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TELEMATICS APPLICATIONS OF SATELLITE NAVIGATION SYSTEMS IN RESTRICTED AREAS

The possibility of the use of satellite navigation systems in the new advanced telematics applications in restricted area depends on the user's latitude, the dimensions and situated area of the obstacles. Additionally in urban area it depends on the angle between the North and street axis. The results of the author's calculations of the satellite visibility and the user's position accuracy for GPS and Galileo systems for different number of theirs satellites operational are presented in this paper.

ROZWIĄZANIA TELEMATYCZNE WYKORZYSTUJĄCE NAWIGACYJNE SYSTEMY SATELITARNE W REJONACH OGRANICZONYCH

Możliwości stosowania nawigacyjnych systemów satelitarnych w rejonach ograniczonych zależą od szerokości geograficznej użytkownika oraz rozmiarów i usytuowania przeszkód, a w zabudowanie miejskiej także od azymutu osi ulicy. W referacie przedstawiono wyniki autorskich obliczeń o widzialności satelitów systemów GPS i Galileo oraz dokładności określanej za ich pomocą pozycji użytkownika dla różnej liczby satelitów operacyjnych.

1. INTRODUCTION

The selected propositions of the new advanced telematics applications in the different modes of the land transport with the use satellites navigation systems (GPS, Galileo) and Satellite Based Augmentation System as EGNOS were presented by the author in [1] & [5]. 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.

Satellites navigation systems deliver positioning data and thus the user can pinpoint within a 15–20 meters or better. However this position can be calculated only from these satellites, which are visible for the user and at the same time theirs elevation angles in observer's receiver are higher than the masking elevation angle H_{min}. That's why the possibility of the use of the new advanced telematics applications in restricted area, in urban area in particular, depends on the dimensions and situated area of the obstacles.

Additionally 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

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position is obtained principally from satellite navigation systems (SNS). At present (June 2005) unique fully operational and global system is American GPS (Global Positioning System – Navstar). 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 operational most likely in 2008. This system of the future will be used in aviation, sea transport and rail and road transport also.

2. VISIBILITY OF GPS AND GALILEO SATELLITES

In satellite navigation systems the satellite geometry is one of the most important parameters in the budget error of the user's position. Therefore the user must know GDOP (Geometric Dilution Of Precision) coefficient value of the constellation of these satellites which can be used for fix position [6]. If the number of satellites visible by the user is less than 4, its "3D" position cannot be obtained (the position is not available – No fix > 0).

As nowadays the number of GPS satellites fully operational (SO) changes [8], the calculations were made for SO between 27 and 30 for actual constellation (the number of satellites on one orbit changes between 4 and 7, the separation in right ascension between orbital planes is not equal 60^O. In the case of Galileo system the calculations were made for SO = 27 (nominal number) and SO = 30 (27 operational + 3 active). The details of the test methods can be found in the earlier author's publications, e.g. [2], [3], [4].

The distributions (in per cent) of satellite elevation angles (H) in open area for different SO for both systems at different user's latitudes (φ) are presented in the Table 1. The calculations were made for $H_{min} = 5^O$ and 15^O for the latitudes, where the land transport is possible; i.e. at latitude less than 70^O. Elevation H was divided in 9 intervals, each 10^O wide: 1st for $0^O<H\leq10^O$, 2nd for $10^O<H\leq20^O$, . . . , 9th for $80^O<H\leq90^O$. We recapitulate that:

- the distributions of angle H values in all 7 zones for both systems (independently of theirs SO numbers) are practically the same,
- for both systems in all 7 zones, about half of satellites are visible below 30^O, while the percentage of satellites visible above 70^O is less than 10.

