INTEGRATION OF GPS, GLONASS AND GALILEO SYSTEMS IN PRECISE REAL-TIME SATELLITE MEASUREMENTS

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Abstract

Global Navigation Satellite System (GNSS) are currently used in a wide spectrum of areas of life and economy such as: navigation, geodesy, geodynamics, precise agriculture, geographic information systems, rescue services and many more. The main goal of the work was the analysis of the impact of attaching observations from GLONASS and Galileo satellites on the results of satellite positioning in comparison to positioning based only on the GPS system. The paper presents the benefits resulting from the use of a combination of GPS and GLONASS or GPS, GLONASS and Galileo systems in relation to a single GPS system. The improvement of satellite conditions of the observation site was shown as a result of the increase in the number of observed satellites. Geodetic measurements with the use of integrated satellite navigation systems enable determination of the position on the areas where it was up to now impossible due to the large overrides of the horizon. The integration of positioning systems also affects the convergence time and contributes to the improvement of the accuracy and reliability of the determined coordinates using the real-time measurement technique. Moreover, it has been shown that there are some systematic errors in RTK measurements, which should be eliminated in order to obtain precise measurement results. As the research has shown, this applies in particular to heights measurement. The developed research methods will be able to be used for positioning studies based on other scenarios of systems integration, e.g. GPS, GLONASS, Galileo and BeiDou.

Keywords: GPS, GLONSS, Galileo, BeiDou, measurement errors, convergence time

Introduction

Precise positioning (Real Time Kinematic - RTK) is a method of position determination using the global satellite navigation system (GNSS). This method uses pseudoranges and carrier phase measurements as well as additional corrections from ground reference stations in order to calculate position with high (subcentimeter) accuracy in the real time in a specific place in the world. The quality of satellite positioning depends significantly on the number of observations used to determine the position basing on existing GNSS systems such as GPS, GLONASS, Galileo and BeiDou (LI, 2015; SIEJKA, 2014; TEUNISSEN et al., 2014). The second important factor that improves the quality of positioning is the effective elimination of errors of the propagation signals in the atmosphere. Using multi-frequency and multi-system GNSS observations, modern receivers equipped with advanced real-time postprocessing algorithms enable the elimination of ionospheric disorders and in this way they contribute to the improviement of the accuracy and reliability of the determined coordinates. Currently, real-time kinematic positioning is used in many areas of life and economy such as: navigation, surveying, precision agriculture, spatial information systems and many more (SIEJKA, 2016; SIEJKA et al., 2017). This article analyzes the use of single GNSS (GPS) in real-time positioning and then the results were compared with more advanced solutions based on integrated observations, coming from two systems (GPS + GLONASS) and three systems (GPS + GLONASS + Galileo). This article has been constructed as follows: Chapter 2 describes the basic information about the current state of GNSS. The potential benefits of using multi-system positioning instead of one were also given. In Chapter 3, the results of RTK measurements based on 3 GNSS combinations were presented and compared. In each case, corrections from a single reference station were used. The limitations of solutions based only on a single GNSS were found and their possible improvement was shown. Chapter 4 presents some proposals for the real-time geodetic measurements that will eliminate systematic errors.

Multi-GNSS

Currently, in space, we are dealing with the coexistence of four global and at least two regional GNSS. The first group includes: American GPS (Global Positioning System), Russian GLONASS (Globalnaja Navigacionnaja Sputnikovaja Sistema), Chinese BeiDou (Big Bear) and European Galileo. The second group is made up of Japanese QZSS (Quasi-Zenith Satellite System) and Indian IRNSS (Indian Regional Navigation Satellite System). In addition, on February 5, 2018, the South Korea announced that it will build another own regional satellite positioning system under called Korean Positioning System (KPS), which will start operating from 2034. The creation of new and the development of existing positioning systems is associated with increasing the accuracy, availability and independence of users from only one GNSS. Currently, there are 124 satellites in space, which are or may be used in the nearest future in positioning and satellite navigation (Table 1).

Table 1. The list of GNSS satellites (July 28, 2018).

