GPS/GPRS on the Road

Virtual Radar for a Swiss Bus Fleet

ADRIAN REMPFLER
METTLER-TOLEDO
HEINZ MATHIS
UNIVERSITY OF APPLIED SCIENCES
RAPPERSWIL, SWITZERLAND

In a down-to-earth design somewhat reminiscent of the automatic dependent surveillance–broadcast (ADS-B) system being implemented in the U.S. airspace, system developers in Switzerland have outfitted a fleet of buses on a private, but narrow and mountainous road system, with combined GPS, GPRS communications, and portable navigation device displays. The system effectively implements a "virtual radar" in the vehicles that enables drivers to anticipate and avoid the approaching traffic on blind corners and perilous stretches of road.

Device mounted in a bus.
Courtesy of Fideriser Heuberge AG

GPS was introduced to much of the consumer market during the 1990s in the form of car navigation systems. This was the era of standalone navigation solutions.

Today, network-based navigation systems are common and, in the context of commercial vehicle tracking, usually required. One application in this field is fleet management for taxi companies. A human operator at the service center coordinates the pickup of the next customer by the closest vehicle.

The goal of the project described in this article was to support a bus company, Fideriser Heuberge AG, with a fleet of vehicles operating on narrow, curving roads in a remote valley of Switzerland. In the course of this project, we developed and implemented a system that allows every bus driver to see around "blind" corners. In effect, we wanted to

provide the driver with a kind of proximity alert whenever another bus is approaching around the next corner.

A Step Ahead

The project discussed here goes a step beyond the example of taxi fleets mentioned earlier. In the Fideriser Heuberge system, the task of the person at the service center is carried out by a computer, which dispatches the incoming messages and broadcasts the information to every device that is currently on air.

This methodology, however, implies the implementation of management software for connections and algorithms to detect any loss in communications. If a connection is lost, the system needs to reestablish the link automatically.

In the operation area of the bus company the only wireless coverage available is by means of GSM or satellite communication. Because satellite communication costs several times as much as GSM, the choice seemed obvious: GSM, or general packet radio service (GPRS), to be more specific.

A proprietary radio system was out of consideration because of the high amount of engineering resources that would have been needed. As client hardware on board the buses, we used a personal digital assistant (PDA) containing all the needed parts that are indispensable to providing the necessary functionality. These are, namely, a 20-channel GPS receiver, GPRS modem, display, and a sound device.

Proprietary hardware was considered too expensive. Furthermore, the physical requirements for the hardware were very high because of the challenging environment in a frequently vibrating bus.

In hilly and mountainous terrain, clear views of the road are not available at all places. Traditionally, mountain buses sound a horn before turning around a potentially dangerous corner. Besides the danger of collision, finding room to pass oncoming traffic on narrow roads can be difficult. However, in an area with no private transportation, all vehicles operating on the road network can be known and equipped with a GPS/GPRS tracking device.

Past approaches to tracking vehicles and goods usually send positions and other parameters of interest to a data server where a human scheduler can take advantage of this information to manage the vehicles.

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In contrast to such fleet management applications, the Fideriser Heuberge system automatically redistributes the real-time positions of all vehicles to every vehicle in the fleet. This allows each driver to visualize the positions of oncoming vehicles well in advance. Acoustic warnings produced by the PDA further alert the driver to the presence of oncoming vehicles in the immediate vicinity.

The bus company has a fleet of 10-12 buses, which are used as necessary, that is, without a fixed time schedule. So, the software had to deal with various combinations and numbers of buses used at any given time. This required software capable of managing all devices dynamically, adding and removing devices as they, respectively, begin transmitting position reports or go out of service and disappear from the air.

Operational Environment

To realize a system such as this, we have to first consider the physical surroundings. In dialog with the customer, the required functionality of the system became clear. During operations, bright sunlight can shine from behind the windshield-mounted PDA rendering the display content unreadable by the driver. For this reason, an acoustic interface was mandatory.

Moreover, we also had to consider the likelihood of vibrations caused by movement of the bus over a bumpy gravel road. However, because the PDA unit that we had selected was designed to act as a car navigation device, the manufacturer had already taken countermeasures in providing an appropriate mounting kit (a "goose neck" style as shown in the accompanying photograph).