The weighted mean number (l_m) of satellite visible by the user and the distributions (in per cent) of satellite azimuths in open area (without any obstacle) for masking angle $H_{min} = 5^O$ and 15^O for different number of SO for both systems at different user's latitudes (φ) are presented in the Table 2. The results are given for 3 zones: $0–10^O$ as low latitude, $30–40^O$ as middle latitude and $50–60^O$ as latitude of Poland. Azimuth (Az) was divided in 8 intervals: 1st for $0^O<Az\leq45^O$, 2nd for $45^O<Az\leq90^O$, . . . , 8th for $315^O<Az\leq360^O$. We can say that:

- distributions of satellite azimuths are practically the same for both systems independently of observer's latitude, masking angle and the number SO,
- the number of satellites in different Az intervals is not equal and it depends on user's latitude, i.e. at latitudes $0–10^O$ the number of satellites with azimuth from interval $0–45^O$ is the highest, while at latitudes $50–60^O$ in the same interval the least,
- at latitudes $50–60^O$ the number of satellites with azimuth from interval $315–045^O$ is less than from adjacent intervals ($045–090^O$ and $270–315^O$) twice or three times and more,
- if for both systems the number SO is the same, the number l_m for Galileo is greater than for GPS in each zone and for each H_{min}.

In urban area the mean number of satellites (l_{ms}) visible above H_{min} and the obstacles blocking the user situated in the middle of the street for different angles between the North and street axis (angle α) for two systems at different observer's latitudes (φ) are demonstrated

in the Tables 3. The calculations were made for two angles H_{min} (5^O and 15^O) for the dimensions of the street: width L = 20 m, height of the buildings B = 10 m, for four angles α (0^O, 45^O, 90^O and 135^O) for three mentioned zones of latitude. We recapitulate that:

Table 1

Distribution (in per cent) of satellite elevation angles (H) in open area for different number of satellites operational (SO) of Galileo system and GPS system at different observer's latitudes (φ)

φ [°]	System	SO	Elevation of angle H [°]								