GNSS	CONSTELLATION STATUS		Orbit Type		
	Total satellites	Operational	MEO	GEO	IGSO
GPS	32	31	32	-	-
GLONASS	26	24	26	-	-
Galileo	26	14	26	-	-
BeiDou	29	15	14	6	9
QZSS	4	4	-	1	3
IRNSS	7	7	-	3	4
Total GNSS	124	95	98	10	16

Source: Own study based on the data from www.gnssplanningonline.com/ (2018)

GPS

The American GPS is the oldest system and is considered the prototype of other GNSS. Its construction began in the 1970s. In the assumptions, the system was built for military purposes, but at the beginning of the 90s it was made available to civilian users. Nominal GPS constellation consists of 24 satellites placed in 6 Medium Earth Orbits (MEO) with inclination of 55°. The current constellation of GPS satellites is 32 satellites, including 31 operational ones. These satellites belong to the second generation, which combines three blocks of satellites: IIR, IIR-M i IIF.

GLONASS

The Russian GLONASS was the response of the then USSR to the construction of the GPS system by the Americans. It was built almost parallel and also in the mid-90s reached full operational capacity. However, the short lifespan of the satellites and the crisis in Russia after political system changes caused that at the turn of the XX and XXI century, GLONASS lost its full operability. It was restored only at the turn of 2010 and 2011. The GLONASS nominal constellation consists of 24 satellites placed on 3 MEO orbits with the inclination of 65°. These satellites belong to three different blocks: M, M+ and K. The current constellation of GLONASS satellites consists of 26 satellites, including 24 operational ones.

Galileo

Galileo is the first civilian navigation system that is being built by EU countries. The current constellation of Galileo consists of 26 satellites, the last four were launched into space on July 25, 2018. It consists of two generations of satellites: 4 satellites of the validation phase (SVN: E101, E102, E103, E104), IOV – In Orbit Validation and 22 satellites (SVN: E201, E202, E203, E204, E205, E206, E207, E208, E209, E210, E211, E2012, E213, E214, E215, E216, E217, E218, E219, E220, E221, E222, FOC – Full Operational Capability) of the of full operational block. As of the 28 July 2018, there were 14 full operational satellites. Two satellites (E104 and E204) were excluded from the active constellation for technical reasons. Two more satellites (E201 and E202) due to the problems of the carrier rocket were elevated to incorrect, highly eccentric orbits and are currently excluded from the full navigational operation. And the four new satellites (E215, E216, E217, E218) launched in space on December 12, 2017 are currently undergoing testing and are being prepared for inclusion in the active constellation in the near future.

BeiDou

The Chinese satellite navigation system called BeiDou according to the current state (status as at 28. 07. 2018) is created by the constellation of 29 satellites. 15 satellites are fully operational, while 14 satellites, despite being in orbits, are currently not included in the operational orbital constellation. However, it should be noted that these are mainly new satellites launched into space in the last two years. Currently, they are being prepared for inclusion in the operational constellation. The Chinese BeiDou system is different from the other three global GNSS, because its satellites are placed on three different types of orbits: geostationary orbit (GEO – Geostationary Earth Orbit), two inclined geosynchronous orbits (IGSO – Inclined Geosynchronous Orbit), three medium orbits (MEO – Medium Earth Orbit). Ultimately, the BeiDou satellite constellation will consist of 35 satellites (27 satellites MEO, 5 GEO, 3 IGSO), and the system is to be fully operational in 2020.

Regional systems

Apart from the four above-mentioned global positioning and navigation systems, there are two more regional systems. Japan has been developing the Quasi-Zenith Satellite System (QZSS) for many years and India - Indian Regional Navigation Satellite System (IRNSS). These systems are created as independent support for global systems, and the signals broadcasted by both QZSS and IRNSS are partially compatible with the GPS system. Generally, these systems are based on satellites placed in geosynchronous orbits, which limits their range to a selected region. However, the advantage of such solution is that geosynchronous satellites in contrast to satellites placed in medium circular orbits MEO, are very well suited for positioning in difficult satellite conditions, in strongly urbanized areas with dense urban housing and high buildings, so called urban canyons, mountainous areas, deep valleys and open-cast mines.

