Design and Implementation of Vehicle Tracking System Using GPS/GSM/GPRS Technology and Smartphone Application

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***Abstract*— An efficient vehicle tracking system is designed and implemented for tracking the movement of any equipped vehicle from any location at any time. The proposed system made good use of a popular technology that combines a Smartphone application with a microcontroller. This will be easy to make and inexpensive compared to others. The designed in-vehicle device works using Global Positioning System (GPS) and Global system for mobile communication / General Packet Radio Service (GSM/GPRS) technology that is one of the most common ways for vehicle tracking. The device is embedded inside a vehicle whose position is to be determined and tracked in real-time. A microcontroller is used to control the GPS and GSM/GPRS modules. The vehicle tracking system uses the GPS module to get geographic coordinates at regular time intervals. The GSM/GPRS module is used to transmit and update the vehicle location to a database. A Smartphone application is also developed for continuously monitoring the vehicle location. The Google Maps API is used to display the vehicle on the map in the Smartphone application. Thus, users will be able to continuously monitor a moving vehicle on demand using the Smartphone application and determine the estimated distance and time for the vehicle to arrive at a given destination. In order to show the feasibility and effectiveness of the system, this paper presents experimental results of the vehicle tracking system and some experiences on practical implementations.**

Keywords—Vehicle tracking; Microcontroller; Google Maps API; Smartphone application; GPS/GSM/GPRS technology;

I. Introduction

Vehicle tracking systems were first implemented for the shipping industry because people wanted to know where each vehicle was at any given time. These days, however, with technology growing at a fast pace, automated vehicle tracking system is being used in a variety of ways to track and display vehicle locations in real-time. This paper proposes a vehicle tracking system using GPS/GSM/GPRS technology and a Smartphone application to provide better service and cost-effective solution for users.

On the basis of statistical data shown Fig. 1, one can observe that the world is experiencing accelerated growth in Smartphone ownership. As a result, Smartphone users are now more prevalent within the overall population than owners of basic mobile phones [1]. As Smartphones become more familiar to people and finding use in the day to day lives, their influence on society continues to grow. The main driving force for this accelerated growth in Smartphone usage is the availability of a large variety of applications to meet the needs of a wide range of users. In our project we developed a Smartphone application along with the in-vehicle tracking device. The two parts work together to offer the most convenience to the users as they become handy to track vehicle locations in real-time.

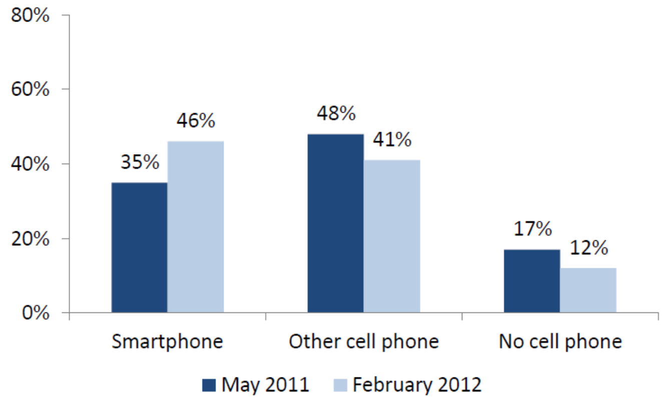


Fig. 1. Changes in phone ownership, 2011-2012. The number of Smartphone owners increased 11% from 2011 to 2012. [1]

A vehicle tracking is a prerequisite of the most basic function in all fleet management systems. A fleet management is the management of a company's transportation fleet. The fleet management system aims at improving the quality and efficiency of the industry by identifying major obstructions on the road and tracking real-time locations of their fleet on a map [2],[3]. Most of the vehicle tracking systems are designed by using GPS/GSM technology [4]. In vehicle tracking systems, a vehicle location is one of the most important components. The location and time information anywhere on earth is provided by using GPS technology [5].

For wireless data transmission, GSM and SMS technology are commonly used. The SMS technology through GSM network and GSM modem provide a user with vehicle location information [6],[7]. Utilization of SMS technology has become popular because it does not require much cost. It is convenient and accessible way of transferring and receiving data with high reliability [8]. Instead of using SMS, the proposed vehicle tracking system uses the Smartphone application to track and monitor a vehicle location obtained from the in-vehicle tracking device controlled by a microcontroller. The vehicle location is automatically placed on Google maps, which make it easier for tracking a vehicle and provides users with more accurate vehicle location information.

