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EVALUATION OF GPS OBSERVATIONS ACCURACY WITHIN LIMITED VISIBILITY BASING ON EMPIRIC DATA

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Abstract. In this paper, the exploration of accuracy of empirical GPS observations within the limited horizon has been conducted. The exploration has been done by assessing the outcome accuracy conducted at six points with a different percentage of limited horizon. The accuracy evaluation has been done in two variants. In the first one, the measured values of one-hour sessions have been compared with the values for the whole period of observations (6–12 hours) taken as standard. In the second variant, in order to get the independent data check, the measurement of distances and heights differences between the indicated points using the electronic total station has been conducted. In the second variant, the accuracy evaluation has been done basing on outcome deviations of one-hour session observations from the values measured by electronic total station. As the inadequate results of accuracy have been received (on the level of dozens of centimeters), it has been decided to check the measurements accuracy on observation sessions with a minimal value of DOP. In order to do this the preliminary planning has been completed and the optimal one-hour sessions of observations at each point have been selected. After that, the absolute errors of observation outcomes have been calculated at these points in both mentioned above variants. The research results prove that upon doing the preliminary planning the accuracy on the level of 0.5–3 cm can be achieved.

Keywords: GPS, GNSS, satellite observations, limited horizon visibility, accuracy, permanent station, electronic total station.

Introduction

The satellite technologies of measurements are widely used for solving various tasks, i.e. starting from mobile mapping to highly accurate geodesic observations. Executing GNSS observations demands locating the receiving devices on open territories. There is a topical objective to apply these devices for surveying on build-up, forested and other areas, which have the barriers for satellite transmission. This issue demands the investigation of limited horizon impact on the accuracy of finding the location. Such border parameters, which prevent from conducting measurements with sufficient accuracy, should be determined.

1. Analysis of research

In the device manuals, manufacturers offer the regression equation for a preliminary assessment of observations accuracy. As a rule, such equations consider the dependence only on the length of vector. However, there are such important factors impacting the accuracy of measurements as the session duration (Tretyak, Shushkova *et al.* 2001; Tretyak 2004; Baran, Chornokin 2004; Kostetska *et al.* 2005), as well as numbers and configuration of observed satellites (Ohrimchuk *et al.* 2011; Gritsyuk, Tretyak 2007; Chernyaga, Yanchuk 2012; Yanchuk 2010).

The significant amount of researches associated with this issue has been done under the guidance of the professor Tretiak K. R. (Tretyak, Shushkova 2001; Tretyak 2004). Particularly, basing on experimental measurements, the dependence of measurements accuracy of vertical vector components from their length *L* (within 2–10 km) and the time duration of observations t (within 10 min to 2 hours) on an open area has been determined. In the study Gritsyuk, Tretyak (2007), the experimentally received dependencies of accuracy of measured height difference from the minimal elevation of satellites above the horizon α (within 5–25°, with the interval 5°), the time duration of observations *t* (0.1–10 hours), and the length of vector *L* (1–10 km) have been provided.

Research questions the accuracy of GPS observations at a closedness horizon involved and foreign scientists, such as Grzegorz Krzan, Karol Dawidowcz, Krzysztof Świątek (Krzan *et al.* 2014).

Methods for increasing accuracy in low visibility conditions proposed in the works (Ben-Moshe *et al.* 2011; Santerre *et al.* 1995; Zimmerman *et al.* 2000).

In the researches (Ohrimchuk *et al.* 2011; Chernyaga, Yanchuk 2012), the sequence of determining the location availability point to conducting GPS observations depending on available barriers, which deter from satellite transmission, has been suggested. For this, the criterion, i.e. the horizon openness coefficient, which allows considering the impact of horizon closedness together with the duration of satellite location within the closed area, has been added. To execute the preliminary accuracy assessment, it has been offered to apply the functional dependencies of accuracy for determining the location basing on the coefficient of horizon openness and observations duration (Ohrimchuk *et al.* 2011), as well as the coefficient of horizon openness, observations duration, and length of vector by doing the preliminary planning of observations sessions (Yanchuk *et al.* 2012). The received regression equations could be used on the stage of projecting GPS observations by selecting the point for observing depending on the value of a horizon open part.

There is a drawback of received regression equations that lies in the fact that they have been received basing on the modelled data of barriers for satellite transmission; and, as it has been noted in these researches, they demand to be checked on practice.

