REAL-TIME VEHICLE PERFORMANCE MONITORING USING WIRELESS NETWORKING

William Jenkins, Ron Lewis, Georgios Lazarou, Joseph Picone and Zachary Rowland
Human and Systems Engineering, Center for Advanced Vehicular Systems
Mississippi State University
200 Research Blvd., Mississippi State, Mississippi 39759, USA
{wjenkins, lewis, glaz, picone, zrowland}@cavs.msstate.edu

ABSTRACT

A cornerstone of next generation intelligent transportation systems (ITS) is a seamless integration of in-vehicle networking with existing wireless telephony infrastructure. Remote access to on-board diagnostics and performance data is a crucial requirement for ITS. In this paper, we present an extensible vehicle performance monitoring system that exploits data transmission capabilities of GSM, and is based on existing in-vehicle automotive standards.

Though many systems currently integrate position tracking and wireless networking to allow for remote position tracking, few systems provide the capability to monitor vehicle performance over the web. Our design is based on a popular new standard for wireless communications — GSM/GPRS. An in-vehicle standard for diagnostic information, ODB-II, is used to gather performance data. We also exploit GPS technology to provide vehicle location. Data is integrated and transmitted to a web server using Apache's Tomcat extensions to provide Internet access via a vehicle tracking web site. The overall system has been in use for several months on a trial basis at Mississippi State, and will soon be tracking the entire campus bus system. The data collected from this pilot study will form the basis for a research initiative in prediction and optimization of vehicle performance.

KEY WORDS

Wireless communications, GPS tracking, data communications

1. Introduction

The next generation intelligent transportation system (ITS) will rely heavily on several vehicle communication systems [1] including peer-to-peer and peer-to-base station communications. Seamless integration of in-vehicle networking with existing wireless telephony infrastructure is a cornerstone of next-generation ITS. Drivers should be able to roam between their cellular phone network and their in-vehicle network. Data access and synchronization happen automatically and transparently. Peer-to-peer communications provides an ability for information to be relayed down a highway so that a transportation system can adapt and respond to events autonomously in real-time.

In this paper, we present an extensible vehicle performance monitoring system that exploits data transmission capabilities of the Global System for Mobile Communication (GSM), and is based on existing in-vehicle automotive standards. Our design is extensible to large metropolitan areas in which millions of vehicles will need to be simultaneously tracked and monitored. Though many systems currently integrate position tracking and wireless networking to allow for remote position tracking, few systems provide the capability to monitor vehicle performance over the web.

Our design is based on a popular new standard for wireless communications — GSM/GPRS [2]. An in-vehicle standard for diagnostic information, OBD-II [3], is used to gather performance data. We also exploit Global Positioning System (GPS) technology [4] to provide vehicle location. Data is integrated and transmitted to a web server using Apache's Tomcat extensions [5] to provide Internet access via a vehicle tracking web site. The overall system has been in use for several months on a trial basis at Mississippi State, and will soon be tracking the entire campus bus system. The data collected from this pilot study will form the basis for a research initiative in prediction and optimization of vehicle performance.

Possible applications for such technology are summarized in Figure 1. Many systems today combine these technologies to create a unique service. For example, OnStar [6] has grown increasingly popular as a way to deal with roadside emergencies. Homeland security applications are placing a significant demand on fleet operators to account for the location and contents of their vehicles. First responders [7] to emergencies, such as

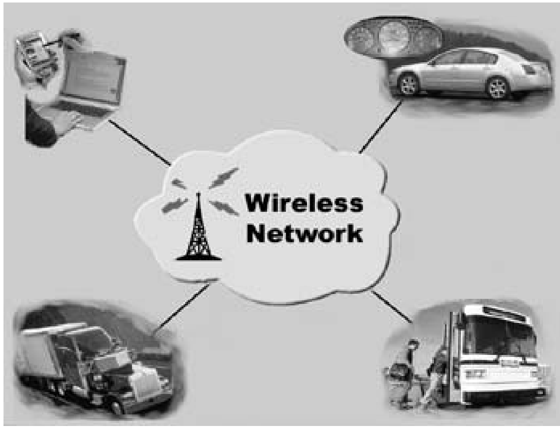

Figure 1: Real-time vehicle tracking and monitoring is evolving from simple systems such as OnStar to more sophisticated systems that provide emergency response capabilities. Providing access to vehicle data (B) via Internet application (A) can lead to intelligent mass transportation (D) and secure fleet management (C).

hazardous material spills or natural disasters, have a great need for rapid delivery of information about vehicle content and location, as well as real-time mapping information. Such applications have the ability to exploit next generation wireless technology that can deliver bi-directional high-speed data connections to moving vehicles, and data warehousing applications that monitor transportation infrastructure. GPS, which began as a military application, has become a viable tool for many commercial and personal applications. One such application has been a vehicle location tracking system (VLTS) [8]. These tracking systems incorporate a GPS receiver and a wireless transceiver that allow a remote unit to track the vehicle's position.

