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SATELLITE NAVIGATION SYSTEMS IN THE NEW ADVANCED TELEMATICS APPLICATIONS

The selected propositions of the new advanced telematics applications in the different modes of the land transport with the use navigation satellites systems (GPS, Galileo) and Satellite Based Augmentation System as EGNOS will be presented in the paper. Today the autonomous GPS receivers combined with a communication system, so–called telematics systems, are found in a vast variety of a land transport applications.

NAWIGACYJNE SYSTEMY SATELITARNE W NOWOCZESNYCH ROZWIĄZANIACH TELEMATYCZNYCH

W referacie omówiono wybrane propozycje nowoczesnych rozwiązań telematycznych w transporcie lądowym wykorzystujących nawigacyjne systemy satelitarne (GPS, Galileo) i satelitarne systemy wspomagające (EGNOS). W chwili obecnej autonomiczne odbiorniki systemu GPS w połączeniu z systemem łączności, zestawy takie noszą nazwę systemów telematycznych, znalazły szerokie zastosowanie w wielu rodzajach transportu lądowego.

1. INTRODUCTION

The continuous information of user's position is one of the most important elements, which determines the safety of the user in the transport. The information about this position is obtained principally from specialized electronic position–fixing systems, in particular satellite navigation systems (SNS). At present (July 2004) unique fully operational and global system is American GPS (Global Positioning System – Navstar). GLONASS (Russian system) cannot be a continuous position fixing system. The Satellite Based Augmentation Systems (SBAS) as WAAS, MSAS and EGNOS are accessible in USA and Canada, Japan and Europe adequately [9].

The new system – Galileo, sponsored by the European Union, is under construction as the European contribution to the next generation of satellite navigation. Galileo will be fully

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operational most likely in 2008. This system of the future will be used in aviation, sea transport and rail and road transport also.

Due to the availability of precise satellite navigation systems plus integrity information, in Europe namely GPS+EGNOS, in the future Galileo, road transport system, car navigation, railway traffic and inland navigation are facing a revolution in terms of flexibility of operations. Today the autonomous GPS receivers combined with a communication system, so–called telematics systems, are found in a vast variety of a land transport and navigation applications.

The world market for vehicle telematics and fleet management solutions for professional and consumer markets is estimated today at 5 billion euro, with annual growth rates forecasted at 50%. Every day, around the world, more than 20,000 vehicles are fitted with telematics system [12]. The railway sector was more reluctant in the past, but today becomes more and more convinced of the benefits of the new advanced telematics applications [1]. The provision of a telematics application based on a river information services RIS will balance the weakness of the waterway [4].

2. SATELLITE NAVIGATION SYSTEMS IN RESTRICTED AREA

In open area the accuracy of the observer's position obtained from the satellite navigation systems depends on a number of satellites (ls) visible above masking elevation angle (H_{min}) and the geometry of systems – GDOP (Geometric Dilution of Precision) coefficient. The detailed distributions of satellite azimuths Az (8 intervals, each 45^{O} wide) and GDOP coefficient (8 intervals) for different angles H_{min} and different observer's latitudes φ (9 zones, each 10^{O} wide) calculated for GPS system and the future system Galileo are presented by the author in [8]. For comparison it was considered 27 satellites fully operational for both systems.

The accuracy of the position solution determined by SNS is ultimately expressed as the product of a geometry factor and a pseudorange error factor [10]:

$$\text{error in SNS solution} = (\text{geometry factor}) \times (\text{pseudorange error factor}) \tag{1}$$

As the error solution can be expressed by σ_ρ – the standard deviation of the positioning accuracy, geometry factor by the dilution of precision (DOP) coefficient and pseudorange error factor by the term σ_{UERE} (UERE –User Equivalent Range Error), the relation (1) can be defined as:

$$\sigma_\rho = DOP \cdot \sigma_{UERE} \tag{2}$$

If we can obtain four coordinates of the observer's position (latitude, longitude, altitude and time – φ, λ, h, t), geometry factor DOP is expressed by GDOP then the position accuracy with 95% confidence level $M^{95\%}_{\varphi,\lambda,h,t}$ can be approximated by:

$$M^{95\%}_{\varphi,\lambda,h,t} \approx 2 \cdot GDOP \cdot \sigma_{UERE} \tag{3}$$