Capabilities and potential of multi-GNSS

The increasing number of available signals and frequencies that can be registered by the receivers of many GNSS users give new positioning possibilities. The greater number of observed satellites and signals plays a key role, which significantly improves the geometry of the observed constellation. This geometry is described by the dilution of positioning precision parameter (Dilution of Precision), which increases the accuracy of determining the position and shortens the time of convergence of the receiver to obtain a solution with given accuracy. New and upgraded GNSS systems broadcast now signals on three, four or even five frequencies. This gives new possibilities in the processing of signals, which is particularly important in the modeling of ionospheric delay, which is one of the main factors causing positioning errors. The use of atomic ruby clocks (RAFS) and simultaneously passive hydrogen masers (PHM) on the new Galileo satellites guarantees a ten times higher standard of time measurement stability than in the case of cesium clocks used, for example, on GLONASS satellites. The use of the multi-GNSS constellation significantly increases the availability, reliability and quality of the determined position. This is mainly due to the increase in the number of independent data from many constellations, reduction of systematic errors and development of new algorithms enforced by the use of multi-GNSS. There are also some problems with the simultaneous use of many GNSS for example, related to the correct integration of such solutions, especially in the aspect of accurate geodetic measurements. The variety of constellations is also important in eliminating orbital factors in GNSS products. It can therefore be assumed that despite these problems, the importance of multi-GNSS constellation solutions will increase in the near future and we will be able to effectively use their advantages.

Implementation of test measurements

Test measurements for the purposes of this work were carried out applying the RTK method, using corrections from a single reference station. The research was carried out in terms of the legitimacy of using one, two or three global GNSS for positioning. The measurements were carried out using the 3 Trimble R10 satellite receivers, which are a modern multi-channel (440 channels) and multi-system geodetic satellite receivers adapted to receiving navigation signals from all currently available global and local GNSS (GPS, GLONASS, BeiDou, Galileo, QZSS, SBAS). At the stage of planning the test measurements for the selected day the analysis of satellite conditions on a test base was made using the application: "Trimble GNSS Planning Online". The results are shown in Fig. 1-3. The following figures show the theoretical conditions of the observation site for different GNSS constellations at the elevation 10°. Basing on them, a thirteen-hour time window was selected, to ensure optimal conditions for receiving satellite data, which took into account the number of visible satellites and their positions in the sky. Figures 1-3 show that the addition of additional positioning systems to the GPS significantly improves the availability and the reliability of position determination and DOPs parameters that determine its accuracy. The application did not take into account the presence of natural and anthropogenic obstacles which reduce the sky visibility. The test measurements consisted of multiple determination of coordinates of 3 test base points, at the same time, using three independent scenarios, in which different combinations of positioning systems were used:

- Scenario I – measurement based on the GPS system,
- Scenario II – measurement based on systems GPS + GLONASS,
- Scenario III – measurement based on systems GPS + GLONASS + Galileo.

