Development of Vehicle Tracking System using GPS and GSM Modem

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***Abstract*—The ability to track vehicles is useful in many applications including security of personal vehicles, public transportation systems, fleet management and others. Furthermore, the number of vehicles on the road globally is also expected to increase rapidly. Therefore, the development of vehicle tracking system using the Global Positioning System (GPS) and Global System for Mobile Communications (GSM) modem is undertaken with the aim of enabling users to locate their vehicles with ease and in a convenient manner. The system will provide users with the capability to track vehicle remotely through the mobile network. This paper presents the development of the vehicle tracking system's hardware prototype. Specifically, the system will utilize GPS to obtain a vehicle's coordinate and transmit it using GSM modem to the user's phone through the mobile network. The main hardware components of the system are u-blox NEO-6Q GPS receiver module, u-blox LEON-G100 GSM module and Arduino Uno microcontroller. The developed vehicle tracking system demonstrates the feasibility of near real-time tracking of vehicles and improved customizability, global operability and cost when compared to existing solutions.**

I. INTRODUCTION

The global number of vehicles is expected to increase as ownership becomes more affordable due to the growing economies of countries such as China and India [1]. However, the adoption of vehicle tracking system is still very much lacking. Such a system can be used for many applications including security of personal vehicle, public transportation systems, fleet management and others. Vehicle tracking systems have been available in the market for some time but they are application specific, region specific and are costly [2-4]. Therefore a system designed for car security will not be suitable for fleet management [5]. It is envisioned that the proposed system will be easily customizable for various applications. The proposed system can be used globally and is expected to be cheaper.

On the other hand, Global Positioning System (GPS) navigation system is widely adopted in vehicles today [6]. It is primarily used to assist the driver in navigating to their destinations with turn-by-turn instructions. It can also be used in tracking the distance traveled on a trip, vehicle mileage, and speed. It can keep the record of driving activity, including address of each destination, names of streets traveled, and how long the vehicle remained at each location. These functions allow users to monitor the usage of their vehicles. However, these systems will not be able to track the vehicle remotely.

GPS is a real-time satellite navigation system for three-dimensional position determination. It was developed by several U.S government organizations, including the Department of Defense (DOD), the National Aeronautic and Space Administration (NASA), and the Department of Transportation (DOT). GPS has three segments: satellite constellation, ground-control/monitoring network, and user receiving equipment. The satellite constellation is the set of satellites in orbit that provide the ranging signals and data messages to the user equipment. The control segment oversees and maintains the space segment which is the satellite constellation in space. The user segment, or the user receiver equipment, receives the signal from the space segment and computes the navigation, timing and other functions [7].

The Global System for Mobile Communications (GSM) is the second-generation digital cellular mobile network [8]. It is widely deployed around the world. Although improvements to GSM such as the next generation systems have been rolled out to cater for faster data centric traffic, backward compatibility to GSM is still maintained. Due to its wide availability, it is chosen as the medium for transfer of location information. The simple and inexpensive Short Message Service (SMS) allows users to send up to 160 characters. For the purpose of this project, the SMS is more than sufficient for sending the location information.

The main components of the vehicle tracking system are the GPS module, which is used to obtain the vehicle's coordinate and the GSM modem, which is used to transmit the location to the user's phone through the mobile network. These components' hardware are the state-of-the-art u-blox NEO-6Q GPS receiver module and u-blox LEON-G100 GSM module. A microcontroller, the Arduino Uno is also employed to control both modules and to provide an easily customizable platform for any required application. Generally, the system will provide the user with the vehicle's location coordinates upon request. It can also be programmed to send the location information periodically if required. These options allow the user the flexibility of both on-demand or continuous tracking of the vehicle.

The rest of this paper is organized as follows. In Section II, the development of the vehicle tracking system will be described in detail. The results of the hardware prototype and discussions are given in Section III. Finally, Section IV concludes the paper and provides suggestions for future work.

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II. VEHICLE TRACKING SYSTEM USING GPS AND GSM MODEM

The development of the vehicle tracking system will be described in detail in this section. The block diagram of the vehicle tracking system is as shown in Fig. 1. The three main components of the systems are the u-blox NEO-6Q GPS receiver module, u-blox LEON-G100 GSM module and Arduino Uno microcontroller. The NEO-6Q GPS receiver module's main function is to obtain the vehicle's coordinates. These coordinates are periodically (user selectable) sent to the Arduino Uno microcontroller. The Arduino Uno processes this information and will then send the location information to the LEON-G100 GSM to be transmitted through the mobile network to the user when requested or on a periodic basis. The modules and microcontroller communicates through the Universal Asynchronous Receiver/Transmitter (UART) interface.

