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GALILEO SIGNAL PRIORITY – A NEW APPROACH TO TSP

Abstract

In this paper the concept and selected results of Galileo Signal Priority project were presented. In the first part of the paper the main aims of project were listed. Next RPP device, which provides better positioning performance than currently used systems, was described. In the second part of the paper microsimulation model development of chosen junction was presented. After that main results, considering different tram priority scenarios, were presented.

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INTRODUCTION

The project "GSP – Galileo Signal Priority" is funded by the European GNSS agency GSA and has the focus on demanding function in public transport (PT). It has been recognized that the best way to cut on carbon emissions in big cities and metropolitan areas is through the positive environmental impact of attractive public transport (PT) services.

Since GPS has reached full operational capability in 1993, the system has been taken up by public transport applications quite slowly compared to automotive navigation devices on the road. Today GPS can handle PT operations such as calculating the estimated time of arrival for traveller information at tram/bus stops. However, more complex applications like transit signal priority (TSP) or track sharp localisation have higher requirements. For those demanding functions, infrastructure based positioning is still being used in PT. This means that in addition to the GNSS unit in each vehicle, many transponder beacons or infrared beacons are installed along the track and every vehicle needs special equipment on-board to read these beacons and initiate corresponding actions. Finally it has to be stated that the effort for calibration and maintenance of infrastructure based systems is rather high and costly.

As a consequence, intermodal traffic control systems (ITCS) apply both technical systems (GPS positioning for traveller information and infrastructure based positioning for TSP). This situation in state-of-the-art ITCS is neither technically reasonable, nor economically affordable and has to be changed.

To solve this situation and make operation of such systems more economically the project Galileo Signal Priority (GSP) has put its focus on the development of a system (software and hardware) which is able to perform all the mentioned functionalities.

Therefore the project focus has been put on TSP to overcome the last obstacle for a sustainable introduction of GNSS to support and improve all functions of PT. With this step the existing infrastructure based systems (which are less flexible and more cost intensive) shall be dispensable, to save cost on equipment and maintenance and explore the full potential of onboard intelligence, where GNSS has a leading role to enable the overall application. In this regard the main achievements of the project are:

– The development of a prototype for robust positioning exploring EGNOS, EDAS or Galileo as main sensor, in order to satisfying all the requirements in PT.
– The development of new traffic light control schemes, which can explore the advantages of GNSS based systems in PT and overcome the deficiencies of costly infrastructure based systems.

The project started in January 2012 and last for 27 months. The consortium consists of four partners across Europe (Germany, Hungary, Czech Republic and Poland) with two SME and two Universities.

1. SCIENTIFIC DEVELOPMENT PLATFORM

At the start of the project a technical feasibility was executed, in order to analyse the potential performance of modern GNSS and especially the positive impact of EGNOS, in order to enhance position accuracy. In this course a benchmarking was executed, which showed, that GNSS + EGNOS is capable to reach similar accuracy as infrastructure based systems. The sensitive point with respect to that technology is given by its limited availability. If the line of sight to the satellites is limited, due to e. g. urban canyons or tunnels, the position determination may be interrupted by a short time period. Thus the concept of the robust positioning prototype (RPP) was born, which uses a hybrid approach to combine the accuracy of GNSS + EGNOS, with the reliability of sensor measurements from the PT vehicle (like distance travelled and turn-rates form gyrometers). In this context a scientific development platform has been set up as important tool, to support an optimal development process, which consists of three main components:

– The Galileo tram, which forms the test vehicle, to conduct real life measurements under normal operation modes for TSP applications.
– The sensor assembly of different technologies for position determination that may contain suitable components for the design of the RPP
– The approach of forcing tape, which allows the detailed analysis of individual sensor combination and their potential contribution towards the RPP

On the basis of these tools the creation of the RPP as suitable reference prototype has been tested under real life conditions and in representative operational scenarios with respect to the target application of PT. The Galileo tram represents an ideal test vehicle, in order to execute representative test trials for the development of adequate positioning modules to drive GNSS based TSP. The high performance measurement equipment on-board the Galileo tram offers excellent tools for the determination of a reference trajectory for the truly driven path during a dedicated test trial. This reference trajectory forms an important pre-requisite to analyse the RPP and its sensor components and help to gain valuable insight into the technical relations. For the determination of a reliable, complete and highly accurate reference trajectory, the following high performance sensor equipment has been installed into the Galileo tram:

– Dual frequency GNSS for GPS, GLONASS, EGNOS and Galileo with differential correction for carrier phase solutions.
– Doppler radar for accurate acquisition of speed in tram systems.
– High performance inertial navigation unit, consisting of 3 ring laser gyros and 3 precision accelerometers.
– Exact track data base, which covers the complete tram network.