In maritime and land area we are mostly interested in horizontal (two–dimensional) position only. Therefore if we can obtain two coordinates of the user's position (latitude, longitude – φ, λ), geometry factor DOP is expressed by HDOP (Horizontal Dilution of Precision) and the position accuracy with 95% confidence level $M^{95\%}_{\varphi,\lambda}$ can be approximated by:

$$M^{95\%}_{\varphi,\lambda} \approx 2 \cdot \text{HDOP} \cdot \sigma_{UERE} \tag{4}$$

In case of GPS system (in July 2004) for the geometry with HDOP = 1.5 and with σ_{UERE} = 7.5 m, the estimate of the horizontal error is given as follows:

$$M^{95\%}_{\varphi,\lambda} = 2 \cdot 1.5 \cdot 7.5 \text{ m} = 22.5 \text{ m} \tag{5}$$

This position accuracy (22.5 m) can be improved by the use of differential mode – DGPS. This mode needs the reference stations and the transmission of the pseudorange corrections, but the horizontal error (95%) decreases to few meters. Now we can say, in oceanic navigation the accuracy of GPS position is sufficient, in coastal navigation and in harbour entrances the position accuracy obtained by DGPS and SBAS is sufficient [6,7]. The fixed position by mentioned methods is accessible in selected areas only because of limited coverage.

In restricted area (coastal navigation, urban area) system accuracy depends on the parameters mentioned for open area and the dimensions and situated area of the obstacles. Position fix can be calculated only from these satellites, which elevation angle in observer's receiver at the moment of measurement is higher than the masking elevation angle H_{min}. If the number of these satellites is less than 4, the position 3D cannot be calculated and the number of No Fix is greater than 0.

Table 1

No Fix (in per cent) and the distribution (in per cent) of GDOP values for the observer situated in the middle of the street (width L = 60 m, height B = 20 m) for masking elevation angle $H_{min} = 5^{O}$ for different angles between the North and street's axis (α) for Galileo system and GPS system for different observer's latitudes φ

φ [°]	α [°]	Sys–tem	No Fix [%]	GDOP coefficient value v [%]						
				V≤3	3<v≤4	4<v≤5	5<v≤6	6<v≤8	8<v≤ 20	v>20
0 – 10	0	GAL	–	58.2	33.0	4.8	2.7	0.7	0.4	0.2
		GPS	0.2	52.0	33.5	6.2	3.9	2.4	1.7	0.1
	45	GAL	–	51.2	32.2	6.6	6.0	2.8	1.0	0.2
		GPS	0.4	42.6	31.7	11.4	5.8	4.0	3.3	0.8
	90	GAL	–	40.6	32.9	7.3	9.5	4.3	4.4	1.0
		GPS	3.6	26.0	28.9	12.1	7.7	7.9	10.5	3.3
	135	GAL	–	59.6	31.8	4.7	1.9	1.2	0.6	0.2
		GPS	0.2	46.5	35.1	8.6	3.8	3.0	2.5	0.3
50 – 60	0	GAL	–	14.9	55.9	16.7	5.5	3.9	2.0	1.1
		GPS	4.7	15.2	34.7	22.2	9.5	6.2	4.9	2.6
	45	GAL	–	16.4	60.9	15.0	4.5	2.3	0.9	–
		GPS	0.7	25.3	42.1	16.1	7.3	3.9	3.9	0.7
	90	GAL	–	22.8	50.8	14.6	4.7	2.9	2.8	1.4
		GPS	–	25.4	45.3	15.6	5.8	3.8	3.2	0.9
	135	GAL	–	24.3	53.4	13.1	4.8	3.1	0.6	0.7
		GPS	0.9	23.1	42.8	18.3	6.6	4.0	3.6	0.7
70 – 80	0	GAL	–	0.1	17.7	44.4	30.6	7.1	0.1	–
		GPS	–	–	10.6	33.4	29.0	19.3	6.1	1.6
	45	GAL	–	–	16.1	45.4	29.2	7.7	1.2	0.4
		GPS	0.6	–	9.7	30.8	28.2	20.7	8.3	1.7
	90	GAL	–	–	15.7	35.5	27.6	15.8	4.4	1.0
		GPS	–	–	7.8	31.2	29.8	19.7	9.8	1.7
	135	GAL	–	0.1	15.5	40.8	29.3	11.4	2.6	0.3
		GPS	0.3	–	8.1	30.7	27.6	18.6	11.3	3.4

For the urban area the calculations were made for the observer situated in the middle of the street for different angles (α) between the North and street's axis for GPS system and Galileo system at different observer's latitudes. No fix (in per cent) and the distribution of GDOP values (in per cent) in 3 zones, 0–10° as low latitude, 50–60° as middle latitude and 70–80° as high latitude are presented in the table 1.