A. Hardware and Software Components

The main hardware components of the system are the u-blox NEO-6Q GPS receiver module, u-blox LEON-G100 GSM module and Arduino Uno microcontroller. The u-blox GPS and GSM modules were chosen because of u-blox is a global leader in the provision of positioning and wireless semiconductors that have proven reliability at an affordable cost [9]. On the other hand, the Arduino group of microcontrollers offers an open-source prototyping platform that is flexible and easily customizable to the required application [10]. The complete list of hardware elements for the design is given below:-

1) *u-blox NEO-6Q GPS receiver module*
2) *u-blox LEON-G100 GSM module*
3) *Arduino Uno microcontroller*
4) *Graphic LCD shield (LCD4884)*
5) *GPS/GSM antennas and SMA connectors*
6) *Sim Card and holder*
7) *Batteries and holder*
8) *Capacitors*

u-blox NEO-6Q GPS receiver module

The u-blox GPS Neo-6Q receiver (as shown in Fig. 2) is a high performance GPS receiver module that is equipped with 50 channels and can provide a time-to-first-fix (TTFF) of less than 1 second (in hot start and 26s in warm and cold starts) [11]. It is a surface-mount device (SMD) type 24-pin chip that comes in a compact size of 12.2 mm x 16.0 mm x 2.4 mm. It can operate with a voltage of 2.7 to 3.6 V and draws a current of 50 mA. Furthermore, the receiver features multiple interfaces including both the UART and Inter-Integrated Circuit (I^2C) compliant Display Data Channel (DDC).

The NEO-6Q GPS receiver pin assignment and connections are shown in Fig. 3 and Table I respectively. The pins VCC_RF and RSD (Reserved) must be connected together as per requirement. The NEO-6Q GPS receiver also

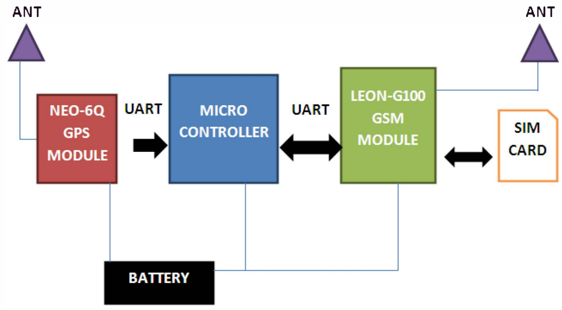

Figure 1: Vehicle tracking system block diagram

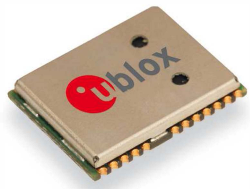

Figure 2: u-blox NEO-6Q GPS receiver module [11]

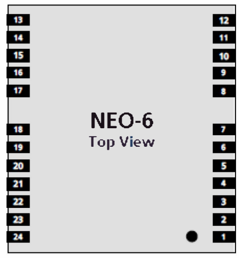

Figure 3: NEO-6Q GPS pin assignment [11]

TABLE I
NEO-6Q PIN CONNECTIONS

No	Pins	Pin number	Connection
1	VCC	24	Battery/ power source
2	GND	10,12,13,24	Ground
3	CFG_COM0	14	Ground
4	TXD1	20	DTE UART
5	RXD1	21	DTE UART
6	VCC_RF	9	RSD
7	RSD	8	VCC_RF
8	RF	11	Antenna SMA connector
9	V_BCK	22	Battery holder
10	Others	Others	Left open

enables boot-time configuration through configuration pins CFG_COM0, CFG_COM1 and CFG_GPS0. In our system, the CFG_COM1 and CFG_COM0 have been set to logic 1 and logic 0 respectively. This sets the module to self-powered mode with UART baud rate of 384000. The CFG_GPS0 is set to logic 1 which means the module will be operating in maximum performance mode (as opposed to economy power mode). More details on the other configuration options can be found in [11-12]. It is worth highlighting that the configuration pins can be left open for logic 1 since it is by default internally lifted high.