The core of the reference systems is the INU, which consists of three ring-laser gyros and three precise accelerometers. This sensor assembly can percept the rotational and translational motion of the vehicle in all three axes, to cover all 6 degrees of freedom with respect to the physical motion. The dual frequency GNSS determines position fixes with centimetre accuracy and is used in conjunction with the Doppler radar as aiding information for the high frequency measurements of the INU. The measurements of the reference equipment are recorded in parallel but strictly independent to the other systems of the RPP and the Galileo tram.

Fig.1. Scientific development platform consisting of PT vehicles and high performance sensor equipment
Source: Own

Finally, the quality of this reference trajectory is verified against the exact track data base, which has been elaborated by external geodetic survey. This provides a trustful and independent prove for the quality of the generated reference trajectories.

2. RESULTS FROM THE ASSESSMENT PROCESS

The Galileo tram as authentic test vehicle in PT is furthermore equipped with the developed RPP, which has been installed for permanent tests in January 2013. Since then the RPP is running in daily operation and used for regular PT services. The advanced position information coming from the RPP is fed into a second ITCS on-board computer in this Galileo tram. This redundant ITCS equipment allows the PT company to allow regular operation with the existing instruments and at the same time monitoring the quality of the RPP and its positive impacts on PT operation.

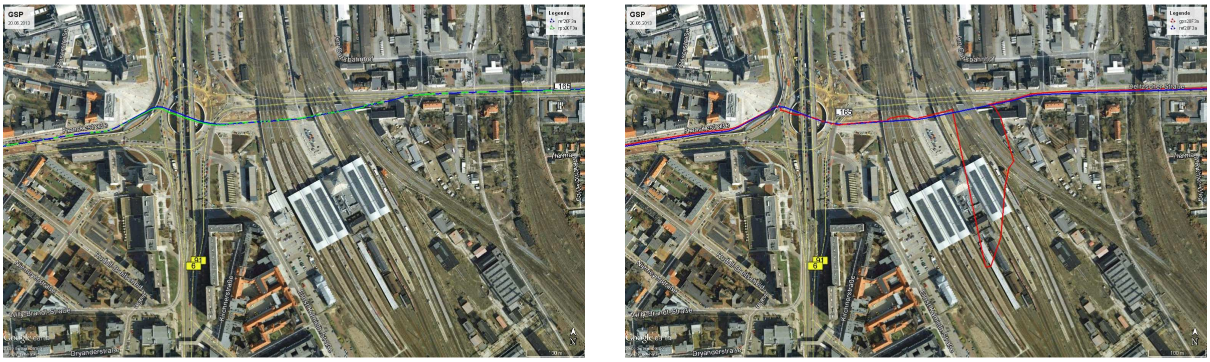

Fig. 2. Example of GNSS error, which can be fully compensated by the RPP
Source: Own

Within the current paper only the main findings from the technical assessment will be presented. In Figure 2 one severe example is shown as comparison between GNSS only operation on the one hand side (plot on the right) and the GPS approach with the RPP operation on the other hand side (plot on the left). Both pictures contain the exact reference trajectory as blue line, while the GNSS results are depicted in red and the RPP outcome is depicted in green. It can be seen, that the red trajectory shows a huge deviation to the south, which represents an error of more than 280 meters. This scenario happened, while the tram was driving under a railway bridge. The photo on the left in Figure 2 shows the same scenario, but with the results of the RPP and it can be clearly seen, that here no problems are arising. Even though this example reflects an extreme example, it is well suited to show the benefits of the hybrid positioning with the RPP. In addition to accuracy the property of availability is very important too. Here the GNSS as standalone solution reached an availability of 98 %, while the RPP reached an availability of 100 %. However such map pictures can only represent a snap shot of the overall performance over days and weeks. Therefore a more compressed representation is given in Fig. 3.