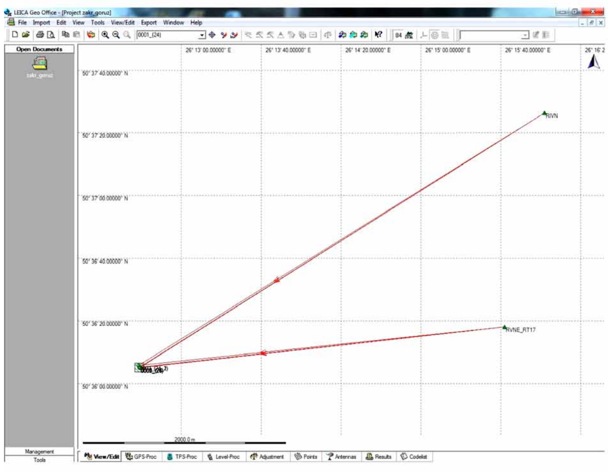

Fig. 1. Scheme of work location area respectively to the used permanent stations

2. Research methods

The paper objective lies in executing the empiric assessment of accuracy of determining the horizontal and vertical positions based on empirical GPS observations within the limited horizon visibility and investigating the measurements accuracy by doing the preliminary planning of observations sessions.

We have evaluated the possibility of conducting observations and the accuracy of spatial determination within the limited horizon visibility by using GPS. In the research, the investigation of satellite observations accuracy within the conditions of limited visibility during 1 hour has been conducted. Observations have processed at the program Leica Geo Office.

To execute the experiment two receiving devices Leica GPS1200 and one receiving device Leica TPS1200 Smart Station have been used. While doing observations (in August 2013) there occurred the following situation: in Rivne, two permanent stations were working – RIVN та RVNE. The distance to the work section from the permanent station RIVN was approximately 4.7 km; as for the distance from the station RVNE it was 3.6 km (Fig. 1) (Yanchuk 2014).

The observations had been conducted during two days at 5 points, whereas one of them was located on a relatively open location area (elevation of barriers was not more than 15°), and the rest ones were located below the buildings with different grades of horizon closedness. On the first day, two receiving devices were installed below the buildings – the points 001–002, and one was put on the open area – 003. On the second day, all three receiving devices were installed below the buildings – the points 005–007. By that, the point 007 was the same point 002, where the receiving device was put on the first day. The interval of observations registration was 1 second. Duration of double frequency observations at the points from 5 to 12 hours (Table 1).

The location scheme of stations is provided in the Figure 2, and the schemes of barriers locations are given in the Figure 3, as well as in the Table 1 (Yanchuk 2014).

Table 1. General duration of observations at the points

№№ of points	Percentage of horizon closedness	Duration of observations
001	42	8h46′
002	50	8h43′
003	17	5h05′
005	37	12h06′
006	60	12h07′
007	50	6h17′

On the 1st stage of research, the provided time intervals were divided into one-hour sessions to work on. To check the accuracy of received outcomes the comparison of solution coordinate increments with true values has been executed (the adjustment values from both permanent stations for the whole period of observations). To calculate the accuracy of horizontal and vertical measurements, the geocentric coordinates (true and calculated ones during investigation) have been changed into the system of plain rectangular coordinates. After that, the root-mean-square errors (RMS) to determine the coordinate increments $m_{\Delta x}$, $m_{\Delta y}$, $m_{\Delta H}$ by the formula of Bessel have been calculated. RMS m_{hor} of the horizontal location of the final point for the base line to the initial has been calculated by the following formula (1):

$$m_{hor} = \sqrt{m_{\Delta x}^2 + m_{\Delta y}^2}\ , \qquad (1)$$

where $m_{\Delta x}$, $m_{\Delta y}$ – are root-mean-square errors for determining the coordinate increments by the x-axis and y-axis accordingly.

For additional control, the distance and heights differences between the points have been determined as direct measurements on the location with electronic total station Leica TPS1200. The results have been displayed in the Table 2.

Table 2. Measured length of lines and heights differences

Line	Measured by electronic total station	
	distance, meter	heights differences, meter
003–001	27.677	+0.364
003–002	27.304	+0.364
001–002	1.600	+0.002
007–005	1.402	+0.003
007–006	7.388	–0.002

On the 2nd stage, in order to check the accuracy of received results the comparison of calculated heights differences with the values measured by electronic total station has been executed; in the same way, the RMS of lines length and heights differences has been determined.

For further, using the preliminary planning some optimal one-hour sessions of observations on each point have been selected. The selection criterion of optimal observations time was the rated values DOP. For example, in the Figure 4, the rated criteria DOP for the point 001 with the horizon closedness 42% are displayed.

