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GPS BASED ELECTRONIC ROAD PRICING SYSTEM

The present invention relates to an electronic road pricing system utilising the Global Positioning System (GPS) commissioned by the Defence Department of the United States of America.

At present, a variety of options are being pursued in various countries with regard to electronic road pricing systems for automatically collecting toll charges from road users without the need for the specific construction of a toll plaza including toll booths, as required at present, so that toll charges can be assessed automatically and either debited from a credit provided on a smart card or subsequently billed from the user.

The object of the present invention is to provide an electronic road pricing system utilising the Global Positioning System (GPS) to monitor vehicle movements and bill users accordingly without the need for erection of expensive and large toll plazas.

According to the present invention there is provided an electronic road pricing system comprising:

a receiver for receiving signals from the Global Positioning System (GPS) and providing positional data in respect thereto;

a controller for receiving said positional data from said receiver and including means for producing billing information according to predetermined parameters and said positional data;

wherein additional means are provided for supplying correctional offsets, combining different possible errors, to said GPS receiver to improve the accuracy of said positional data provided by said

receiver.

Preferably, said controller outputs said billing information directly to a card reader, which is preferably a smart card reader, which may, for example, be charged with a predetermined credit level so that said billing information may be utilised to deduct specified amounts from said credit level or alternatively indicate a debit level if said credit is fully consumed. Preferably said smart card reader includes means for indicating the level of credit available, or alternatively, the amount of debit incurred up to a permitted level.

The GPS system utilised by the present invention comprises a network of ground stations and a constellation of 24 satellites positioned in an altitude of 11,000 miles, orbiting the earth every 12 hours in such a way that at least 4 satellites should be visible to any receiver at all times enabling the system to give a reasonably accurate indication of the terrestrial location of the receiver at any particular time. Each satellite is equipped with an atomic clock which assists with the generation of a complicated pre-defined Pseudo-Random sequence which is unique to each satellite. Two separate forms of code are then transmitted on two difference channels. The P-Channel is heavily scrambled and encrypted and is primarily intended for military use, while the C/A-Channel is receivable by moderately complicated receivers, allowing more generalised use of the system.

Given the sequence to be transmitted from the satellites and by means of a clock synchronised with the GPS clock, a receiver can generate the same code sequence and by measuring the time difference between

the arrival of the same code from different satellites, can determine its relative position to the satellites. Since the signature and thus the position of each satellite is already known, the receiver can calculate the proximity of the reception area. This principle is currently utilised in all the commercially available GPS based Land Survey systems.

Unfortunately, the system is not free from error, sources of the errors that can affect resolution of the calculations are:

1) Signal Path Delays, e.g. Atmospheric and Ionospheric conditions;

2) Orbital variations, primarily caused by satellite deviations from their intended orbits; and

3) Selective availability, which is a random decommissioning of satellites by the U.S. Department of Defence to degrade its military reliability and thereby prevent hostile military forces from utilising the GPS service.

The combined effect of the abovementioned error sources can cause positional accuracy to vary between 20 metres to 100 metres.

Since a coarse resolution of proximity information does not enable a GPS based system to be a strong contender for an application such as electronic road pricing, it is necessary to provide a means for improving the accuracy of said positional data primarily on a local basis. By such a means, if the GPS receiver is supplied with correctional off-sets, combining different possible errors, highly accurate positional

calculations down to 5 meter resolution can be readily achieved.

The present invention will now be described further with reference to the accompanying drawings, in which:-

Fig. 1 illustrates an electronic road pricing system according to the present invention;

Fig. 2 illustrates the in-car smart card reader and receiver unit;

Fig. 3 illustrates an enforcement set-up; and

Fig. 4 illustrates the enforcement equipment in more detail.

As can be seen from Fig. 1, the system comprises a fixed GPS receiver positioned in a known location and which is utilised to enable the calculation of the instantaneously combined error offsets per detected satellite. This information is time multiplexed into a local FM broadcast covering a predetermined area. In each vehicle which is fitted with such a GPS electronic road pricing system, a low-cost in-vehicle GPS receiver is installed which is firstly capable of receiving the coarse positional data, and secondly able to receive the local FM broadcast containing said correctional information from said fixed GPS receiver to enable the in-vehicle GPS receiver to take into account the correctional offsets and output highly accurate positional data.

The in-vehicle GPS receiver is provided with a Micro-strip antenna Structure capable of receiving low power RF signal. The carrier frequency is 1.57528 Ghz and the signal power is well below the background noise level of -120 dBm. This makes it almost impossible to

jam the GPS signal. The receiver comprises of RF receiver circuitry, control and a DSP engine.

