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GNSS-Condition Impacts on Land Boundary Coordinates and Land Area Determination

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Abstract

Background: Determining the location, boundaries and areas of land properties accurately in the land cadastre is essential. The named data are provided using coordinates, acquired from field measurements. Since 2008, the Slovenian land cadastre claims positioning in the national realization of the ETRS89, so the GNSS use is practically indispensable. **Objectives:** Contrary to real-time, we can change parameters in GNSS post-processing. The aim of this paper is to simulate different measurement conditions for GNSS in order to determine how to acquire the best possible coordinates for further use in land area calculation. **Methods/Approach:** Simulations of obstacles near points followed the increasing of the cut-off angle. Furthermore, shortening the observation interval resulted in different occupation duration. The final condition evaluation for coordinate quality acquisition followed from fuzzy logic. **Results:** The results show that for short baselines, occupation duration is the most important factor in acquiring high quality coordinates and avoiding the multipath. Differences in coordinates from specific strategies can sometimes exceed the tolerance and evidently affect the area calculation. **Conclusions:** The findings confirm that only good measurement conditions lead to high quality coordinates and well-defined areas of land properties, which are the fundamental factor in relation to the issues of property valuation and assessing land taxes or rents.

Keywords: land cadastre, GNSS post-processing, occupation duration, cut-off angle, fuzzy logic, land area
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Introduction

The initiation of GNSS into geodesy has drastically changed the methods of positioning. Today, high precision GNSS methods are widely used in all fields of geodetic engineering, including cadastral surveying. GNSS allows us to determine global coordinates, which present the basis for land property's boundaries determination as well as its area calculation. The latter presents the basis in land management applications and is an important factor on the issues of land property valuation and assessing the land taxes or rents (Bird et al., 2004). In this context, it is necessary to determine coordinates of a highest possible accuracy.

The complete cycle of coordinate determination by the use of GNSS includes acquisition of observations at the field as well as their processing either in real time or in post-processing. To achieve the best possible coordinates from GNSS, it is essential to perform observations in decent conditions. At the locations both fixed (buildings, vegetation) and mobile (means of transport) facilities should not attenuate the reception of GNSS signals. Obstructions disable the reception of satellite signals, so the positioning is worsening and in some cases even blocked.

Research studies, which deal with the GNSS positioning performance in severely degraded conditions, are unique and usable in different geographic locations. The problems are more acute in urban environments with the limited visibility of satellites and the multipath or interference effects. Petovello (2013) explains the difference between non-line-of-sight receptions from multipath and interference. In the context of multipath mitigation Groves (2011) proposes a novel positioning method for the GNSS urban canyons with tall buildings and narrow streets, namely shadow matching. It combines the knowledge of 3D building models and prediction, which satellites are visible at specific times from different locations. Gandolfi and La Via (2011) describe the same problem of poor satellite visibility, but they incorporate also practical real-world examples, which result from the software Skyplot_DEM.

