vehicle Classification (AVC)

In the proposed method, vehicles are classified considering vehicle length, height, and speed. A combination of all three factors is used to determine the required amount of toll.

1) *Length detection:* In order to classify vehicles passing through the tollbooth into five different classes, namely extra large (E), large (L), medium (M), small (S), tiny (T), five sets of static sensors are used as shown in Fig. 3. Vehicle length is determined based on the change in the output level of a certain number of sensors. In Fig. 3, the car entering will be

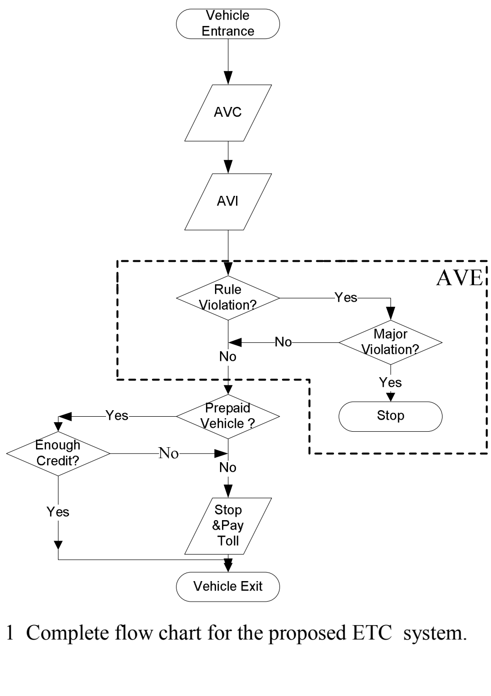

Fig. 1 Complete flow chart for the proposed ETC system.

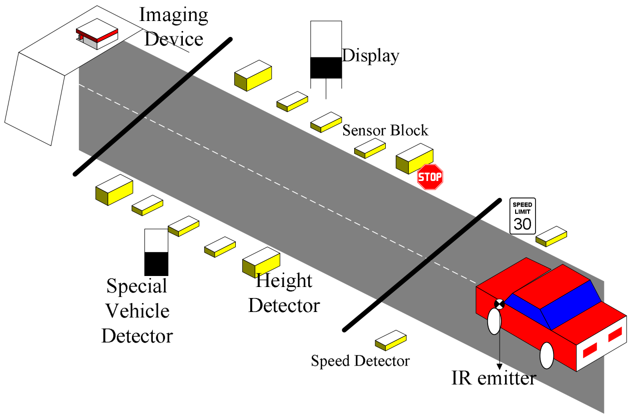

Fig. 2 Schematic view of ETC system.

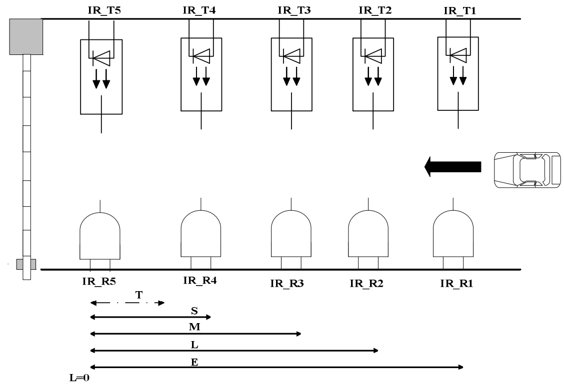

Fig. 3 Schematic view of length detection in implemented prototype.

measured as a class "T" since it will eventually obstruct only IR_T5 and IR_R5. A back up length detection is also performed by measuring the time that a vehicle needs to pass between the transmitter and receiver of one set of sensors (not shown in Fig. 2) along with the speed of the vehicle. The lengths detected by both the methods are averaged.

2) *Height detection:* One array of sensors arranged vertically is used to detect the vehicle height. Number of sensors in the array depends on the number of class of vehicles. Provision is kept for a back up height detection using another array of sensors.