An input signal is first down converted through several stages of multiplication and filtering. It is then compared against the outputs of a number of pseudo-random sequence generators. Each code generator is capable of reproducing the unique code sequence of any of the available 24 satellites. These code generators are controlled by a search algorithm that identifies the most likely cluster of codes that should be tried. If a match is found, the DSP engine is signalled to lock to that satellite and retrieve the information. Based on the recovered information, the distance to each detected satellite is calculated. A simple FM receiver on a fixed frequency is also included which receives burst correctional data from the local FM station. The correctional offsets, plus distances to each satellite will be used by the DSP engine to calculate the exact co-ordinates of the receiver. Furthermore, to counter the Doppler effect caused by relative movement of satellites and the receiver, numerically controlled oscillators are implemented that feed the code generators and the signal matching modules.

The positional data from said GPS receiver is output to an interface module and system controller respectively capable of interpreting and reformatting the receiver data running billing and system control software. Data relating to billing zones and tariffs is stored in a data bank. The data bank is essentially an EEPROM that can be accessed and uploaded through a protected port. The port can be accessed by specially designed matching instruments that execute a predetermined dialogue and exhibit specially encoded passwords. These matching access devices are

exclusively made and encoded for the enforcement authorities. The processor is programmed to recognise and allow access to matching instruments which adhere to a pre-determined protocol and transmit the right access codes. The matching instruments are also serial numbered. Everytime an access takes place, the serial number of the matching instrument plus the date and time of the access is recorded both in the EEPROM as well as inside the Smart Card. Therefore, at any point in time, two identical copies of the access history are held by the system. Each update is also time stamped so that it should go into effect at a particular time and date. It is therefore possible to activate and enforce a new tariff regardless of when the actual update has been loaded into the system. If so desired, it is even possible to update the zonal and tariff information through the FM data channel.

Since the system has an accurate built-in time measurement, the tariffs can be applied according to a pre-scheduled timebase to enable different tariffs to be applied during different times of the day, e.g. to increase billing rates during peak travel periods and to reduce billing rates during off-peak periods, whilst also being able to adjust billing rates according to location and type of road.

The positional information used by the billing system operated by the controller with its billing software is utilised to determine in which charge zone a vehicle is currently travelling and, based upon tariffs set for that particular zone and considering parameters of time and day, it will determine whether or not a debit command should be output, and if so, the amount of any such debit which may be required. Such debit command is suitably output to a smart card reader, as

shown, although such could be utilised for another form of billing, if preferred. With a smart card, such could typically be charged with a predetermined amount of credit prior to commencement of a journey and such credit could then be debited appropriately each time the vehicle is utilised within a chargeable road system.

The smart card reader is essentially an electromechanical structure for read/write of magnetic cards, whilst the billing mechanism, on the other hand is a digital processor that decides based on the position of the vehicle and the time and calendar information what tariffs should be applied and how the charges should be accumulated. It has the ability to apply the tariffs not only on a per entry basis, but also on the amount of time the vehicle spends in the zone.

Furthermore, the system would allow negative values to be accumulated in the smart card. The minimum value beyond which the system should dis-allow entry could also be determined and programmed into the system.

In a system as envisaged in the present invention, the in-car unit would be provided in a sealed housing incorporating anti-tamper devices and would suitably be powered by the electrical system of the vehicle and the functionality of the system indicated by a visible tamper-proof light installed inside or outside the vehicle.

The smart card bears the same serial number as given on the housing of the in-car unit. It contains three different files. First, the stored value of the card, and the last "N" transactions. Second, is the last "N" time stamps and the serial numbers of the

matching boxes that have accessed and updated the zonal and tariff information. And third is a log file that records the last "N" violations and non-functional status of the unit. Comprehensive status codes are defined that cover all possible violations, including attempts to tamper with various components of the unit or attempts to gain entry into tariff zones while Smart Card is under-valued. Whenever possible, the log file contains the coordinates of the occurred violations. In all the abovementioned cases, N to be determined by the enforcement authorities.

The system controller is programmed to run a built-in self-test program on a continuous basis, according to which various components of the system are continuously interrogated and monitored for their correct functionality. The output of this self test program is collected and transmitted to a status monitoring block. Based on the received information, the status monitoring block decides what action should be taken. These could range from logging status to activating status lights. This also drives an LCD screen on the unit on which the zonal information as well as the value of the smart card are displayed.

