POLISH RESEARCHES ON ELECTRONIC TOLL COLLECTION

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Abstract

Motor Transport Institute has developed functional structure of the National Automatic Toll Collection System (NATCS). It consists of the following elements: two intelligent on-board units (OBUs), two control gates and laboratory model of National Automatic Toll Collection Centre (NATCC). OBU automatically calculates the amount of charge due, taking into account the vehicle category (admissible weight, number of axles), the emissions class and road distance. OBU is equipped with GPS, GSM and DSRC module, so it is interoperable with other electronic toll systems in the EU member states and meets requirements of directive 2004/52/EC and EC decision of 6 October 2009. The NATCS has recognized not only OBU Tripon – EU but also OBU from Toll Collect (Germany) and Passango from France which proved interoperability with another different types of systems in the EU. The efficacy of automatic detection of number plates was 98%, after process analysis it increases to 99.9%. For the purposes of NATCS it was assumed that value of Position Dilution of Precision.(PDOP) should be 90 percent and the value between 0.1 and 3. The tested OBU with the number of measurements were respectively 90%, of perfect values (0.1-1), and 8% excellent values. For the purposes of NATCS it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of the loss of signal from one of them. The test results showed that the number of satellites used for the purpose of location was 99% of measurements from 5 to 11 satellites.

Keywords: *NATCS, NATCC,OBU, GPS, GSM, DSRC, European Electronic Tolling Service*

1. Introduction

Motor Transport Institute has identified NATCS's functional structure, which consists of the following elements:
- Intelligent on-board device called TRIPON-EU, which was installed in 4 test vehicles,
- OBU device installation system using a chip card,
- two control gates (with DSRC modem and a vision tolling system),
- laboratory model of National Automatic Toll Collection Centre (NATCC),
- a proxy server for data exchange between headquarters and the OBU system via GPRS,
- control centre to manage the OBU devices allowing for management of OBU and analyses of data relating to the collection of tolls,
- analytical tools for DSRC, image analysis and classification of vehicles.

The design of the system included the following technologies:
- satellite positioning via GPS, and Galileo in the future,
- wireless communication via GSM (TS 03.60 / 23.060),
- dedicated short range communications - DSRC (5.8 GHz).

The onboard device TRIPON-EU (Fig. 1) is available in two different versions. The test system used the version mounted in a single casing collecting all components, including GPS and GSM antennas. This version is designed for installation on the windscreen of the vehicle.

The OBU device should store the following data: vehicle class, vehicle weight, axles or class of emission, registration numbers and contractual details. Data can be entered into the device using a chip card.

The GPS module used in OBU devices supports computing navigation *(*DR, *dead reckoning)* to improve the accuracy of positioning.

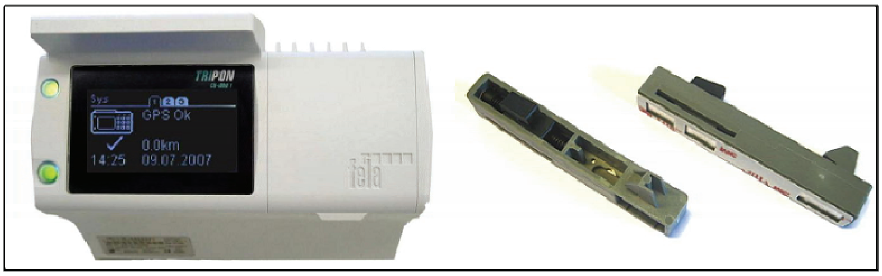

Fig. 1. An onboard OBU device and its mounting brackets

GPS data (from satellites), supplemented by the results of computing navigation are used as an input for detection of on-ground facilities. Detected events are logged in the event file. The European EGNOS system can be enabled or disabled through the configuration file activated at the time of start-up. The device is designed to cooperate with Galileo.
The concept of toll control gates in the system tested in Poland is based on experiences of FELA company, collected during the operation of the Swiss system. The following devices are installed on control gates:

- DSRC locator to carry out transactions with the traffic lane controller (according to EN 15509 standard),
- vision system ANPR (automatic number plate recognition and photographic documentation (ANPR, only from the front)
- a local driver software for the registration fee collection.

2. NATCS test results

Tests of the NATCS system (Fig. 2) including control of OBU devices, tolling segments at selected sections of roads as well as control gates were conducted in July and August, while vehicles passing through the control gates were registered from 1st July to 30th November 2010.