3) *Speed detection:* The speed of the vehicle is measured from the time required by the vehicle to pass two specific sensors separated by a known distance.

Amount of toll payment for each class determined above can be defined based on different road pricing policies, such as usage only or access only or combined and linear or non-linear pricing depending on socio-economic condition [7].

B. Automatic Vehicle Identification (AVI)

In the proposed scheme, vehicle verification for prepaid vehicles and identification for all vehicles are implemented.

1) *Vehicle identification:* In order to identify a vehicle, an image of the number plate is captured by the camera placed in the tollbooth (Fig. 2). The name plate image can be further processed to recognize the characters. In the proposed scheme, the image itself is stored in the database of the local server for template matching, which may require in some special cases. Two optional cameras capable of capturing slowly moving images can be used to take the side views of the vehicle. It is to be mentioned that instead of the whole image, some key features can easily be extracted from the image data for future recognition task.

2) *Vehicle verification:* All the registered prepaid vehicles are verified using the identifying device mounted on it. When the prepaid vehicle reaches near the toll plaza, it receives signal from the tollbooth. After receiving the signal the device mounted on the vehicle starts transmitting a unique code containing vehicle information. When the detector in the toll-plaza receives a signal from any vehicle, first it matches vehicle. For sufficient balance in the account, the vehicle is allowed to pass, otherwise the vehicle is stopped and a toll according to the vehicle class is charged (Fig. 1). Moreover, an SMS is sent to the cell phone number previously registered against the vehicle. This SMS contains credit remaining in that account and a history of violation of rules (if applicable).

C. Automatic Violation Enforcement (AVE)

Depending on the measured speed, a speed limit checking is performed in the local server and an SMS is sent immediately to the registered number if the vehicle violates the speed limit i.e., intends to cross the tollbooth without paying the toll at a high speed. According to the database, a vehicle which is listed in the lost category can also be identified while passing the tollbooth by comparing the received signal from the vehicle with this database. In a similar fashion, the lost identifying device can also be found and the car carrying such a stolen device can be identified. If necessary, the case when a same identification device is intentionally used for multiple vehicles can also be detected by a template matching with the nameplate image stored in the database. Similar principle can also be employed to detect vehicles with fraud number plates.

III. PROTOTYPE IMPLEMENTATION

A prototype of the proposed ETC system is shown in Fig. 4. The description of all the major blocks is given below.

A. Sensor Block :

In the sensor block of the implemented prototype low cost static infrared (IR) emitter and receiver set is used. Since the properly biased IR sensors provide output with logic level appropriate for digital devices, no cost is involved in employing additional circuits in this regard. But these sensors are vulnerable to interruption by noise and not suitable for real life applications.

B. Prepaid Vehicle Identification Device

The circuit diagram of the prepaid vehicle identification device designed in the proposed ETC is shown in Fig. 5. The transmitter emits a 38 kHz IR signal, which is modulated to transmit a unique 8 digit code for each vehicle. This signal is generated using a microcontroller (ATtiny13). In the receiving end, the detector is a special 38 KHz IR receiver which only considers IR signals at 38 kHz while ignoring others. Thus, it has a greater immunity to noise and other interruptions than those of the static IR receivers.

C. Motor and Barrier Controlling Block

In designing barriers to control the entrance and exit of the vehicles, low power DC gear motors are used. The motor shafts are strongly coupled with the barrier. In case of non-prepaid vehicles, barriers are controlled by the booth operator.

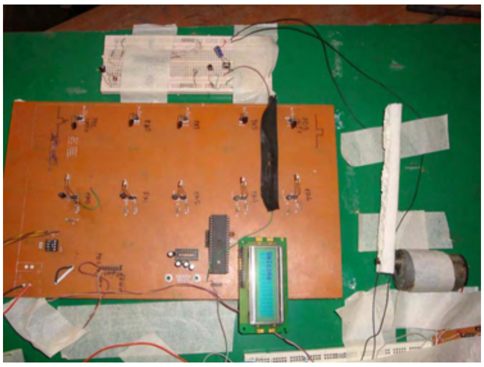

Fig.4 The implemented prototype of the toll plaza. (Communication unit is not shown here).

