The sentient car
context-aware automotive telematics

P Vidales and F Stajano
University of Cambridge, U.K

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ABSTRACT

This paper proposes the creation of a sentient space in vehicles with the objective of providing cooperation and adaptation capabilities to on-board systems. The Sentient Car is presented as the testbed for research in this area. Finally, the conceptual model of the context-aware system is presented in a developed application: The Adaptive Pollution Map. This application runs in the Sentient Car and deals with simple context-awareness issues.

1 Introduction

Automotive telematics is the combination of informatics with wireless communications in order to provide services. Telematics is a growing market. Only Americans spend one billion hours a week in their cars, and they want to receive new services while they drive. Today carmakers include telematics only in 5% on the new models, however this is changing and by 2006, 33% of the car models will include some sort of telematics. According to Telematics Research Group, automotive telematics is in the infancy stage and is at the start of an explosive growth cycle.

In-vehicle information systems of non-trivial complexity are already commonplace for electronic engine management, entertainment, voice communications and safety systems. GPS-based mapping and guidance systems have made their commercial debut and are already widely deployed in markets such as Japan.

These subsystems will increase their usefulness once they cooperate with each other to form an integrated system, and once they adapt their behaviour to suit the situation. For example, the mobile telephone that is already present in many cars might be used by the mapping and safety subsystems as a long-range data communications channel for sending out traffic and pollution information of the area currently visited by the car, and for receiving such information for the area the car plans to visit next. The route finder might then choose to avoid an otherwise convenient-looking route in favour of another that uses a less congested road. Similarly, monitoring driver behaviour (steering, braking, accelerating) and atmospheric conditions may allow the safety subsystem to give early warning of dangerous driving situations.

We are exploring the above scenarios in the field. A vehicle has been equipped with several sensing, computing and communicating subsystems, all interconnected to form an integrated sentient car systems with a framework being built to allow each of these subsystems to act as a supplier or a consumer of contextual information about the car, the driver and the environment.

In future experiments, a central server will also collate and redistribute the information from several cars. We are also interested in seamless context-driven handover between communication channels of different capacity, coverage and cost, such as GSM and 802.11b, as well as in the implications that emerge from a model with multiple servers and a fleet of sentient cars.

2 System Resources

We have equipped our experimental vehicle, a Ford Transit, with two dashboard LCD displays, one for the driver and a larger one for the navigator, and with an electrical subsystem to support the power demand of the equipment. The sentient car also has the following subsystems.

Sensing. We measure various air quality indicators (nitric oxide, nitrogen oxides, ozone, nitrogen dioxide) and carbon monoxide and hydrocarbons from the tailpipe emissions with sophisticated sensing equipment. We also have an interface into the Electronic Control Unit (ECU) of the vehicle to extract velocity, acceleration, temperature, steering wheel position, and other vehicle performance indicators. A GPS receiver gives the geographical position of the car to 15 m accuracy. We also sense other context aspects as availability of the computing and communication resources: network connectivity, communication cost, communication bandwidth, device profile, etc.

Computing. A full-size tower PC in the back of the van has interfaces to all the sensing and communicating devices, as well as ample storage and computing capacity.

Communication. A GSM cellular phone and modem respectively provide voice and low-speed data connection with almost universal coverage. An 802.11b network card provides a much higher speed data link but with limited coverage.

3 Conceptual model

The conceptual model of the sentient car system considers each of the sensors and subsystems as an input (location, velocity, vehicle status, etc.) to an *adaptation middleware*, which delivers context information to the on-board systems.

4 Adaptive Pollution Maps

One of the first working applications we have developed senses the air quality around the car and overlays it on a map of the area that the car is visiting. In due course, multiple cars will upload such pollution data to a server that will then redistribute a more complete and up-to-date map to all of them.

The delivery of the maps is affected by context. Hence, we want to implement a thin client solution, which adapts data transfer between client and server according to the context information provided by the adaptation middleware.