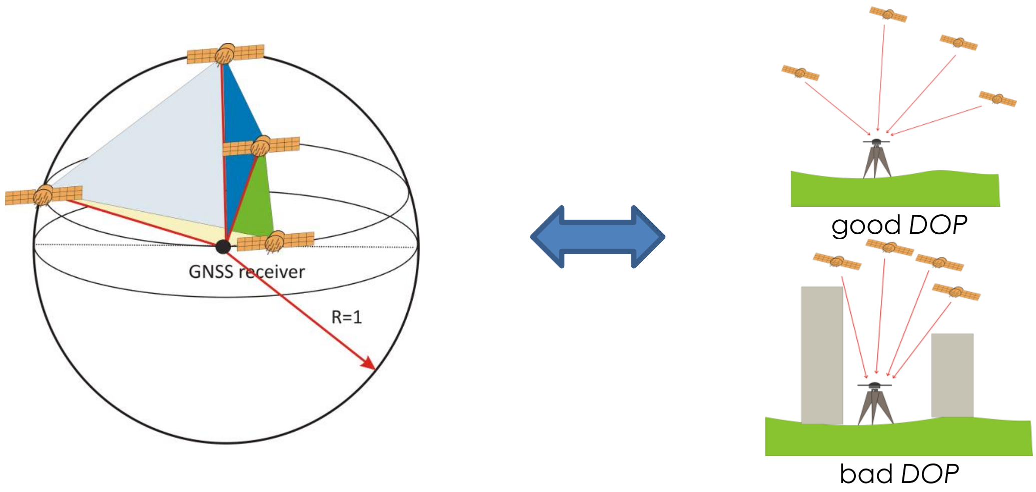
The first challenge in this paper is to show different observation conditions influence the quality of coordinates drastically. Besides, a special challenge in high-quality positioning is to use carrier-phase observations and their ambiguity assessment as integers. In some situations it can happen, that despite good observation conditions ambiguities cannot be resolved, which affect final coordinate determination. This is the case in unpredictable space weather conditions or due to the bias resulting from bad synchronization of the transmitted (from the satellite) and generated (in the receiver) signal (Gao, 2006). Since our study followed relative positioning by using dual-frequency GNSS receivers with longer observation duration in a quiet space weather conditions, we omitted the study of ionosphere conditions. In addition, since our data for simulations came from good measurement conditions, acquired with high quality instruments, the topic of multipath was not the part of this study.

Secondly, our study highlights the importance of manipulating with best possible coordinates in land area estimation. The study does not include several important topics, presented for example in Chrisman and Yandell (1988), which derive a statistical model for the precision of area, where nodes of polygons have errors. Ghilani (2000) discusses the uncertainty in computed areas with the statistical procedure based on the familiar coordinate neighbourhood. Furthermore, Navratil (2003) presents an extended study for the precision of area computation. However, the aim of this particular study is somehow different, but in connection to the studies mentioned. We wanted to stress out the importance of establishment of the relations between points of the specific land area by avoiding independent determination of each specific point's coordinates of the particular closed polygon shape (i.e. land property geometry).

Literature review

In GNSS relative positioning, it is important to consider several factors according to the baseline length and the height difference between the ends of a baseline (Okorocha et al., 2014). There is a variety of credentials to set parameters in post-processing properly. Software set them as default values. We exclude epochs or observations failing the following quality checks to acquire best promising results. There are two ways to do this, either by receiver settings at the field or by filters in the processing software. For quality positioning, we should realize the best potential conditions or use an alternative way to set coordinates indirectly from other, for example terrestrial measurements. However, the awareness that bad measurement conditions at the field could happen only for a shorter period is significant. Computed coordinates depend on the occupation duration, where redundancy plays a prominent role in meeting the best accuracy (El-Mowafy, 2011). In case of longer baselines, high accuracy results usually require long observation sessions (Dawidowicz, 2012). A number of authors studied GNSS positioning in difficult conditions (Bakula, 2013; Dawidowicz et al., 2014). While using many types of instruments at the baseline ends we should consider also the length of the processing baseline and vertical difference between the ends. An important factor in processing is also the use of specific, i.e. broadcast or precise, ephemerides (Montenbruck et al., 2015).

