A STUDY OF ROAD PRICING SYSTEMS BASED ON GNSS/CN

Juan G. Jordán,
Francisco R. Soriano,
Pablo Catalá,
Soledad Montes
LISITT – Instituto of Robotics
University of Valencia
Aptdo. 2085, 46071 – VALENCIA – SPAIN
Tel: +34 96 354 35 77 – Fax: +34 96 354 35 50
E-mail: jjordan@robotica.uv.es

SUMMARY

EFC/road pricing systems based on satellite positioning systems, combined with cellular communications, offer the minimum required road side infrastructure, can give service to an unlimited number of vehicles and without a speed limit. Our project consists in the implementation of a pilot GNSS/CN-based road pricing system. The main objective of the project is to evaluate the performance of these systems, comparing different satellite positioning and communications technologies, and to make a feasibility study for the deployment of these systems in Spain, at a national level and in specific zones of the country.

INTRODUCTION

The traditional tax concept for funding the road infrastructure has proven to be not only economically unsustainable but also unfair from the user’s point of view. The costs of building of new roads and specially the costs of maintenance of the road infrastructure should be addressed to the users that actually make use of this infrastructure. Consequently, several governments around Europe are thinking on alternatives to their traditional tax systems. One of the most solid approaches is what we call road pricing systems.

Basically, these systems transfer part of the incoming for the use of the roads, from traditional taxes to other concepts, directly related with the use of the vehicle, the infrastructure costs and the environmental costs, as the driven distance, vehicle weight, emission class, etc.

In Europe, some initiatives related to Road Pricing have currently emerged, which are possibly not as coordinated as they should be. Such solutions range from the ones given by the short-range technology to the ones based on satellite and cellular networks, which will be obtaining advantages from the beginning of the Galileo project in a short period of time. The different solutions can be classified in the following groups:

- EFC systems based on dedicated short range communications (DSRC)
- Road pricing systems based on global navigation satellite systems (GNSS), usually combined with Cellular Network systems (CN), known as GNSS/CN systems.
- Hybrid systems, using both technologies (DSRC and GNSS/CN). These systems are envisaged as the future solution for European interoperable road pricing systems.
DSRC SYSTEMS

EFC systems based on DSRC are widely deployed along Europe nowadays. They were designed to enhance traditional toll plazas with fully automated lanes, where the vehicle makes use of an on board equipment (OBE) to communicate with the roadside equipment (RSE) to transfer some financial data which allows charging the toll to the user. The RSE includes:

- a DSRC system to communicate with the OBE
- a vehicle detection and classification system (VDAC) to automatically detect and classify the vehicle
- additionally, non-stop systems without barriers need an enforcement system to identify and persecute offenders.

Fig. 1: example of configuration for a free flow DSRC system

This equipment has to be installed over the road, on gantries. The roadside infrastructure for DSRC systems is expensive, and must be installed in traditional toll plazas, which need a lot of space to be deployed. Sometimes it is difficult to build new toll plazas in roads which were not designed to be toll-roads, because of the lack of space, physical restrictions, mountains, etc. It is also difficult to deploy a road pricing system into a city because different RSE using the same frequencies must be separated by a re-use distance, which is the minimum distance needed to prevent interferences between them.

Recent developments of multilane free-flow systems make use of gantries over the road to install the roadside equipment, avoiding the need of building a complete toll plaza. This provides a solution for the lack of space in some roads, but makes more difficult to deal with the offenders, since there are no barriers.

Fig. 2: a free-flow multilane EFC system based on DSRC

Interoperability of different DSRC systems is still an issue. Not only there is no consensus for a European standard on the technical level, but also there should be a common solution at the procedural (common transaction) and contractual (clearing between operators) levels. The CARDME project is working on these non-technical issues. CEN TC278 is leading the standardisation activity at
the contractual level, and has issued the pre-standard ISO 14904 – Interface specification for clearing between operators.

GNSS/CN SYSTEMS

A road pricing system based on satellite navigation systems combined with cellular networks requires less infrastructure on the road side than DSRC systems, because it makes use of two widely deployed systems with highly developed infrastructure and global coverage.