4.1 System objective

The *Adaptive Pollution Map* was created to demonstrate the usefulness of context-awareness in vehicles. By creating a sentient space from which the application

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receives context information, we can have adaptive delivery of collected measurements and maps (in terms of computing and communication resources).

4.2 Implementation

The vehicle acts as a sensor, collecting data while it is in motion. The data is sent to the base station, and also displayed on a geographical information system that receives maps from the base station. To control the link between the mobile host and the base station, the application receives the information about its context and adapts the delivery to the particular situation. The current version of this system is a client-server application that is split into a client-side map viewer, running in the car, and a server-side map repository running at the fixed base station. We wish to explore the architectural issues that arise when maps have to be delivered over a channel of varying capacity and therefore we pretend that the whole map will not fit on the in-car computer's hard disk. This is not true for our current experimental setup, but it may be the case once we move to richer media including for example real time video footage of highway traffic. It is common to have limited storage space in mobile devices. Therefore, it is useful to have thin clients that do not rely on huge storage capacity to work.

The map viewer is arranged into layers. Currently, we have two: a bitmap layer showing the actual map and a pollution layer showing our air quality measurements. Many other layers could be added: for example a waypoints layer, a vector map layer, a traffic layer and so on.

The portion of map that the viewer displays is affected by user input (scroll, zoom in, zoom out) and by the current context, which consists primarily of the car's location and velocity as reported by the on-board GPS. The channel capacity is another interesting input since it changes as the car moves. We request a new bitmap to cover the relevant area, but we do so taking into account the time it will take to download it over the available channel.

For example, using 8 cm x 10 cm map tiles of 176 kb each, the time it takes to download one tile over the 9.6 kb/s GSM modem is 18.3 seconds. If we are travelling at 100 km/h heading NE, which tile should we request from the server, and at what scale, so that we are still in the middle of it when we have finished downloading and displaying it, 18.3 seconds later? This is a context-dependent calculation, which is affected by position, velocity and channel capacity.

We are interested in the architectural issues of managing such updates in real time and with a pool of several cooperating cars all uploading and downloading information into a collective map database.

4.3 Maps and pollution data transmission

As part of the sentient car we have a simple subsystem to deal with real time data transmission over channel with varying properties. The objective is to make a seamless handover between two network interfaces with distinct characteristics (coverage, bandwidth, reliability, etc).

The current version of the communication subsystem works with two main software components, one in the client and another in the server. They are located between the application and the network interface(s). In the client, the application connects to the middleware component and starts an IP communication. Leaving the middleware component to manage the communication channels.

The middleware component deals with the selection of the most suitable network interface, and redirects the flow to it. After this, the information goes to the server, where a middleware component receives the information and buffers it to the application. In case of a vertical handover, the flow is buffered so the server side does not realise it.

5 Conclusions

We presented the sentient car project as a testbed for context-awareness research. Introducing sentient spaces into vehicles is a useful approach to react to such variant environment. Mobile environments are highly heterogeneous. Furthermore, due to high mobility vehicles are exposed to unexpected changes in computing and communication resources. One possibility to support these variations and be capable of offering good quality in the services is to prepare for the occurrence of such transitions. Introducing context-awareness to on-board systems follows this idea.

Adaptive pollution maps is the first application. We think that the sentient car is a good testbed for mobile services and location-based systems. Furthermore, through the implementation of the pollution maps we show the utility of combining a geographical information system with sensing capabilities, it results in the possibility of collecting data that can be used in traffic models, opening new perspectives to analyse vehicle impact on the environment.

One of the most difficult parts is to deliver true seamless connectivity all the time. The future wireless scenarios will be made of many overlaying technologies, each of them with their own set of characteristics, vehicles must control handover between technologies, and freedom while roaming between different subnets. We have detected the principles issues that arise from these requirements; context-awareness can reduce the impact of them on telematics services' delivery.

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Note: A condensed version of this material also appears as a poster in Ubicomp 2002.