When we examined the track along which the buses travel, we identified some regions of weak or absent GSM coverage. This increased the requirements for the software in terms of

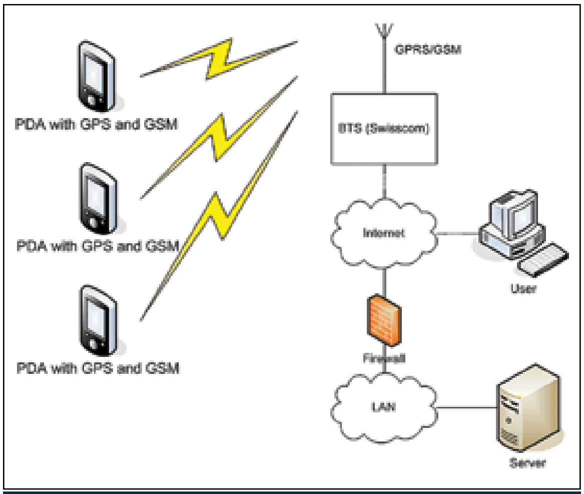

FIGURE 1 Schematic system overview.

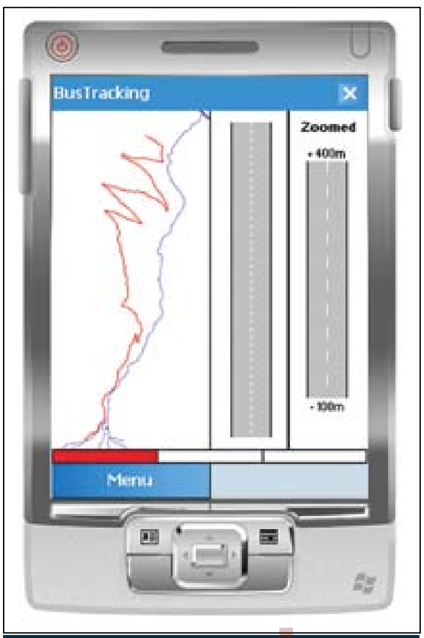

FIGURE 2 Screenshot of the application on the mobile device.

robustness. It had to be able to detect a connection loss and wait for the GSM signal to rise above a certain level, then start to reestablish the connection.

System Overview

Figure 1 shows a schematic illustration of the system architecture. The mobile devices (essentially PDAs with GPS and GSM built in) transmit their positions through an operator's entrance point to the Internet. Only waypoint identifiers with a resolution of 50 meters are transmitted; so, a positioning accuracy for the buses on the order of 10-20 meters works fine. This data flows all the way down to a server sitting at the other end of the chain.

The server can also send back information to the mobile device using the same link in the reverse direction. A third-party observer can passively jump in and, using a web browser, observe the positions of the buses on a map.

Role of Mobile Devices

The mobile unit's primary task is to determine its position by means of the embedded GPS receiver. However, the system functions properly only if the locations of the other devices (and the buses on which they are installed) are known, too. So, the devices need to establish a more or less continuous connection to the system server using the GPRS provided by the GSM network.

As mentioned earlier, a recurring problem that arises in areas off the main roads is the existence of an insufficient network signal. Therefore, the mobile device has to track the signal strength of the GSM system and wait until the signal level is high enough to connect.

Furthermore, the mobile device has to continuously monitor the connection status and intervene if the connection is lost. If the communications link is lost, the device checks the GSM receiving level and waits to reestablish the connection until the GSM signal reaches a minimum strength.

The mobile device maintains a list of received device IDs, their current locations, and timestamps of their last reception. So, if a device is switched off or does not transmit its position within a certain time span — two minutes — due to loss of transmission, the remote device is temporarily removed from the list and is no longer displayed on the local device's map until the communications link is reestablished.

The communications "blind" spots create a small potential risk of an untracked bus encountering another bus. Practically, however, this would occur only if a bus has come to a halt for a long time in a blind spot. In motion, a bus will eventually emerge from the communications blackout.

To provide the bus driver with the necessary information, the device needs to process data from the GPS module as well as information from the PDAs of the other buses. In view of the small display, we had to find a good compromise between detail resolution and an overview of traffic on the road network.

Three different views are provided side-by-side on a single screen of the PDA. The driver has a graphical overview of the buses on the road on a simplified miniature map, on a linear track representation, and on a zoomed linear section (see **Figure 2**). The zoom function, which has a range from 100 meters behind and up to 400 meters in front of one's own vehicle, provides the driver with a capability for multilevel situational awareness of traffic around the bus.

