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PLANNING MEASUREMENT CAMPAIGNS FOR PRECISE GNSS POSITIONING IN VARIOUS OBSERVATION CONDITIONS

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Summary

Currently, GNSS (Global Navigation Satellite System) positioning systems are becoming widely used not only in geodesy, but in broad positioning in very many areas of the economy and society. The growing popularity of GNSS, especially recent, is related to their significantly increasing availability and a reduction of measurement time to a minimum, while maintaining high positioning accuracy. High positioning accuracy is ensured, among other things, by applications that allow planning observation sessions so that measurement is taken at the best time windows. It is the moment when the impact of measurement errors due to the constellation of observed satellites is the smallest. The following paper presents an example of the use of such an application and its benefits for planning GNSS observations. This type of research is particularly important for urban areas, where conditions for receiving GNSS signals are particularly difficult. Increasing the number of observable satellites and simultaneously minimizing the value of the Position Dilution of Precision (PDOP) parameter allows obtaining position coordinates (3D) with high accuracy from the point of view of relevance to GNSS measurements. The paper demonstrates the fundamental significance of satellite constellation geometry for GNSS applications requiring high accuracy position determinations, for which correct planning of a measurement campaign is crucial. It avoids this way large errors or conditions that render the observations of a particular GNSS measurement method impossible.

Keywords

GNSS • DOP • satellite observation planning • Mission Planning

1. Introduction

The development of the ASG-EUPOS Active Geodetic Network and commercial networks such as TPI NETpro, VRSNET, SmartNet, and Nadowski NET had a significant impact on the popularization of GNSS technology in Poland, making precise real-time positioning widely available and cheaper. The second very important factor in their popularization was the development of existing navigation systems (GPS and GLONASS) and the emergence of new systems, such as European Galileo and Chinese

BeiDou. This solved the fundamental problem of the availability of satellite signals due to the varying conditions of the observation site during GNSS measurements.

Employing more than one navigation system significantly increases the availability of positioning and offers the chance to obtain satisfactory observation results, especially in areas with difficult terrain conditions for satellite measurements. Such areas include, in particular, mountainous areas with natural barriers to the open horizon and highly urbanised areas with intensive, dense and tall development, so-called urban canyons. In such areas, as well as in forests or coppices (e.g. parks or other recreational spaces), using one or even two systems [Januszewski 2006, Oleniacz and Świętoń 2018] might be insufficient for finding a correct solution.

This paper presents research carried out in two respects. The first included research on the availability of positioning using various combinations of GNSS systems (GPS, GLONASS, Galileo, BeiDou) under changing satellite conditions, caused by various types of obstacles limiting the reception of satellite signals. The second involved determining the impact of an additional navigation system on the results of RTK (Real Time Kinematic) measurements performed under the same satellite conditions. Tests that were carried out to determine the impact of an additional navigation system on the results of RTK measurements used GPS as the basic system, with the following systems added: GLONASS, Galileo and BeiDou.

The proposed solution, based on a multi-system GNSS, meets the contemporary requirements for measurement techniques and computing systems for practical applications. Apart from classic surveying, GNSS is used in many other areas of economic and social life. such as civil engineering, opencast mining, onshore and offshore drilling, transport and forwarding, environmental protection, and management. GNSS positioning is increasingly used in studying land surface movements in seismically susceptible areas, e.g. during the exploitation of coal mines and after they are closed [Sokoła-Szewioła and Siejka 2021]. In recent years, GNSS has also begun to play an increasingly important role in the application of satellite technologies in modern agriculture [Ciećko and Oszczak 2007] and forestry [Grala and Brach 2009, Szostak and Wężyk 2013]. It is gaining popularity also in the public security sector [ISOK 2015, Fellner and Fellner 2015] because this type of observations can be collected over large areas continuously with high temporal resolution. The issue of availability and accuracy of GNSS positioning in difficult observational conditions has been addressed by many authors. Ciećko and Maliszewski [2011], and Siejka [2015], among others, conducted research on the impact of difficult observation conditions on the accuracy of measurements made using the RTK technique with GPS and GPS+GLONASS satellites. An assessment of repeatability and performance of RTK positioning using GPS and GPS+Galileo systems in difficult field conditions for satellite measurements was also undertaken by [Pirti and Yucel 2022]. In this paper, we propose to employ all four currently available GNSS systems for precise positioning.

2. Current state of autonomous GNSS

Currently, there are four global and two regional autonomous navigation systems. Global Navigation Satellite Systems (GNSS) include American GPS (Global Positioning System), Russian GLONASS (Globalnaja Navigacionnaja Sputnikova Sistema), Chinese BeiDou (Great Bear) and European Galileo. The second group consists of regional systems, which include the Japanese QZSS and the Indian IRNSS (Indian Regional Navigation Satellite System). Thus, as of today, within an available location the user has at his disposal a multi-GNSS navigation satellite constellation consisting of a total of about 145 satellites, distributed in four types of orbits (Table 1).