Fig. 3 shows the general architecture for a GNSS/CN system. The vehicle holds and on board equipment (OBE) that computes the toll and sends to the central system a transaction with the charging information.

A GNSS receiver provides the positioning information of the vehicle to the on board equipment (OBE), which uses this positioning information to compute the toll. For the determination of the toll, some geographic events can be used, like computing the driven distance, detecting the entry/exit of a road or area or crossing a virtual gantry (the equivalent to a DSRC gantry, which only exists as a set of coordinates). Also, other parameters can be taken into account, like the amount of time that the vehicle uses a road, type of vehicle, emission class, etc. The CN communications equipment is used to send transactions to the central system, and to exchange control and enforcement messages. It can also be used to update the geographic and tariff information of the OBE. If proper interfaces are defined between the CN equipment and the on board unit (OBU), the CN equipment can be used by other applications to provide value added services to the user. This is an interesting feature of these systems on the way to make them socially acceptable.

GNSS/CN road pricing systems don't have restrictions on the vehicle speed, since the transaction is not carried out in a dedicated zone. These systems solve problems of lack of space, because few infrastructures on the roadside are needed. The enforcement system may need the installation of equipment on gantries, but these gantries can be placed at specific points. There are also mobile solutions for the enforcement which complement these spot check points.

On the other hand, the OBE complex and expensive, compared to a DSRC OBE, and the installation has to be done by expertise personnel. GNSS/CN systems have to deal with availability problems of the positioning signal. The more common approach consists in using a combination of positioning sensors, ranging from a GNSS receiver to inertial systems. Also the enforcement is a complex issue as there are no barriers, and the OBE must be monitored against manipulation.
HYBRID SYSTEMS

This approach provides the framework for the deployment of European interoperable road pricing systems, since it includes both DSRC and GNSS/CN technologies.

Furthermore, this alternative is supported by the European Commission as a long term solution for European EFC (Electronic Fee Collection) systems. The EC, taking into account that the present national EFC systems implemented in Europe (Italy, France, Portugal, Slovenia, Norway) are not compatible, and that the standardisation process for DSRC has been too much delayed, has launched a Directive on EFC, with the objective of implementing the regulatory frame and tools ensuring the deployment of a European EFC service in two stages:

- First stage: Heavy Goods Vehicles (HGV) and Long Distance Coaches, for 2005
- Second stage: All vehicles, for 2010

The directive foresees a mid-term and a long-term solution:

- The mid-term solution will be based on existing technologies, which include DSRC using microwave technology and GNSS/CN technologies. The solution should be based in one of these two technologies, or the combination of them. Operators will be allowed to deploy new systems based on DSRC until 2008.
- The long-term solution will be based only on GNSS/CN technologies. From 2008, DSRC will be considered an obsolete technology, and all new systems shall be based on GNSS/CN. Furthermore, in 2008 the European GNSS system GALILEO will be fully implemented. From 2012 all the EFC systems shall be based on GNSS/CN.

STATE OF THE ART

Initially, due to the positioning equipment current costs, and the accuracy and availability problems of the GPS positioning system, this kind of systems is focused towards road pricing for goods vehicles in main road networks. However, with the future costs reduction and the introduction of other, more reliable, positioning systems such as EGNOS and GALILEO, these systems may be affordable for private cars and with a broader application field.

At present, several countries have seriously considered the introduction of these new road pricing systems: that’s the case of Switzerland, Germany, United Kingdom, France and Holland.

In Switzerland, a road pricing system for heavy vehicles became operative from January 2001, with the aim of collecting a kilometre charging fee on all public roads within the country. The system is based on microwave DSRC and GPS technologies, and a connection to the vehicle’s tacograph. The on-board unit records the driven distance, which the vehicle owner periodically downloads on a chipcard. The information is then transmitted to the Swiss Customs Authority in order to generate the billing.