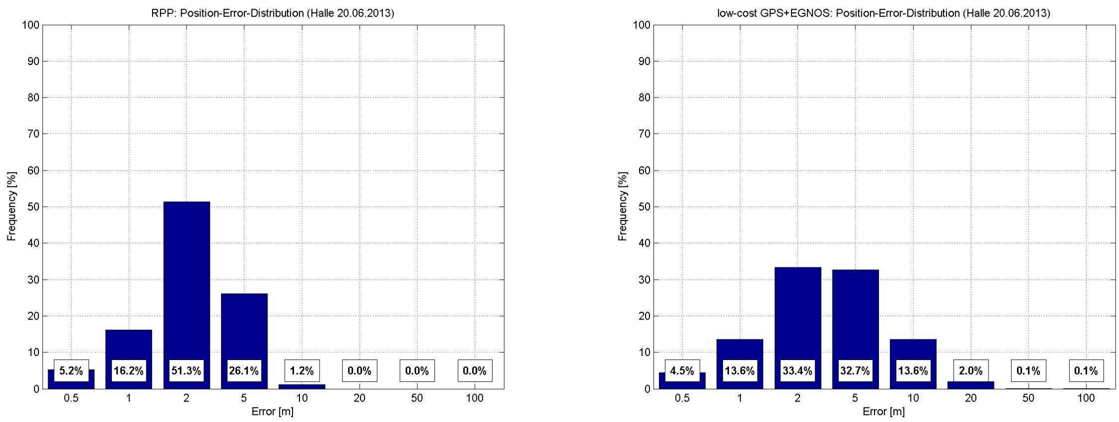

Fig.3. Comparison between GNSS and RPP accuracy in form of position error distribution plot
Source: Own

This type of diagram has the advantage to provide a statistics for several error classes as normalized graph, which is well suited to compare the performance of different systems to each other. In total eight error classes have been defined (Tab. 1):

The distinction of these eight classes is well suited for most land based applications in traffic and transport. With the half-meter class it represents very accurate positions, which would suite even highest requirements (e.g. for road user charging or eTicketing). In contrast the hundred-meter class represents an error group that is unacceptable for almost every application in this domain and thus no further distinction would be necessary.

Comparing the introduced types of plotting the GNSS performance the error-density diagram is considered most suitable to execute an assessment process for the achieved positioning performance. In this plot the achieved results of GNSS as standalone solution is presented on the right hand graph, while the outcome of the RPP is presented on the left hand graph. The most obvious difference is the size of the beam representing the errors in the 2 meter class. Here the RPP has a much higher score compared to GNSS standalone. But the important numbers of these plots are shown on the right end of the x-axes for both graphs. Here we see the occurrence of errors in the twenty, fifty and hundred meter class. While GNSS shows such big errors in all this classes, the RPP is capable to prevent this and stay within the limits of the ten-meter-class. Even though the difference in the percentage is low, the main message can be derived from these assessment results.

The RPP combines the accuracy and flexibility of GNSS + EGNOS, and assures the reliability of the good old infrastructure based systems. Therefore the RPP is well suited to satisfy the high demands in all PT services.

3. MICROSIMULATION MODEL DEVELOPMENT

One of the challenges in GSP project was to assess how new TSP scheme, using RPP device and GNSS systems, will work in real conditions. While it was possible to have test trials with Galileo tram in Halle, it was not feasible to do this in Krakow due to technical limitations. Thus it was decided to develop microsimulation model to evaluate different TSP scenarios. PTV VISSIM was chosen to be used in microsimulation analysis. However this sophisticated software provides lot of functionalities, authors found that, it has some limitations in terms of PT vehicles positioning. That limitations were overcame with use of available software functionalities. The analysis was made for one junction in Halle and one junction in Krakow. Since at junction in Halle there’s already PT working only results for junction in Krakow, which authors found most interesting, will be presented.

Fig.4. Analysed junction in Krakow
Source: Google Earth

Analysed junction of Królewska and Kijowska streets is located in Krakow. The total traffic volume on junction during peak hour is around 1200 vehicles. When the model was developed there were 6 tram lines with interval of 10 or 20 minutes, what gives 30 trams in each direction per one hour. On perpendicular direction to the tram there are 2 bus lines, with service interval of 11 and 12 minutes, what gives 10 buses in each direction per one hour. There are no significant congestions during the day, however due to fixed time traffic lights controller tram gains high time loss. The scheme of the junction was presented in Fig. 4.

