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Integrated Electronic Toll Collection System Using RFID and GSM Technology

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Abstract: The electronic toll collection system in the Philippines at the time of this research uses microwave technology. It is dubbed as e-pass, it allows motorists to pass through the toll gates by simply slowing down until the system detects the signal. However, microwave detectors are expensive. Hence, the full deployment is not practicable. As the number of vehicles that use the tollgates increases, the need to fully implement the e-pass system is desirable. RFID offers a cheaper alternative.

The Integrated Electronic Toll Collection System using RFID and GSM Technology (ETC RFID) developed in this study has four main functions: (1) to detect the RFID tag of a vehicle that enters the tollgate, (2) to detect the RFID tag of a vehicle that exits the tollgate, (3) to send the data read by the reader to the database server and (4) to notify the balance of the customer's RFID tag through SMS. The graphical user interface that shows the computation of the toll fee is displayed using Visual Basic6.0.

The ETC RFID system is implemented in a pseudo toll gate. The system comprises the reader, the tag, the GSM module, a local PC containing the GUI for the logs and a central server that contains the database. The reader is placed in the pseudo toll gate, while the tag is installed inside the vehicle. Several tests were done to determine the optimum angle of the reader with respect to the tag. The angles are 30^0, 45^0, 60^0, and 90^0. It is observed that as long as the speed of the vehicle is 50 kph or less, the position of the reader does not affect its detecting capability. A 100% success rate is achieved. However, when the speed is increased, only the 45^0 angle position enabled the reader to detect the tag installed in the vehicle that is running at a maximum speed of 80 kph.

The GSM capability test shows in all trials hundred percent success rate in sending the notification whenever the customer's account is below the set limit.

Key Words – RFID; microwave detectors; eletronic toll gate; SMS; ETC; e-pass

1. INTRODUCTION

Toll gates are common in most countries and are typicaly used in expressways to collect additional revenues for the government. These revenues are given back to the toll gate users through continuous improvement and maintenance of the roads. At the time of this study, there are two types of toll ticketing in NLEX and SLEX, on-site ticketing and e-pass. For on-site ticketing, vehicles stop at the tollgates, pay the toll and the barrier moves up to allow the vehicle to pass through. If there is a heavy volume of cars, the toll gate becomes a bottleneck and this slows down traffic.

For e-pass, a transponder that is installed in the vehicle communicates with a microwave device inside the designated toll gate. The vehicle owner tops up his account by purchasing credit loads at designated toll booths or toll offices. The e-pass is a lot faster than the on-site ticketing since the vehicle only slows down for the reader to detect the transponder in the vehicle, then it can speed up again. With the anticipated increase in the number of vehicles that pass through the expressways, it is desirable to have all toll-gates with e-pass. However, microwave-based e-pass is relatively expensive. This is the biggest obstacle why the government cannot impose the installation of transponders in all vehicles. It is imperative that a cheaper yet reliable technology be used to replace the microwave system in order to realize a smooth-pass through toll gates [Arao]. One alternative is RFID also known as Radio Frequency Identification. There are two types, active and passive RFID. Passive RFID tags are relatively cheaper and have a life span of 20 years [FTC]. These tags, unlike microwave devices, have limited detection range. This study aims to determine detection range by finding the optimum angle of the reader relative to the location of the tag. In order to determine the possibility of removing the barriers in the toll gates, test on the maximum speed of the vehicle at which the reader can still recognize the tag is also done. Since some vehicles may use the toll gates only a few times a year, it would not be practical for them to buy prepaid loads. This is remedied by allowing the system to log the corresponding toll fees in the database that is to be sent to the government agency involved in the annual registration of vehicles. A GSM feature is also included that sends an SMS to the owner of the vehicle to his registered cellphone that informs him of his load balance.

2. THE ELECTRONIC TOLL COLLECTION-RFID STRUCTURE

The block diagram of the Electronic Toll Collection system is shown below. It comprises of the hardware components such as the tag, the reader, the server, and the GSM module (Figure 1). The bulk of the study though is the development of the database management system and its integration to the system.

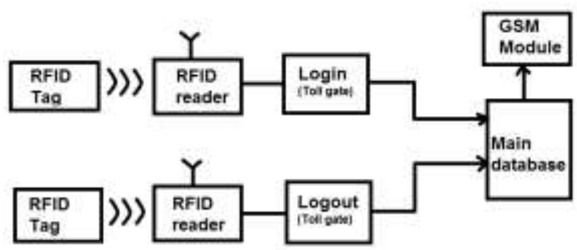

Figure 1. Block Diagram of the ETC-RFID

The operation of the whole system starts with the reading of the tag in the tollgate. Once detected, the information in the tollgate subserver is passed on to the main database server for logging and processing. The log information includes the ID of the vehicle, and the time of entry in the toll gate. When the vehicle exits another tollgate, the same process is done except this time instead of a log-in, the system logs it out. The entry and exit information are used to calculate for the total toll fee. This is then deducted to the current balance in the vehicle owner's account. The balance in the owner's account is sent to his registered cellphone via SMS. The following subsections discuss further the operation of each block.