Table 1. List of GNSS satellites (as of 03.04.2022)

GNSS	Status in the constellation		Orbit type		
	Total number of satellites	Number of operational satellites	MEO*	GEO*	IGSO*/ QZO*
GPS	32	29	32	–	–
GLONASS	25	23	25	–	–
Galileo	26	22	26	–	–
BeiDou	49	44	29	8	12
QZSS	5	4	–	1	4
IRNSS	8	8	–	3	5
Total GNSS	**145**	**130**	**112**	**12**	**21**

* Orbit Type: MEO = Medium Earth Orbit, GEO = Geostationary Orbit, IGSO = Inclined Geosynchronous Orbit, QZO = Quasi Zenith satellite Orbit

Source: Authors' own study based on https://qzss.go.jp/en/technical/satellites/index.html#GLONASS

In February of 2018, South Korea declared that it is going to build another navigation system. Its purpose is to provide another regional system of satellite positioning under the name of the Korean Positioning System (KPS), which was planned to launch before 2035. Each of these systems has the essential task of independently determining coordinate points on the Earth's surface and in its immediate vicinity. The main reason for creating new GNSS systems, as well as for the development and modernization of existing ones, is the fact that owning a satellite navigation system currently provides with large military and economic possibilities, and allows to guide the strategic industry branches. Therefore, three major world powers (USA, Russia, China) have their own global satellite navigation systems. The European Union, which is building its own system called Galileo, also aspires to join this group. Another reason for setting up new systems is to improve the safety and ensure the continuity of navigation services. As past experiences prove, the continuity of navigation services can be disrupted by a system failure or an introduction of intentional interruptions by the operators to eliminate unauthorised users. There have been several such failures in recent years, one has occurred in July of 2019 and has shut off the Galileo system for a week. At the same time, it should be noted that all these systems are constantly being improved, upgrading the positioning characteristics for all modern positioning systems. The main parameter that keeps changing is the accuracy of position determination which continuously is being improved. The US GPS system, for example, has permanently improved its positioning accuracy in a standalone solution over the past 25 years from about 100 m (2DRMS) in 1993 to $\leq$ 8 m in 2020. Increasing the accuracy of GPS absolute positioning results in a very significant increase of possible applications of this system. The analogous situation also applies to other GNSS positioning systems.

3. Research methodology

Due to the development of internet online services – such as free and user-friendly applications – planning in advance and assessing the observation site's satellite conditions does not pose any problem for GNSS. The research presented in this paper is based on the *GNSS Mission Planning* application for designing GNSS measurement campaigns. By using the IGS (International GNSS Service), the application provides detailed information on the satellites available at a specific time and at a location of the planned observations. Then, by using the selected parameters, the software is capable of assessing in detail the satellite conditions of the observation site, which allows finding the optimal time window at any location on the surface of the Earth, defined by the coordinates (*BLh)*.

For the research purposes, satellite observation planning was conducted as of 31 March 2021 for the following locations: Poland, Kraków, University of Agriculture Campus, Balicka Street 253c ($B = 50.083167^{\circ}$, $L = 19.852861^{\circ}$, $h = 272.9$ m). A point on the roof of the Faculty of Environmental Engineering and Land Surveying building near the KRUR reference station, the tallest building in the area (Fig. 1) with no other tall buildings or structures in the immediate vicinity, was selected for the study. This point is characterized by good conditions for satellite measurements, with an open horizon for the elevation $> 0^{\circ}$, without obstructions and difficulties in the availability of GNSS positioning. The adopted research strategy takes into account the variety of effects that obstructions can have on the availability and accuracy of measurements through changes in the elevation angle settings (zenith distances) of the observed satellites. Planned measurement campaigns are supposed to use between one to four observations of global navigation systems, in various combinations: GPS, GLONASS, Galileo, and BeiDou, for the adopted time window of 25 h. This paper does not include regional systems, i.e. QZSS and IRNSS, as they have a limited local scope and do not cover the area of the conducted research.

Source: Authors' own study

Fig. 1. Location of the basic measurement point

In the first stage of the research on the site of planned GNSS observations, based on the Sky Plot imaging, an analysis of the predicted routes of Artificial Earth Satellites (AES) flights was run in terms of:

1) the number of available satellites for individual multi-GNSS systems,
2) the quality of observable satellite constellations defined by the DOPs parameters.