Fig. 2. Research Team and elements of the system

The tests of the system were conducted by the following research team:
- Motor Transport Institute (Instytut Transportu Samochodowego) (Gabriel Nowacki, Anna Niedzicka band Ewa Smoczyńska),
- FELA Management AG (Thomas Kallweit),
- Autoguard SA (Robert Rozesłaniec, Tomasz Garbacz and Krzysztof Pusłowski).

The architecture of the system is in conformity with Directive 2004/52/EC [2] and Commission Decision of 6th November 2009 [1] as well as the CEN standards. During the test four OBU Tripon EU units were examined, whose task was to detect all events associated with the collection of toll directly in OBU, as well as in the log file and display them on the screen. OBU is also meant to send log files to the proxy server and receive data from the server (data, status information and software updates.) For testing purposes four vehicles were added to the database: Volkswagen Golf – research vehicle of Autoguard, reg. no. WF 93311; Fiat Ducato, vehicle of Autoguard SA, reg. no. WF 4244E, total weight 1 968 kg, number of axles – 2; Volkswagen Crafter, vehicle of Autoguard SA, reg. no. WF 1831E, total weight 3 508 kg, number of axles – 2; Volkswagen Transporter, research vehicle of ITS *(Motor Transport Institute)*, reg. no. WH 15904, No. of axles – 2.

Out of the several proposed test route options, the Płońsk - Garwolin, Garwolin – Płońsk route was chosen (Fig. 3).

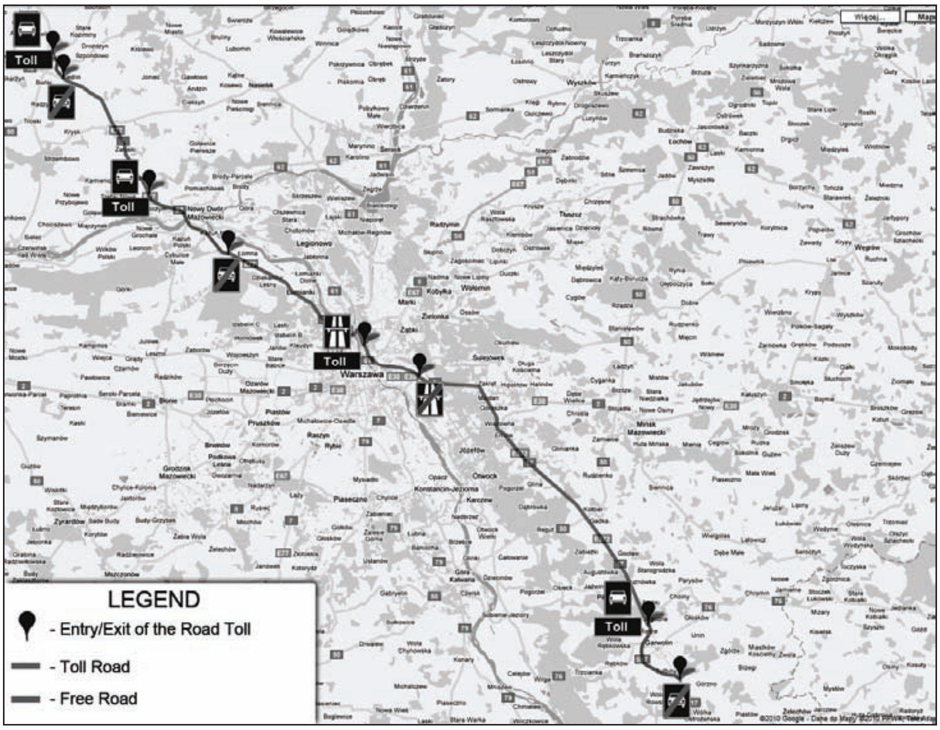

Fig. 3. Test route Płońsk – Garwolin, Garwolin – Płońsk (Made by Niedzicka, A. & Smoczyńska, E. with using the map segments from htpp.maps.google.pl)

It is the most diverse one that allows for checking the greatest number of elements of the system, including, in the immediate vicinity of the route, both control gates and allowing the use of even three actual segments of expressways:
- two segments of expressway S7 (planned route Gdańsk – Rabka with total length of 720 km): eastern bypass of Płońsk (a section of 4.7 km, opened for use on 3rd June 2009), western bypass of Nowy Dwór Mazowiecki (a section of 14,6 km, Zakroczym – Ostrzykowizna – Czosnów),
- one segment of expressway S17 (planned road on the Warsaw – Hrebenne route): bypass of Garwolin of 12.8 km length with two carriageways (each with two lanes and a 2.5 metre wide emergency lane and a 4 metre wide median strip, opened for use on 26th September 2007,
- some segments of the national roads: 61 and 637.