Figure 4: u-blox LEON-G100 GSM module [13]

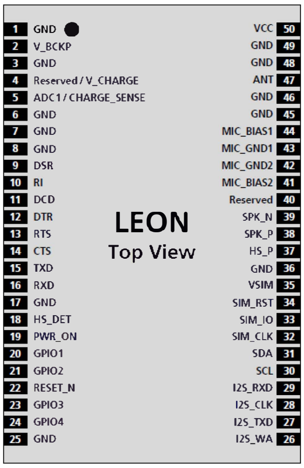

Figure 5: LEON-G100 GSM pin assignment [13]

u-blox LEON-G100 GSM module

The u-blox LEON-G100 GSM module (as shown in Fig. 4) is a cost-efficient GSM module that features full quad-band operation with voice functionality and GPRS data [13]. It is also a SMD type chip with 50 pins that comes in a marginally larger size of 18.9 mm x 29.5 mm x 3 mm. It can operate with a voltage of 3.35 to 4.5 V with a peak current consumption of 410 mA. It provides a maximum RF output power of around 30 dBm (1 W). The GSM module features both the UART and general purpose input/output (GPIO) interfaces. Conveniently, it can also communicate with the u-blox GPS Neo-6Q receiver through the DDC interface.

The LEON-G100 GSM module pin assignment and connections are shown in Fig. 5 and Table II respectively. For our application, the LEON-G100 GSM module is setup in normal operation but without the speaker, headphone or microphone. It is designed just for sending and receiving SMS. Other features can be configured in future work to enable more functionality. Hence, the only external components that need to be connected to the module are the SIM card holder, SMA connector, capacitors and ESD diodes. Furthermore, only the data transmit (TXD) and data receive (RXD) lines are used. For this setting, the clear to send (CTS) line must be connected to the ready to send (RTS) line and the data terminal ready (DTR) must be grounded [14].

Arduino Uno microcontroller

The Arduino Uno microcontroller board (as shown in Fig. 6), now in revision 3, is the latest in the group of USB Arduino boards and will be the reference model of the Arduino open-source electronics prototyping platform. It has the ATmega328 8-bit microcontroller as its core chip. It operates with a voltage of 5 V. The Arduino Uno provides 14 digital pins, 6 analogue pins, 32 kB of flash memory, 2 kB SRAM, 1 kB EEROM, 16 MHz clock speed and a USB connection. It supports shields, or boards, that are plugged on top of it to extend its capability. Many shields are available including display, sensor, motor driver, Xbee (Zigbee), interface, input, Ethernet and others. Specifically, for this project, the Graphic LCD shield (LCD4884), will be used to display messages to the user. Fig. 6 shows the Arduino Uno with the graphic LCD shield.

TABLE II
LEON-G100 PIN CONNECTIONS

No	Pins	Pin No	Connection
1	VCC	50	Parallel of capacitors: 10pF,39pF,100nF,330mF, ESD and battery or power source
2	GND	1,3,6,7,8,17,25, 36,45,46,48,49	Ground
3	V_BCK	2	100 mF and ground
4	TXD	15	DTE UART
5	RXD	16	DTE UART
6	DTR	12	Ground
7	CTS	14	RTS
8	RTS	13	CTS
9	PWR_ON	19	Ground
10	ANT	47	Antenna 50 impedance wire
11	VSIM	35	Parallel capacitors: 47pF,100nF, ESD and pin 1 and 6 of sim card
12	SIM_RST	34	Parallel capacitors 47pF, ESD and pin 2 of sim card
13	SIM_IO	33	Parallel capacitors 47pF, ESD and pin 7 of sim card
14	SIM_CLK	32	Parallel capacitors 47pF, ESD and pin 3 of sim card
15	Others	Others	Left open

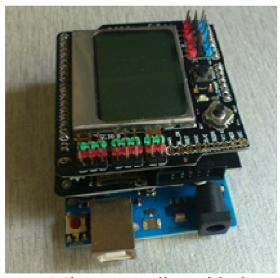

Figure 6: Arduino Uno Microcontroller with the graphic LCD shield

Arduino Integrated Development Environment (IDE)

In order to program the Arduino Uno microcontroller, the Arduino Integrated Development Environment (IDE), a cross-platform application written in Java that is self-installable, is used. The Arduino programs are written in C/C++. The Arduino IDE provides a powerful yet user-friendly programming environment. It allows compilation and uploading programs to the board through a USB connection.