2.1 RFID Tag and Reader

RFID is a technology that makes use of radio waves to transfer data from the tag to another equipment usually a computer through an RFID reader. For purposes of this study, EPC Class 2 Gen 2 Passive RFID tag is utilized. This type of reader can read and write up to 96-bit of data to a passive tag [4]. Figure 2 shows the basic transponder (tag)-reader set-up.

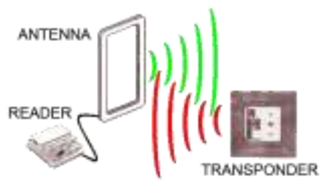

Figure 2. Basic RFID tag and reader System [Oklahoma]

The tags are installed on the center position of the windshield of the vehicles. The reader on the other hand is installed at the center of the lane which is 2.5 meters above ground. Figure 3 shows an illustration of the installation.

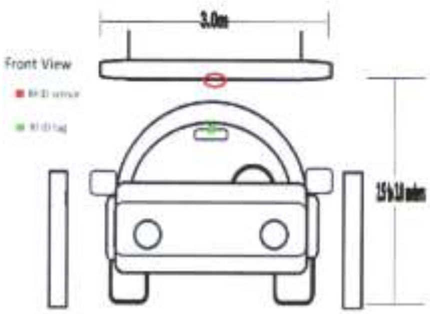

Figure 3. Actual Installation of the RFID Reader

In this study, the location of the smart card reader is delimited to the height of a typical car. Trucks and other taller vehicles are not considered. Each of the tag is registered before its issuance to the vehicle owner. In real deployment, this shall happen during the first registration of the vehicle. Figure 4 below shows the Graphical User Interface (GUI) that the group developed to register the vehicle. This is also the same GUI used to update or edit an existing registered owner. The form contains the Customer Number, Last Name, First Name, Address, Plate Number, Registration Number, Description, RFID No., and Class (of Vehicle). Different classes of vehicles pay different toll fees. This is included in the program for the computation of the total fees.

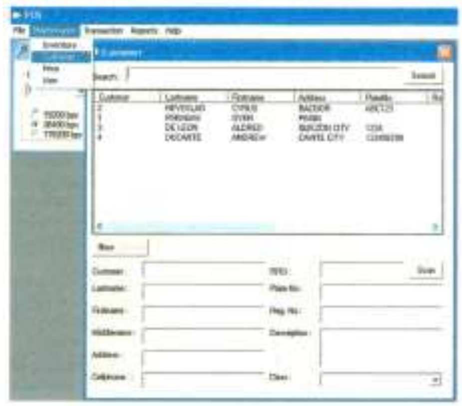

Figure 4. POS Customer Window

The information read by the reader is sent to the Main Database center which is typically located in the main office of the tollway management. The network configuration used to cover all the tollgates is star configuration (Figure 5).

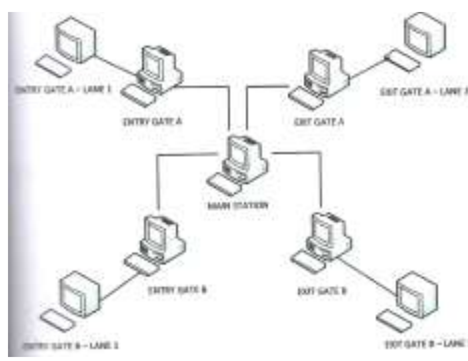

Figure 5. Star Network of the ETC-RFID

2.2 Database Management

The bulk of this study is in the development and management of the database. Seven database tables were created to cover all the information needed to be stored and retrieved from the database. These tables are named *ArTrnDetail* Table, *ArTrnSummary*, *tblCustomer*, *tblCustomer Movement*, *tblInventory*, *tblPrice*, and *tblUser*. The database diagram containing all the tables is shown in Figure 6. The first table *tblInventory* stores the information from the Inventory window. The *StockCode* serves as the link to the *ArnTrnDetail* table which holds all the transaction details. The *Invoice* in the *ArnTrnDetail* monitors the invoiced items and acts as a link to the *ArTrnSummary* table. The *ArTrnSummary* table holds all the information that is recorded for every transaction of the customer like the payments and the item prices. The *Username* in this table connects to the user accounts stored in the *tblUser* while the *Customer* information came from the stored customer's data in the *tblCustomer*. From here, the *Customer* is connected to the *tblCustomerMovement* which keeps track of the movement and transactions of the *Customer*. In the *tblCustomer* table, the *Class field* is connected to the *tblPrice* which contains the toll fees that are being used as basis to compute for the toll fee given its entry and exit points.