			0 – 10	10 – 20	20 – 30	30 – 40	40 – 50	50 – 60	60 – 70	70 – 80	80 – 90
0 – 10	GAL	27	18.8	21.2	19.8	14.7	9.5	7.3	5.0	2.7	0.9
		30	19.1	21.1	19.8	14.7	9.5	7.2	4.9	2.8	0.9
	GPS	27	19.4	21.3	20.3	14.3	9.7	6.9	4.5	2.8	0.8
		28	19.4	21.5	20.3	14.2	9.7	6.9	4.5	2.8	0.7
		29	19.4	21.4	20.2	14.0	9.7	6.9	4.9	2.7	0.8
		30	19.4	21.5	20.2	14.2	9.7	6.9	4.6	2.7	0.8
10 – 20	GAL	27	22.4	18.6	15.4	14.4	12.1	7.8	5.3	3.0	1.0
		30	22.5	18.6	15.4	14.3	12.1	7.8	5.3	3.0	1.0
	GPS	27	22.7	18.8	14.9	15.2	11.8	7.7	5.2	2.8	0.9
		28	22.9	18.9	14.8	15.2	11.8	7.7	5.1	2.7	0.9
		29	22.9	18.8	14.8	15.2	11.8	7.8	5.0	2.8	0.9
		30	22.9	18.8	14.9	15.2	11.8	7.8	5.1	2.7	0.9
20 – 30	GAL	27	21.4	17.1	14.5	12.7	12.4	10.7	6.3	3.7	1.2
		30	21.5	17.0	14.6	12.7	12.3	10.7	6.4	3.6	1.2
	GPS	27	21.6	16.6	14.9	12.9	12.8	10.6	6.5	3.1	1.0
		28	21.7	16.7	14.9	12.8	12.6	10.7	6.5	3.1	1.0
		29	21.6	16.6	14.9	12.9	12.8	10.6	6.5	3.1	1.0
		30	21.6	16.7	15.0	12.9	12.6	10.6	6.5	3.1	1.0
30 – 40	GAL	27	21.0	16.8	13.9	12.5	11.0	9.6	9.1	4.5	1.6
		30	20.8	16.8	14.0	12.5	11.0	9.7	9.1	4.6	1.5
	GPS	27	20.2	16.8	14.6	12.3	11.0	10.4	8.8	4.5	1.4
		28	20.2	16.9	14.6	12.3	10.9	10.4	8.8	4.5	1.4
		29	20.2	16.8	14.6	12.4	11.0	10.4	8.7	4.5	1.4
		30	20.0	16.9	14.6	12.4	11.0	10.5	8.7	4.5	1.4
40 – 50	GAL	27	23.0	16.7	14.3	11.8	9.9	8.5	7.6	6.1	2.1
		30	23.0	16.6	14.2	11.9	9.9	8.5	7.7	6.1	2.1
	GPS	27	22.4	16.6	14.5	12.0	10.3	8.6	7.4	6.1	2.1
		28	22.3	16.6	14.6	12.0	10.2	8.6	7.4	6.2	2.1
		29	22.3	16.6	14.5	12.1	10.3	8.6	7.4	6.1	2.1
		30	22.2	16.6	14.6	12.0	10.4	8.6	7.4	6.1	2.1
50 – 60	GAL	27	23.0	19.7	14.5	11.8	9.3	8.2	6.4	4.8	2.3
		30	23.0	19.7	14.3	12.0	9.3	8.2	6.4	4.8	2.3
	GPS	27	24.3	18.5	14.1	12.0	10.0	6.5	6.5	4.7	2.1
		28	24.3	18.6	14.1	11.9	10.1	7.8	6.5	4.6	2.1
		29	24.4	18.5	14.1	12.0	10.0	7.8	6.5	4.6	2.0
		30	24.3	18.5	14.1	12.0	10.0	7.9	6.5	4.7	2.0
60 – 70	GAL	27	18.2	21.5	18.4	13.1	10.2	8.5	6.5	3.3	0.3
		30	18.1	21.4	18.4	13.2	10.2	8.6	6.5	3.3	0.3
	GPS	27	19.2	22.5	17.5	13.0	10.2	8.6	6.1	2.8	0.1
		28	19.3	22.3	17.5	13.0	10.2	8.6	6.1	2.8	0.2
		29	19.3	22.3	17.5	13.0	10.2	8.7	6.1	2.8	0.1
		30	19.2	22.3	17.6	13.0	10.3	8.6	6.1	2.8	0.1