Figure 1
DOP Factors



Source: Authors' work

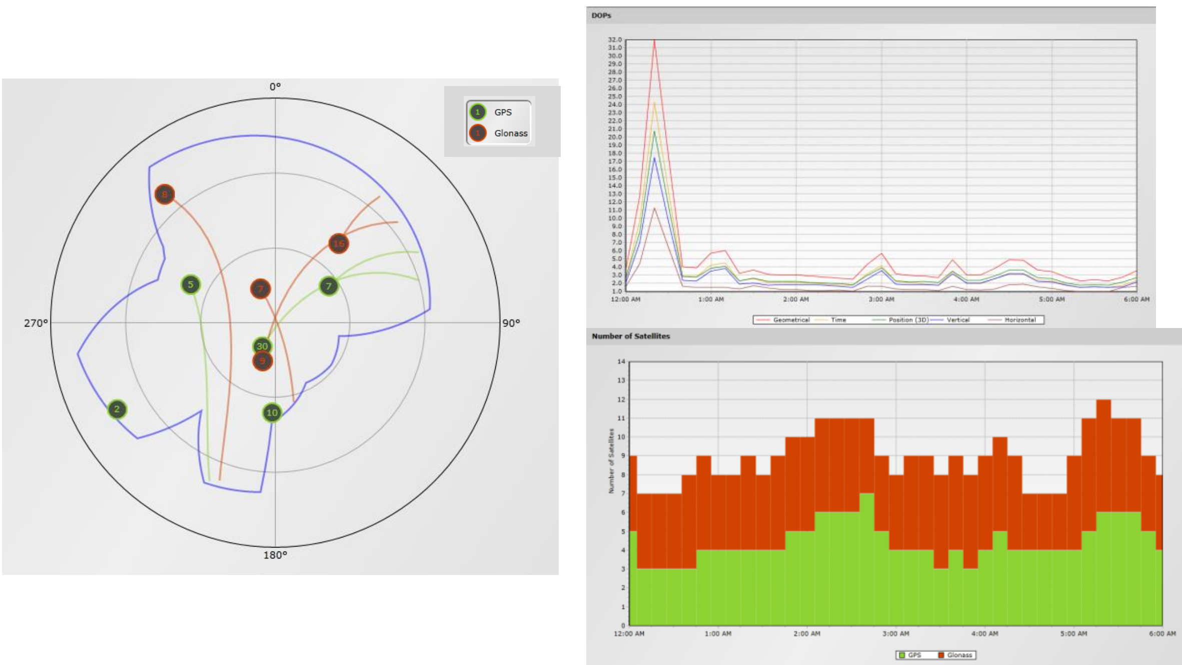
In GNSS, we perform observations in conditions, which are in most cases unpredictable. Therefore, a variety of empirical tests gives us the insight into the problem under predicted conditions. The focus throughout this study is to analyse the quality of coordinates by using several carrier-phase receivers. We performed GNSS measurements in almost ideal conditions and further processed them under simulated worsen conditions. The goal hereby is to stress factors, which influence the accuracy of coordinates drastically. The aim of investigations is to acquire the knowledge for best coordinate assessment by the use of GNSS, which we use in calculation of the land areas. This is important since land cadastral and management as well as property valuation activities rely on properly defined areas of land properties.

It is a common fact, that we access better accuracy of coordinates by the use of GNSS throughout redundancy. One of the major factors that affect the point coordinates' accuracy is the geometry of satellites in view. When the satellites are located relative close to each other, the overlapping area of position uncertainty is larger and vice versa. The volume of the unit tetrahedron, formed by four GNSS satellites and the receiver, is in the connection to *DOP (Dilution of Precision)* factors. We use *DOPs* to specify the effect of satellite geometry on quality positions. Larger tetrahedron's volume means smaller *DOP*, which indicates good measurement conditions (Figure 1) for appropriate position acquisition. As *DOP* increases, both the horizontal and vertical precision of the position decrease (Hofmann-Wellenhof et al., 2002).

There are several recommendations that baseline lengths should be short, for example, 5 km (Okorocha et al., 2014). Different atmospheric conditions affect the quality of longer baselines. In both cases, but especially in the latter one, occupation duration is important. However, some epoch we should exclude, especially if (The Connecticut Association of Land Surveyors, 2008):

- there are observations from the satellite vehicle (SV) closer than 10° to the local horizon; we know the credential as setting the cut-off angle. In some cases, it is set also to a lower value, most commonly value used is 15°,
- any occupation duration with less than five visible GNSS satellites in common for stations where the baseline is computed and
- any epoch with a *PDOP* (Position Dilution of Precision) greater than 6 (sometimes the values is set to 7), and for the heights, any epoch with a *VDOP* (Vertical Dilution of Precision) greater than 6 (in some cases 7).

Figure 2
GNSS Surveying Conditions



Notes: (a) Sky plot (left picture), (b) DOP factors = upper right picture and (c) number of GPS + GLONASS satellites at the location φ = 46° 01' 50" N, λ = 14° 28' 53'' E for simulated obstructions
Source: Trimble online planning application (GNSS online planning, 2017)

In some rare cases, the increasing the cut-off angle to about 20° can be even advantageous. Such situations might come from the disturbed atmosphere. In other cases, we should be aware that the increasing the cut-off angle means the lower number of visible satellites and further higher values of *DOPs*.