The basic purpose of a vehicle tracking system is to track a specific target vehicle or other objects. The tracking device is able to relay information concerning the current location of the vehicle and its speed, etc. Most of such tracking systems consist of an electronic device as usually installed in-vehicle and can be used for tracking motor cycles, buses, and trains. The vehicle tracking system proposed in the paper has the following features:

- Acquisition of a vehicle's geographic coordinates and a vehicle's unique ID from an in-vehicle device in real-time using the GPS module
- Transmission of a vehicle's location information and a vehicle's ID to a web server after a specified time interval using the GSM/GPRS module
- Database is designed to store and manage received vehicle's location information
- Whenever a user requests the vehicle location, it can be accessed from the database and monitored on Google maps in real-time using a Smartphone application

II. RELATED WORKS

Vehicle tracking systems are used around the world in many fields such as vehicle position tracking systems, vehicle anti-theft tracking systems, fleet management systems, and intelligent transportation systems (ITS).

A. Bus Tracking System

Lau [9] proposed simple bus tracking system in UCSI University, Kuala Lumpur, Malaysia. The tracking system provides students with the location information of a bus within a fixed route. The students are provided with a status of the bus after specified time interval using LED panel and a Smartphone application. Real-time bus tracking systems are beneficial to college students who attend colleges with large campuses. With the bus tracking system, they can spend more time studying, sleeping, or relaxing rather than waiting for a delayed bus. Spending less time waiting for a bus improves the comfortable and effective time management of the students as well. Also, the bus tracking system helps improve children's safety when it is equipped in school buses.

B. Vehicle Tracking and Anti-Theft Tracking System

An anti-theft tracking system is one way to prevent or detect unauthorized access of devices considered valuable. Ramadan, Al-Khedher, and Al-Kheder [10] proposed design and implementation of a vehicle tracking and anti-theft system for protecting a vehicle from any intruders using GPS/GSM technology based on tracking systems. The system used Kalman filter [11] to reduce positional errors, thus improving the accuracy of the position determination. When a vehicle's ignition is turned on, a vehicle's owner receives a confirmation SMS that a vehicle is running now. If the access to the vehicle is illegal, the vehicle's owner sends a SMS to turn off the vehicle. A laptop embedded with Google Earth is used for tracking and viewing the location and a status of the vehicle on a map. A Smartphone will be good alternative to replace the work that the laptop performs. Fig. 2 shows block diagram of the proposed system.

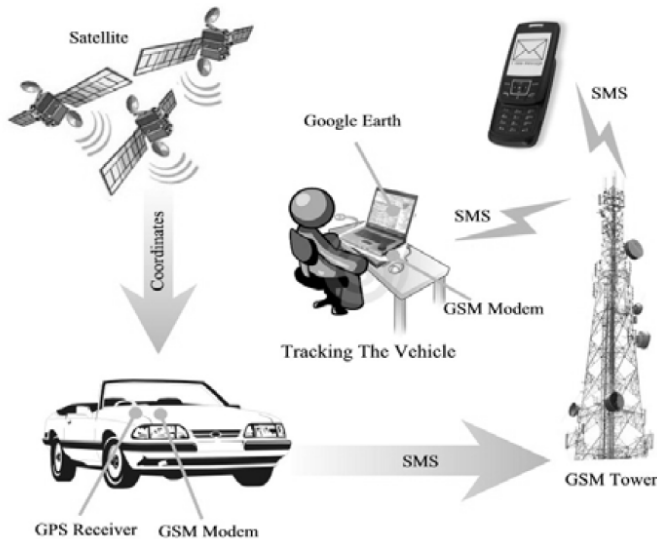


Fig. 2. Block diagram of Vehicle Tracking and Anti-theft System [10]

C. Vehicle tracking system using Social Network Service

Vehicle tracking systems based on social network services such as Twitter and Facebook has attracted interest in a number of users [12]. Each in-vehicle device has an account of the twitter social network and can identify the vehicle location in social network on a regular basis. A web interface is used to display a vehicle location placed on Google maps, and a status of a vehicle like door open/close, and ignitions on/off. Also, users can send commands from the web interface to the in-vehicle device to restart the vehicle or to shut down the vehicle. The proposed system can be accessed from a Smartphone more easily because the Smartphone has available social network services. So, the system would become more efficient to users of social network and Smartphone, they allow quick monitoring of the location and status of the vehicle.