While the bus is operating, the sun may shine from behind the windshield-mounted device and thus make it impossible for a driver to recognize the content on the PDA's display. In this case, to reveal a bus that is approaching from the other direction, the mobile device sounds an alert in an increasing volume.

Communications Costs

As the cost for data transmission on GPRS is quite expensive (SFr 0.10 per 10 kB), the mobile device compresses the data transmitted to the server. This is very efficiently done because of the *a priori* knowledge of the road network.

The track is represented by waypoints equally spaced over the whole course of a bus's route. Using the mapping software, waypoints were selected so as to produce unambiguous trajectories, which are particularly difficult for serpentines. So, the mobile device determines which waypoint is closest to the bus's actual position and transmits only its own ID and the waypoint number — if it differs from the preceding transmitted waypoint.

Hence, the positioning update rate through the network depends on the

Buses passing on a snowy road. In situations with even more snow, passing is almost impossible due to deep ruts that make avoiding a collision difficult.

velocity of the bus and is not equidistant in time. This method allows the system to compress position data from several bytes down to one byte. If we assume that a bus drives up and down the road 10 times a day and therefore passes 10 × 2 × 250 waypoints, the amount of data sent to the server reaches the order of 10 kB.

The communication costs for one bus is SFr 0.10 a day. With two buses in the system, the costs total SFr 0.40; with three buses SFr 0.90. Theoretically the cost of a system of N buses amounts to N^2 × SFr 0.10. However, the GSM provider rounds up the cost for the transmitted data to the next 10 kB each time a connection is lost. Because this is quite often the case, the actual expenses are much higher.

Server Tasks

The server acts as a node for the whole system. Its main task is to retransmit the incoming messages from every device to all other devices. To do so, the server needs to know the IP address and port number of each device.

Because the assignment of the IP address to the mobile device is a task of the GSM system, the server knows the correct IP and port number only after the first transmission from the mobile device to the server. The server stores its number for the backward link in a list together with a timestamp.

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The timestamp is updated every time the device is received. If the device is not received within a certain time span, the entry of that device is deleted and therefore no further data packets are forwarded until communications are reestablished.

On the other side, all mobile devices need to know the IP address and the correct port number of the server application. The server is the only constant in a system of dynamic IPs and port numbers.

To provide the people waiting at the station on top or down in the valley with information about the arrival time of the next bus, the server has to process the incoming messages, which consist only of an ID and a waypoint number, in order to display the bus positions on a map.

For this purpose an Internet–based mapping application is deployed. So, the server has to convert the waypoint numbers to a real coordinate of latitude and longitude and write these values into an XML file. This XML file is then parsed by a JavaScript in the user's browser and the bus positions are displayed on the map panel.

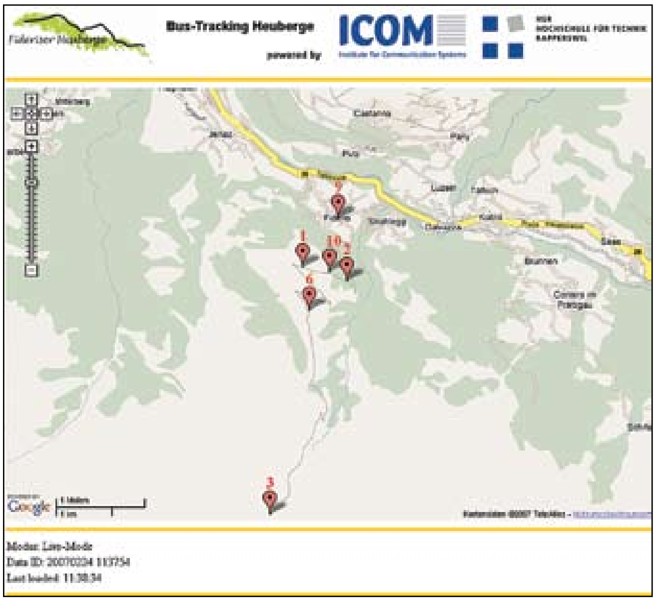
Technology and Challenges

The mobile devices' operating system is Windows Mobile with the .NET Compact Framework 2.0. The program on the mobile devices as well as the one on the server were written in C#. To transmit data over the GSM network, the system takes advantage of the mobile devices' GPRS capabilities.