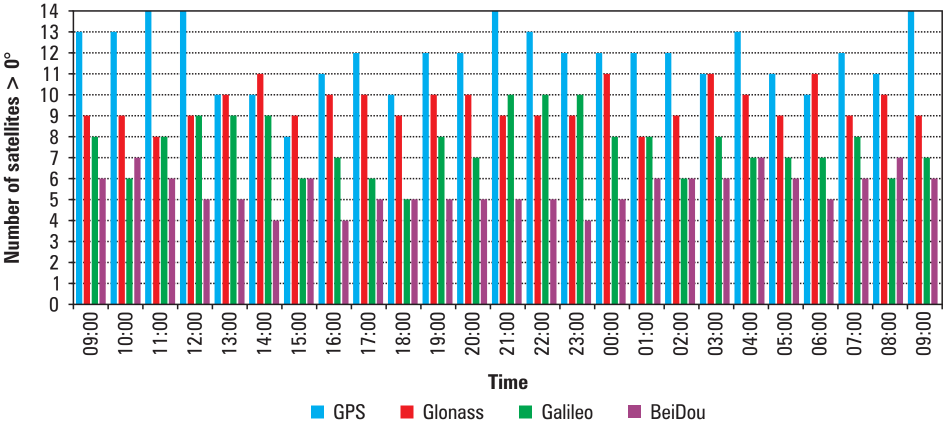
On their basis, for individual topocentric heights (variants), the most favourable time windows can be planned and determined, for taking GNSS measurements under optimal satellite conditions. These conditions are connected to two basic satellite parameters: the number of satellites observed and their geometry above the observation site.

The analyses were performed using the "*GNSS Mission Planning*" application with a time resolution of 1h in six different variants: for the following topocentric heights of satellites (elevations): 0^o , 10^o , 20^o , 30^o , 40^o , 50^o.

4. Results and discussion

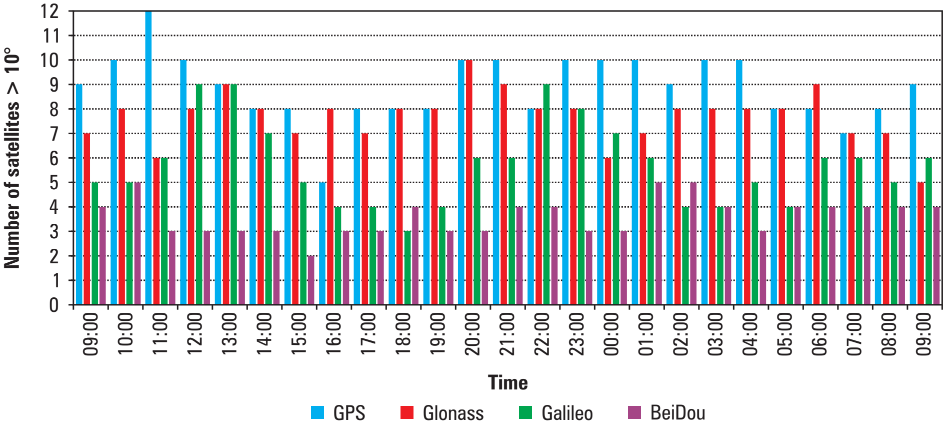
Analysis of satellite conditions in terms of the number of GNSS satellites available

The number of satellites observed is an important parameter, because it is necessary for accurate and reliable position determination and other calculations. Figures 2–7 show the number of available satellites for individual systems (GPS, GLONASS, Galileo, and BeiDou) in the analysed period of 25h, with an interval of 1h.



Source: Authors' own study

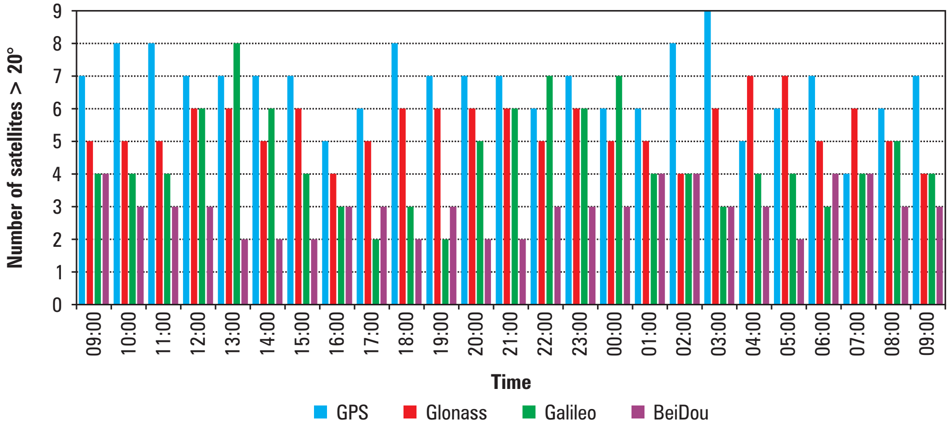
Fig. 2. The number of available satellites to be used per day, within global multi-GNSS, for elevations > 0° above the horizon