The DSRC equipment is used for detecting crossings of the border, by installing communication gantries at eighty border crossings, and for enforcement tasks in several spots within the country. For distance counting within Switzerland, the on-board unit is based on the signal coming from the vehicle’s tacograph or odometer. The GPS equipment is used as a controlling and verification subsystem. Supporting the DSRC system, in the case it does not properly detect the border crossing, the GPS system communicates this situation to the driver and unlocks the OBU for allowing manual declaration. Complementing the tacograph input for distance calculation, GPS signal is used, aid of movement and speed estimating sensors, for testing the accuracy of the kilometres counting, detecting calibration errors at the odometer, and in case of lack of signal from the odometer, detecting the error and calculating the driven distance.
The main objective of the German project is the replacement of the current fee collection system for heavy vehicles (Eurovignette) by a road pricing system based on GNSS/CN technology, which will become operative in August 2003. The project is also focused on the possibility of using the system for providing value-added services, in order to achieve a higher acceptance of the users.

The on-board unit is equipped with a GPS system for location, complemented with some sensors and broadcast beacons in places with bad reception or where the GPS signal is not enough accurate. A mobile communication system, GSM, is used both for charging transaction and for value-added services. Enforcement is performed by means of infrared DSRC communications, at road gantries for fixed enforcement, and in vehicle-to-vehicle communication for mobile enforcement. This technology may also be used for future value-added telematic applications, as the communication means with service entry points at beacons, and for information exchange with other vehicles. Moreover, to provide interoperability with ETC systems based on 5.8 GHz DSRC, at least the truck OBUs will have support a “dual band” short range communication.

The United-Kingdom will introduce a road pricing system for heavy vehicles from 2005 or 2006. At present, the Transport Ministry is implementing the DIRECTS project in Leeds, which will lead to the development of national standards for road pricing.

In the same way, the French government has announced the intention of establishing a road-use fee to the infrastructure funding. The initiative, which would become operative from 2006, aims to set a distance-based fee to trucks driving in motorways.
The Dutch project, that considered fee collection for private cars and transport vehicles, has been interrupted due to a government change, staying as an experimental project. This project emphasized the need to include value-added services in order to improve the social acceptance of the system.

ISO TC204 joint with CEN TC278 have initiated standardization activities concerning ETC systems based on GNSS/CN. In the same way, the integration of DSRC and GNSS/CN technologies constitutes a long-term need, towards the implementation of pan European systems. Otherwise, in few years, transport vehicles should be equipped with an intolerable amount of on-board equipments. INITIATIVE project does research into the interoperability of free-flow multiline systems based on DSRC and systems based on GNSS/CN.

THE PROJECT

The Institute of Robotics, which belongs to the University of Valencia, taking into account the recent developments and future perspectives of the GNSS/CN technologies, has launched a project, jointly with the University of Murcia, which is financed by the Ministry of Transport of Spain. This project focus on the study and implementation of a pilot road pricing system based on GNSS/CN technologies.

The main objectives of the project are:

- To develop a pilot road pricing system based on GNSS/CN.
- To evaluate at the technical level the feasibility of a road pricing system based on GNSS/CN, and find the technical limitations of these systems, and alternatives to solve them.
- To compare the performance of different GNSS and CN technologies.
- Designing and building a prototype for the OBE.
- To provide a demonstration of an ITS (Intelligent Transport Systems) application using the EGNOS/GALILEO signal.
- To contribute to the development of applications to the future European GNSS system, GALILEO.

The following GNSS technologies will be considered:

- The GPS system (Global Positioning System), since it is considered the current global positioning standard, and is widely implemented in the car industry.
- The EGNOS system (European Geostationary Navigation Overlay System), which is an augmentation of the GPS signal making use of geostationary satellites, and provides better precision, availability and integrity, compared with the GPS signal.
- The SISNET signal (Signal-In-Space through the interNET), which is another extension of the GPS signal for environments with poor visibility of the satellites.
- The future GALILEO system, which will also provide better precision, availability and integrity than the current GPS signal. Furthermore, GALILEO will not be under military control. The project will consider GALILEO on a theoretical level, because it will not be fully implemented until 2008. The prototype won’t include a GALILEO receiver, but it will be designed thinking on a migratory path to GALILEO technology.