Remote access to on-board diagnostics and performance data is a crucial requirement for ITS. The 1990 Clean Air Act required an on-board diagnostic system, which provides an early warning of malfunctions to major engine components such as emission controls. The Society of Automotive Engineers (SAE) standardized the networking protocols and information parameters. The Environment Protection Agency (EPA) adopted these standards and mandated these standards and practices to all automobile manufacturers in 1996. OBD-II is the SAE second-generation of these standards and practices.

In this paper, we describe a vehicle position and performance tracking system (VPPTS). A background of the relevant technologies is given in Section 2. Section 3 describes the implementation and testing of a VPPTS prototype. Section 4 compares and contrasts this system with other VLTS systems. Finally, in Section 5, we conclude with a discussion of future directions for this research project, and discuss our deployment for a campus bus tracking system available at *http://www.isip.msstate.edu/projects/cbn*.

2. Background

The VPPTS prototype consists of three underlying technologies: GPS, GSM/GPRS, and OBD-II.

GPS provides highly accurate position information and can be used for a variety of land, sea, and air applications. GPS was developed by the U.S. Department of Defense (DoD). The system consists of a constellation of 24 geostationary satellites, shown in Figure 2, orbiting around 11,000 miles above the Earth's surface [9]. GPS was dedicated solely for military use and has recently been declassified for civilian use.

To acquire GPS information, a wireless receiver capable of the civilian L1 frequency (1575.42 MHz) is required. The GPS receiver measures distances to four or more satellites simultaneously. Using triangulation [9] the receiver can determine its latitude, longitude, and altitude.

GSM has become the world's fastest growing mobile communication standard. It allows for seamless and secure connectivity between networks on a global scale. Digital encoding is used for voice communication, and time division multiple access (TDMA) transmission methods provide a very efficient data rate/information content ratio [10]. While GSM is becoming the standard for person-to-person communication, the circuit-switched network limits data transmission. General Packet Radio Service (GPRS) was developed to relieve this limitation.

GPRS is a data communication layer built over the GSM wireless transmission link [2]. GPRS uses the remaining capacity leftover from GSM voice communication [11] and has a theoretical max speed of 171.2 Kbps making it a viable choice for wireless data transfer [10]. Using a packet format for data transmission allows for full compatibility with existing Internet services such as HTTP, FTP, email, instant messaging, and more.

Since 1996, on-board diagnostic (OBD) systems [3] have been incorporated into vehicles to help manufacturers

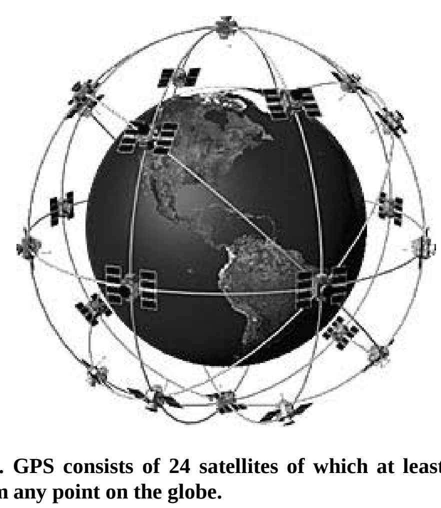

Figure 2. GPS consists of 24 satellites of which at least 5 can be seen from any point on the globe.

meet emission standards set forth by the Clean Air Act in 1990 and the Environmental Protection Agency (EPA). The Society of Automotive Engineers (SAE) developed a set of standards and practices that regulated the development of these diagnostic systems. The SAE expanded on that set to create the OBD-II standards. The EPA and the California Air Resources Board (CARB) adopted these standards in 1996 and mandated their installation in all light-duty vehicles.

The OBD-II system allows for monitoring of most electrical systems on the vehicle. Monitored items include speed, RPM, ignition voltage, and coolant temperature. This system can also inform an engineer when an individual cylinder has a misfire.