For successful GNSS positioning, it is important to have best possible conditions at the vicinity of points. By knowing point's approximate coordinates, we can simulate conditions, the number of visible satellites and *DOPs* before performing measurements (Figure 2). By changing the cut-off angles at different azimuths (left picture in Figure 2, where trajectories of visible satellites are presented), we simulate physical obstructions for reception of the satellite's signal near point's location. Right pictures of the Figure 2 depict *DOP* factors for a certain period in the future (upper) and the number of available satellites (lower). In the present study, the positioning followed the use of GPS and GLONASS, since now they are most widely global navigation satellite systems used at the territory of Europe. Such investigations and simulations are precious when trying to perform positioning in bad conditions. According to the prior estimated number of satellites and *DOPs* we can estimate, which observation time will be the most effective.

Data and methods

Evaluation of the influences of different parameters in GNSS processing followed the relative carrier-phase static positioning with a short length of the baseline (approximately 4 km). All coordinates acquired initiated from the same set of carrier-phase observations. Further post-processing followed changing the parameters with the final goal to compare coordinates. For the land area calculation, coordinates followed the transformation to the state plane positions in the Slovenian realization of the ETRS89 (European Terrestrial Reference System 1989), namely D96/TM.

In further analysis, we used coordinates from optimal conditions as the reference. The analysis based on the comparison of state plane coordinates as well as the comparison of ellipsoid heights (h). However, we present results from the height component separately. The reason comes from the common fact, that in GNSS positioning, the accuracy of the height component is almost twice worsened comparing the horizontal coordinates (Pavlovčič Prešeren et al., 2010) and that we still calculate land areas from the horizontal coordinates.

Observations

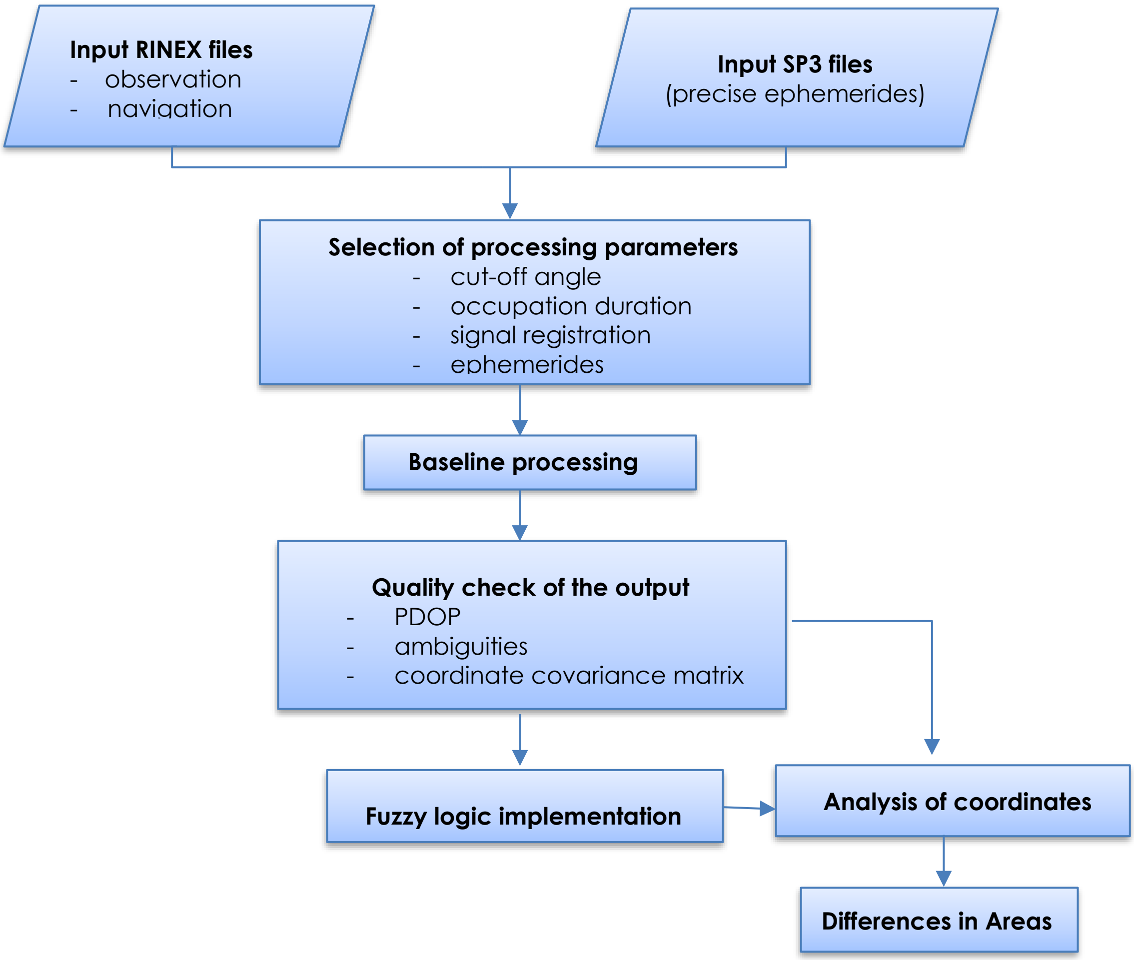
All observation-data in our research refer to the same set of RINEX-files from the common observation interval. We performed GNSS observations at points, where the conditions for the conducting of GNSS measurements were appropriate. There were no sources of affecting the GNSS signals from buildings or mobile (means of transport) facilities. We set the Leica Viva GS15 receiver on the GST20 tripod with Leica GDF121 tribrach. The accuracy was from 0.5 mm to 1.5 mm (Leica GeoSystems, 2017). For the baseline processing, we used the program Leica Infinity (Leica GeoSystems, 2017). While measuring, we used the interval of registration of one second and the elevation cut-off angle was set to 0°. The known point at the beginning of the baseline in Ljubljana was a part of the Slovenian continuously operating reference GNSS stations.