Source: Authors' own study

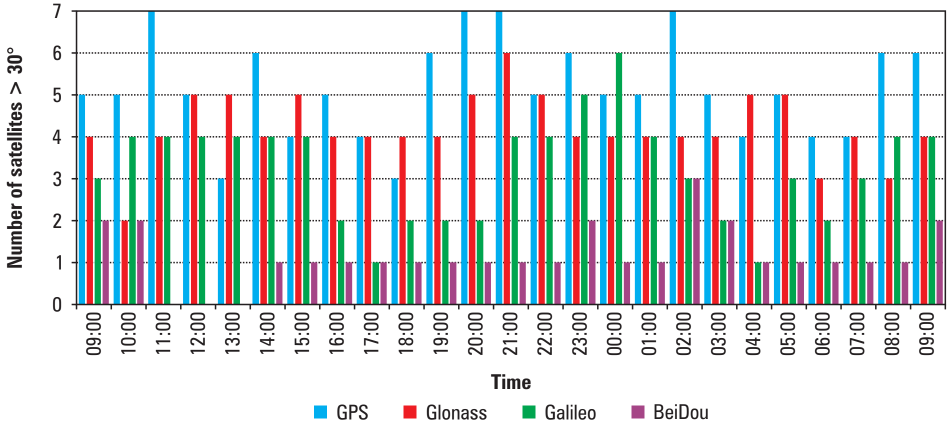
Fig. 3. The number of available satellites to be used per day, within global multi-GNSS, for elevations > 10° above the horizon

When analysing the general satellite conditions of a site of planned observations in terms of the availability of GNSS satellites, it should be mentioned that with the increase in the elevation angle from 0° to 50°, the number of observed satellites for each GNSS decreases (Fig. 2–7). It should be also noted, however, that the largest number of satellites occurs for elevations above 0° for GPS satellites. In the analysed period of 25h, up to 14 GPS satellites can be used to make simultaneous observations in four 1h time windows (Fig. 2). However, the Chinese BeiDou system in the same time interval can make observations during only 3 time windows of 1h, with up to 7 BDS satellites maximum deployed to this task (BeiDou Navigation Satellite System).



Source: Authors' own study

Fig. 4. The number of available satellites to be used per day, within global multi-GNSS, for elevations > 20 ° above the horizon



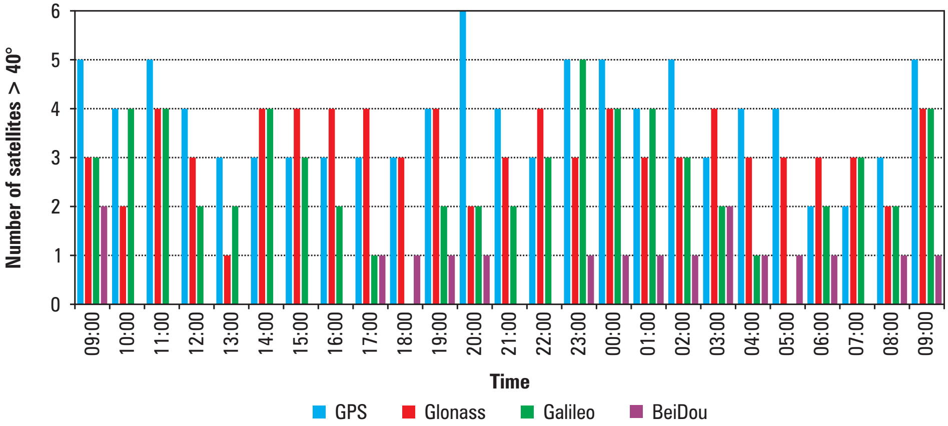
Source: Authors' own study

Fig. 5. The number of available satellites to be used per day, within global multi-GNSS, for elevations > 30 ° above the horizon

In addition, as the elevation angle of the observed satellites increases for the analysed time interval, there is a gradual decrease in the maximum and minimum number of observable GNSS satellites, respectively for (Fig. 3-7):

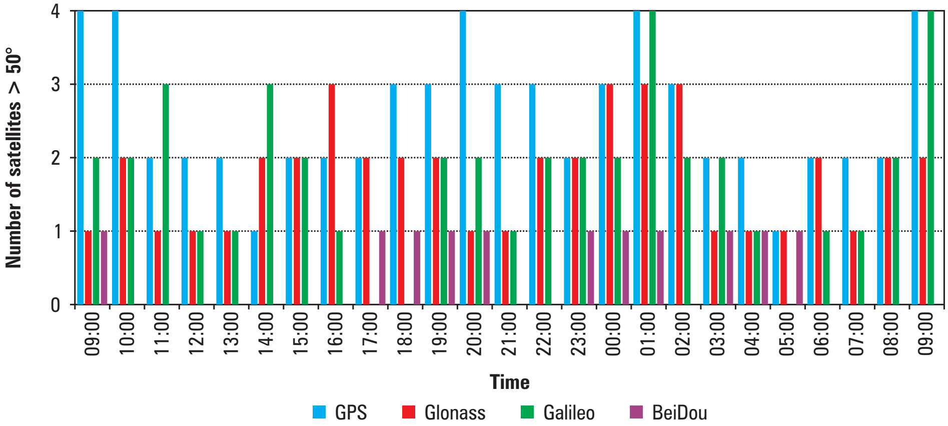
- GPS from 12 to 4,
- GLONASS from 10 to 3,

- Galileo from 9 to 4,
- BeiDou from 5 to 1.