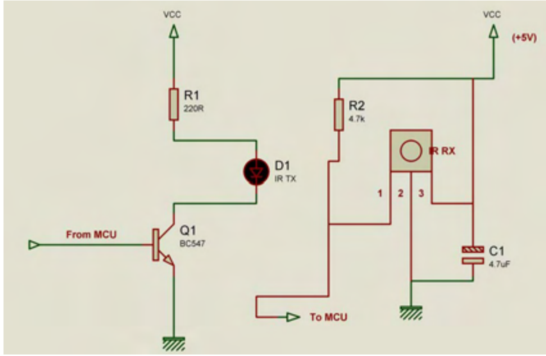

Fig. 5 The circuit diagram of the proposed identification device. IR TX is the transmitter and IR RX is the detector for the 38 kHz IR signal.

D. *Display and Camera Unit*

To display the vehicle information and toll payment status an LCD display in front of the booth is used. The display shows vehicle information including violation. In the camera unit a webcam placed in a suitable location (Fig. 2) is used to capture the image of the vehicle number plate information.

E. *Communication Unit*

The flow diagram of the communication unit is depicted in Fig. 6. The local server (i.e. the computer in the tollbooth) using a Python script communicates with microcontroller in the vehicle detector system using serial communication. Another Python script is used to control the webcam which captures the image of the vehicle number plate. The local server at the tollbooth sends the encrypted vehicle data via internet to the central server in a specified format as given in Fig. 7. The central server sends the information to the user or traffic control room according to the requirement.

IV. SMS Based Notification System

Whenever a vehicle with identifying device installed on it is identified in a toll booth, the owner will be informed by an SMS. It is recommended that this is done from the server side. As soon as the server receives an information string from a toll booth, it makes a request with necessary information to an SMS server (configured using Kannel [8]). After receiving http request, SMS server sends an SMS to the vehicle owner's registered number by using either a local mobile connected with the server PC or by using an SMS gateway. This SMS notifies the vehicle owner about the time, location of vehicle crossing a toll booth, credit information (in case of prepaid user), bill information (in case of post paid user), and traffic violation notification (if any).

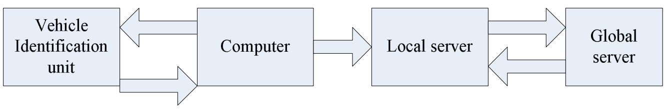

Fig. 6 Flow diagram of the communication unit of the proposed system

Date	Time	Booth ID	Vehicle class	Vehicle ID	Vehicle Information
29062010	154522	741011	F	81223974	LH123P

Fig. 7 An example of the data string used for communication between central server and tollbooth

V. Data Transmission Security

For secured data communication in the proposed scheme, two stages of security are implemented, one at the user end and the other at the server end.

A. *User End Security*

The unique alphanumeric 8 digit code transmitted from each vehicle can easily be altered or modified if no security measure is taken. In order to ensure security, the code is digitally watermarked using a simple yet robust time domain watermarking algorithm. Instead of conventional approach of using only the LSB bit of a digit, we propose to embed a watermark into multiple and deeper LSB layers. In case of a character, only single bit of a digit is used for watermarking, while for a number, two bits of a digit is used. However, the information of the watermark bit(s) of that digit is preserved safely in an unused bit. Moreover, the sequence of placement of the watermark bits is varied in a random fashion, which is only comprehendible by a prescribed decoder.

B. *Server End Security*

A robust algorithm is proposed to encrypt the data while transmitting from tollbooth to global server. A key string which is available to both local and global server is used to encrypt and decrypt the data string, respectively. During the encryption process, the data string as described in Fig. 7 is compared with the key string. If there exists no mismatch in ASCII values for consecutive N number of positions, it is encrypted as N. But whenever a mismatch is found, it is encrypted as

$$\lambda = \text{'A'} + \Delta - 1 \tag{1}$$

where Δ is the difference in ASCII values. Thus, the encryption process enhances the level of security of the data communication.