The calculations were made for different height B and different width L. No fix (in per cent) and the distribution of GDOP coefficient values for $\alpha = 0^{O}$ for both systems for the observer's latitudes 50–60° (latitude of Poland) are demonstrated in the table 2. The other calculations and results were presented by the author in [6] and [7].

Table 2

No Fix (in per cent) and the distribution (in per cent) of GDOP values for the observer situated in the middle of the street with different width L and different height B for masking angle $H_{min} = 5^O$ for angle between the North and street's axis $\alpha = 0^O$ for Galileo system (GAL) and GPS system (GPS) at observer's latitudes $50–60^O$

B [m]	L [m]	Sys–tem	No Fix [%]	GDOP coefficient value v [%]						
				$2<v\le3$	$3<v\le4$	$4<v\le5$	$5<v\le6$	$6<v\le8$	$8<v\le20$	$v>20$
20	80	GAL	–	38.6	43.6	11.9	3.5	0.8	1.1	0.5
		GPS	0.1	35.1	43.0	15.6	3.4	1.7	0.9	0.2
	75	GAL	–	34.3	45.0	12.3	4.8	1.4	1.5	0.7
		GPS	0.2	31.7	41.8	17.5	5.0	2.2	1.3	0.3
	70	GAL	–	28.4	47.2	12.7	6.6	2.4	1.8	0.9
		GPS	0.4	27.8	40.7	19.3	6.3	2.9	1.9	0.7
	65	GAL	–	23.7	46.9	12.9	8.7	3.9	2.4	1.5
		GPS	1.0	22.5	38.5	21.4	7.7	4.7	3.1	1.1
	55	GAL	0.3	13.7	40.8	13.9	14.6	8.4	5.6	2.7
		GPS	6.0	15.5	31.5	21.9	9.0	7.8	4.4	3.9
8	35	GAL	–	44.9	39.9	11.5	2.4	0.5	0.5	0.3
		GPS	–	39.7	43.3	12.8	2.6	1.0	0.5	0.1
	30	GAL	–	34.3	45.0	12.3	4.8	1.4	1.5	0.7
		GPS	0.2	31.7	41.8	17.5	5.0	2.2	1.3	0.3
	25	GAL	–	20.5	47.4	13.3	9.4	5.2	2.5	1.7
		GPS	1.8	20.4	37.8	20.8	8.7	5.2	3.6	1.7

Although satellite navigation system (SNS) has a very high availability, mission planning is important, especially if the location has terrain features, which may block the visibility of satellites. Therefore the typical input parameters used to perform SNS mission planning are:

- location of the observer; especially its latitude,
- mask angle H_{min},
- terrain mask; especially in restricted (urban) area; the azimuth and elevation of terrain (buildings, mountains).

As the new advanced telematics applications can be used in urban area, in particular, the results the most interesting for the users concern the possibility of fix position and position accuracy in this area.

We can recapitulate that:

- in urban area the satellite position in mode "3D" cannot be obtained, if the number of satellites visible by the observer above masking elevation angle H_{min} and at the same time above the buildings is less than 4;
- in urban area the position accuracy is less than in open area considerably for both systems. This accuracy depends on the height of the buildings, the width L of the street and the angle between the North and street's axis;
- as the distribution of satellite azimuths depends on observer's latitude, the position accuracy in the town depends on its geographic situation. It means that the accuracy in the street with the same widths and the height of the buildings is in e.g. Oslo, Lisbon and Dakar different;

- in urban area for the observer situated in the middle of the street (with given width and height of the buildings) the dependence of position accuracy on angle between the North and street's axis is for Galileo system less than for GPS system.

GPS and GLONASS are system under military control and do not fulfil the requirements (accuracy, integrity, availability, continuity of service) for safe navigation. In order to meet these requirements, augmentations systems to the existing satellite navigation systems (GPS and GLONASS) have been established or are under development:

- **W**ide **A**rea **A**ugmentation **S**ystem (WAAS) in the USA and Canada. The objective of the WAAS is to enhance the GPS standard positioning service in commercial aviation, in particular. The Federal Aviation Administration (FAA) commissioned the WAAS system for operational use on July 10, 2003. The WAAS does not include augmentation to GLONASS;
- **E**uropean **G**eostationary **N**avigation **O**verlay **S**ystem (EGNOS) in Europe and North Africa. EGNOS includes augmentations to GPS and GLONASS, and can be considered (July 2004) as operational;
- **M**ulti–functional **S**atellite–based **A**ugmentation **S**ervice (MSAS), fully operational in Japan and **Q**uasi **Z**enith **S**atellite **S**ystem (QZSS), new system under development, in Japan also.