Figure 6. Database Diagram

2.3 Billing Process

Billing is another important aspect in the deployment of this type of technology. This considers several factors like the vehicle class, entry and exit points, closed loop and open loop toll system, and prepaid and postpaid payment system. This study is delimited to consider a closed loop toll system. In the closed loop system, the toll fee is computed based on the entry and exit points. A matrix containing these fees are included in the database (*tblPrice*). The ETC system considers prepaid payment system where the customer purchases load credits in the designated offices or toll booths or in the future even in stores or malls. The load is added to his account. If the car rarely uses the expressway, a postpaid system is desirable where the amount to be paid is added to his account and will be charged to him during registration in case payment of the said toll is not made. The postpaid system is not considered in this study. It is however, just a matter of adding few lines to the source code.

The flow of the billing process is shown in Figure 7. As the vehicle enters a toll gate, the reader verifies and acquires the data of the tag in the vehicle and sends this to the PC containing the *login* program. The program stamps the vehicle's entry point to its corresponding entry in the database including the tag ID and the time of entry. The time is the information required to know if the gate is an entry or exit gate. All these information are sent to the main database that pulls customer information from the *tblCustomer* database table. As soon as the reader at the exit reads the tag, a POS program computes for the total price, then deducts this from the current balance in the customer's account. In order to make sure that the customer has enough balance to pay for the fees, the POS program checks if the current load balance is enough to pay for the highest toll based on the longest possible entry-exit pairs. If the balance is not sufficient, the customer is notified via an SMS so that he can top-up his balance.

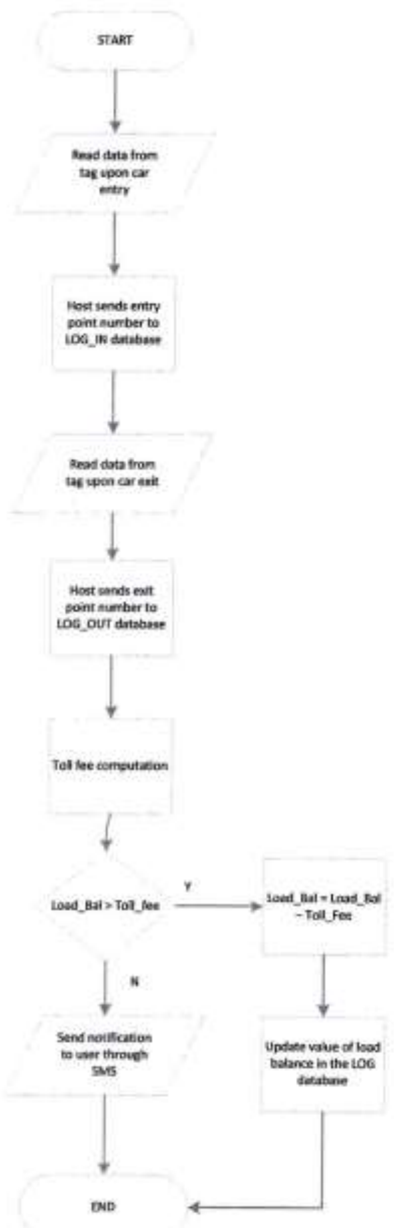

Figure 7. Billing System Process Flowchart

3. DATA AND RESULTS

3.1 RFID Detection

One crucial aspect in the deployment of RFID-based ETC is its precision and accuracy to detect the RFID installed in cars. It is assumed here that if this is adopted by the government, all vehicles will be required to be equipped with an RFID tag. Hence, the only thing that the system must ensure is that it is able to detect all cars that pass through the toll gate. The maximum speed of the vehicle as well as the optimum angle to which the reader is mounted relative to the tag are determined (Figure 8).

Figure 8. 30⁰ Reader Placement with respect to the Y-axis

For each angle position of the reader, the test was run five times. Table 1 and Figure 9 show the success rate for a 30⁰ reader placement. It can be seen that from 60 kph to 80 kph, the reader was not able to detect the tag in one or two of the runs. This registered an 84% success rate.

Table 1. Detection success rate for system test with Reader Mounted 30⁰ with respect to the Y-axis

Speed in kph	Correct entry gate	Correct exit gate	Run 1	Run 2	Run 3	Run 4	Run 5
20	Y	Y	P	P	P	P	P
30	Y	Y	P	P	P	P	P
40	Y	Y	P	P	P	P	P
50	Y	Y	P	P	P	P	P
60	Y	Y	P	P	F	P	P
70	Y	Y	P	F	P	F	P
80	Y	Y	P	P	P	P	F

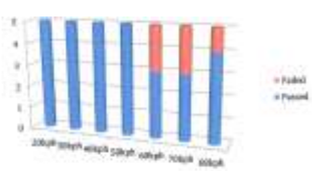

Figure 9. Graphical representation of the results tabulated in Table 1.