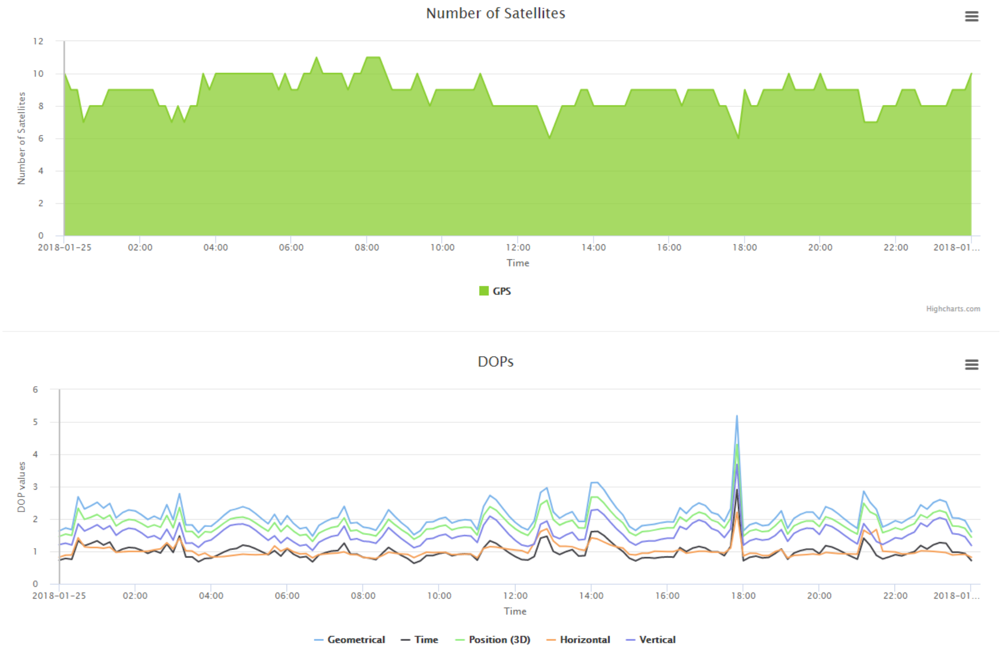

Fig. 1. The theoretical satellite conditions of the observation site using one GNSS (GPS) and an angle of cut off the horizon of 10°.
Source: Own elaboration based on: Trimble GNSS Planning Online (https://www.gnssplanningonline.com).

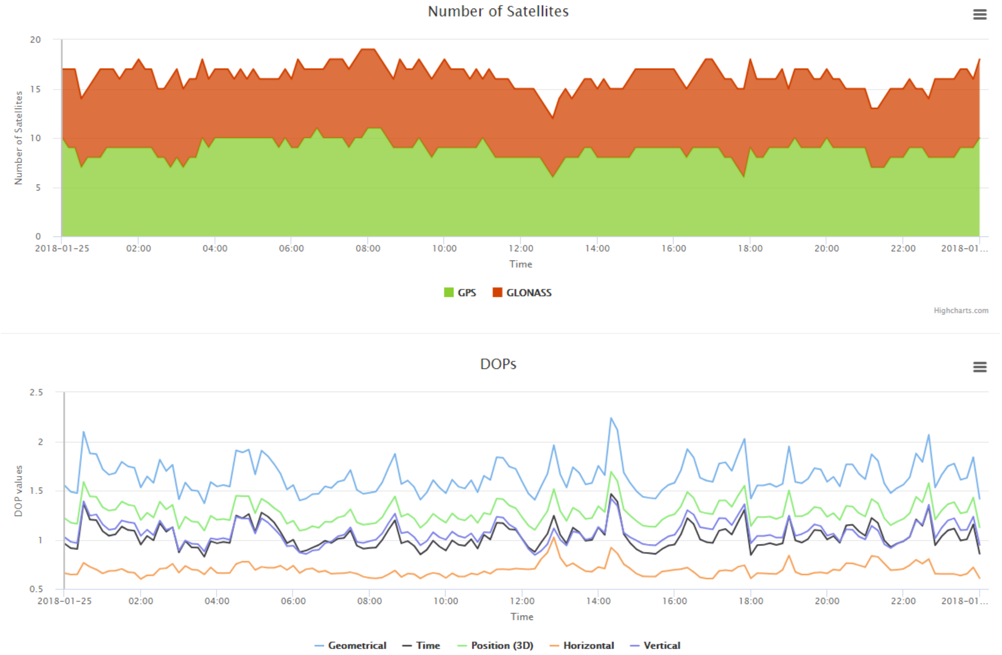

Fig. 2. Theoretical satellite conditions of the observation site using two GNSS (GPS+GLONASS) and an angle of cut off the horizon of 10°.
Source: Own elaboration based on: Trimble GNSS Planning Online (https://www.gnssplanningonline.com).