Methodological approach

Good measurement conditions followed the estimation of the influences of static point occupation duration while surveying as well as different cut-of elevation angles. Figure 3 presents the schematic presentation of the methodologic process. Post-processing followed changing the parameters, i.e.:

- minimal cut-off angles,
- application of ephemeris (broadcast or precise),
- shortening the observation duration and
- use of different signal registration interval.

Figure 3
Schematic Presentation of the Methodological Approach



Source: Author's work

The overall quality assessment followed from the comparison of *DOP* values (maximal value should not exceed 6), computed carrier-phase ambiguities as integers or real numbers as well as the estimated 3D ETRS89 coordinates (*x, y, z*) and their covariance matrix, given by:

$$\boldsymbol{\Sigma} = \begin{bmatrix} \sigma_{x_i}^2 & \sigma_{x_i y_i} & \sigma_{x_i z_i} \\ \sigma_{y_i x_i} & \sigma_{y_i}^2 & \sigma_{y_i z_i} \\ \sigma_{z_i x_i} & \sigma_{z_i y_i} & \sigma_{z_i}^2 \end{bmatrix} \quad (1)$$

In order to avoid extreme cases, known as »good« or »bad« positioning, determined only from one specific parameter (for example only from *DOP*), we further determined various states between those two. We acquired simple answers by the implementation of fuzzy logic in the study. Fuzzy logic, presented by Lotfi Zadeh in 1960s, is widely used different numerical problem solutions by linguistic terms. Because it incorporates a rule-based approach, it is a tool to control the problem (Hájek, 1998). Output linguistic variables are described by the terms (in case of three terms: *good, medium, bad*) or by pre-defined numbers for ratings, as in our case. Fuzzy logic algorithm consists of four steps: first, defining inputs (in our case *DOP* and occupation durations) and outputs (coordinates' accuracies). Second we define membership functions, create rules and finally by simulating results of fuzzy logic system we get the ratings under different conditions. For ratings we can use words or as in our case numbers or weights. Information from experiences in GNSS quality positioning, described by rules, followed into fuzzy logic system. We followed the rules according to Kostov (2012):

- *DOP* is high (above 6), the solution is not good (1st membership function)→ *low weight*,
- *DOP* is medium and accuracy of coordinates is small (2nd membership function)→ *weight is medium* and
- quality of coordinates is good (as far we have oriented ourselves on kinematic positioning, we have used the 5 cm accuracy for 3D point positioning as a good result), we have good solution (2nd membership function)→ *weight is high*.