III. IMPLEMENTATION DETAILS

In the development of the vehicle tracking system controlled by a microcontroller, hardware and software design techniques are needed.

A. Arduino Microcontroller

The Atmega328 based Arduino UNO R3 [13] microcontroller is used as the brain to control the vehicle tracking system. Arduino Shields are used for the GPS and the GSM/GPRS modules. A software program to control them is written in the C programming language, compiled and then saved into the microcontroller's flash memory.

B. GPS module

The Global Positioning System in vehicle tracking systems is commonly used to provide users with information such as the location coordinates, speed, time, and so on, anywhere on Earth. In this work, a GPS module and a GPS receiver available from the Sparkfun website, is adopted to implement the in-vehicle device. The GPS module has the GPS receiver with antenna. There are two slide switches and one push button switch.

The GPS module is identical to the one shown in Fig. 3. Ref. [14] offers detail about the GPS module. In Fig. 3, (1) is the switch for UART and DLINE selection. When the DLINE is selected, R_x and T_x in the GPS module will be connected to microcontroller digital pins 2 and 3, respectively. If the UART was selected, R_x and T_x in the GPS module will be connected to microcontroller digital pins 0 and 1, respectively. In this work, T_x and R_x in a GSM/GPRS module uses microcontroller digital pins 2 and 3. So, the GPS switch 1 must be set to the UART position, otherwise if DLINE position is selected its digital pins will overlap that of the GSM/GPRS module. Even when UART is selected, while trying to uploaded program code to the Arduino, users will see error message in the microcontroller because the UART uses the same pin numbers that are used for programming, but nothing should get damaged. For these reasons, the GPS module should select the switch in the UART position after the source code is uploaded. In Fig. 3, (2) is the GPS receiver. It is required for getting the location information. The GPS receiver module uses the 20 channel EM-406A SiRF III receiver.

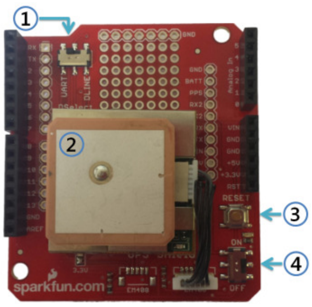


Fig. 3. GPS module. (1) UART and DLINE selection switch, (2) GPS Receiver, (3) Reset switch, (4) Power switch

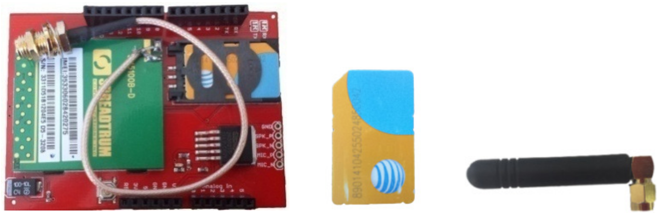
Once the microcontroller and the GPS module have everything assembled, the GPS module is almost ready to get the vehicle's location information. The TinyGPS library [15] was used to communicate with and access data from the GPS module. The EM-406 works at 4800 bps, but if users are using another type of GPS, they should identify the correct baud rate for their specific device.

C. GSM/GPRS module

The GSM/GPRS module [16] is responsible of establishing connections between an in-vehicle device and a remote server for transmitting the vehicle's location information, using TCP/IP connection through the GSM/GPRS network.

1) Hardware

The cellular shield for a microcontroller includes all the parts needed to interface the microcontroller with an SM5100B cellular module. The SM5100B chip on the GSM/GPRS shield is a compact quad-band cellular module. A SIM card and a cellular antenna are functionally essential for working with a GSM/GPRS module. The SIM card manufactured by AT&T needs enough data quantity for testing. The GSM/GPRS module and the cellular antenna were purchased through the Sparkfun website. As shown in Fig. 4, a GSM/GPRS module, a SIM card (pre-paid or straight from your phone), and a cellular antenna are required to implement the proposed vehicle tracking system.



(a) (b) (c)

Fig. 4. (a) GSM/GPRS module with SM5100B, (b) AT&T SIM card (50MB), and (c) Quad-band Cellular Duck Antenna SMA

The Serial.begin() command is used to set up the communication data rate in bit per second (baud) for the serial port.