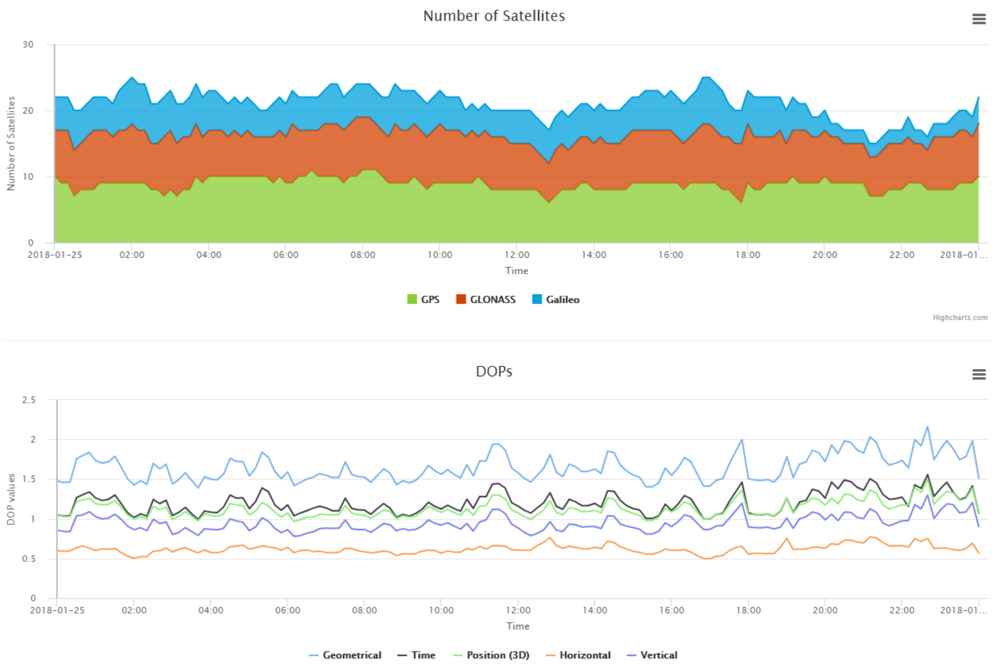

Fig. 3. Theoretical satellite conditions of the observation site
using three GNSS (GPS+GLONASS+Galileo) and an angle of cut off the horizon of 10°.
Source: Own elaboration based on: Trimble GNSS Planning Online (https://www.gnssplanningonline.com).

For each of the three scenarios, 13 measurement sessions were carried out, each lasting one hour. The measurement was carried out automatically in the interval of 10 seconds, at the standard angle of cutting the horizon of 10 degrees. During each of the 13 sessions, approximately 360 RTK measurements were performed at each checkpoint. In total, approximately 14,000 measurements were made throughout the entire experiment.

The research on the accuracy of measurements

The research involved the detailed analysis of 39 independent coordinate measuring sessions composed of time series with the resolution of 10 seconds. Number of measurements (*n*) in each session was equal 360. The classic approach was adopted assuming that the average of the long measuring series approaches the true value. Adopting this assumption for each observation session, a systematic measurement error was determined for each coordinate, according to the formula:

$$\delta_x^j = \frac{\sum_{i=1}^{i=n} \Delta x_i}{n}, \quad \delta_y^j = \frac{\sum_{i=1}^{i=n} \Delta y_i}{n}, \quad \delta_h^j = \frac{\sum_{i=1}^{i=n} \Delta h_i}{n}, \tag{1}$$

where:

$\Delta x_i = x_i - x_k$, $\Delta y_i = y_i - y_k$, $\Delta h_i = h_i - h_k$ - absolute errors of the *i*-th measurement, respectively of the coordinate: north (x), east (y), height (h)

(x_i, y_i, h_i) - coordinates of the measured control point based on the *i*-th measurement,

(x_k, y_k, h_k) - (true) reference coordinates, of the control point,

j - series number, *n* - series length.

To illustrate the differentiation, the basic numerical characteristics of systematic measurement errors were determined as well as the lengths of confidence intervals for the determined mean values, estimated at a confidence level of 0.95, which are presented in the tables 2, 3, 4, 5, 6 and 7.