Numerical values of all the above-explained rules and weights of the specific rule followed from the equation (Kostov, 2012):

$$p_i = \frac{min(parameter)}{value_i} \tag{2}$$

The minimal parameter corresponded to the specific membership function (in our case Z-shaped function was used). Computed values of weights (Equation 2) were in the range of [0, 1]. For this particular case, we defined the weight value 0.25 for bad solution, 0.50 for medium and 0.75 for good solution. If the values exceeded 0.75, the point positioning would be of a better quality as expected, if the values were below 0.25, the solution would be even worse as expected.

The influence of different coordinates' accuracy on the quality of land area computation followed from the comparison of land areas according to the reference. The latter came out from the computation from best quality coordinates. In this particular case we presumed, that only one point was not well defined.

Figure 4 shows the situation where the geometric shape of the square property with the points 1 to 4 can change drastically in the situation where only one point's coordinates are inaccurate. The situation is getting worse when several points' positions are under the consideration. When using independent GNSS measurements in point positioning, we can risk such situations. We can solve the problem by determination of GNSS baselines between the polygon's points of the individual property or by performing inter-relation terrestrial measurements (distances and angles). The land area computation in the state plane coordinate systems follows the equation:

$$\mathrm{P} = \frac{1}{2}[(e_1 - e_2)(n_1 + n_2) + (e_2 - e_3)(n_2 + n_3) + \cdots + (e_N - e_1)(n_N + n_1)] \tag{3}$$

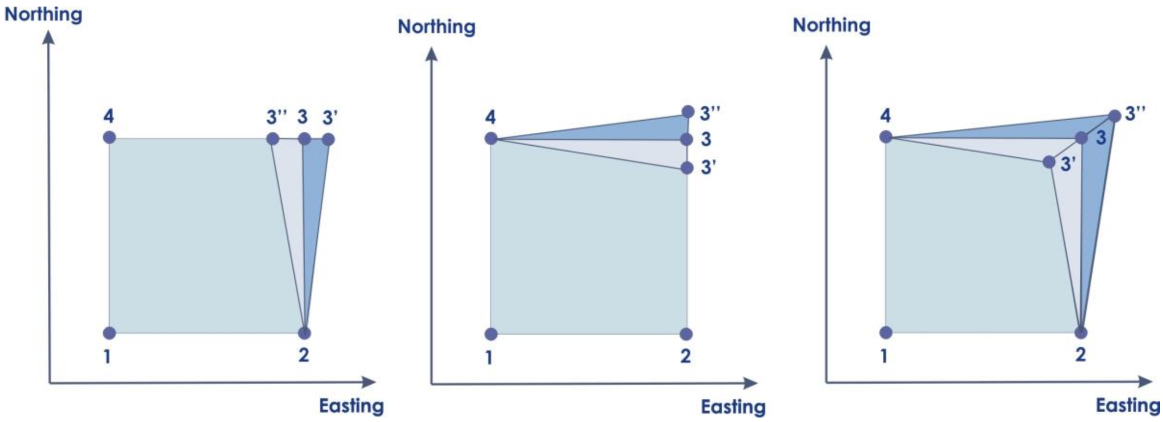
(n_i, e_i) are the state-plane coordinates and i stands for the number of the successive land cadastral point $(i = 1,2, \ldots, N)$, respectively. The computation of the influence of quality in coordinates on the land area P follows the total differential formulation:

$$[\mathbf{dP}] = \mathbf{J} \cdot \mathbf{dx} \tag{4}$$

$\mathbf{dx} = [de_1 \quad dn_1 \quad \cdots \quad de_N \quad dn_N]^T$ includes coordinate deviations and $\mathbf{J}$ *stands for the Jacobian matrix,* in this particular case Jacobian is a vector with the elements: $\mathbf{J} = \left\lfloor \frac{\partial P}{\partial e_1}, \quad \frac{\partial P}{\partial n_1}, \quad \cdots \quad \frac{\partial P}{\partial e_N}, \quad \frac{\partial P}{\partial n_N} \right\rfloor$, *i. e.:*

$$\mathbf{J} = \frac{1}{2} \lfloor (n_2 - n_N), \quad (e_N - e_2), \quad \cdots \quad (n_1 - n_{N-1}), \quad (e_{N-1} - e_1) \rfloor \tag{5}$$