The SAE recognizes three communication patterns described in Table 1. The SAE J1850 VPW standard uses a variable pulse width modulation signal [12]. It operates at 10.4k Baud with one signal wire and a ground wire. The SAE J1850 PWM standard uses a pulse width modulation signal [12]. This operates at 41.7k Baud by using a differential transmission scheme. The ISO 9141-2 standard uses two signals (K and L) [12]. One signal travels on a full-duplex wire, and the other operates on a half-duplex wire. Most communications with the OBD-II bus occur on the K signal while the L signal is required for initialization of the bus.

Table 1: The SAE recognizes three protocols in the J1850 standard, which define how electrical signals will propagate through the vehicles communication bus.

Protocols	Signal Type	Manufacturer
SAE J1850 VPW	Variable Pulse Width	GM
SAE J1850 PWM	Pulse Width Modulation	Ford
ISO 9141-2	Two Serial Lines: Half-duplex (L) Full-duplex (K)	European, Asia, and Chrysler

3. VPPTS Prototype

Off-the-shelf items, acquired to establish proof of concept, were used to assemble our initial VPPTS prototype. A Garmin GPS 35-PC receiver is used to collect the recommended minimum data sentence (GPRMC) from the NMEA standard protocol [15]. OBD-II data is gathered by a BR-3 interface. The interface incorporates a Microchip BR16F84-1.07 microcontroller, which operates on all SAE J1850 protocols. A Sony Ericsson GC-82 EDGE PC card is used to access the Cingular Wireless GSM/GPRS network. A laptop, equipped with two serial ports (DB9) and a PCMCIA port, acts as a hub through which data is routed. This system was designed with these components to support rapid experimentation and data collection.

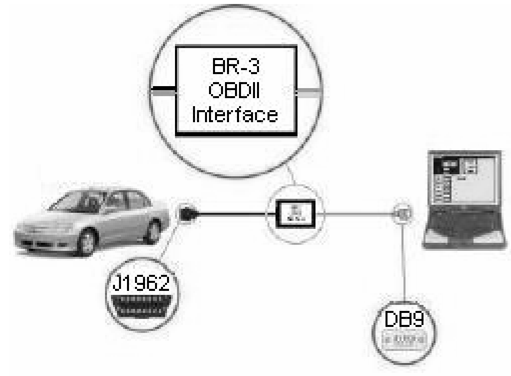

Figure 3: The BR-3 interface is used to communicate with the vehicle's on-board diagnostic system, which offers performance data to the data collector software via RS232 port.

The data collection software was developed with Microsoft C# using a Visual Basic 6 serial port API. Tomcat web server together with MySQL database server act as the gateway for users to view the location and performance data of each vehicle. The user interface was developed with JAVA SDK 1.4.2_05.

The data collection software combines GPS coordinates and OBD-II data into a single data stream that is sent to the server via the GSM/GPRS network. The data is retrieved from the OBD-II system by continuous polling. Transmission of data to the server is triggered by a received event from the GPS device, which is connected to a serial port. This allows for a one second minimum resolution.

The BR-3 OBD-II interface is connected to the vehicle via the SAE J1962 [13] connector located within three feet of the steering column. A serial RS232 port on the laptop allows the data collector software to communicate with the BR-3 OBD-II interface. Figure 3 shows the BR-3 connection diagram.

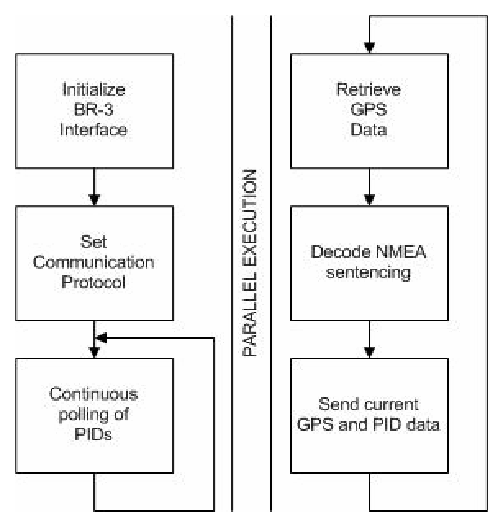

Figure 4: The data collector polls the vehicle for performance information and receives new GPS coordinates simultaneously.

The baud rate between the BR-3 and the laptop is 19,200 Baud with no handshaking. A CRC byte, specified by SAE J1850 [12], is checked to confirm a successful transmission. All three protocols specified by SAE J1850 standard can be accessed with the BR-3. The VPPTS prototype uses generic parameter identifications or PIDs defined in SAE J1979 [14]. These PIDs include vehicle speed, engine RPM, calculated throttle position sensor (TPS), engine load, engine coolant temperature, and air intake pressure. Car manufacturers such as GM and Ford have enhanced PIDs that are specialized for their vehicles.