The program for this project initializes and checks for a valid coordinate from the NEO-6Q GPS receiver and display on LCD. It then sends this coordinate to the LEON-G100 GSM module to be transmitted through the SMS.

B. PCB Design with Eagle

The CadSoft Eagle software is useful for designing the printed circuit board (PCB) and features useful functions such as schematic capture, board layout and autorouter. The design is processed through its CAM processor to deliver the de factor industry-standard Gerber format files that is later used for fabrication of the PCB. The Eagle software has rich libraries that are predefined to aid the user.

However, the u-blox NEO-6Q GPS module and u-blox LEON-G100 GSM module are not available in the library of the software. Therefore, these modules should be newly defined with the precise footprint and paste mark as provided by the manufacturer [12, 14], to ensure the PCB can be easily soldered accurately later with the u-blox SMD modules. In order to define a new library for a new component, three steps are needed as each component library has three parts: symbol, package and device. The symbol is used by the Eagle schematic in the diagram, the package is used in the Eagle board and the device is the integration of the package and symbol for routing the signal of the pins. Figs. 7 and 8 show the defined device library for NEO-6Q and LEON-G100 respectively.

Lastly, the recommended schematic connection provided by the u-blox manual is carefully taken into consideration in order to have the chip functioning precisely and properly. The final part of design process is to draw the complete circuit on the Eagle board, transform it into Gerber format and submit it to the PCB fabrication room. Figs. 9 and 10 show the project schematic and PCB design respectively.