- the number l_{ms} for Galileo system is always greater than for GPS system,
- the number l_{ms} depends on the user's latitude for each angle H_{min} for each angle α for both systems,
- the number l_{ms} decreases and the relation l_m/l_{ms} increases with angle H_{min} in each zone for each angle α for both systems.

Table 2

Distribution (in per cent) of satellite azimuths for different masking elevation angles (H_{min}) for different number of satellites operational (SO) of Galileo system and GPS system at different user's latitudes (φ), l_m – weighted mean number of satellites visible by the user

φ [°]	H_{min} [°]	System	SO	l_m	Satellite azimuth [°]							
					0–45	45–90	90–135	135–180	180–225	225–270	270–315	315–360
0–10	5	GAL	27	10.0	15.0	9.9	10.0	14.9	15.0	9.8	10.2	15.2
			30	11.1	15.3	9.9	10.0	14.8	14.8	9.7	10.2	15.3
		GPS	27	9.8	14.9	10.3	9.9	15.2	15.1	9.8	9.7	15.1
			28	10.2	14.9	10.3	10.0	15.2	15.1	9.8	9.7	15.0
			29	10.5	14.8	10.3	10.0	15.2	15.1	9.7	9.8	15.1
			30	10.9	14.8	10.3	10.0	15.2	15.1	9.6	9.8	15.2
	15	GAL	27	7.8	16.1	9.7	9.7	14.4	14.3	9.7	10.0	16.3
			30	8.7	16.4	9.6	9.6	14.5	14.1	9.5	9.9	16.4
		GPS	27	7.6	16.1	10.4	9.6	14.2	14.2	9.7	9.6	16.2
			28	7.8	16.0	10.3	9.6	14.4	14.4	9.6	9.5	16.2
			29	8.1	15.9	10.4	9.7	14.3	14.4	9.6	9.6	16.1
			30	8.4	15.9	10.4	9.6	14.3	14.4	9.5	9.6	16.3
30–40	5	GAL	27	8.8	10.7	17.0	11.3	10.8	11.4	10.9	16.7	11.2
			30	9.8	10.8	17.2	11.1	10.8	11.2	10.8	16.9	11.2
		GPS	27	8.6	9.6	18.1	10.9	11.3	11.2	10.8	18.5	9.6
			28	8.8	9.7	18.1	10.9	11.4	11.2	10.7	18.5	9.5
			29	9.2	9.7	18.1	10.9	11.4	11.2	10.6	18.7	9.4
			30	9.5	9.6	18.1	10.9	11.3	11.2	10.6	18.7	9.6
	15	GAL	27	7.0	10.5	17.7	11.1	10.1	11.1	10.9	17.3	11.3
			30	7.8	10.8	17.8	11.0	10.2	10.8	10.8	17.4	11.2
		GPS	27	6.8	9.7	19.0	11.0	10.5	10.5	10.5	19.0	9.8
			28	7.0	9.7	19.0	10.9	10.5	10.6	10.5	19.0	9.8
			29	7.3	9.7	19.0	11.0	10.6	10.5	10.4	19.1	9.7
			30	7.5	9.7	18.9	11.0	10.5	10.5	10.4	19.1	9.8
50–60	5	GAL	27	9.7	8.6	18.2	12.3	10.5	11.4	12.6	17.8	8.6
			30	10.8	8.7	18.3	12.2	10.5	11.2	12.4	18.0	8.7
		GPS	27	9.1	6.8	17.8	13.8	11.4	11.2	12.4	19.4	7.2
			28	9.4	6.8	17.9	13.8	11.4	11.2	12.4	19.3	7.2
			29	9.7	6.8	18.1	13.7	11.4	11.1	12.6	19.2	7.1
			30	10.1	6.7	18.2	13.6	11.3	11.2	12.7	19.2	7.1
	15	GAL	27	7.1	4.0	20.7	13.6	11.4	12.2	14.1	20.3	3.7
			30	8.0	4.0	20.8	13.6	11.3	12.1	13.8	20.5	3.9
		GPS	27	6.8	2.4	19.7	15.3	12.4	11.8	14.2	21.6	2.6
			28	7.0	2.4	19.8	15.3	12.4	11.8	14.2	21.6	2.5
			29	7.3	2.4	20.0	15.3	12.3	11.8	14.3	21.4	2.5
			30	7.6	2.3	20.0	15.2	12.2	11.9	14.4	21.5	2.5