First the geometry and traffic organisation scheme of junction was prepared in microsimulation model. Then existing fixed time traffic light algorithm was implemented. In reference case fixed time traffic light programme has length of 80 seconds. It provides no TSP for trams and buses. Existing detectors are used only for traffic data collection.

To meet TSP requirements it was necessary to develop new accommodated TLA. Designed algorithm operates on 3 stages. Two of them are for Kijowska street with pedestrian crossings (or without them), and one stage is for Królewska street. Stage for Królewska street is the preferred stage and the algorithm remains on it until pre-emption on the Kijowska street occurs. During the day, due to the traffic volume of vehicles and pedestrians, the algorithm works basically on 2 stages. Pre-emption is given at the moment of leaving the previous stop. The theoretical arrival time includes passenger boarding time. In case of tram stop location beyond the junction boarding time is excluded. The validity of pre-emption is set to 120sec. Based on the arrival time, algorithm recognizes if the current stage is need to be extended, i.e. if it is a stage for Królewska street, the possibility of transition to a stage for Kijowska street with a minimum extension of 10 seconds before the end of the passenger boarding time is checked. Transition to the stage for Kijowska street is done without checking the extension caused by vehicles. In case of operating two competing tram pre-emptions, the algorithm attempts to handle the first one, assuming that the second one may have greater time loss.

4. RESULTS FROM MICROSIMULATION MODEL

Four traffic scenarios where considered:

- Reference case – there's no TSP at the junction.
- Infrastructure – PT telegram is sent using infrastructure beacon (induction loop).
- GSP – PT telegram is sent using RPP device; tram position may be actuated in case of disturbances.
- GSP+stops – PT telegram is sent using RPP devices, tram position may be actuated in case of disturbances; tram stops are moved beyond the junction.

Since no TSP and infrastructure based TSP scenarios were not problematic, it was not possible to implement directly GSP based priority in used software. VISSIM does not provide possibility of floating pre-emption point or sending PT telegram with tram position. Thus it was decided to include tram positioning indirectly into the microsimulation model. Two approaches were tested. First approach considered changing pre-emption point location according to positioning errors assigned to tested GSP technology with RPP device. Second approach was based on different desired speed distribution were assigned to trams to image positioning errors. In both cases different location of pre-emption point and different tram speed distribution were used to represent RPP device reliability.

The results of microsimulation for particular scenarios are shown in Fig. 5 and Fig. 6. Fig. 5 shows travel times between specified sections before and beyond junction, while Fig. 6 time losses. For each parameter not only trams, but also cars and buses were considered. In travel times as well as in time losses boarding time was included in calculations.

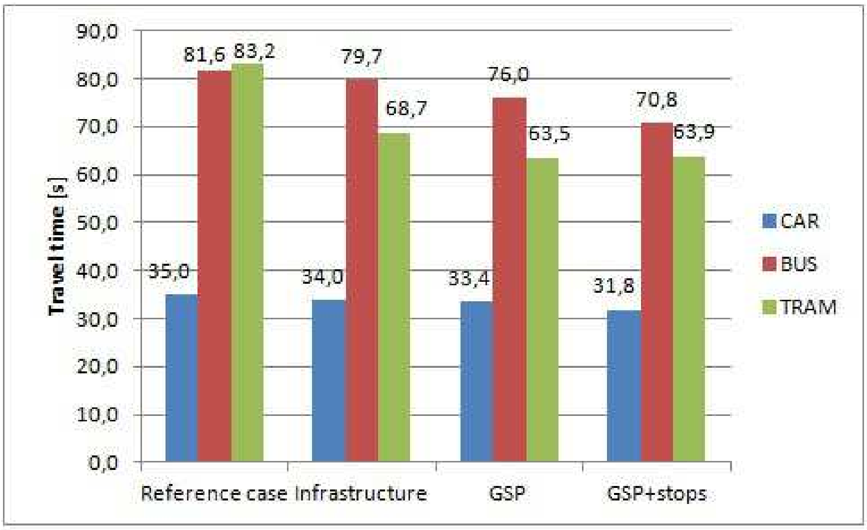

Fig.5. Results of microsimulation – travel times
Source: Own

In Fig. 5 it can be seen that the highest reduction of travel time was gained for trams. This is because the TLA was set up for full tram priority. GSP based TSP provides few percent shorter travel time than the infrastructure based TSP. The difference is not significant, but it shows that GSP has higher reliability than infrastructure. Thanks to introduction of fully adaptive traffic control scheme for all vehicle travel time reduction was achieved. Interesting is that moving tram stops beyond junction increased travel time. It may be caused by random passenger boarding time, what provided better results for scenario with stops before junction.