Figure 4 illustrates a state diagram for the data collector. The BR-3 must be initialized and, depending on the make of the vehicle, a proper protocol must be set. Once these are established polling for data will commence on a continuous basis. The GPS data is transmitted as character arrays known as sentences. These sentences correspond to the NMEA standard [15] for GPS data. The GPRMC sentence, which contains UTC time, UTC date, longitude, and latitude, is decoded. The software parses the sentence and prepares the GPS data along with the current OBD-II data. The data is then sent to the server via GSM/GPRS.

The server was built using a dual processor PC, which is used to run the necessary software for the prototype system. Tomcat, MySQL, and Apache constitute the software needed to run the data and the applet. Five Tomcat httpservlets are used to maintain the data flow. MySQL was chosen to be the database management service, and Apache handles all HTTP page and image requests.

The httpservlets handle all the connections made to the database server (MySQL). There are two servlets that receive data from the collector through an http post. The data is then updated to the database. The other servlets make queries to the database package the data into specialized classes and send the classes to the applet when the data is requested. Figure 5 shows the data flow to and from the server.

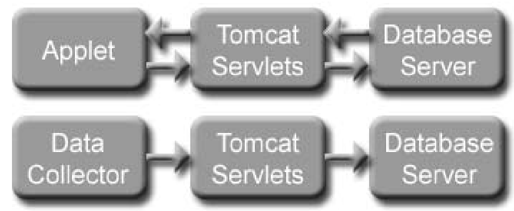

Figure 5: The data flows to the users applet interface after being processed by the server.

Several tables are used to maintain separation of data within the database. The *stops* table contains a label and GPS coordinates for each bus stop on all routes. The *routes* table contains a list of the routes and the order at which the stops are traversed. The *buses* table contains the current location and route information for each bus. The gauges database contains the telemetry data from each bus. There is also a table for each bus that contains all the past telemetry readings for that specific bus. This data can be stored indefinitely so it can serve as a tool for analysis and simulation of vehicle performance.

The Java applet was developed to display the tracking and performance information to the public via the Internet. The applet displays vehicle location on a digital map. Route information about the vehicles, in this case the campus bus system, is also available. When a bus is selected the user can view the current vehicle gauge data via graphical gauges such as in Figure 6. This implementation allows the public to track a bus of interest, and fleet managers to monitor bus performance.

4. VPPTS Integration

The final design is a single-board that integrates modular chipset solutions for the automotive bus interface, a GPS

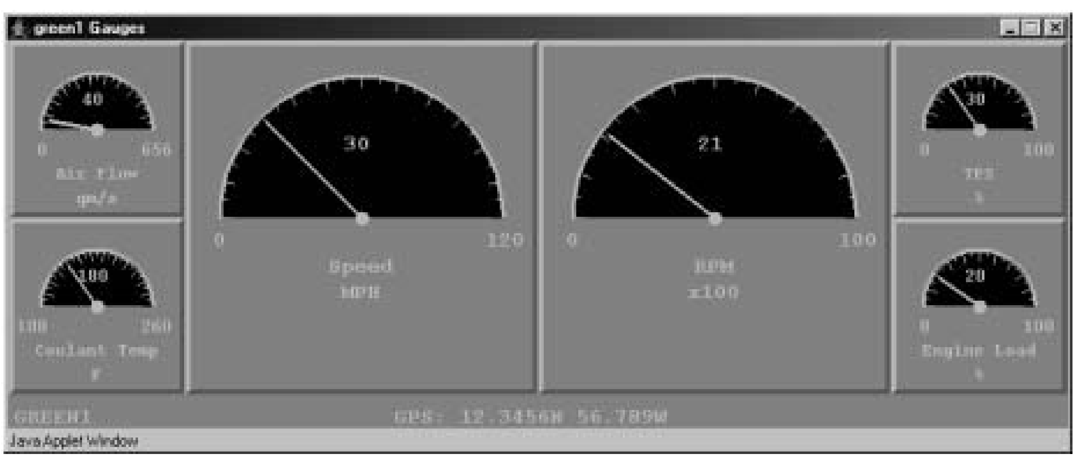

Figure 6: The analog gauges applet displays real-time performance parameters.

receiver, and a GSM/GPRS modem into a less than 16 in^2 board located inside the dashboard or in the trunk of a vehicle. The system is powered directly off the on-board diagnostic connector that includes 12V power.