Based on the recorded data, transmitted by the vehicle in the form of messages, it was possible to recreate the exact route of the vehicle with the OBU device.

One of the most important parameters determining the accuracy of measurement and transmitted in location messages is PDOP (Position Dilution of Precision) - defect in determination of position precision. PDOP is a coefficient describing the relationship between the error of user's position and the error of satellite position.

The value of any of the parameters equal to 0 means that at any given time measurement of position is impossible due to interference, weak signals from the satellites, too few visible satellites, etc. The smaller the value of this parameter (but greater than zero), the more accurate is the measurement. The following descriptions, signal quality, depending on the value of PDOP, are assumed: 1 (perfect), 2 - 3 (excellent), 4 - 6 (good), 7 - 8 (moderate), 9 - 20 (poor), above 20 (bad).

The following charts depict the distribution of the PDOP parameter obtained in the tests. The horizontal axis (X) depicts values for PDOP. The vertical axis (Y) depicts the number of measurements (in percentages) during which a given value of PDOP was obtained. The statistics were calculated based on 4627 measurements of position.

For the purposes of NATCS it was assumed that value of PDOP should be 90 percent of excellent (between 0.1 and 3), for more accurate calculations of position.

The presented graphs (Fig. 4) show that the tested OBU with the number of measurements were respectively 90%, of perfect values, and 8% excellent values. The number of results in the category of poor results (PDOP 9.9 - 2%) exactly matches the number of results corresponding to the absence of visible satellites.

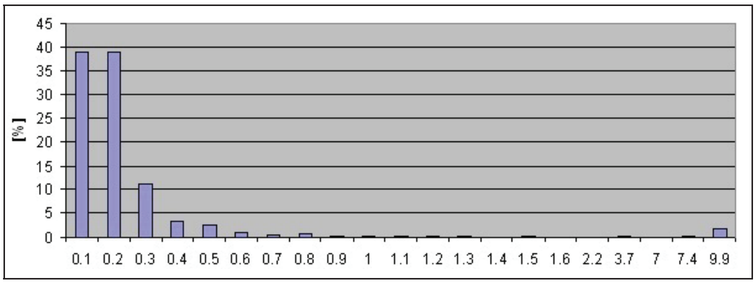

Fig. 4. Distribution of PDOP for all OBU

As stated earlier, the values of the PDOP parameter are conventionally described depending on the value, hence: values greater than 0 and less than 1.0 are considered ideal, and from 2.0 to 3.0 excellent, and above 9.0 poor.

Analysis of the measurement data of the PDOP parameter and the number of satellites used during the test showed that more than 90% of the PDOP measurements were lower than 1, which should provide location accuracy with an error of no more than 6 meters. For 8% of the measurements the PDOP parameter was between 1 and 3, but 2% was poor value (9.9), this happened at the time of activation of OBU and was associated with synchronizing the GPS receiver.

The number of satellites used for measurements of all OBU devices is presented in Fig. 5. For the purposes of NATCS it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of the loss of signal from one of them.

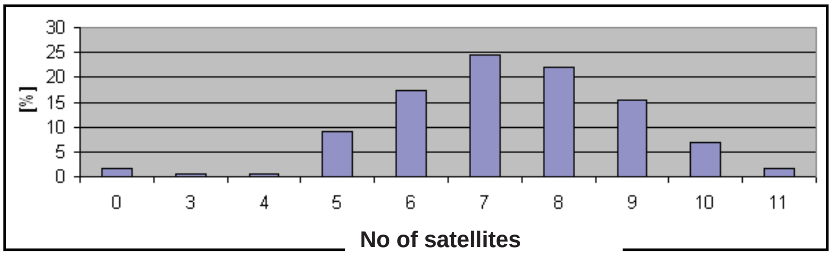

Fig 5. Number of GPS satellites used for location measurement

The presented data shows that the maximum number of satellites used for the purpose of location was 11, and in the case of 99% of measurements at least 5 satellites were used (5 - 10%, 6 - 17%, 7 - 25%, 8 - 22%, 9 - 16%, 10 - 7%, 11 - 2%).