The other parameter, which is more representative, is time loss shown in Fig. 6. Time loss is defined as a difference between travel time in real traffic conditions and travel time while there won't be any obstacles, in this case traffic lights. It can be seen in Fig. 6 that introducing TSP on analysed junction can provide reduction of time losses for trams by almost 50%. The best performance of tram priority is achieved, when tram stops are beyond the junction. This is quite obvious because travel time from pre-emption point to stop line does not depend on passenger boarding time. Difference between scenario with stops beyond and scenario with tram stop after the junction is clearly seen in Fig. 6, where few percent reduction was gained.

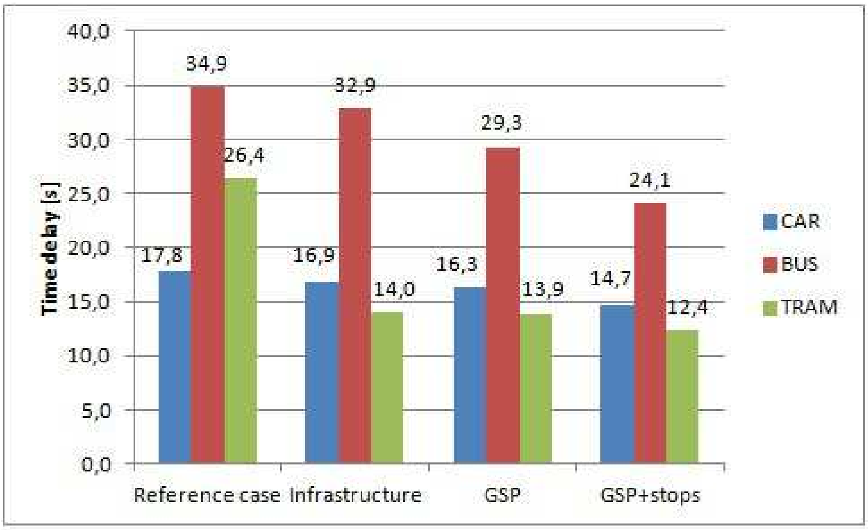

Fig.6. Results of microsimulation – time delays
Source: Own

SUMMARY

Transit signal priority is a crucial point in development of PT management systems. On the one hand priority systems should provide good performance, while on the other reasonable investment and maintenance costs. Existing priority systems usually use fixed pre-emption point where PT telegram is sent using infrastructure or GNSS beacon, which are expensive in terms of maintenance. While the tram track is separated it provides good performance thanks to low probability of disturbances between pre-emption point and stop line at the junction. In case when other vehicles or pedestrians can occur on tram track reliability of infrastructure based priority decreases. RPP device, which minimize outages (especially in street canyons) comparing to existing GNSS systems, can provide reliable tram position using for instance floating pre-emption point or PT vehicle position update.

However the paper as well as GSP project concentrated on trams, the RPP device can be also used in buses. Even in case of separated bus lanes, other vehicles can occur, e.g. turning right. Using same detector loops traffic light controller cannot recognize if there's a bus or car. GSP approach would be suitable in this case, because PT telegram can be sent independently to TLA and bus can be granted priority.

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GALILEO SIGNAL PRIORITY – NOWE PODEJŚCIE DO PRIORYTETÓW W TRANSPORCIE PUBLICZNYM

Streszczenie

W referacie przedstawiono założenia oraz wybrane wyniki projektu Galileo Signal Priority. W pierwszej części przytoczone zostały cele projektu. Następnie opisano urządzenie RPP, które wykorzystując systemy GNSS i EGNOS pozwala na dokładniejszą lokalizację tramwaju niż obecnie działające systemy nawigacyjne. W drugiej części referatu opisano budowę modelu mikrosymulacyjnego wybranego skrzyżowania oraz przedstawiono wyniki testowania różnych scenariuszy priorytetów dla tramwajów na skrzyżowaniu z sygnalizacją świetlną.

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