Figure 4
The Influence of Quality Coordinate on Land-area Computation



Note: Differences in coordinates of a single component (Easting (*e*) or Northing (*n*)) or in both for the single point (in this case point No. 3) can drastically change the geometry and the area of the land property.
Source: Authors' work

Results

The goal of experiments was to gain and compare results in post-processing of relative GNSS carrier-phase positioning based on the identical baseline of a short length (4 km). First, we acquired deviations in coordinates from the same sets of observations, with the only difference in the elevation cut-off angle while processing. Table 1 includes differences in coordinates, acquired from different measurement conditions.

The results from Table 1 show that by using the cut-off angle 20° the coordinates are mostly the same. By increasing the cut-off angle from 20° to 45°, deviations in heights increase significantly. The increasing the cut-off angle means observation processing with a lower number of common satellites in view. It also means that high barriers in the surrounding of the point restrict the number of satellites and therefore contribute to the geometric constellation of satellites available. This affects the position quality. Deviations in coordinates can reach from some millimetres to about a centimetre at the cut-of angle 45°. At the cut-off angle of 50°, differences in coordinates are obvious. This is due to the fact the carrier-phase ambiguities in such worsen conditions could not be resolved as integers.

Table 1
Differences in Coordinates from Different Cut-off Angles

	Differences in coordinates		
Cut-off angle	Δe [m]	Δn [m]	Δh [m]
20°	–0.001	–0.001	0.000
25°	–0.003	–0.001	0.003
30°	–0.006	–0.005	0.019
35°	–0.004	–0.010	0.023
40°	–0.012	–0.007	0.063
45°	–0.011	–0.012	0.082
50°	–0.231	–0.310	0.105

Note: Differences in coordinates of the same set of two RINEX files by setting different cut-off angles in processing. The reference used were the results (coordinates) from the elevation cut-off angle 15°
Source: Authors' work.

Numerical values from Table 2 follow from the fuzzy logic answers for the prior assessment of conditions for point positioning. Computed weights come from different measurement conditions, namely the occupation duration and the cut-off angle. Higher computed weight implies good measurement conditions.

Table 2
Fuzzy Logic Results for Linguistic Evaluation of Measurement Conditions

	Computed weights					
Occupation duration	Cut-off angle 5°	Cut-off angle 10°	Cut-off angle 15°	Cut-off angle 20°	Cut-off angle 25°	Cut-off angle 35°
5 min	**0.80**	**0.80**	**0.80**	**0.80**	0.72	0.50
2.5 min	**0.80**	**0.80**	0.72	0.72	0.72	0.50
1 min	0.72	0.72	0.72	0.65	0.65	0.45
30 s	0.65	0.65	0.65	0.50	0.45	0.45
15 s	0.30	0.30	0.25	0.25	0.22	0.22
5 s	0.30	0.30	0.25	0.25	0.18	0.18

Note: Fuzzy logic results for the prior assessment of the conditions for coordinate determination based on different occupation duration and the cut-off elevation angle (kinematic GNSS processing)
Source: Authors' work

According to the fuzzy-logic results from Table 2 (computed weights), where good conditions are valuated above 0.75, medium 0.50 and bad 0.25, we can see there are only small differences between 5-minute and 2.5-minute occupation durations, but there are significant differences of 2.5 minutes to just a few seconds' occupation durations. Values, presented in Table 2, are according to our expectation since we know that longer occupation duration leads to well-determined point coordinates. However, we should know that for some other locations or for different durations and by the use of different instruments the results of coordinate determination could vary. The reason is that GNSS follows dynamic satellite constellation changing during the day (in case of GPS constellation repeats after 12 sidereal hours). This means that in some particular cases, where more satellites could be available, coordinate determination could be faster or vice versa, but in cases with less than five satellites, which is minimal number for the algorithms using both GPS and GLONASS, carrier-phase solution of the ambiguities might be only float (real-values).