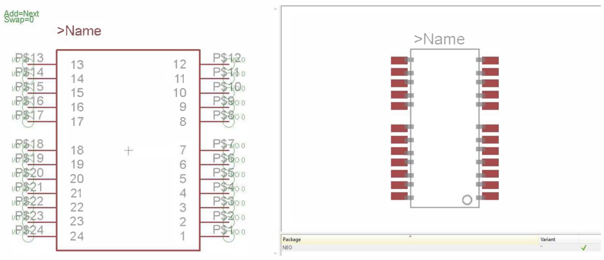

Figure 7: Device library for NEO-6Q

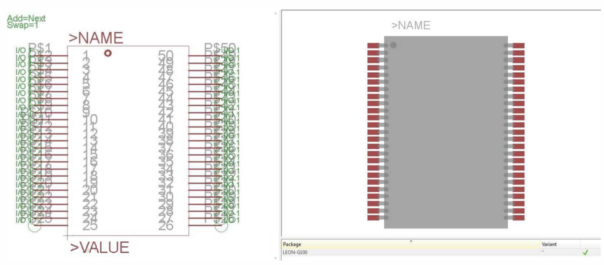

Figure 8: Device library for LEON-G100

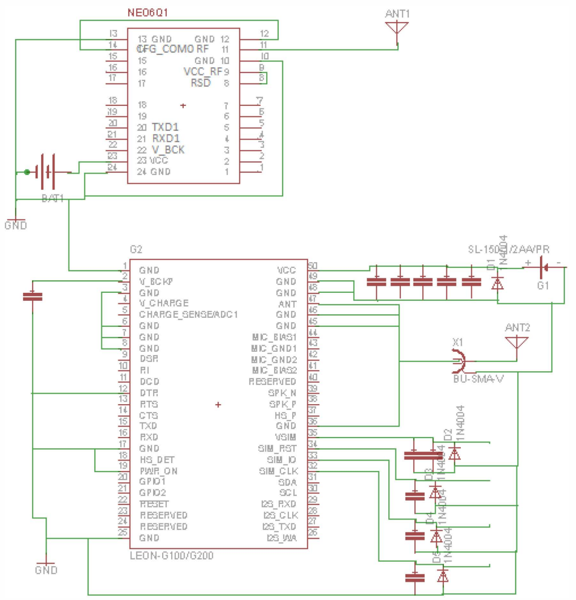

Figure 9: Project schematic

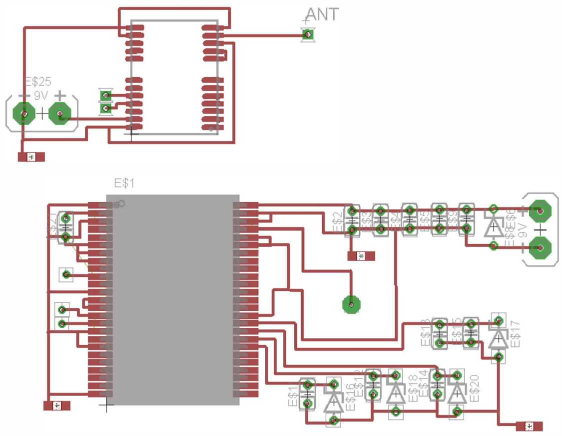

Figure 10: PCB design

III. RESULTS AND DISCUSSIONS

The fabricated single side PCB is shown in Fig. 11. A single side PCB was fabricated due to the limitation of the available PCB facility. Because of this, several jumper wires are used to connect different parts of the PCB. The fabricated PCB is inspected to ensure that all the designed layout and dimensions are correct. All the required components including both the NEO-6Q and LEON-G100 modules are soldered onto the PCB. The completed PCB prototype is shown in Fig. 12.

The Arduino Uno will communicate with both the NEO-6Q and LEON-G100 modules through the UART port. Since the UART ports of both the Arduino Uno and the modules are in TTL level (0 to VCC), they can communicate with each other without the need of an RS232 converter. In order to receive the signals from the modules, their TXD and RXD lines are connected together.

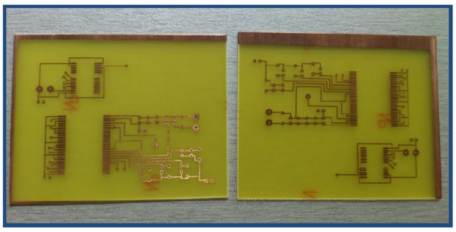

Figure 11: Fabricated PCB

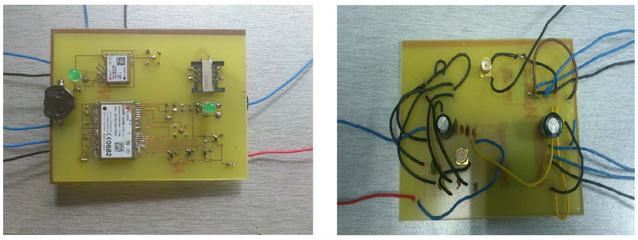

Figure 12: PCB prototype (front and back view)

With the GPS antenna located in an area with an open view of the sky, the GPS coordinates can be obtained from the NEO-6Q module after a few minutes after a cold boot start. After the boot start, the NEO-6Q module will deliver several messages as parts of the NMEA protocol, which are GSV, RMC, GSA, GGA, GLL, VTG, and TXT (see [15] for full list of NMEA message). Some messages may contain the coordinates such as RMC, GGA, and GLL. The procedure for fetching the GPS coordinate from the satellite is observed as follows: boot start, getting UTC time and date, getting GPS coordinate and any other auxiliary figure such as number of satellite used.

A received RMC (Recommended Minimum Data) message with coordinates is shown in Fig. 13. The RMC message is comprised of 14 comma-separated fields. In detail, the fields corresponds to UTC time, data validity status, latitude, N/S, longitude, E/W, speed, course, date, followed by several unused fields and a checksum respectively. Therefore the RMC message showed in Fig. 13 is recorded at time of 13:06:01, “A” stands for valid data, with a coordinate of 4.3869960 N, 100.9632128 E (note that the coordinate has been converted from ddmm.mmmm N and dddmm.mmmm E given in RMC message to degrees only), 0.453 knot speed and date of 4th December 2012.

As for the LEON-G100 module, it is operating as a Data Circuit-terminating Equipment (DCE) and the Arduino Uno microcontroller is a Data Terminal Equipment (DTE). Testing and registering the module over the mobile network will includes four steps (as shown in Fig. 14):

1) *sending “AT” and receiving the response “OK”.*
2) *sending ”AT+COPS?” to check the registration status and operator information and receiving the response “+COPS: 0,0, “DIGI” OK”* (where DIGI is the operator in this case).
3) *sending the SMS with the GPS coordinates “AT+CMGS=”mobilenumber”<enter>SMS message<CTRL-Z>” and receiving the response “OK”.*