As part of the project, two DSRC gates with tolling system were prepared. This has allowed for testing of the following functions:
- operation of DSRC microwave devices,
- operation of visual system ANPR system (automatic number plate recognition).

Data obtained from the passage of vehicles through the gates were stored in a separate database. Gates used for testing were described as follows:
- ITS Demo (UID=1000, 2),
- Autoguard Demo (UID=1001, 3).

Based on the tests, tables were developed for each of those gates:
- Image Records – contain records on photographed vehicles (possibly identified by ANPR),
- DSRC Records – contain records on passing vehicles detected by the DSRC system.

From 1st July till 30th November 2010, 2964 vehicles passing through control gates were registered n the database of the system. Not all vehicles were equipped with OBU.

During the tests at the ITS Demo and Autoguard Demo gates, using the DRSC system, passage of 24 test vehicles was recorded. During the tests at the ITS Demo gate as many as 667 photographs of passing vehicles were taken (e.g. Fig. 6).

Fig. 6. Registered vehicle, registration number WH 15904, taken on 15.07.2010 at 07.22:26, accuracy-0.960

During the tests at the Autoguard Demo gate 2297 photographs of passing vehicles were taken. Example of the vehicle photo is presented in Fig. 7.

Fig. 7. Picture of vehicle registration number WWY 07512, taken on 28.09.2010, at 09.25:53, accuracy - 0.980

The registered vehicle was equipped with a French made OBU device - Passango (DSRC) and a German made Toll Collect (GPS / GSM). It was fully identified in the system as a user, which means that the NATCS system is interoperable and can work with both, systems of DSRC type as well as GPS / GSM systems.

During each and every passage the operation of control gates as well as the conformity of the DSRC data with the ANPR (automatic number plate recognition) reading was verified. For the purpose of the second stage the onboard OBU devices were replaced with new ones. Due to a mistake the devices were wrongly installed, however the system immediately discovered the error.

Also the operation of the control gates was tested – mainly with respect to the detection of various vehicle speeds. Thanks to this, it was possible to adjust the software and then to check the newly replaced onboard OBU devices with respect to the correctness of detection of vehicles coming up to the control gate at especially low selected speeds. The system detects vehicles travelling at speeds of 1 to 200 km/h.

Discrepancies between indications of impulses from the road or tachograph were verified – depending on the vehicle – and the GNSS readings. The verification was performed using the "Delta Tacho". Thanks to that it was determined that in the case of Volkswagen Transporter the tachograph readings were 2-3% lower than the satellite measurements, while in Autoguard's vehicle the road impulses were 2-3% higher than the satellite measurements. This fact shows that in the case of loss of GNSS signals, one can measure distance on the basis on devices checking if the passage of vehicle through a tolling point took place via the appropriate route.

Furthermore another parameter was checked - the correctness of detection of irregularities by the OBU onboard unit by disconnecting the tachograph signal, and then purposeful incorrect switching on of this signal while driving. The unit acted correctly and the red diode came on – thus showing a malfunction – instead of the green diode until the time of stoppage.

We also verified attempts to pull out on the route between the segments as well as attempts to drive via alternative routes and secondary passages through segments and gates.

In addition to testing the drives and checking the functionality, the efficacy of the gates was checked, recording all vehicles passing at the premises of MTI *(Motor Transport Institute)* and at the premises of the AutoGuard company in various weather conditions and at various times of day. The efficacy of automatic detection of number plates was 98%. Errors in recognition related only to invisible letters ("lost") and not wrongly recognised ones. This was mainly due to the reflections of the sun, which indicates that an adjustment of parameters could eliminate this problem almost completely. The system control centre has a post for analysis of unrecognised registration number plates, which accurately detects the vehicle registration numbers, and thanks to this the efficacy of the system increases to 99.9%. In one case, a passenger car number plate was obscured by the semi trailer of the preceding vehicle, as a result of which the first two letters were not read. In this case, the right solution might be to change the camera angle.