Table 3
Differences in Sizes of Land Properties from Different Quality Coordinates

Size of property [m²]	Deviations in one point (*de*) [m]	Deviations in one point (*dn*) [m]	**Absolute error dP [m²]**
100	0.01	0.00	0.05
	0.10	0.00	0.50
	0.10	0.10	1.00
	0.30	**0.30**	**3.00**
1,000	0.01	0.00	0.16
	0.10	0.00	1.58
	0.10	0.10	3.16
	0.30	**0.30**	**9.48**
5,000	0.01	0.00	0.35
	0.10	0.00	3.54
	0.10	0.10	5.00
	0.30	**0.30**	**15.00**
10,000	0.01	0.00	0.50
	0.10	0.00	3.54
	0.10	0.10	7.07
	0.30	**0.30**	**21.20**
100,000	0.01	0.00	1.58
	0.10	0.00	15.81
	0.10	0.10	22.36
	0.30	**0.30**	**67.08**

Note: Differences in areas of land properties due to bad quality of coordinates. We presumed the square geometric form of land area. The reference used were the results (sizes), acquired from quality coordinates.
Source: Authors' work

To show the coordinate quality influence on the land area calculation, we simulated several scenarios. We presumed that only one of four of land property's points was of a worsen quality (Figure 4), but the accuracy differed from 1 cm (when ambiguities were integers) to 30 cm (when ambiguities were float) (Table 3).

When the size of the land property increased, the absolute error in size increased as well. As seen from Table 1, bad measurement conditions, especially from obstacles near the point's occupation, can affect the accuracy of coordinates' drastically. In case of 30-centimetre error in both horizontal components (*Easting* and *Northing*), lead to 3 m² error in land area. When the size is 1,000 m², the error is more than 9 m². In case of large land-properties, for example, 100,000 m² the 30-centimetre error in just one point's coordinates leads to the 67-m² error in the land area. The findings show that only from good GNSS measurement conditions we can acquire coordinates for further well-defined land areas.

Conclusion

The experiments of the measurements conditions impacts in GNSS positioning can be useful in everyday geodetic practice. In the research, we provided several results based on different scenarios in order to describe the importance of optimal conditions in high accuracy GNSS applications. Scenarios with obstacles followed the increasing the cut-off angle at different azimuths. Processing followed also the shortening of the occupation duration. The results showed worsening of the horizontal coordinates and heights with high obstacles near the site of occupation.

The results from specific processing strategies showed, which parameters are important while positioning. Simulations showed occupation duration is more effective than setting the signal registration to a minimum. The finding shows that different satellite constellations lead to better results and because of that, static GNSS method still has its preferences according to the kinematic methods.

Performing experiments of this kind is often limited in some aspects. In our research, we assumed bad measurement conditions due to obstacles affect only the number of visible satellites, while others, for example, the signal multipath and the interference were not included into the study. Second, the study did not consider anomalous atmospheric impacts on longer baselines. However, maybe at first recognised limitation of the study by showing that only one mistaken coordinate can affect the area determination, followed the deliberately incorporation of the scenario. The aim was to show the importance of the establishment of relations between the points of the same closed polygon structure for optimal geometric structure estimation. In the future, we plan to incorporate also other applications, for example a multi-level specification problem with the association of the data set reduction, already presented by Drobne and Lakner (2016).

Our research findings are important especially to people, working in the geodetic practice. The awareness that worsen quality of coordinates affect the compactness of the closed polygon's shape and its size is important. Since the land area presents the basic factor on the issues of property valuation and taxing, we have to devote a special emphasis on good data acquisition. The fuzzy logic ratings can serve as an additional tool in the prior assessing the overall quality of positioning at different conditions and therefore, can be an applicable tool in everyday geodetic projects.

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