All mentioned above systems are contributions to a first generation of a **G**lobal **N**avigation **S**atellite **S**ystem (GNSS–1) and intend to provide seamless coverage of the whole globe with the position accuracy (95%) few meters or better [9,11]. These systems work by enhancing the data provided by GPS system, offering greater precision and signal continuity. They are also known as **S**atellite–**B**ased **A**ugmentation **S**ystems (SBAS). An alternative solutions are **G**round–**B**ased **A**ugmentation **S**ystems (GBAS), broadcasting corrections on Very High Frequency (VHF).

3. TELEMATICS APPLICATIONS IN THE TRANSPORT

In land transport in the Thales Telematics Solution the SNS is one of the most important elements in two steps of the procedure chain – from data capture and integration to customer applications and services [12]:

- design and development; satellites deliver positioning data,
- installation,
- positioning and communication, satellites can pinpoint position within a few meters,
- data integration,
- customer applications,
- customer support.

The Telematics system has many features and capabilities:

- easy to use, proven system,
- professional help desk and training facility,
- street–level mapping for pinpoint accuracy,
- standard or customised management reporting,

- zone and route setting management feature,
- proven stolen vehicle recovery service,
- vehicle engine information,
- advanced driver recognition.

Satellite navigation systems and Satellite Based Augmentation Systems find different telematics applications in car, land and inland navigation [5]. As the EGNOS service is distributed mainly through EGNOS transponders on three Geostationary Earth Orbit (GEO) satellites, in the case of urban areas, land mobile applications suffer from the obstruction and attenuation of the GEO signal. That's why the new service, called SISNeT, is developed by European Space Agency. This service allows retrieving the EGNOS messages across the Internet in real time, usually employing wireless like GSM or GPRS. In case of low visibility of the GEO satellites, in North Europe, in particular, users can continue taking the most of the EGNOS potential, via SISNeT.

3.1. CAR NAVIGATION

The road sector is one of the major potential market for GNSS applications and therefore it is very promising for future EGNOS and Galileo applications. Improved road transport systems calls for systematic access to vehicle information (position and speed). Among road applications, some requires guaranteed navigation services, often with high accuracy positioning requirements; today these requirements are not met with the existing navigation systems, with GPS system in particular.

EGNOS and Galileo will provide better accuracy of GPS and will make available the data integrity information, that is the basis to certify and guarantee the service. The "tolling" application falls into this category and represents an important commercial opportunity. The goal of this new application is an extended service concept of road tolling, including both basic tolling service and additional "pay–per–use service" on motorways and urban environment (parking and access to restricted zones) [3].

Car navigation will be one of the major drivers in the European GNSS market segment. As each year in Europe, 40,000 people die and 1,700,000 are injured in road accidents, the new project, known as ARMAS (Active Road Management Assisted by Satellite), will be a system for monitoring vehicles via satellite based on EGNOS. These are only the initial steps to full automated solutions for car navigation and monitoring which would greatly improve safety and comfort reducing simultaneously costs in the road related segment [2].

3.2. LAND TRANSPORT AND MARITIME NAVIGATION

EGNOS can be used in road and maritime transport. The details on prototype EGNOS terminal hardware and the implemented applications proposed by the international consortium are the following [14]:

- management, driving aid and documentation of road winter services: EGNOS integrity and Wide Area Differential Corrections are used for aiding task and in the future for legal recordings;
- tracking and corridor surveillance for dangerous goods transport: EGNOS integrity is used to enable there enforcement of transport restrictions and regulations for these specific transport;

- maritime map display and navigation aid: EGNOS integrity and WAD corrections are used for aiding the steering task in particular in narrow and shallow waters.

In railway sector German firm Kayser–Threde is successfully involved in the low–cost wagon tracking, fleet management and positive train control businesses. In this area it is required to group complementary sensors (e.g. accelerometers, digital track maps) and/or alternative communication components around the GPS receiver and the communication subsystem which today is GSM in most cases [1].

The selected commercial railway tracks provided varying terrain features such as plains, hills, mountains, forests and tunnel passages. These "in the field" tests prove the feasibility of GNSS–based sensor fusion systems for future use in train navigation and signalling control.