Serial.begin(9600)

For communicating with the computer, the SM5100B cellular module works at 9600 bps. When a GPRS module is turned on, the microcontroller responds the following messages which is used for checking the operating conditions and whether a SIM card is connected or not.

```
+SIND : 1 (SIM INSERTED)
+SIND : 10,"SM",1,"FD",1,"LD",1,"MC",1,"RC",1,"ME",1
(SIM READY)
+SIND : 11 (GPRS REGISTERED TO NETWORK)
+SIND : 3 (CALL READY)
+SIND : 4 (SMS READY)
```

2) AT Command

Devices like modems use the so-called AT commands to communicate with other devices. AT commands are used to control TCP/IP on SM5100B. The AT commands for TCP/IP and their parameters for SM5100B can be found at [17]. The AT command syntax is as follows.

AT<command…> <CR>

Almost every line with commands starts with the AT, followed by one or more commands, and terminated with a carriage return (CR) character. The first step is to attach a GPRS to the network. Therefore, the microcontroller sends the following command to attach to a GPRS network.

AT+CGATT=1

The next step is to set or edit the Packet Data Protocol (PDP) context parameters such as the Access Point Name (APN). It is important that the correct APN is used (for example, *wap.cingular* for the service provider AT&T). Otherwise the SIM card will not be allowed to connect to the network. The APN needs to acquire access to the Internet when communicating information between a GPRS module and the mobile network through a gateway. The command looks as follows: (The APN is provided by a network service provider.)

AT+CGDCONT=1, \"IP \", \"APN \"

The network service provider (AT&T) offers a user name and a password to authorize a network connection. The next step is to get authorization from the network service provider using the user name (WAP@CINGULARGPRS.COM) and the password (CINGULAR1). The command looks as follows:

AT+CGPCO=0, \" user name \", \" password \ ", 1

The command of the next step is used to activate a PDP context.

AT+CGACT =1,1

D. HTTP communication

A HTTP communication takes place usually through TCP/IP connection. The standard port for HTTP servers is 80. In order to send data over the Internet, a socket connection needs to be established. In this work, the socket is useful for working with our server and it enables users to establish a TCP socket connection for sending data. The socket is characterized by three main entities, a protocol, an IP address / a host name, and a port number. The commands "AT+SDATACONF" and "AT+SDATASTART" are used to configure remote host and port and open socket for TCP connection respectively. These commands look as follows:

AT+SDATACONF=1, \"TCP\", \"Server address\", 80

AT+SDATASTART=1,1

The first parameter means the transport protocol type (TCP/UDP), second parameter is the IP address / the host name of a web server, and the last parameter is the port number. When the connection to the server is established, the microcontroller is ready to send the location information to the server. There are two difference ways to send the location information by AT commands for the SM5100B. In this work, the command "AT+SDATATSEND" is used instead of "AT+SSTRSEND". This command "AT+SSTRSEND" is terminated by the line breaks (carriage return and line feed). Instead, the command "AT+SDATATSEND" does not interpret the characters as any kind of control codes. First, the command needs to give the GSM/GPRS module the length of the packet we are sending. And then, we should wait for '>' character from the module to tell us if it is ready to send the packet. Once it is ready we transmit the packet and terminate it with Ctrl+Z character (0x1A). The initial part of the command looks as follows:

AT+SDATATSEND=1, "+String(packet length)+"\r

E. Web Server and Database

A free web hosting service is used for a web server construction. A web page was composed of simple PHP that can directly connect to and manipulate a database table. The command "mysqli_connect" is used to establish a connection to a MySQL database. The command syntax is:

```
$con = mysqli_connect($hostname, $username, $password)
```

After the connection is established, the vehicle's location information can be entered into a designated table by executing SQL INSERT statement through PHP function "mysqli_query". A simple example to insert the vehicle's location information into a GPSDATA table in relational database is shown below.

```
$sql="INSERT INTO GPSDATA (VehicleID, Latitude, Longitude)
VALUES ('$_GET[id]','$_GET[lt]','$_GET[ln]')";
$retval = mysqli_query($con, $sql);
if (!$retval)
{
  die('Error: ' . mysqli error($con));
}
```

The structure of the GPSDATA table is listed in TABLE I. It consists of ID fields (ID, VehicleID) and a vehicle's location information fields (Time, Latitude, and Longitude). The "ID" field is a Primary Key designed to have auto_increment attribute so it can be used to distinguish respective rows. Sequence numbers are assigned automatically when the vehicle's location information is inserted. "VehicleID" field can be used to store as a vehicle's unique ID if users want to track multiple vehicles. The "Time" field automatically stores current time due to use of CURRENT_TIMESTAMP when the location information of a vehicle is received.