Source: Authors' own study

Fig. 6. The number of available satellites to be used per day, within global multi-GNSS, for elevations > 40 ° above the horizon



Source: Authors' own study

Fig. 7. The number of available satellites to be used per day, within global multi-GNSS, for elevations > 50 ° above the horizon

Table 2 summarises the number of available satellites for all GNSSs in the studied time window, depending on the assumed elevation angle. These results prove that the number of observed satellites simultaneously up to four GNSS systems changed significantly with the increase in the angle of the elevation and amounted to:

Table 2. Summary of the total number of multi-GNSS satellites with a time resolution of *h* for different elevations

Elevation	Time/Number of satellites GNSS (GREC)																								
	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00
0°	36	35	36	37	34	34	29	32	33	29	35	34	38	37	35	36	34	33	36	37	33	33	35	34	36
10°	25	28	27	30	30	26	22	20	22	23	23	29	29	29	29	26	28	26	26	26	24	27	24	24	24
20°	20	20	20	22	23	20	19	15	16	19	18	20	21	21	22	21	19	20	21	19	19	19	18	19	18
30°	14	13	15	14	12	15	14	12	10	10	13	15	18	15	17	16	14	17	13	11	14	10	12	14	16
40°	13	10	13	9	6	11	10	9	9	7	11	11	9	10	14	14	12	12	11	9	8	8	8	8	14
50°	8	8	6	4	4	6	6	6	5	6	8	8	5	7	7	9	12	8	6	5	3	5	4	6	10

Source: Authors' own study

- for an elevation angle of 0 degrees, it was in the range of 29–38 satellites,
- for an elevation angle of 10 degrees, it was in the range of 20–30 satellites,
- for an elevation angle of 20 degrees, it was in the range of 15–23 satellites,
- for an elevation angle of 30 degrees, it was in the range of 10–18 satellites,
- for an elevation angle of 40 degrees, it was in the range of 6–14 satellites,
- for an elevation angle of 50 degrees, it was in the range of 3–12 satellites.

Thus, for the studied region, measurements using four GNSSs are possible throughout the day for obstructions of the horizon up to 40° elevation angle. For the elevation angle of 50° there are time windows in which only 3 or 4 satellites can be used for observation. Such a number of observed satellites makes it impossible to carry out real-time measurements (RTK / RTN), which require a minimum of 5 satellites with an appropriate constellation.

Table 3. Summary of observed satellite statistics for a single GNSS for different angles of satellite elevation

GNSS	**Elevation**																	
	0°			**10°**			**20°**			**30°**			**40°**			**50°**		
	Number of satellites																	
	Min	**Max**	**Av**	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**	**Min**	**Max**	**Av**
GPS	8	14	**12**	5	12	**9**	4	9	**7**	3	7	**5**	2	6	**4**	1	4	**3**
Glonass	8	11	**10**	5	10	**8**	4	7	**5**	2	6	**4**	1	4	**3**	1	3	**2**
Galileo	5	10	**8**	3	9	**6**	2	8	**4**	1	6	**3**	0	5	**3**	0	4	**2**
BeiDou	4	7	**5**	2	5	**4**	2	4	**3**	0	3	**1**	0	2	**1**	0	1	**0**

Source: Authors' own study

Table 3 summarises the basic statistics for the observed satellites of individual GNSS systems, in the form of: the minimum (MIN), maximum (MAX), and average (AV) number of satellites available for observations (GPS, GLONASS, Galileo, BeiDou) as a function of different elevation angles of satellites. On this basis, we conclude that using a single GPS or GLONASS system continuously around the clock we can achieve positioning for satellite elevations up to 20°. Whereas for higher elevations, it is necessary to use more than one navigation system.

Analysis of satellite conditions in terms of the quality of GNSS satellite constellations

The accuracy of GNSS positioning is also significantly influenced by the geometrical arrangement of satellites in the sky. The optimal distribution (minimum of four satellites) is one satellite high at the zenith above the observation site, and three others evenly distributed near the horizon (above the elevation mask). In GNSS measurements, the quality of the geometric constellation of satellites significantly affects the error of position determination. This error is typical of the factor called Dilution of Precision (DOP). Its value is calculated on the basis of the matrix of coefficients of the system of observational equations. Several types of DOPs are used:

- HDOP – for determining horizontal coordinates,
- VDOP – for determining the vertical coordinate,
- PDOP – for determining spatial coordinates (3D),
- TDOP – for the determination of time.