The following CN technologies will be considered:

- GSM
- GPRS

Fig. 6 shows the architecture of the pilot road pricing system:
The system consists in the following modules:

- **Location module.** This module is responsible of the location of the vehicle. The module is based on a signal offered by a GNSS receiver. In addition the positioning can be complemented with other methods as sensors or tachometers.

- **Mobile communications module.** It allows the system to contact with the central system in the payment transactions, Control transactions and in the updates of the OBE context data.

- **Data base.** The data base of the system will store all the necessary data for the processes that will be executed in the system.
  
  - Vehicle characteristics. The vehicle characteristics must be stored in the OBE so that they are available for the computing of the toll.
  
  - Central Systems List. The OBE must keep data about the central systems from the service provider responsible for distributing the contexts. This information will allow him to communicate with the corresponding central system.
  
  - Context information. Information about the defined Geographic Objects in the context, the type of object, its coordinates and additional information relative to these coordinates. Also it contains information about the Context Rules that specify the behaviour of the OBE and include the types of events and the actions to carry out according to the triggering of each event. Finally, it also contains information on the tariffs applicable to each element of the context and the validity period of the data.
  
  - OBE data registry. The OBE will have to maintain a complete registry of the position of the vehicle and of the generated events, keeping the date and the hour from the event, the type of event, and other details about the event, for example the amount of the toll or the parameters that have been used for the calculation of the tolls.
  
  - Transactions registry. Registry with information on the payment transactions made by the OBE. The payment process is made in a date and specific hour and must be registered in the OBE.

- **User Interface.** The user interface of the OBE consists of a small keyboard by means of which the driver will be able to introduce data and a display to show information to the driver (text).

- **OBE Process.** This module of the OBE is performs the control and coordination of all other modules. It consists in a series of sub-processes that will be responsible of the different modules in which the system is divided. The main module is in charge of controlling tasks and
communicating to the rest of processes. This main process is also in charge of receiving and generating the events and transmitting them to the corresponding processes, besides to provide the necessary data to them for the accomplishment of the action. The rest of processes are in charge of the management of the diverse modules that compose the system.

- **Optional modules.** Within the EFC system there are two functions that are considered optional, the Enforcement, and the Security, with the use of a smart card.
  
  o **Enforcement.** The Enforcement process will allow that the supplier of services can verify the correct use of the system on the OBE side, establishing a communication by means of a DSRC connection with the OBE.
  
  o **Security Module.** The communications between the OBE and the central system can be carried out in a secure environment, keeping the integrity of the exchanged data. In order to maintain the data integrity a smart card could be used. In addition, security policies should be defined.

**CONCLUSIONS**

The Institute of Robotics, jointly with the University of Murcia, are working on the development of a road pricing system based on GNSS/CN technologies. One of the main objectives of the project is to evaluate the performance of GNSS signals for road pricing, to find the limitations of these technologies and find alternative solutions for the vehicle positioning. Also, the costs associated to the CN communications will be considered, comparing the different technologies available. Different tolling schemes will be tested. Finally, a prototype will be designed and build, taking into account the limitations associated to an on board equipment.

**REFERENCES**

(1) CEN Report N798 Road Transport and Traffic Telematics (RTTT) – Electronic Fee Collection (EFC) – Application Requirements for Global Navigation Satellite Systems and Cellular Networks (GNSS/CN) based EFC

(2) Draft CEN/TS ISO CD 17575 Road Transport and Traffic Telematics (RTTT) – Electronic Fee Collection (EFC) – Application Interface Definition for Global Navigation Satellite Systems and Cellular Networks (GNSS/CN)

(3) CEN TC278 WG1 SG5, Cellular networks / GNSS - concept and scope, April 1996

(4) HVF – in concrete terms. The Heavy Vehicle Fee/HVF: Background – Fees – Recommendations – Alternatives

(5) Bernhard Oehry. Inside LSVA – Technical Concepts of Kilometre Charging in Switzerland. 8th World Congress on ITS; Sydney, Australia, October 2001.

(6) Rainer Beyer. ETC Project Germany. Technologies to support the road pricing Seminar, Valencia, Spain, September 2002.