Table 2. Measurement based on the GPS system, systematic errors of measurements along with the length of confidence intervals (d / 2) at the confidence level of 0.95 and minimum ($PDOP_{min}$) and maximum ($PDOP_{max}$) values of the PDOP parameters (Position Dilutions of Precision) for each series.

Series number *j*	δ_x^j ±d/2 [m]		δ_y^j ±d/2 [m]		δ_h^j ±d/2 [m]		$PDOP_{min}$	$PDOP_{max}$
1	-0.0062	± 0.0017	-0.0232	± 0.0014	0.0068	± 0.0036	1.863	3.337
2	-0.0096	± 0.0009	-0.0246	± 0.0005	-0.0072	± 0.0014	1.719	2.541
3	0.0019	± 0.0010	-0.0235	± 0.0005	-0.0054	± 0.0016	1.563	2.880
4	0.0021	± 0.0010	-0.0244	± 0.0006	0.0087	± 0.0012	1.547	1.856
5	-0.0021	± 0.0009	-0.0262	± 0.0006	0.0151	± 0.0016	1.437	2.230
6	-0.0008	± 0.0011	-0.0230	± 0.0007	0.0096	± 0.0016	1.483	4.721
7	-0.0024	± 0.0010	-0.0294	± 0.0006	0.0034	± 0.0015	1.440	2.251
8	-0.0075	± 0.0007	-0.0263	± 0.0005	0.0000	± 0.0014	1.549	2.078
9	-0.0022	± 0.0011	-0.0251	± 0.0006	0.0099	± 0.0015	1.513	2.927
10	-0.0009	± 0.0011	-0.0266	± 0.0005	0.0028	± 0.0012	1.488	2.680
11	-0.0016	± 0.0007	-0.0252	± 0.0006	-0.0005	± 0.0016	1.756	2.298
12	0.0002	± 0.0008	-0.0273	± 0.0006	-0.0032	± 0.0017	1.414	2.256
13	-0.0049	± 0.0007	-0.0295	± 0.0005	-0.0015	± 0.0016	1.832	2.362

Source: Own elaboration.

Table 3. Measurement based on the GPS system, basic statistics for systematic errors of measurements together with the length of confidence intervals (d/2) at the confidence level of 0.95 and minimum ($PDOP_{min}$) and maximum ($PDOP_{max}$) values of the PDOP parameters (Position Dilutions of Precision).

The value of the statistics	δ_x ±d/2 [m]		δ_y ±d/2 [m]		δ_H ±d/2 [m]		$PDOP_{min}$	$PDOP_{max}$
min	0.0002	± 0.0008	-0.0230	± 0.0007	0.0000	± 0.0014	1.414	1.856
max	-0.0096	± 0.0009	-0.0295	± 0.0005	0.0151	± 0.0016	1.863	4.721
AV	-0.0026	± 0.0010	-0.0257	±0.0006	0.0030	±0.0017	1.573	2.591
SD	0.0035	± 0.0010	0.0021	±0.0006	0.0067	±0.0017	0.154	0.739

Source: Own elaboration.

Table 4. Measurement based on the GPS +GLONASS systems, systematic errors of measurements along with the length of confidence intervals (d / 2) at the confidence level of 0.95 and minimum ($PDOP_{min}$) and maximum ($PDOP_{max}$) values of the PDOP parameters (Position Dilutions of Precision) for each series.