This paper presents a detailed analysis of daily changes in the PDOP coefficient, which plays the most important role for determining spatial coordinates and is responsible for the so-called position dilution of precision (3D). The PDOP coefficient [Czarnecki 2014] has a geometric interpretation in the form of a number proportional to the inverse of the volume V of the pyramid formed by the observed point (K) and the positions of the satellites ($S_{1, 2, 3, 4}$), used to determine its coordinates according to the formula (1).

$$\text{PDOP} \sim \frac{1}{V(S_{1,2,3,4,}K)} \tag{1}$$

The larger the volume of the pyramid, the lower the PDOP, which indicates a better configuration of satellites relative to the designated station. PDOP that determines the optimal arrangement of the satellite constellation in relation to the observer is approx. 1. Therefore, it is assumed that if PDOP equals 1–2, conditions for observation are very good, if 2–4 – they are good, if 4–5 – poor (but sufficient), if 5–6 – very poor (not always sufficient), while if PDOP >6, observations should not be made. During measurements, the PDOP is calculated successively, so the observer can control its value in real time on the receiver's display or field controller.

A key element of planning a GNSS mission, which should precede each measurement campaign, is the determination of the daily interval of minimal PDOP for the site of planned observations. Since the orbits of the satellites are known, PDOP can be predicted for any time and location. Minimising DOP is the key element from the point of view of taking GNSS measurements that enables obtaining position coordinates with high accuracy [Specht 2007].

Using various applications for planning measurement missions, it is possible to determine the values of all DOP coefficients (HDOP, VDOP, PDOP, TDOP) and thus predict their values for a given time window.

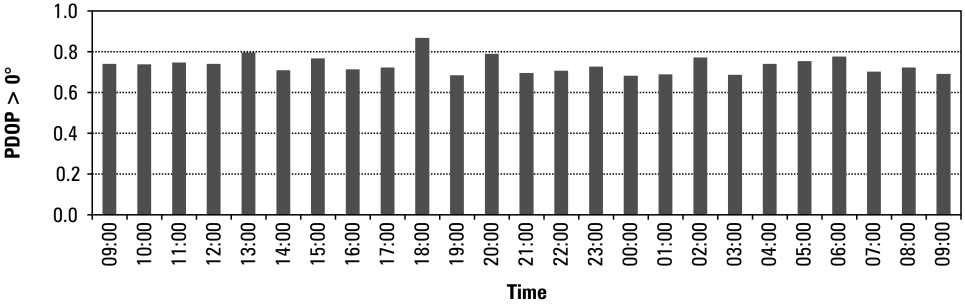
In accordance with the general technical recommendations adopted for the GNSS positioning standards, the limit values of the PDOP coefficient [GGK 2011] should not exceed the following levels:

- for the execution of static satellite measurements of PDOP ≤ 6,
- minimum conditions for measuring RTK PDOP < 6.

Additional conditions:

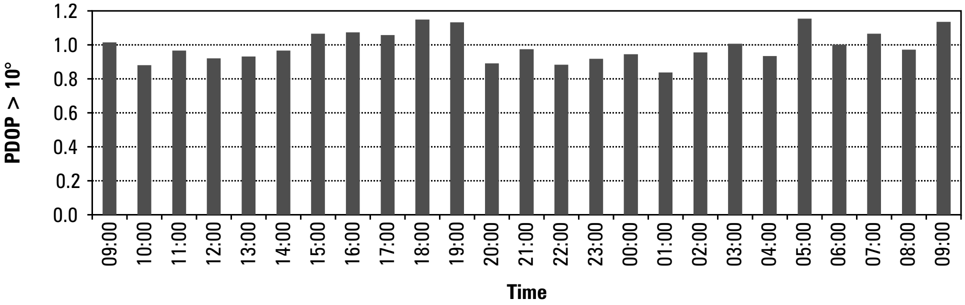
- situational and height measurement control network points, situational details as the subject of land and building register, adjustment points used in the transformation: PDOP ≤ 3,
- situational details belonging to the I and II accuracy groups: PDOP ≤ 4.

The PDOP coefficient describes the magnitude of the dilution error in position accuracy for the three coordinates (3D). Figures 8–13 show the distribution of PDOP coefficient values for all the GNSS satellites used in the research area, as a function of the satellite horizon angle for the entire study period with a time interval of 1h. It is clear that the increase in the angle of the elevation of the satellites implies an increase in the maximum value of the PDOP coefficient. For the elevation of 30°, the coefficient reaches PDOP = 3.5. This is the limit for reliable real-time kinematic positioning. For elevation of 40° and higher, the PDOP coefficient is > 6, and in some time windows, it is impossible to determine, which means that GNSS measurements cannot be performed in a given area.