TABLE I. THE STRUCTURE OF THE GPSDATA TABLE IN THE DATABASE

Field	Type	Attributes	Default
ID	int(5)		
VehicleID	int(5)		
Time	timestamp	ONUPDATE CURRENT_TIMESTAMP	CURRENT_ TIMESTAMP
Latitude	double(7,5)		0.00000
Longitude	double(7,5)		0.00000

F. Google Maps API

A Google maps API for iOS is used to display a vehicle location on a Smartphone application in real-time using an HTTP request. The Google maps API automatically handles access to the Google Maps servers, displays map, and responds to user gestures such as clicks and drags. The legs array contains information about two locations within the given route. "distance" and "duration" fields from the legs array are used in the Google directions API [18]. Those fields provide users with the calculated distance and time information between the current location of a vehicle and the user location within the given route. "start_address" and "end_address" fields are used to indicate an address of a vehicle and a user, respectively.

IV. RESULT

Fig. 5 shows our vehicle tracking system layout. It can help understand how the project is implemented.

A. Testing In-vehicle device

As shown in the diagram, starting from the satellite at the top of the diagram, the GPS module receives geographic coordinates from the satellites. The vehicle's location information is read in from the GPS module by the microcontroller. The vehicle's location information and the vehicle's ID are then transmitted to the web server through GSM/GPRS network. The GSM/GPRS module is used for

TCP/IP communication. The received vehicle's location information and the vehicle's ID are sent from a form with the GET method for transmission to the server. The GET method looks as follows:

```
GET /s.php?lt=43.01343&ln=-83.7149&id=2013 HTTP/1.1
```

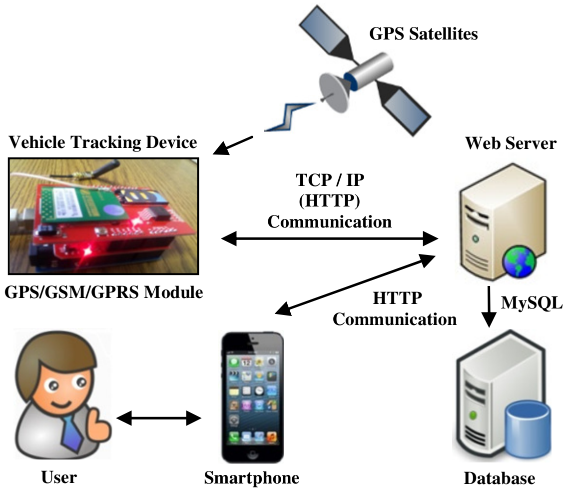


Fig. 5. The proposed vehicle tracking system layout

B. *Testing Web Server and Database*

The web server is connected to a database, and then the vehicle's location information is stored in the database. Some real experimental data for a vehicle's location information, collected and uploaded to a database based on a test run, is listed in TABLE II. The experimental results show the minimum time interval of 8 seconds for updating the vehicle's location information. This time interval is actually configurable according to the movement of the vehicle. So for fast moving vehicles we could update the position information faster than for slow moving or stopped vehicles.

TABLE II. A REAL VEHICLE'S LOCATION INFORMATION

ID	VehicleID	Time	Latitude	Longitude
36	2013	2013-10-10 07:28:18	43.01491	-83.71395
37	2013	2013-10-10 07:28:27	43.01459	-83.71360
38	2013	2013-10-10 07:28:36	43.01462	-83.71347
39	2013	2013-10-10 07:28:44	43.01433	-83.71321
40	2013	2013-10-10 07:28:52	43.01376	-83.71273
41	2013	2013-10-10 07:29:02	43.01353	-83.71255
42	2013	2013-10-10 07:29:11	43.01351	-83.71253

C. *Testing Smartphone application*

In order to demonstrate operation of the vehicle tracking system successfully, an iPhone was configured with the developed Smartphone application. Two locations, one for the vehicle and the other remotely located user appear on the Google map. The location of the vehicle is updated from the in-vehicle tracking device. Also, the distance and time information between the two locations within the given route can be displayed. Whenever a vehicle location changes, the vehicle's address will be updated regularly. Fig. 6 shows our Smartphone application with the most recent vehicle's location information from a database.