As it is clear from the Figure 3 the optimal time frame for taking is the period between 12^{20} pm та 1^{20}

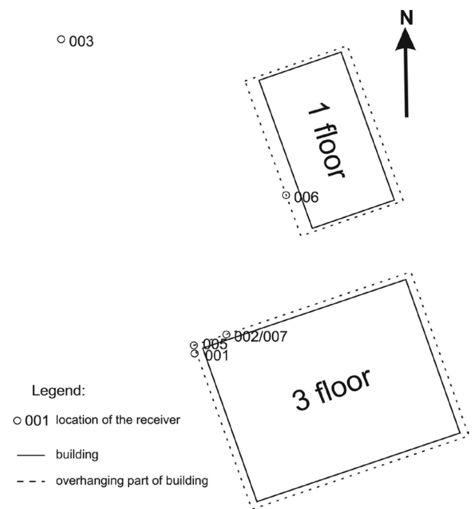

Fig. 2. Scheme of location of observations points within two days (Yanchuk 2014)

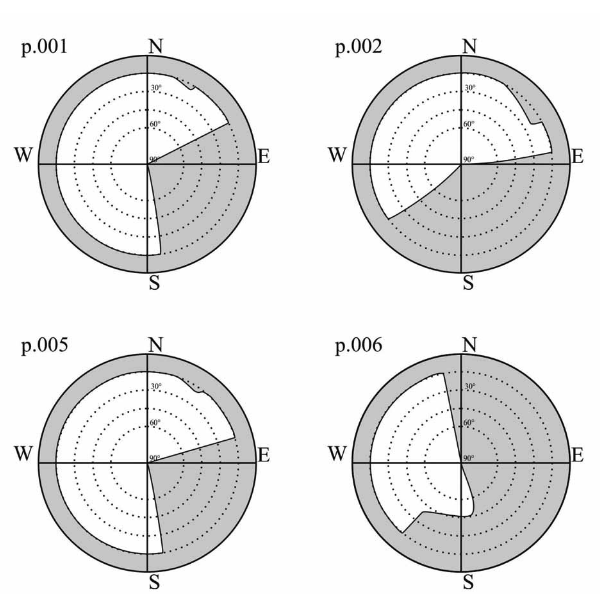

Fig. 3. Scheme of barriers location at the observations points (Yanchuk 2014)

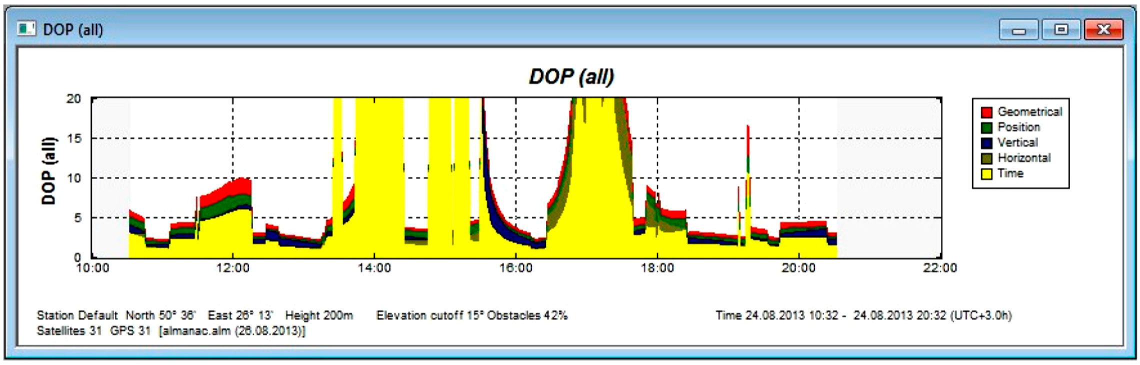

Fig. 4. Value of DOP criteria for the point 001 with the horizon closedness 42% received from the program planning

pm (local time). In the same way, the optimal observations intervals for other points have been selected.

On the 3rd stage, the comparison of calculated heights differences from optimal observations sessions (selected from the preliminary planning) from true values (the equated values from both permanent stations for the whole period of observations) has been executed; by the latter ones, the RMS of lines length and heights differences has been determined.

On the 4th stage, the comparison of calculated heights differences with optimal observations sessions (selected from the preliminary planning) with the rated values by electronic total station has been executed; by the latter ones, the RMS of lines length and heights differences has been determined.

3. The results of the research

The results of the first stage of investigation by solution from each permanent station separately and equated values from both stations have been displayed in the Table 3.

The results of the second stage of investigation, where the deviations of received results from the values measured by electronic total station were assessed, are displayed in the Table 4.