Series number *j*	δ_x^j ±d/2 [m]		δ_y^j ±d/2 [m]		δ_h^j ±d/2 [m]		$PDOP_{min}$	$PDOP_{max}$
1	-0.0066	± 0.0007	-0.0161	± 0.0006	-0.0162	± 0.0011	1.219	1.703
2	-0.0094	± 0.0006	-0.0204	± 0.0006	-0.0140	± 0.0013	1.199	1.686
3	-0.0081	± 0.0008	-0.0197	± 0.0004	-0.0105	± 0.0010	1.111	1.710
4	-0.0091	± 0.0007	-0.0183	± 0.0004	-0.0037	± 0.0014	1.089	1.477
5	-0.0109	± 0.0007	-0.0193	± 0.0005	-0.0083	± 0.0014	1.185	1.498
6	-0.0078	± 0.0007	-0.0196	± 0.0005	-0.0129	± 0.0011	1.177	1.555
7	-0.0094	± 0.0008	-0.0214	± 0.0004	-0.0157	± 0.0011	1.176	1.735
8	-0.0110	± 0.0005	-0.0209	± 0.0005	-0.0117	± 0.0013	1.208	1.545
9	-0.0066	± 0.0008	-0.0196	± 0.0005	-0.0106	± 0.0013	1.196	1.854
10	-0.0092	± 0.0007	-0.0230	± 0.0005	-0.0180	± 0.0010	1.140	1.758
11	-0.0092	± 0.0006	-0.0220	± 0.0005	-0.0120	± 0.0011	1.177	1.451
12	-0.0069	± 0.0007	-0.0215	± 0.0005	-0.0124	± 0.0011	1.135	1.498
13	-0.0088	± 0.0008	-0.0212	± 0.0004	-0.0117	± 0.0012	1.262	1.485

Source: Own elaboration.

Table 5. Measurement based on the GPS+GLONASS systems, basic statistics for systematic errors of measurements together with the length of confidence intervals (d/2) at the confidence level of 0.95 and minimum ($PDOP_{min}$) and maximum ($PDOP_{max}$) values of the PDOP parameters (Position Dilutions of Precision).

The value of the statistics	δ_x ±d/2 [m]		δ_y ±d/2 [m]		δ_H ±d/2 [m]		$PDOP_{min}$	$PDOP_{max}$
min	-0.0066	± 0.0007	-0.0161	± 0.0006	-0.0037	± 0.0014	1.089	1.262
max	-0.0110	± 0.0005	-0.0230	± 0.0005	-0.0180	± 0.0010	1.451	1.854
AV	-0.0087	± 0.0007	-0.0202	±0.0005	-0.0121	±0.0012	1.239	1.442
SD	0.0014	± 0.0007	0.0018	±0.0005	0.0036	±0.0012	0.059	0.182

Source: Own elaboration.

Table 6. Measurement based on the GPS +GLONASS+ GALILEO systems, systematic errors of measurements along with the length of confidence intervals (d / 2) at the confidence level of 0.95 and minimum ($PDOP_{min}$) and maximum ($PDOP_{max}$) values of the PDOP parameters (Position Dilutions of Precision) for each series.

Series number *j*	δ_x^j ±d/2 [m]		δ_y^j ±d/2 [m]		δ_h^j ±d/2 [m]		$PDOP_{min}$	$PDOP_{max}$
1	0.0084	± 0.0009	-0.0162	± 0.0007	-0.0114	± 0.0016	1.155	1.646
2	0.0099	± 0.0005	-0.0241	± 0.0006	-0.0193	± 0.0011	1.091	1.336
3	0.0124	± 0.0009	-0.0244	± 0.0004	-0.0102	± 0.0011	1.038	1.319
4	0.0091	± 0.0007	-0.0227	± 0.0004	-0.0024	± 0.0010	1.001	1.353
5	0.0098	± 0.0011	-0.0236	± 0.0006	0.0051	± 0.0012	1.118	1.532
6	0.0102	± 0.0008	-0.0249	± 0.0004	-0.0086	± 0.0011	1.037	1.327
7	0.0060	± 0.0008	-0.0231	± 0.0005	-0.0167	± 0.0008	1.066	1.299
8	0.0105	± 0.0006	-0.0225	± 0.0004	-0.0129	± 0.0009	1.070	1.355
9	0.0111	± 0.0006	-0.0215	± 0.0004	-0.0020	± 0.0011	1.057	1.640
10	0.0092	± 0.0005	-0.0247	± 0.0005	-0.0222	± 0.0009	1.093	1.602
11	0.0080	± 0.0006	-0.0251	± 0.0005	-0.0198	± 0.0012	1.045	1.340
12	0.0078	± 0.0005	-0.0268	± 0.0004	-0.0172	± 0.0011	1.046	1.294
13	0.0093	± 0.0007	-0.0271	± 0.0007	-0.0146	± 0.0018	1.182	1.437

Source: Own elaboration.