VI. Comparative Study

A. *General Features*

Presently in ETC system, different radio frequency based detection methods are widely used[]. A comparative performance study among some radio frequency based methods reported in [1] is presented in Table I along with the proposed scheme. It is found that electromagnetic interference created from radio frequency identification (RFID) chip is hazardous for sensitive medical equipments, like pacemaker and defibrillator [11]. The proposed ETC sys-

TABLE I

PERFORMANCE COMPARISON AMONG VARIOUS SYSTEMS

Features	**Barcode**	**Magnetic card**	**RFID**	**Proposed**
Read number	One at a time	One at a time	Several at a time	One at a time
Pollution degree	Vulnerable to pollution	Vulnerable to pollution	Hazardous to medical equipment	Anti-pollution
Abrasion	Smaller	Smaller	None	Smaller
Distance (data carrier to reader)	0-50 m	Direct contact	0-100 m	0-10 m
High speed read	Restricted	Restricted	Unrestricted	Unrestricted
Cost	Low	Lower	High	Much lower
Required testing equipment	Low	Medium	High	Very low

tem is free from any kind of medical hazard as it uses comparatively much lower frequency (38 kHz) than those used in RFID (i.e. 915 MHz, 2.45 GHz, 5.8 GHz) [2]. Besides, the designing of IR systems is comparatively much easier than RF systems and using this frequency does not require any kind of permission [3]. From this comparison it is evinced that the performance of the proposed system is much better in terms of different features than those of the existing DSRC based systems.

B. Low Cost

Considering the expenses of the real life implementation, an expected cost estimate is shown in Table II. It is obvious that the proposed system offers a very low cost of implementation which gives an opportunity to use this system in the third world developing countries.

C. Secured Communication: Watermarking and Encryption

The data communication of the proposed system, unlike the RFID based systems, ensures high level of security as it employs two-stage security. First, digital watermarking is used to send signals from vehicle to the detector in the tollbooth. Second, the data sent from local server to the global server are encrypted using a robust encryption algorithm. Thus, the proposed system can be an attractive option where secured communication is highly desired.

D. Research Friendly Database

The database to be maintained in the proposed ETC system can serve the demands of the research based on data mining [9], congestion pricing [12], and travel time prediction [13], which are merely present in the existing ETC systems.

E. User Friendliness

In order to offer better service to the prepaid vehicles, the proposed system is facilitated with SMS based information notification, which would definitely make the scheme popular.

VII. CONCLUSIONS

In the design of the proposed ETC scheme, all three major intelligent systems, such as AVC, AVI, and AVE have been included, where in each case some advanced technological features have been introduced. Moreover, inclusion of two stage security protocols with a robust encryption algorithm for data communication and the SMS based notification make the proposed system unique among all other existing methods. A prototype has been developed based on the proposed design and found to meet the desired performance specifications. In the implemented prototype the use of simple infrared technology incurs minimal installation and operating cost as well as least operational complexity with a large number of features in comparison to those of some of the existing technologies [10]. Because of its very low cost and ease of implementation, it can be easily installed in some developing countries. Apart from these advantages, as it offers multi dimensional advanced features, it would be even an appropriate choice for technologically advanced countries.

TABLE II

COST ESTIMATION FOR THE PROPOSED SYSTEM

Components	**Cost (USD)**
Computer and its accessories	500
DVI card, camera and mountings	300
Sensor network setup	50
Motor and barrier setup	200
Display unit	150
Wiring setup	150
Internet setup	100
Accessories	50
Total	1500

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude towards the authorities of the Department of Electrical and Electronic Engineering and Bangladesh University of Engineering and Technology (BUET) for providing constant support throughout this research work.

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