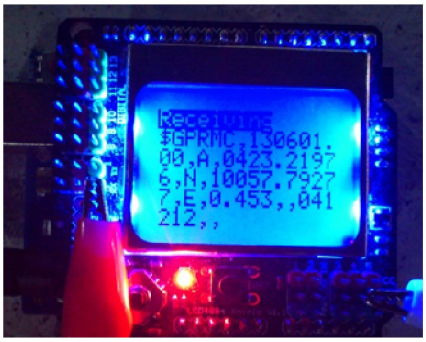

Figure 13: RMC message with coordinates

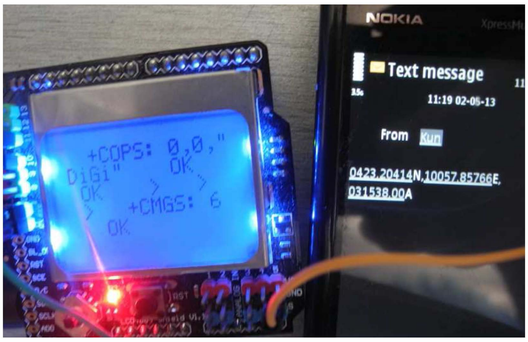

Figure 14: SMS message sent with coordinates

TABLE III

FIELD TEST OF COMMERCIAL GPS UNITS AND PROPOSED SYSTEM

Location	Garmin Nuvi 40	Garmin Nuvi 200	Proposed System
V5 Futsal Court	N 04^{0}23’12.6 (4.386833) E 100^{0}57’49.5 (100.963750)	N 04^{0}23’12.9 (4.386917) E 100^{0}57’49.0 (100.963611)	N 04^{0}23’12.5 (4.386806) E 100^{0}57’49.4 (100.963722)
V4 Field	N 04^{0}23’20.6 (4.389056) E 100^{0}57’53.8 (100.964944)	N 04^{0}23’20.7 (4.389083) E 100^{0}57’53.6 (100.964889)	N 04^{0}23’20.6 (4.389056) E 100^{0}57’53.7 (100.964917)
V2 Café	N 04^{0}23’16.5 (4.387917) E 100^{0}58’04.0 (100.967778)	N 04^{0}23’16.6 (4.3867944) E 100^{0}58’04.1 (100.967806)	N 04^{0}23’16.3 (4.387861) E 100^{0}58’04.1 (100.967806)
V3 Café	N 04^{0}23’13.8 (4.387167) E 100^{0}57’55.8 (100.965500)	N 04^{0}23’13.6 (4.387111) E 100^{0}58’00.2 (100.966722)	N 04^{0}23’13.6 (4.387111) E 100^{0}58’00.0 (100.966667)
Pocket C	N 04^{0}23’00.2 (4.383389) E 100^{0}57’49.9 (100.963861)	N 04^{0}23’00.0 (4.383333) E 100^{0}57’50.0 (100.963889)	N 04^{0}23’00.1 (4.383361) E 100^{0}57’49.9 (100.963861)

Finally, the SMS will be received at the corresponding phone/GSM modem with the specified mobile number in the command.

In order to determine the positioning accuracy of the proposed system, we have performed field test and compared the results from the proposed system and commercial GPS units. The commercial units used in the field test are Garmin Nuvi 40 and Garmin Nuvi 200. The field test has been performed in five locations within the campus of Universiti Teknologi PETRONAS. The results are shown in Table III. There is only a marginal difference between the results of our proposed system and the commercial GPS units. It is interesting to note that these marginal differences are also found between the two commercial GPS units. These results show that the positioning accuracy of the proposed system is as good as the commercial units.

After the user receives the GPS coordinates, it can be copied to mapping applications such as Google Maps to identify the location in a user-friendly graphical map display. An extension of this work can include developing a mobile application that identifies the SMS and automatically displays the location in Google Maps. The whole system costs around USD 150 to build. However, it is expected that this can be reduced significantly at production with sufficient economies of scale. This compares well with current solutions that cost more than USD 200.

IV. CONCLUSION AND RECOMMENDATIONS

The development of a vehicle tracking system's hardware prototype has been presented in this paper. The system is able to obtain a vehicle's GPS coordinate and transmit it using the GSM modem to the user's phone. The developed vehicle tracking system demonstrates the feasibility of near real-time tracking of vehicles, which can be used for security of personal vehicle, public transportation systems, fleet management and many other applications. The system can provide improved customizability, global operability and cost when compared to existing solutions. For future work, further design on multilayer PCB can be undertaken to reduce the wires on the prototype. The reliability of the system can be improved and additional features can also be added. Once the system is complete, the vehicle tracking system has the potential to be commercialized as a standalone product since its utility is quite popular.

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