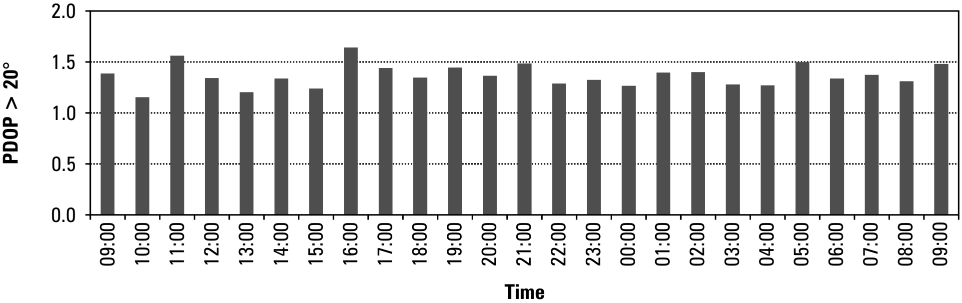
Source: Authors' own study

Fig. 8. Changes in PDOP value, by day, within global multi-GNSS (GREC) for elevation > 0° above the horizon



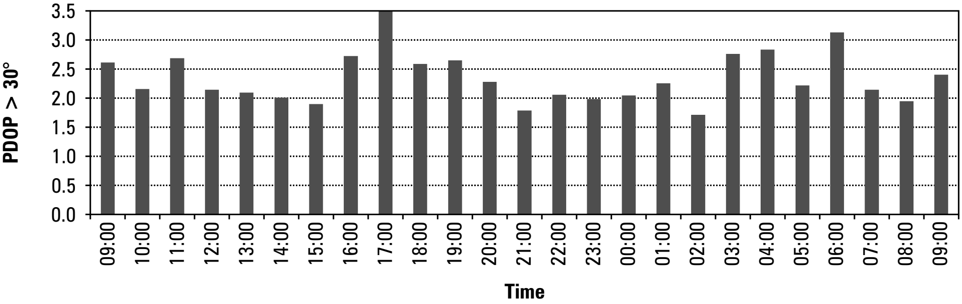
Source: Authors' own study

Fig. 9. Changes in PDOP value, by day, within global multi-GNSS (GREC) for elevation > 10° above the horizon



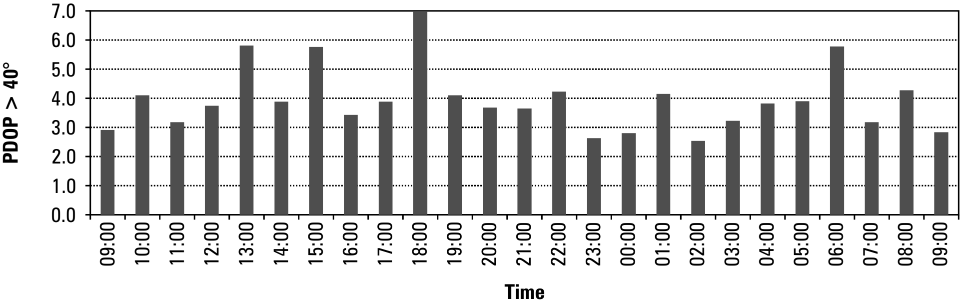
Source: Authors' own study

Fig. 10. Changes in PDOP value, by day, within global multi-GNSS (GREC) for elevation > 20° above the horizon



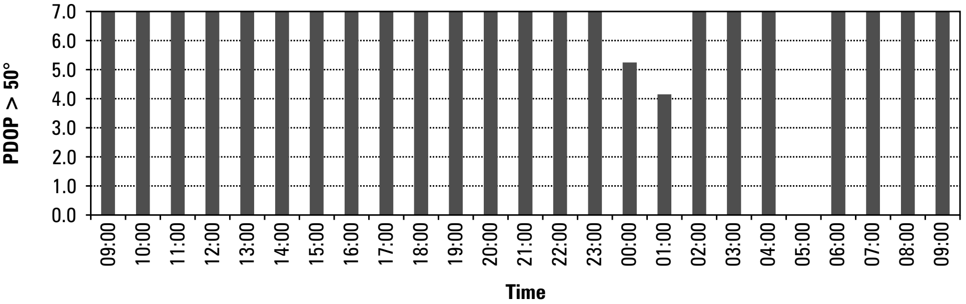
Source: Authors' own study

Fig. 11. Changes in PDOP value, by day, within global multi-GNSS (GREC) for elevation > 30° above the horizon



Source: Authors' own study

Fig. 12. Changes in PDOP value, by day, within global multi-GNSS (GREC) for elevation > 40° above the horizon



Source: Authors' own study

Fig. 13. Changes in PDOP value, by day, within global multi-GNSS (GREC) for elevation > 50° above the horizon

Table 4 summarises the values of the Position Dilution of Precision coefficients showing the dilution error for three position coordinates, depending on the quality of the satellite constellation for the multi-GNSS (GREC) four-system solution. The PDOP values are summarised in seven ranges: 0–1≥; 1–2≥; 2–3≥; 3–4≥; 4–5≥; 5–6≥ and PDOP >6, because different PDOP coefficient values are required for different measurement techniques and accuracy conditions [GGK 2011]. All calculations of PDOP values for the analysed time interval (25h) were run using the *GNSS Mission Planning* application in accordance with the formula (1). Analogous lists of PDOP coefficients are summarised in Tables 5–8 for individual navigation systems, respectively: GPS, GLONASS, Galileo, BeiDou.