Table 7. Measurement based on the GPS+GLONASS+GALILEO systems, basic statistics for systematic errors of measurements together with the length of confidence intervals (d/2) at the confidence level of 0.95 and minimum ($PDOP_{min}$) and maximum ($PDOP_{max}$) values of the PDOP parameters (Position Dilutions of Precision).

The value of the statistics	δ_x ±d/2 [m]		δ_y ±d/2 [m]		δ_H ±d/2 [m]		$PDOP_{min}$	$PDOP_{max}$
min	0.0060	± 0.0008	-0.0162	± 0.0007	-0.0024	± 0.0010	1.001	1.294
max	0.0124	± 0.0009	-0.0271	± 0.0007	-0.0198	± 0.0012	1.182	1.646
AV	0.0094	± 0.0007	-0.0236	±0.0005	-0.0117	±0.0012	1.077	1.421
SD	0.0016	± 0.0007	0.0027	±0.0005	0.0080	±0.0012	0.050	0.134

Source: Own elaboration.

Discussion and conclusions

The conducted research has shown that the application of additional GLONASS and Galileo systems to the basic GPS positioning system significantly improves the availability of positioning. The number of satellites observed increases and the positioning conditions described in the DOPs parameters improve (see fig. 1-3 and tables: 3, 5, 7). The number of available satellites and their distribution in the sky play an important role for the accuracy of the position being determined (SIEJKA, 2015; ODOLINSKI et al., 2013). The number of observed satellites gains the special significance in kinematic measurements carried out using RT (Real Time) methods among others for the needs of the real estate cadastre and the precision agriculture. Because in this type of work there are often limitations in the availability of positioning, and at the same time, high accuracy of measurement must be maintained. Therefore, in this type of work, positioning based on multi-GNSS solutions is recommended. However, the solutions of this type require an appropriate level of interoperability and compatibility of the used systems, they are also more technologically advanced solutions. The lack of full synchronization of the systems usually results in additional, systematic errors of positioning. This paper presents the effect of applying an additional positioning system on the amount of systematic errors that appear in the multi-GNSS solution. It was shown that in the case of :

- **The Northern component (x) -** attachment to the GPS observations, additional observations from GLONASS satellites - increases the systematic error from δx_{gps} = -0,0026 m to δx_{gpsglo} = -0,0087 m, while attachment of the observations from an additional, third Galileo system causes the change of the systematic error sign to the opposite and its further increase to $\delta x_{gpsglogal}$ = 0,0094 m.
- **The Eastern component (y)** attachment to the GPS observations, additional observations from GLONASS satellites reduces the systematic error from δy_{gps} = -0,0257 m to δy_{gpsglo} = -0,0202 m, while attachment of the observations from an additional, third Galileo system causes the increase of the error to $\delta y_{gpsglogal}$ = -0,0236 m.
- **The height component (H)** attachment to the GPS observations, additional observations from GLONASS satellites increases systematic error from δ_{Hgps} = 0,0030 m to $\delta_{Hgpsglo}$ =-0,0121 m, causing at the same time the change of its sign to the opposite, while attachment of the observations from an additional, third Galileo system causes slight reduction of this error to $\delta_{Hgpsglogal}$ = -0,0117 m.

The results prove that attachment of the additional systems to the basic GPS positioning system, shifts the measurement result in one direction in relation to the true value. In the case of the northern coordinate (x) and height (H), the values of systematic errors exceed 2 and 1 cm respectively and should be eliminated so as not to distort the measurement results. It should also be noted that the measurable effect of attaching observations from GLONASS satellites to the GPS observation is a significant reduction in the standard deviation (SD) for each coordinate (tables 3 and 5) which proves that the precision of measurements is increased. The attachment of additional observations from the Galileo system (Table 7) worsens these values. In this case, however, it should be noted that the Galileo system is not yet fully operational and therefore not fully compatible with GPS and GLONASS systems. However, it should be assumed that in the future this will change and the effect of adding observations from Galileo satellites will also be positive.

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