The success rate for each of the angle placement is provided in Figure 10. As can be seen, the 45^0 angle is the optimal angle since all tags are detected for all speeds up to 80 kph.

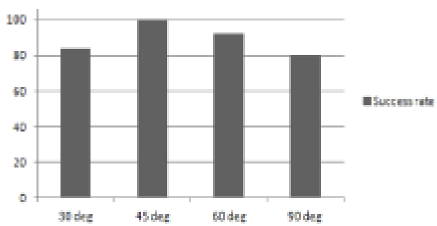

Figure 10. Comparison of the Success rates for different angle placement of the reader

Four tags, three of which are raw and one is encapsulated in a plastic card, were used (Figure 11). It was noted that the three raw tags are easily detected while the encapsulated tag is not. The tags were mounted on the windshield of the car.

Figure 11. Tags used during the test runs

3.2 Database Performance

The updating of the data base was done either manually or automatically depending on the transactions. For the addition of credit loads to each customer, the update is done manually. This simulates the scenario where the customer purchases additional load to his account. The automatic updating happens when the tag is detected at the point and consequently at the exit point. This was demonstrated through two sets of reader assigned as entry and exit gates respectively. Several tags were used to show the movement of transactions for each user. And for all transactions, the database specifically the load balance of the customer was updated accordingly.

3.3 GSM Module

The GSM module sends an SMS to the customer's registered cellphone once its remaining load balance goes below the toll fee equivalent to the fee for the longest end-to-end toll gates. The GSM module was tested in conjunction with the Database test. For all tests, it successfully sent an SMS as the balance went below the minimum amount set in the program. For purposes of this study, a 'Globe Tattoo' was used as the gsm service.

3.3 Car Volume Throughput

The expected toll transactions for both manual and electronic toll are shown in Table 3 below. The volume of cars that can be accommodated per toll gate per hour for the electronic toll is computed using the equation

Car throughput = Vs /d

Where Vs – speed of the vehicle

d – detection distance from arc to field

The detection distance is measured to be 2 meters. This is the reading range of RFID between the positioning of the reader on the arc and the positioning of RFID tag on the windshield of the car.

For the manual transactions, two scenarios are considered, the exact toll lane, and the regular lane. In the exact toll lane, the driver of the vehicle hands the cash, then the cashier generates the receipt and the car leaves the toll gate. Based on the observations done by the proponents, the minimum time spent to do this transaction is 17 seconds including lane queuing. For the regular lane, the time to compute for the bill change and give the change are added to the exact toll time. This is estimated to be 21 seconds to 37 seconds depending on whether the bill is small or a bigger bill. To compute for the volume in manual toll, the following equation is used:

Car volume/ hr = 1 / T

Where T – average time spent at the tollgate of each car

Table 2. Estimated Car Volume for Electronic toll and Manual toll System

Type of toll gate	No. of cars
Manual, regular lane	172
Manual, exact toll lane	212
ETC without barrier (for the slowest speed of 20 kph)	10,000

4. CONCLUSION

The ETC-RFID proposed in this study promises a cost-effective yet efficient toll system. The optimum angle of placement of the reader mounted at the middle top of the tollgate is found to be 45^0 at a speed of 80 kph. It is possible that a higher speed can be obtained but due to time constraints, only up to 80 kph was tested. The speeds used to test the accuracy of detection of the reader were 20 kph, 30kph, 40 kph, 50kph, 60kph, 70 kph, and 80 kph. A passive tag of class EPC2 is used in this study. The range of detection is also measured to be 2 meters from the arc where the reader is mounted. This allows the removal of barrier which is present in the current toll system. The database operates accurately.

It has also been observed that RFID tags encapsulated in plastic cards are hard to detect, hence raw tags were used instead. It is recommended to develop the appropriate encapsulation material for the RFID. It is further recommended that the following features be added: postpaid billing system, more robust information security, and more interactive GSM program. The interactive GSM program shall allow the system to know if the cellphone registered has received the notification message, if not, a report is generated and the message is sent to another contact like an email. The customer may also change his contact through the SMS he receives.

During the test of this study, the pseudo toll gate uses only USB cables to connect the PCs that act as servers. When the cable gets longer, the data transmission gets slower. It is therefore important that a faster internet connection between the subservers and the main servers be utilized for the full deployment of this study.

5. REFERENCES

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