3. NO FIX AND DIMINUTION OF POSITION ACCURACY

The calculations for urban area were made for the user situated in the middle of the street with the buildings on both sides; the building height B = 10 m, the width L of the street was 20 m for different angles between the North and street axis (α). No Fix (in per cent) and the comparison of the distribution (in per cent) of GDOP coefficient values for this urban area

Table 3

Mean number of satellites l_{ms} visible above H_{min} and the obstacles by the user situated in the middle of the street (width L = 20 m, height B = 10 m) for different angles H_{min} for different angles between the North and street axis (α) for different number of satellites operational (SO) of Galileo system and GPS system at different observer's latitudes φ, l_m – weighted mean number of satellites visible by the user

φ [°]	H_{min} [°]	System	SO	l_m	Angle α [°]							
					0		45		90		135	
					l_{ms}	l_{ms}/l_m [%]	l_{ms}	l_{ms}/l_m [%]	l_{ms}	l_{ms}/l_m [%]	l_{ms}	l_{ms}/l_m [%]
0–10	5	GAL	27	10.02	5.03	50.2	4.70	46.9	3.97	39.7	4.72	47.1
			30	11.12	5.58	50.2	5.21	46.9	4.40	39.6	5.23	47.0
		GPS	27	9.84	4.85	49.3	4.59	46.6	3.82	38.8	4.58	46.5
			28	10.18	5.01	49.3	4.74	46.6	3.94	38.8	4.74	46.5
			29	10.53	5.18	49.2	4.90	46.6	4.08	38.7	4.90	46.5
			30	10.92	5.37	49.2	5.08	46.5	4.23	38.7	5.10	46.6
	15	GAL	27	7.84	4.95	63.2	4.39	56.0	3.79	48.4	4.43	56.5
			30	8.68	5.49	63.2	4.87	56.1	4.20	48.3	4.90	56.4
		GPS	27	7.57	4.76	62.8	4.27	56.4	3.64	48.1	4.22	55.7
			28	7.82	4.92	62.9	4.41	56.4	3.76	48.0	4.37	55.8
			29	8.09	5.08	62.8	4.57	56.4	3.88	48.0	4.52	55.8
			30	8.39	5.27	62.8	4.73	56.4	4.03	48.0	4.70	55.9
30–40	5	GAL	27	8.83	4.27	48.4	5.05	57.2	5.10	57.7	5.04	57.1
			30	9.85	4.76	48.3	5.64	57.3	5.68	57.7	5.65	57.4
		GPS	27	8.58	4.13	48.2	4.90	57.1	4.94	57.6	4.91	57.3
			28	8.85	4.26	48.2	5.06	57.2	5.08	57.4	5.07	57.3
			29	9.17	4.41	48.1	5.25	57.1	5.27	57.4	5.25	57.2
			30	9.52	4.58	48.1	5.44	57.2	5.47	57.5	5.43	57.1
	15	GAL	27	7.01	4.16	59.4	4.72	67.4	4.91	70.1	4.72	67.4
			30	7.82	4.64	59.3	5.27	67.4	5.47	70.0	5.29	67,6
		GPS	27	6.79	3.99	58.2	4.58	67.5	4.77	70.2	4.59	67.7
			28	7.00	4.12	58.2	4.73	67.5	4.91	70.1	4.74	67.7
			29	7.26	4.26	58.7	4.90	67.4	5.09	70.0	4.91	67.6
			30	7.53	4.43	58.7	5.08	67.4	5.28	70.1	5.09	67.5
50–60	5	GAL	27	9.67	4.04	41.8	4.99	51.6	5.13	53.1	5.01	51.8
			30	10.84	4.53	41.8	5.59	51.6	5.75	53.0	5.63	51.9
		GPS	27	9.09	3.75	41.3	4.73	52.0	4.97	54.7	4.87	53.6
			28	9.36	3.87	41.4	4.88	52.1	5.13	54.8	5.02	53.6
			29	9.71	4.01	41.3	5.06	52.1	5.32	54.8	5.19	53.5
			30	10.06	4.16	41.4	5.25	52.2	5.53	54.9	5.38	53.5
	15	GAL	27	7.14	3.74	52.4	4.73	66.3	4.93	69.0	4.70	65.8
			30	8.02	4.19	52.3	5.30	66.1	5.52	68.8	5.29	65.9
		GPS	27	6.84	3.57	52.3	4.45	65.1	4.79	70.0	4.58	67.1
			28	7.05	3.69	52.3	4.60	65.2	4.94	70.1	4.72	67.0
			29	7.30	3.82	52.2	4.77	65.3	5.12	70.1	4.89	66.9
			30	7.58	3.96	52.3	4.96	65.4	5.32	70.2	5.06	66.8

and open area for the user's latitude 50–60° are presented in the table 4, for latitude 0–10° and 30–40° in the table 5. It was considered angle $H_{min} = 5^{\circ}$. As in land navigation in urban area user's receiver is located in the car, it was considered that receiver's antenna height $H_{ant} = 0$ m. We recapitulate that:

- the increasing of No Fix and GDOP coefficient values depends on the angle α and the observer's latitude zone for both systems,

Table 4

No Fix (in per cent) and the comparison of the distribution (in per cent) of GDOP values for restricted urban area (RUA) for the user situated in the middle of the street (width L = 20 m, height B = 10 m) and for open area (OPA), for masking elevation angle $H_{min} = 5^{\circ}$ for different angles between the North and street axis α at user's latitude 50–60° for different number of satellites operational (SO) of Galileo system and GPS system; ''+'' stands for increasing values, ''–'' for decreasing values, and ''0'' for no change