External antennae are added to increase the reliability of GSM and GPS reception. Tracking more parameters and adding feedback features such as peer-to-peer communications further increases the system effectiveness. Integration of Bluetooth and IEEE 802.11b wireless (WiFi) technology eliminates the cost and labor of point-to-point wiring within the vehicle.

Figure 7 shows the system communication architecture. This communication architecture allows a web-enabled application to monitor various sensors in a vehicle across the GSM/GPRS network.

Our system design incorporates both light-duty and heavy-duty communication protocols. The SAE standards J1708 [16] and J1939 [17] explain the heavy-duty protocols and parameters. J1939 describes the next generation of heavy-duty vehicle network based on controller area network (CAN) [18]. Heavy-duty vehicles include semi-trucks and buses.

The database can be extended to include cargo contents, driver identification, and named-based location data such as cities, street names, and businesses. Our system design incorporates Geographic Information System (GIS) [19] data, which allows for faster response times in map drawing. This is crucial for applications involving emergency response to hazardous material spills, vehicular accident, etc. GIS is a standard digital mapping format that uses GPS coordinates. GIS allows the final design to be scalable to wider areas such as citywide, statewide, and even nationwide.

Many systems offer vehicle security and tracking. Systems such as Trackn, OnStar, and TrimTrac offer remote lock mechanisms and roadside assistance. Subscription services are required for these systems. Our

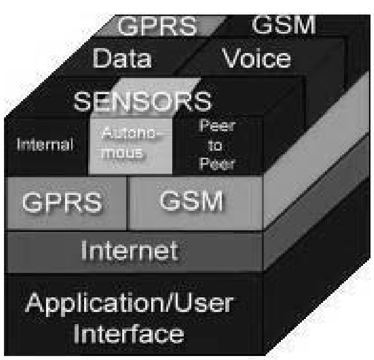

Figure 7: This communication architecture allows a web-enabled application to monitor various sensors in a vehicle across the GSM/GPRS network.

VPPTS offers vehicle tracking using a well-established GSM/GPRS network and also offers performance tracking for the host vehicle, which can be monitored over the web.

Timing has been a major issue in the development of this system. Initially, a system timer was used to trigger an event that would send the GPS and current OBD-II data. The intervals conceived were between ¼ and 5 seconds. This small resolution could not be achieved because polling at least 6 PIDs took longer than ¼ seconds. To keep an accurate resolution the GPS signal was used as an event trigger. This kept the resolution at multiples of one second.

5. Conclusion

In this paper, an extensible vehicle position and performance tracking system prototype (VPPTS) was presented. The system uses off-the-shelf technology and interfaces to industry-standard communications channels. A network of these systems is being used at Mississippi State University as a proof of concept demonstration of a next-generation intelligent transportation system (ITS).

By exploiting GPS technology, a vehicle's location can be pin pointed to within a couple of meters. An in-vehicle standard for diagnostic information, ODB-II, is used to gather performance data. Using a GSM/GPRS modem. the location and diagnostic information can be made available to a remote site via the Internet. Data is integrated and transmitted to a web server using Apache's Tomcat extensions to provide Internet access via a vehicle tracking web site. Many existing systems offer these technologies with a subscription service. Our system design has an open architecture that can be easily expanded to other applications.

There are two important upgrades planned for this system. First, we will integrate a GIS relational database of our region into the system using technology based on ESRI's ArcGIS [19]. This will greatly reduce the amount of data that must be downloaded to the client, and vastly increase our ability to interact with the maps. The State of Mississippi has been leading the nation in developing detailed statewide digital maps [20]. Our system will be able to interact with this information and produce many types of value-added features such as information queries (e.g., "What is the closest fast-food restaurant to the Union bus stop?). More importantly, this will allow the system to work well on low bandwidth devices with small displays, such as cell phones and PDAs.

Second, we are developing a third generation of this system that will include seamless in-vehicle communications with existing wireless devices, as well as an ability for buses to interact in a peer-to-peer manner. This new hardware will support other vehicle communication protocols such as the SAE J1708 and

J1939 communication standards for heavy-duty vehicles (e.g., passenger buses and semi-trucks).

We expect this system to be operational on our campus bus system in Spring'05. Our current plan is to expand its use to the local community, and selected university vehicles, in Fall'05. A demonstration will be available at *http://www.isip.msstate.edu/projects/cbn*.

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