During the test run and the other functional tests we verified the system by finding individual weaknesses that were reported as needing rectification. It should be emphasised that some of the improvements were implemented in real time - adjustment of parameters, fixing of minor errors. Other amendments required time – from one hour up to several hours to fix, such as remote modification of the vehicle data in the OBU or change of segment definition.

All objections were resolved on an ongoing basis, thus allowing us to trust the efficacy of such a system in practice. Contact with the operators of the system was fast and seamless. The testes also proved that any attempts to "deceive" the system or any atypical action resulted in correct responses served in the prescribed manner. The compatibility of the system and the OBU devices with the interoperability requirements of the European Union allows one to hope that the idea of a single device, single contract and single invoice is realistic.

The lack of a developed infrastructure - with a minimum of supervision and control infrastructure - and the ease and flexibility of changing the definition of segments and the addition or exclusion of alternative routes, classifications and remote changes in key parameters shows the superiority of the GNSS / GSM solutions over solutions requiring the communication infrastructure for each tolling point or segment, such as the systems based on direct DSRC communication.

During the test actual segments of expressways S7 and 17 were used. In addition, segments of roads No. 637 and No. 61 within the boundaries of Warsaw were classified as toll roads. The ability to define any classification of virtual segments is another element that shows the flexibility of the system, potentially also in terms of defining the same tolls for primary routes and alternative routes. In addition, the segments were defined in terms of individual directions (different number of segments, tolling points in various locations).

All the segments were identified correctly by the onboard devices, and there were no problems in this respect. Each segment consisted of three points, and in order for each one of them to count, all three segments had to be detected by the OBU device. As a result of this drivers who will cut through toll roads, or only pass through them, will not be registered in the system.

The tests were successful and confirmed the efficacy of the selected solutions in accordance with the assumptions of the project.

3. Conclusions

From 1st July till 30th November 2010, 2964 vehicles passing through control gates were registered in the database of the system. In addition to testing the drives and checking the functionality, the efficacy of the gates was checked, recording all vehicles passing at the premises of Motor Transport Institute and at the premises of the AutoGuard company in various weather conditions and at various times of day. The efficacy of automatic detection of number plates was 98%. Errors in recognition related only to invisible letters ("lost") and not wrongly recognised ones. The system control centre has a post for the analysis of unrecognised number plates, which accurately detects the vehicle registration numbers, and thanks to this the efficacy of the system increases to 99.9%.

Analysis of the measurement data of the PDOP parameter and the number of satellites used during the test showed that more than 90% of the PDOP measurements were lower than 1, and 8% had value from 1 to 3.

For the purposes of NATCS it was assumed that GPS receiver in OBU should track at least 5 satellites, for more accurate calculations and in the event of the loss of signal from one of them. Tests results showed that in the case of 99% of measurements at least 5 satellites were used for the purpose of location (the detailed results of satellites: (5 - 10%, 6 - 17%, 7 - 25%, 8 - 22%, 9 - 16%, 10 - 7%, 11 - 2%).

All objections were resolved on an ongoing basis, thus allowing us to trust the efficacy of such a system in practice. Contact with the operators of the system was fast and seamless. The tests also proved that any attempts to “deceive” the system or any none-typical actions resulted in correct responses in the prescribed manner. The compatibility of the system and the OBU devices with the interoperability requirements of the European Union allows one to hope that the idea of a single device, single contract and single invoice is realistic.

The researches clearly confirm that under the existing conditions (development of new technologies, Directive 2010/40 and the European Commission's decision of 6th October 2009), a tolling system, using GPS satellite positioning and GSM will be the best future solution for each EU Member State, particularly in terms of interoperability and flexibility when toll systems may be used for more categories of roads (or all roads) and each category of vehicle.

Tests of NATCS project has been a complete success. The system uses GPS/GSM technologies, but also recognises devices such as DSRC and OBU. During tests, the system recognised French made DSRC Passango device and a German made Toll Collect device of the GPS / GSM type, installed in a vehicle which did not participate in the test, but accidentally ran through the control gate. This implies that the NATCS system is interoperable and can cooperate with both GPS/GSM systems as well as with DSRC types of systems existing in other EU Member States.

Acknowledgements

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References

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[2] *Directive 2004/52/EC of the European Parliament and of the Council of 29 April 2004 on the interoperability of electronic road toll systems in the Community*. OJ of the EU, L 166/132, 30.04.2004.