A total of six LED's are provided. These are defined as:

System Functional
Signal is being received
Violation is detected
Smart Card is charged
Chargeable Zone
Smart Card has insufficient value

The antenna compartment is also controlled by status monitoring block. It essentially consists of

four different components. First, is a micro strip antenna for receiving GPS signal from satellites. Second is an FM antenna receiving the differential GPS information and other data from a local broadcast. Thirdly, an array of LED's are built in to provide for communication with interrogation stations using Infra Red.

Fourthly, the antenna compartment will house a double tone, visible status light. One tone signifies Functional Status, and the opposite tone will indicate a non-functional status. These lights are activated by special codes that the unit transmits to them through a connecting cable. The compartment is also constantly interrogated by the unit for status codes.

The zonal information as well as tariffs are down loaded into the system through a protected serial bus with proper passwords. The activation of the tariffs is time programmable. The status of the unit can also be read through the same serial bus when vehicle checks are done.

There is a self-test mechanism activated at all times. In the following instances the Enforcement light will be lit and the Date and Time of the incident as well as coordinates of the vehicle will be logged inside the unit. The same information is also written into the smart card.

1. If the unit or the Enforcement Light are tampered with.
2. If the stored value of the smart card falls below the permitted negative value, and the vehicle attempts to enter a zone for which charges are applicable.

3. If the antenna is covered for a pre-specified period of time (resulting in signal interruption).

Moreover, since each unit is identified by a unique serial number, when the unit detects any of the abovementioned conditions, the serial number of the unit plus date and time could be interrogated. Police could easily identify and track the vehicle by utilising the unit serial number. When the vehicle in question is secured, the GPS box as well as the smart card could be accessed and the log could be compared against received information. This would give the police three different sets of data all registering the incident.

The interrogation system is basically a network of Integrated Camera and Interrogation Enclosures to be installed underneath selected bridges and flyovers. Referring to Fig. 3 it can be seen that it is necessary to install one assembly per lane of traffic. These camera boxes will be interconnected through dedicated communication lines to a central office. Each camera box will be capable of storing a limited number of captured images for batch access. Equally, the central office will be able to interrogate each camera box for individual image retrieval based on date/time and/or ERP Box Serial Number. As depicted in Fig. 4, each assembly contains the following major components:

1. Two Sealed, Weather and Tamper Proof enclosures
2. Network Communication Port for remote access
3. High Resolution, Shock and Vibration Proof Camera
4. Integrated Flash and control electronics
5. Light Spot for Moving Vehicle Detection
6. Infra-Red Transmitter for Vehicle Interrogation
7. Infra-Red Receiver for Vehicle Response reception

Although the enclosure is depicted in Fig. 4 as

one box, it is actually divided into two parts, to be installed at two opposite edges of the flyover. One box will be facing the front end of the incoming traffic, which is called Front End Box (FEB). And the other box will be facing the back end of the outgoing traffic, which is called Back End Box (BEB). FEB contains a Light Spot and Infra-Red Interrogation Mechanism. BEB contains a Light Spot and the Camera/Flash assembly. The communication and control and data processing sub-systems will be housed appropriately in one of the boxes.

A passing vehicle is detected while moving underneath the projecting Light Spot of FEB. The Interrogation circuitaries are then fired to shoot a 60 bit interrogation pattern to the vehicle. The vehicle should respond within an appropriate amount of time. Otherwise, it will be assumed that the vehicle's ERP box is either disconnected or not installed. If the vehicle responds, the 60 bit Response pattern is analysed for the presence of any Error Code. If the vehicle does not respond or the response contains error codes, then the BEB is instructed to capture the vehicle's photograph. The camera will be fired as soon as the vehicle crosses BEB's Light Spot.

Intelligence will be built into the system to tandem the two Light Spots in such a way that tail gating vehicles or extremely fast or slow moving vehicles will be differentiated and the appropriate delays in photographic capture be adjusted. Provisions will also be made to trigger the corresponding camera in case the driver manages to change lanes between FEB and BEB. The image is then compressed, indexed and stored for subsequent retrieval either on a random basis or on a batch mode transfer.

The antenna structure is also shown in Fig. 4. It consists of a ring of visible dual tone light for external visual inspection, as well as LED Array for Infra-Red communication plus the DPGS-FM and RF antennas. The FM antenna is built-in for the reception of local broadcast of Differential GPS information.