The data contained in Tables 4–8 show that the best values of the PDOP availability coefficient for the entire examined period occur only when the solution of the multi-GNSS maintains for the entire examined time interval the PDOP coefficient value in the range of 0–1≥ (Table 4).

Table 4. Daily values of PDOP availability coefficients for GNSS (GREC)

Elevation (GNSS)	GNSS availability coefficient in [%]						
	PDOP <0–1≥	PDOP <1–2≥	PDOP <2–3≥	PDOP <3–4≥	PDOP <4–5≥	PDOP <5–6≥	PDOP <6
0°	100						
10°	58	42					
20°	–	100					
30°	–	25	67	8	–	–	–
40°			17	46	21	12	4
50°					4	4	92

Source: Authors' own study

Table 5. Daily values of PDOP availability coefficients for GPS

Elevation (G)	GPS availability coefficient (G) in [%]						
	PDOP <0–1≥	PDOP <1–2≥	PDOP <2–3≥	PDOP <3–4≥	PDOP <4–5≥	PDOP <5–6≥	PDOP <6
0°	17	83					
10°		58	38	4			
20°			67	12	17	4	
30°			12	17	17	8	46
40°							100
50°							100

Source: Authors' own study

Table 6. Daily values of PDOP availability coefficients for GLONASS

Elevation (R)	GLONASS availability coefficient (R) in [%]						
	PDOP <0–1≥	PDOP <1–2≥	PDOP <2–3≥	PDOP <3–4≥	PDOP <4–5≥	PDOP <5–6≥	PDOP <6
0°		92	8				
10°		38	29	33			
20°			29	29	4		38
30°				8	8		84
40°							100
50°							100

Source: Authors' own study

Table 7. Daily values of PDOP availability coefficients for Galileo

Elevation (E)	Galileo accessibility coefficient (E) in [%]						
	PDOP <0–1≥	PDOP <1–2≥	PDOP <2–3≥	PDOP <3–4≥	PDOP <4–5≥	PDOP <5–6≥	PDOP <6
0°		58	25	9	4		4
10°		21	21	21	8		29
20°			17	21	4		58
30°					4		96
40°							100
50°							100

Source: Authors' own study

Table 8. Daily values of PDOP availability coefficients for BeiDou

Elevation (C)	BeiDou (C) availability coefficient in [%]						
	PDOP <0–1≥	PDOP <1–2≥	PDOP <2–3≥	PDOP <3–4≥	PDOP <4–5≥	PDOP <5–6≥	PDOP <6
0°	21	79					
10°		100					
20°		33	50	17			
30°			13	21	13	8	45
40°				8		13	79
50°							100

Source: Authors' own study

5. Conclusions

The paper presents the results of the analysis of the impact of the horizon angle on the satellite conditions of GNSS positioning. The conducted research shows that currently a user equipped with a multi-GNSS multi-system receiver can employ over 140 satellites of various autonomous satellite navigation systems. An additional assumption that a single satellite usually transmits observation signals on several frequencies simultaneously significantly increases the number of pseudo-distance and phase measurements, and consequently the positioning accuracy. For this reason, the development of multi-system receivers is today the main way of using the GNSS systems in navigation and precise geodetic positioning. This development is implemented not only through precise geodetic receivers, but also through cheaper multi-GNSS code receivers, which, compared to a single-system solution (e.g. GPS), allow to obtain significantly higher measurement accuracy. In each solution, the simultaneous tracking of satellites of several GNSS positioning systems increases the number of observations, resulting in an increase in accuracy and a higher level of reliability of position determination resulting from a higher number of additional observations. Furthermore, as a result of tracking a larger number of satellites, the value of the Dilution of Precision (DOP) coefficients decreases, as demonstrated in this paper by the PDOP example. In urbanised areas, PDOP is a key enabler of higher accuracy position availability relative to single-system solutions. In addition, the value of the PDOP coefficient together with information on the number of available satellites may be valuable information for the observer when positioning interruptions may occur in a given area during observations due to too few satellites being tracked by the receiver. Also, the use of a larger number of GNSS positioning systems increases the receiver's resistance to intentional interference of satellite signals, e.g. jamming.

The use of integrated satellite measurements using four GNSS systems (GPS + GLONASS + Galileo + BeiDou) allows positioning even in difficult observation conditions with an elevation mask up to 40°. As shown in the paper, achieving position availability with a certain (accuracy) error value requires additional campaign planning that minimises the value of DOP coefficients.

The defined percentage values of daily PDOP availability coefficients in the adopted ranges allow determining time windows in which the error of determining the position coordinates will be less than or equal to the arbitrarily determined value.

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