α [°]	System	SO	NO FIX [%]	GDOP(RUA) – GDOP(OPA) = v [%]						
				v≤3	3<v≤4	4<v≤5	5<v≤6	6<v≤8	8<v≤20	v>20
0	GAL	27	23.1	– 63.1	– 6.4	+ 12.0	+ 9.6	+ 9.9	+ 9.2	+ 5.7
	GPS	27	47.8	– 45.8	– 27.6	+ 4.1	+ 3.5	+ 4.3	+ 9.0	+ 4.7
		28	44.0	– 46.3	– 26.6	+ 5.2	+ 4.0	+ 5.7	+ 8.8	+ 5.2
		29	39.7	– 54.9	– 20.7	+ 7.8	+ 4.6	+ 7.4	+ 10.3	+ 5.8
45	GAL	27	1.5	– 60.3	+ 10.8	+ 16.4	12.2	+ 9.6	+ 7.0	+ 2.8
	GPS	27	21.9	– 43.2	– 18.2	+ 10.7	+ 7.6	+ 9.3	+ 8.6	+ 3.3
		28	19.9	– 43.4	– 16.7	+ 11.8	+ 8.3	+ 8.0	+ 8.6	+ 3.5
		29	15.4	– 49.5	– 6.5	+ 11.2	+ 8.7	+ 8.4	+ 8.6	+ 3.5
90	GAL	27	2.0	– 54.6	+ 10.4	+ 14.8	+ 9.9	+ 7.6	+ 6.2	+ 3.7
	GPS	27	16.6	– 42.4	– 14.2	+ 10.2	+ 6.5	+ 8.7	+ 10.2	+ 4.4
		28	15.2	– 41.6	– 14.4	+ 11.2	+ 7.4	+ 7.8	+ 10.1	+ 4.3
		29	9.9	– 46.0	– 6.4	+ 12.2	+ 8.9	+ 10.9	+ 8.3	+ 2.2
135	GAL	27	2.4	– 54.8	+ 13.8	+ 12.1	+ 9.3	+ 7.3	+ 5.9	+ 4.0
	GPS	27	17.0	– 43.2	– 14.4	+ 9.6	+ 8.5	+ 8.2	+ 9.2	+ 5.5
		28	15.6	– 42.7	– 12.9	+ 8.8	+ 9.2	+ 6.3	+ 9.8	+ 5.9
		29	10.3	– 46.7	– 7.2	+ 11.2	+ 9.9	+ 7.4	+ 9.2	+ 4.8

Table 5

No Fix (in per cent) and the comparison of the distribution (in per cent) of GDOP values for restricted urban area (RUA) for the user situated in the middle of the street (width L = 20 m, height B = 10 m) and for open area (OPA), for masking elevation angle $H_{min} = 5^O$ for different angles between the North and street axis α at user's latitude (φ) 0–10^O and 30–40^O for different number of satellites operational (SO) of Galileo system and GPS system; ''+'' stands for increasing values, ''–'' for decreasing values, and ''0'' for no change

φ [^{O}]	α [^{O}]	System	SO	NO FIX [%]	GDOP(RUA) – GDOP(OPA) = v [%]						
					v≤3	3<v≤4	4<v≤5	5<v≤6	6<v≤8	8<v≤20	v> 20
0 – 10	0	GAL	27	0.9	– 63.3	+ 25.2	+ 7.1	+ 12.8	+ 8.8	+ 6.2	+ 2.3
		GPS	27	22.1	– 59.7	+ 8.0	+ 7.7	+ 6.9	+ 5.6	+ 7.5	+ 1.9
			28	19.0	– 60.7	+ 9.1	+ 9.6	+ 6.5	+ 6.1	+ 7.4	+ 3.0
			29	12.5	– 63.1	+ 13.8	+ 10.8	+ 6.4	+ 7.0	+ 8.8	+ 3.8
	90	GAL	27	17.8	– 79.6	+ 11.5	+ 7.7	+ 14.0	+ 9.3	+ 12.6	+ 6.7
		GPS	27	43.4	– 68.6	– 0.9	+ 5.7	+ 6.3	+ 3.4	+ 7.4	+ 3.3
			28	38.2	– 69.0	+ 1.5	+ 9.0	+ 5.8	+ 3.6	+ 6.7	+ 4.2
			29	35.6	– 63.1	+ 5.6	+ 10.7	+ 6.6	+ 5.1	+ 7.7	+ 4.8
30 – 40	0	GAL	27	13.2	– 85.7	+ 20.8	+ 9.8	+ 18.1	+ 7.8	+ 10.6	+ 5.4
		GPS	27	38.5	– 55.5	– 7.8	+ 2.7	+ 4.3	+ 5.1	+ 9.1	+ 3.6
			28	34.5	– 56.2	– 6.3	+ 5.3	+ 4.2	+ 5.3	+ 9.0	+ 4.2
			29	30.8	– 60.5	– 4.7	+ 7.9	+ 5.5	+ 5.8	+ 10.1	+ 5.1
	90	GAL	27	0.3	– 76.0	+ 31.9	+ 8.0	+ 17.6	+ 6.9	+ 8.4	+ 2.9
		GPS	27	20.1	– 45.1	– 5.0	+ 6.3	+ 5.6	+ 4.9	+ 8.4	+ 4.8
			28	17.5	– 46.7	– 2.5	+ 7.6	+ 5.4	+ 5.6	+ 8.8	+ 4.3
			29	9.0	– 51.1	+ 1.0	+ 11.2	+ 7.8	+ 9.1	+ 9.1	+ 3.9