Since the system inherently incorporates a GPS receiver as part of the electronic road pricing system, it is envisaged that such could be extended to include traffic information, broadcast through the local FM channel dedicated to the system, to enable the vehicle driver to be aware of the traffic situation in his vicinity and could possibly incorporate a visual indication of toll arrangements, possibly by means of a mapped display. Further sophistication could be added by incorporating a CD-ROM Drive and a simple keyboard arrangement to provide navigational information systems with varying degrees of sophistication and a voice synthesiser could be added to give directional information to the driver from his departure point through to a predetermined destination.

Further, since the system is a zonal system rather than an entry based system the need for gating or toll booth set-ups are avoided and so that implementation is less expensive and more flexible than existing toll booth entry based systems.

The present invention thus provides a relatively low cost electronic road pricing system utilising the GPS system with the assistance of local correctional off-sets to provide an adequate degree of accuracy for the positional data from the GPS receiver to thereby enable accurate billing of road use to be provided in accordance with predetermined local zones and tariffs.



CLAIMS

1. An electronic road pricing system, comprising:

an in-vehicle receiver for receiving signals from the global positioning system (GPS) and providing positional data in respect thereto;

a controller for receiving said positional data from said receiver and including means for producing billing information according to predetermined parameters and said positional data;

wherein additional means are provided for supplying correctional offsets, combining different possible errors, to said GPS receiver to improve the accuracy of said positional data provided by said receiver.

2. An electronic road pricing system as claimed in claim 1 in which said controller outputs said billing information directly to a billing device.

3. A system as claimed in claim 2 in which said billing device comprises a card reader which is chargeable with a predetermined credit level and which, when said credit level is exceeded up to a maximum amount, such debit is then deductable when a charge card is next inserted.

4. A system as claimed in claim 2 or 3 in which the billing device includes means for indicating the level of credit available or alternatively, the amount of debit incurred up to a permitted level.

5. A system as claimed in claim 4, including means for disallowing entry into a billing zone when the maximum amount of debit, up to said predetermined permitted level, has been reached.

6. A system as claimed in any preceding claim in which variable tariffs are available depending upon the time of day and location of a vehicle in which said billing device is installed to enable variable billing rates to be applied.

7. A system as claimed in claim 6 in which billing is performed either on a per entry basis or upon the amount of time a vehicle spends in a billing zone.

8. A system as claimed in any preceding claim provided as an in-car or in-vehicle unit powered by the electrical system of the vehicle and incorporates anti-tamper devices to prevent unauthorised access to or disabling of the unit.

9. A system as claimed in any preceding claim wherein the charge card is a smart card having memory capacity for storing various items of information relating to the charge value and a list of transactions relating to the use of the smart card; a log relating to the history of use of the card indicating time and locations of use; and a log file recording violations and status information relating to the unit.

10. A system as claimed in any preceding claim wherein the receiver incorporates display means for showing the status of the unit and other relevant information including; the systems functional state, that a signal is being received; that a violation is detected, that the unit is in credit; that the unit is in debit; or that the device is within a chargeable zone and possibly indicating the charge zone.

11. A system as claimed in any preceding claim incorporating a first antenna for receiving GPS signals

from satellites, a second antenna for receiving FM signals from local stations providing differential GPS information and an LED array for communication with interrogation stations using infra-red.

12. A system as claimed in claim 11 including an antenna compartment, which additionally houses a double tone, visible status light, one tone of which signifies a functional status, whilst a second tone indicates a non-functional status.

13. A system as claimed in any preceding claim incorporating a self-test mechanism which continuously monitors the status of the in-vehicle receiver and if violations are detected, an enforcement light is illuminated and the date and time of an incident is logged for later retrieval.

14. A system as claimed in claim 13 in which violation conditions include: attempts to tamper with the unit or the enforcement light; attempts to enter a billing zone when credits are used up or debits are incurred beyond a permitted level; or reception of information is impaired due to interference with the antenna.

15. A system as claimed in claim 13, wherein the unit is identified by a unique serial number, and means are provided for logging said unique serial number, the date and the time, when any of said violation conditions occurs, for retrieval and subsequent verification.

16. A system as claimed in any preceding claim including means for relaying traffic information to the vehicle driver, and a direction display means.

17. A system as claimed in any preceding claim which additionally incorporates a CD-ROM drive and input device to enable the system to be utilised as a navigation unit.

18. A system as claimed in claim 17, in which a voice synthesiser is incorporated to provide directional information to the vehicle driver from a first location to a second location.

19 An interrogation system for use with the device of any preceding claim comprising a network of integrated camera and interrogation enclosures positioned within a charging zone and capable of storing a limited number of captured images, for batch access, for monitoring traffic movement and enabling interrogation of individual in vehicle units, said network of integrated camera and interrogation enclosures being connected to a central control office.