The link between server and mobile devices is based on the Internet User Datagram Protocol (UDP) protocol and socket programming.

Multithreading. As long as only one thread exists in a program, the behavior of the code is very predictable. However, the software on the mobile device has three simultaneous threads running. The most obvious one is the GUI thread to keep the program responsive to the user. But there are two more: a timer thread to periodically read the own position off the GPS receiver and a thread to maintain the device list (removal of timed-out devices).

Such device lists are held independently on all mobile devices as well as on the server. The third thread is triggered from the UDP socket to update the positions of the other devices. Special care had to be taken to eliminate interference between different threads when they access the same resource, for example, the device list. Debugging by stepping through the code was hardly possible because the other threads were



Web page shows the location of Fideiser Heuberge vehicles

running full speed while the one in focus is stepped through.

Connection reestablishing. Managing the GPRS data stream caused some problems. While testing the first releases of the software on the mobile device, we discovered that the GPRS stream does not recover itself if a lack of GSM coverage occurs. So, the program needs a criterion to decide if the link is broken and a connection recovery needed.

Luckily, the operating system's application programming interface (API) allows access to the system state. Two properties are of interest: the number of connections and the phone signal strength. A timer thread checks every few seconds if the number of connections is larger than zero. If not, the signal strength is examined.

If the signal level is high enough for a connection, another attempt is made to reestablish a connection, and, if successful, the program can continue normal operation. Otherwise, it waits for the next timer event when the signal strength is examined again. This loop is executed until the signal quality exceeds the minimum required level.

Browser incompatibilities. A troublesome issue is the incompatibility between different web browsers, especially when JavaScripts were embedded in the website. Mozilla Firefox has comprehensive debugging tools to eliminate script errors and problems with the html code while some older versions of Internet Explorer have no equivalent tools.

Therefore, the website was first tested on Firefox and then "made compatible" to the Internet Explorer. For example the DOMtree (Document ObjectModel) of the website varies on each browser. So, accessing an element by its index number is a bad idea. The safe way is to name each element that needs to be modified by the JavaScript and then access the element by name.

Conclusions

A new decentralized fleet management system has been introduced using standard components such as an ordinary personal computer and widely available PDAs with integrated GPS and GSM. Depending on the point of view, one can call this system a virtual RADAR, an anticollision system, or a virtual postbus horn.

Special attention has been given to tackle the challenges of robustness (both mechanical and network-wise), a friendly user interface, and low maintenance costs. A variety of technologies was applied, i.e., GPS localization, GPRS transmission, client programming, and Internet-based mapping. Vector quantization reduces the connection costs due to high data compression.

The system has been in use for one winter season and has proved useful for the bus drivers. In one reported instance it has avoided an accident that would have occurred without the system.

Acknowledgment

This article is based on a paper presented at the European Navigation Conference 2007 in Geneva, Switzerland.

Manufacturers

The PDA used on board the buses is the MIO A701 from **Mio Technologies Corp.** (a subsidiary of the MiTAC Corporation), Taipei, Taiwan, incorporating a 20-channel SiRFStar III chipset receiver from **SiRF Technology, Inc.**, San Jose, California, USA, and a tri-band GPRS-capable GSM modem].

The mapping function is performed using Google Maps from **Google, Inc.**, Mountain View, California, USA. The server and mobile device software is written in C# with Microsoft Visual Studio 2005 by **Microsoft Corporation**, Redmond, Washington, USA. The mobile devices' operating system is Microsoft's Windows Mobile with the .NET Compact Framework 2.0. Positions are extracted from the embedded GPS receiver using the Microsoft GPS Intermediate Driver.

Authors

Adrian Rempfler received a diploma in electrical engineering from the University of Applied Sciences Rapperswil, Switzerland. He was working as a soft- and hardware research assistant at the University of Applied Sciences Rapperswil. He is now an R&D engineer with Mettler-Toledo.

Heinz Mathis is a professor of mobile communications at the University of Applied Sciences Rapperswil, Switzerland. He received a diploma in electrical engineering from the Swiss Federal Institute of Technology (ETH), Zurich, and a Ph.D. in electrical engineering at the same university. His research interests include signal processing for wireless communication systems and positioning systems. IG