Table 6

No Fix (in per cent) and the comparison of the distribution (in per cent) of GDOP values for restricted urban area (RUA) for the observer situated 35 m from the obstacle (height B = 15 m) on the one hand (E, W, N or S) and for open area (OPA), for masking elevation angle $H_{min} = 5^O$ for different angles between the North and obstacle axis α at observer's latitude 50–60^O for different number of satellites operational (SO) of Galileo system and GPS system; "+" stands for increasing values, "–" for decreasing values, and "0" for no change

Angle α [^{O}]	Side	System	SO	NO FIX [%]	GDOP(RUA) – GDOP(OPA) = v [%]						
					v≤3	3<v≤4	4<v≤5	5<v≤6	6<v≤8	8<v≤20	v>20
0	E	GAL	27	0	– 11.8	+ 10.1	+ 1.2	+ 0.5	–	–	–
		GPS	27	2.1	– 23.3	– 2.6	+ 9.1	+ 5.1	+ 3.0	+ 4.7	+ 1.9
			28	2.1	– 23.3	– 1.9	+ 8.9	+ 4.9	+ 2.7	+ 4.6	+ 2.0
			29	1.0	– 24.8	+ 3.0	+ 8.7	+ 4.3	+ 2.7	+ 3.4	+ 1.7
	W	GAL	27	0	– 13.1	+ 10.4	+ 2.4	+ 0.2	+ 0.1	–	–
		GPS	27	2.8	– 24.8	– 1.2	+ 8.3	+ 5.6	+ 4.3	+ 4.2	+ 0.8
			28	2.8	– 24.6	– 1.0	+ 8.2	+ 6.6	+ 3.4	+ 3.8	+ 0.8
			29	0.8	– 28.2	+ 5.1	+ 10.3	+ 6.5	+ 2.6	+ 2.3	+ 0.6
45	E	GAL	27	0	– 7.5	+ 7.2	+ 0.1	+ 0.2	–	–	–
		GPS	27	0.8	– 20.6	+ 4.1	+ 7.5	+ 2.5	+ 2.2	+ 3.2	+ 0.3
			28	0.8	– 20.1	+ 4.3	+ 6.3	+ 2.3	+ 2.5	+ 3.4	+ 0.5
			29	0	– 19.8	+ 6.4	+ 6.2	+ 3.1	+ 1.2	+ 2.6	+ 0.3
	W	GAL	27	0	– 24.0	+16.9	+ 6.4	+ 0.7	–	–	–
		GPS	27	1.5	– 22.8	+ 0.9	+ 8.2	+ 4.9	+ 3.0	+ 3.4	+ 0.9
			28	1.3	– 22.9	+ 1.3	+ 8.7	+ 5.3	+ 2.0	+ 3.4	+ 0.9
			29	0	– 26.1	+ 7.6	+ 8.2	+ 5.9	+ 1.3	+ 2.6	+ 0.5
90	N	GAL	27	0	– 21.0	+ 11.9	+ 8.1	+ 1.0	–	–	–
		GPS	27	0.9	– 23.4	+ 1.4	+ 8.2	+ 4.4	+ 3.5	+ 4.0	+ 1.0
			28	0.5	– 23.5	+ 2.0	+ 7.5	+ 5.7	+ 2.7	+ 4.2	+ 0.9
			29	0	– 26.2	+ 6.9	+ 7.8	+ 6.1	+ 2.5	+ 2.6	+ 0.3
	S	GAL	27	0	– 9.0	+ 8.9	+ 0.1	–	–	–	–
		GPS	27	0.1	– 21.1	+ 5.9	+ 7.9	+ 2.5	+ 1.8	+ 2.6	+ 0.3
			28	0.1	– 19.4	+ 4.8	+ 6.7	+ 2.6	+ 2.2	+ 2.7	+ 0.3
			29	0.1	– 18.6	+ 7.5	+ 6.0	+ 2.6	+ 1.5	+ 0.9	–
135	N	GAL	27	0	– 17.5	+ 11.6	+ 5.6	+ 0.3	–	–	–
		GPS	27	1.5	– 21.6	+ 1.0	+ 7.6	+ 4.5	+ 1.7	+ 3.3	+ 2.0
			28	0.1	– 21.5	+ 2.2	+ 6.2	+ 4.9	+ 1.5	+ 3.6	+ 1.9
			29	0.1	– 22.3	+ 5.9	+ 6.4	+ 3.9	+ 2.0	+ 3.9	+ 1.1
	S	GAL	27	0	– 7.0	+ 6.8	+ 0.2	–	–	–	–
		GPS	27	0.7	– 21.4	+ 5.0	+ 8.3	+ 3.8	+ 1.2	+ 2.3	+ 0.1
			28	0.7	– 19.9	+ 3.7	+ 7.8	+ 4.1	+ 1.2	+ 2.2	+ 0.2
			29	0	– 19.0	+ 6.0	+ 7.6	+ 3.2	+ 1.2	+ 1.1	–