Table 3. Received RMS of determining base vectors by deviation of one-hour sessions from the values taken as standard

No. of points	Percentage of horizon closedness	Stations								
		RVNE			RIVN			RVNE та RIVN		
		Root mean square, meter								
		horizontal	vertical	spatial	horizontal	vertical	spatial	horizontal	vertical	spatial
001	42	0.049	0.084	0.097	0.255	0.115	0.280	0.218	0.166	0.274
002	50	0.319	0.268	0.417	0.623	0.550	0.831	0.648	0.498	0.817
003	17	0.003	0.004	0.005	0.004	0.002	0.005	0.003	0.003	0.005
005	37	0.049	0.045	0.066	0.014	0.013	0.019	0.145	0.059	0.157
006	60	0.049	0.083	0.096	0.326	0.275	0.427	0.206	0.147	0.252
007	50	0.065	0.041	0.076	0.210	0.124	0.244	0.206	0.125	0.240

Table 4. Received RMS of determining base vectors by deviation of one-hour sessions from the values measured by electronic total station

Line	Stations					
	RVNE		RVNE		RVNE та RIVN	
	Root mean square, meter					
	distance differences	heights differences	distance differences	heights differences	distance differences	heights differences
003–001	0.042	0.111	0.165	0.155	0.092	0.147
003–002	0.192	0.267	0.493	0.492	0.454	0.435
001–002	0.230	0.263	0.201	0.516	0.328	0.471
007–005	0.040	0.117	0.123	0.159	0.170	0.185
007–006	0.088	0.066	0.259	0.269	0.128	0.187

The results of the third stage of investigation, where the deviations of received results of optimal sessions were assessed (selected by the preliminary planning) from the values taken as standard, are displayed in the Table 5.

The results of the fourth stage of investigation, where the deviations of received results from optimal sessions (selected with the preliminary planning) from the values measured by electronic total station were assessed, are displayed in the Table 6.

Conclusions

From the executed practical investigations, the following conclusion can be provided that using one-hour sessions of observations by the horizon closedness 50%, the accuracy of measurements will not be better than one decimeter. Thus, the results obtained in practice worse than values obtained by simulated artificial obstacles. One of the main reasons of accuracy deterioration, respectively to simulated data from the publications (Ohrimchuk *et al.* 2011; Yanchuk *et al.* 2012), in our opinion, is the impact of multipath of transmission.

Having analyzed the sessions data, selected with the help of preliminary planning, one should mention the accuracy of measurements within 1–3 cm. It means that due to selecting the observations period with the minimal values DOP the significant improvement in results occurs.

Therefore, the outcomes of executed investigations prove the practical possibility of conducting measurements in the conditions of the partly horizon closedness with the centimeter accuracy. The significant difference between the results of assessment accuracy by the data taken as true and those independent ones measured by electronic total station should be provided. As it is clear from the results of the independent check displayed in the Table 6, the errors of vertical component are fundamentally higher than the accuracy of horizontal component. The received results demand further investigations on bigger observation areas. Moreover, the accuracy issues depending on the direction of horizon closedness, the material of barriers, and the distance from it are important.

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Table 5. Received absolute errors of base vectors results by deviation of optimal sessions from the values taken as standard

№№ of points	Percentage of horizon closedness	The planned observation session (local time)	Stations								
			RVNE			RIVN			RVNE та RIVN		
			Absolute errors, meter								
			horizontal	vertical	spatial	horizontal	vertical	spatial	horizontal	vertical	spatial
001	42	12^{20}–13^{20}	0.018	–0.007	0.020	0.016	–0.002	0.016	0.017	–0.005	0.018
002	50	17^{30}–18^{30}	0.002	–0.005	0.005	0.003	–0.004	0.005	0.002	–0.004	0.005
003	17	16^{00}–17^{00}	0.002	–0.004	0.005	0.004	–0.003	0.004	0.002	–0.004	0.005
005	37	07^{41}–08^{41}	0.012	–0.004	0.012	0.010	–0.010	0.014	0.011	–0.007	0.013
006	60	18^{00}–19^{00}	0.025	+0.044	0.050	0.025	+0.046	0.052	0.025	+0.045	0.051
007	50	17^{20}–18^{20}	0.022	+0.014	0.026	0.026	+0.005	0.026	0.024	+0.009	0.025

Table 6. Received absolute errors of solving base vectors by the deviation of optimal sessions from the values measured by electronic total station

Line	Stations					
	RVNE		RVNE		RVNE та RIVN	
	Absolute errors, meter					
	distance differences	heights differences	distance differences	heights differences	distance differences	heights differences
003–001	0.004	+0.123	0.006	+0.124	0.005	+0.123
003–002	0.002	+0.102	0.001	+0.098	0.001	+0.099
001–002	0.009	–0.023	0.009	–0.027	0.009	–0.025
007–005	–0.004	+0.104	–0.002	+0.101	–0.003	+0.103
007–006	–0.054	+0.020	–0.054	+0.009	–0.054	+0.015

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