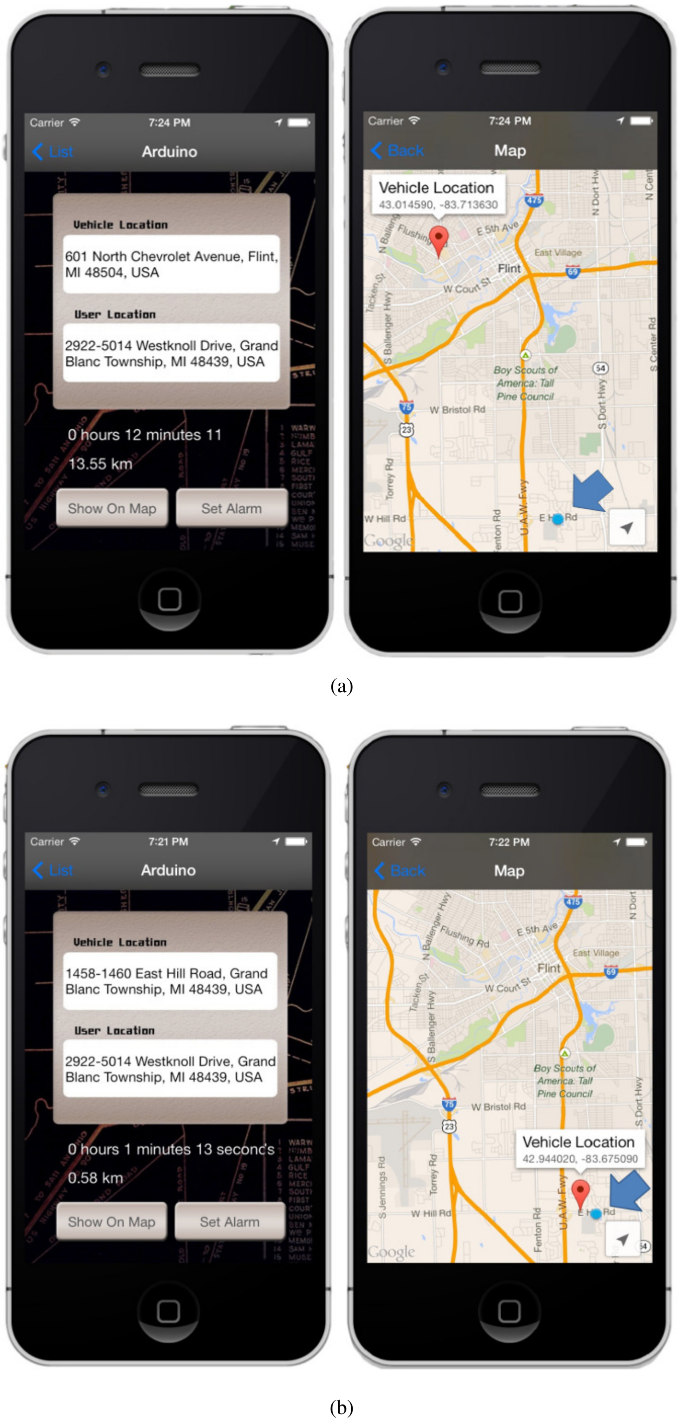


Fig. 6. Vehicle Tracking Application test. The arrow indicates a user location (a) Initial position of the vehicle (b) The vehicle is approaching to the user.

V. CONCLUSION

We developed and tested a vehicle tracking system to track the exact location of a moving or stationary vehicle in real-time. This paper has described the design and implementation of our vehicle tracking system. An in-vehicle device, a server and a Smartphone application are used for the vehicle tracking system. In this work, the in-vehicle device is composed of a microcontroller and GPS/GSM/GPRS module to acquire the vehicle's location information and transmit it to a server through GSM/GPRS network. On the other end, the web interface written in PHP is implemented to directly connect to a database. A vehicle's geographic coordinates and a vehicle's unique ID obtained from an in-vehicle device are recorded in a database table. And a Smartphone application has been created to display a vehicle location on Google maps. The system was able to experimentally demonstrate its effective performance to track a vehicle's location anytime from anywhere. Furthermore, our implementation is low-cost that is based on easily accessible off-the-shelf electronic modules.

ACKNOWLEDGMENT

The authors would like to thank to Mengyi Zhou and Junsheng Xu from Tongji University for valuable contributions on the Smartphone application and the web service system. The authors would also like to acknowledge an initial project work done by a Kettering University undergraduate student, Lex (Joseph) Lombardi, under supervision of one of the authors. The project was on a GPS tracking and data logger, with a prototype built for a proof of concept.

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