3.3. INLAND NAVIGATION

The widely use of inland waterways as a commonly used transport mode is a main objective of the traffic policy in Europe. The project River Information Services (RIS) provides a concept for a telematics system for inland navigation [4]. This project is the first step towards the introduction of EGNOS and finally Galileo to the next generation through:

- replacement of conventional RIS local Differential GPS stations by direct reception of the EGNOS Signal In Space (SIS) in shipboard navigation equipment,
- augmentation of the EGNOS SIS by retransmitting the EGNOS differential corrections and integrity data via Automatic Identification System (AIS) Base Stations in areas without direct EGNOS reception, as urban canyon, under bridge, mountainous terrain;
- analysis of transition scenarios from today's GPS and DGPS based RIS system architecture towards the implementation of Galileo and EGNOS.

In other project, called MUTIS (Multi Modal Traffic Information Services), the experiences will be used to set up not only EGNOS but also Low Earth Orbit (LEO) satellites as Iridium or Globalstar and satellite based communication technologies [13]. The tests of these projects cover Danube and Rhine region westwards Vienna to Amsterdam and from Vienna eastwards to the Black Sea. The goal is generation operating figures regarding system availability and typical transmission delays in the whole pan–European transport corridor.

4. CONCLUSIONS

We can recapitulate that:

- as the new telematics applications in the transport need the knowledge of the user's position, the navigation satellite systems and satellite based augmentation systems, considering their accuracy, integrity, availability and continuity of service, can be used in the different modes of the transport, in particular in land transport, in restricted area as urban canyon also;
- the use of EGNOS in telematics applications proves that will be possible to obtain DGPS accuracy without the cost of extra reference terrestrial stations or radiodata links;

- nowadays only GPS is fully operational, the exploitation of the second system, as GLONASS or Galileo (in 2008), will assure in maritime and urban restricted area the possibility of fix position in almost all cases and increase of its accuracy. That's why the question GPS or Galileo doesn't exist already, now the slogan is GPS **and** Galileo!
- as the distribution of satellite azimuths depends on observer's latitude, the satellite position accuracy in urban restricted area depends on its geographic situation, latitude in particular.

BIBLIOGRAPHY

[1] BEDRICH S., MÜNCHEBERG S., Concepts for Railway Traffic management with GNSS–based Sensor Fusion Systems, The European Navigation Conference GNSS 2004, Rotterdam 2004
[2] BRANCO. P., SANTOS R., Intelligent Car Navigation Systems – technology Preview and Future European Directions, The European Navigation Conference GNSS 2004, Rotterdam 2004
[3] GUIDA U.G. others, EGNOS for Vehicule Remote Tolling, The European Navigation Conference GNSS 2004, Rotterdam 2004
[4] JANDRISITS M.T., TROEGL J. T., PFLIEGL R.P., EGNOS Train Solutions for River Information System, The European Navigation Conference GNSS 2004, Rotterdam 2004
[5] JANUSZEWSKI J., Data Transfer for High Precision Users in the Sea, Road and Rail Transport, II International Conference Transport Systems Telematics TST'02, Katowice – Ustroń 2002
[6] JANUSZEWSKI J., Position Accuracy of Satellite Navigation Systems in Restricted Area, 21st International Communications Satellites Systems Conference, Jokohama 2003
[7] JANUSZEWSKI J., Geometry and Visibility of Satellite Navigation Systems in Restricted Area, The European Navigation Conference GNSS 2003, Graz 2003
[8] JANUSZEWSKI J., Comparison of Visibility and Geometry of Galileo and GPS 27 satellites constellation, Reports on Geodesy, no 2(62), ISSN 0867–3179, Warsaw 2002
[9] JANUSZEWSKI J., System GPS i inne systemy satelitarne w nawigacji morskiej, Fundacja Rozwoju Akademii Morskiej, Gdynia 2004
[10] KAPLAN E.D.: Understanding GPS Principles and Applications. Boston London, Artech House Publishers 1996
[11] SEEBER G., Satellite Geodesy, de Gruyter, Berlin New York 2003
[12] Telematics Solutions for People, for Buisness, for Government, Thales Telematics SAS, Malakoff 2003
[13] TROEGL J.T. others, EGNOS and LEO for Telematics Applications in the Inland Waterway Segment – Project MUTIS, The European Navigation Conference GNSS 2004, Rotterdam 2004
[14] ZUNKER H., Road Transport and Maritime EGNOS Application Terminals, The European Navigation Conference GNSS 2004, Rotterdam 2004

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