- for the same number SO (27) No Fix value (independently of angle α and user's latitude) is for Galileo less than for GPS considerably, e.g. at latitude 30 – 40^O and α = 90^O is equal, adequately, 0.3 and 20.1,
- as the distribution of satellite azimuths depends on observer's latitudes, the increasing of GDOP for α = 90^O is at latitude 0 – 10^O the highest, at latitude 50 – 60^O the least,
- GDOP coefficient values are greater in urban restricted area than in open area for both systems considerably [3], [5],

- if the number SO of GPS increases No Fix and GDOP coefficient values decrease in each case.

No Fix (in per cent) and the comparison of the distribution (in per cent) of GDOP values for the observer situated 35 m from the buildings (height = 15 m) on the one hand (East, West, North or South) and for open area (OPA), for different angles between the North and street axis α for Galileo system and GPS system are presented in the table 6. It was considered $H_{min} = 5^O$ at user's latitude 50–60^O. We can say that:

- for the same number SO (27) the increasing of GDOP coefficient value is for Galileo less than for GPS considerably,
- for the same number No Fix value is for Galileo equal 0 always, for GPS its value depends on angle α and the buildings side; e.g. if $\alpha = 0^O$ and the side is W No Fix = 2.8, if $\alpha = 90^O$ and the side is S No Fix = 0.1 only,
- GDOP coefficient value depends on the angle α and the buildings side for both systems,
- if the number of GPS satellites (SO) increases No Fix and GDOP coefficient value decrease in each case.

4. CONCLUSIONS

We can recapitulate that:

- as in open area about the half of GPS and Galileo satellites is visible by the user below 30^O, in urban area the possibility of the use of satellite navigation systems in the new advanced applications is very often limited (user's position accuracy decreases) and sometimes impossible (user's position cannot be obtained),
- as at the present time GPS satellite constellation [8] differs from baseline constellation [7], its actual GDOP coefficient is usually greater than few years ago,
- if the number of GPS SO increases (e.g. from 28 to 29) in urban area GDOP coefficient value decreases and No Fix value can decrease. The scale of this decreasing depends on this new satellite position (orbit and slot),
- as the distribution of satellite azimuths depends on observer's latitude, the possibility of the user's fix position and its accuracy depend on user's geographic location, street orientation and in the case of the one–side buildings, on this buildings side also.

BIBLIOGRAPHY

[1] 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
[2] 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
[3] JANUSZEWSKI J., Position Accuracy of Satellite Navigation Systems in Restricted Area, 21st International Communications Satellites Systems Conference, Jokohama 2003
[4] JANUSZEWSKI J., Geometry and Visibility of Satellite Navigation Systems in Restricted Area, The European Navigation Conference GNSS 2003, Graz 2003
[5] JANUSZEWSKI J., Satellite navigation system in the new advanced telematics applications, IV International Conference Transport Systems Telematics TST'04, Katowice – Ustroń 2004
[6] KAPLAN E.D., Understanding GPS Principles and Applications. Boston London, Artech House Publishers 1996
[7] SEEBER G., Satellite Geodesy, de Gruyter, Berlin New York 2003
[8] www.navcen.uscg.gov

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