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MULTIPATH AND ITS MANIFESTATIONS IN THE REAL ENVIRONMENT OF GEODETIC PRACTICE

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Abstract. The paper is concerned with the negative manifestation of the multipath factor in application of the GNSS technology. It points to manifestations of the multipath effect in a specific situation of surveying practice. The evaluation is based on a model situation under intentionally deteriorated observational conditions by the presence of a building.

Keywords: multipath, GNSS, geodetic practise, NAVSTAR GPS, GLONASS.

Introduction

The observation concentrates on a negative effect of the multipath signal spreading on accuracy of the measurement during observations close to building objects. The study describes the situation in the terrain, determines the goals, the evaluated method together with the measurement methodology, and evaluates the outcomes. Importantly, the proposed experimental positions represent situations in which geodesists can find themselves during their surveying activities.

Many publications dedicated to GNSS technology and the sources of systematic errors mention the multipath factor as the greatest source of natural errors in the instruments. The main goal involves experimental observations, which are exposed to reflections. We will deal with issues connected with safe distance from a potential reflective surface. For these purposes, four points were proposed.

1. Observational conditions intentionally deteriorated by the presence of a building object

The premises of VSB – Technical University of Ostrava were chosen for execution of the experimental observation. The position is near a multipurpose sports hall. Special requirements were specified for the choice of location where the observations were to be performed. It was not only the presence of a significant potential reflective surface in the form of the building's wall. The selection was also determined by other criteria. It was necessary to choose a location with points of the horizontal control so that the situation could allow a comparison of outcomes from the GNSS observation and a terrestrial measurement.

Another important condition involved deterioration of the observational conditions by other factors in the area (no large vegetation, no other buildings, water surfaces, cars or other elements). These criteria were proposed so that the sports hall could be considered a dominant object and the only significant negative factor. The orthophoto image in Figure 1 below shows the location of the experimental observation. The blue-hatched area illustrates the position of stations for the experimental measurements.

The geometric base for the subsequent terrestrial measurement consisted of points of the horizontal control. They represented points attached to the trigonometric point 89. As the heights of aiming points 3611-89.3 and 89.4 according to the geodetic data were determined by levelling, they would also be used as a height reference for the trigonometric measurement (Staňková, Černota 2013).

An important parameter which plays an important role in the multipath (multipath signal spreading) is the actual height of the building (reflective surface). In the measurement area, the multipurpose sports hall is 8.5 m high, a part of the building is lowered to 5 m.

A drawing with a side view of the situation is shown in Figure 2. The wall of the building consists of plastic sheathing whose surface is very smooth and glossy. Thus, from the point of view of reflectivity, there is a higher risk of the multipath than in the case of buildings with coarser facade materials. The given illustration proportionally corresponds to the real situation in the terrain with its dimensions (in the vertical direction).

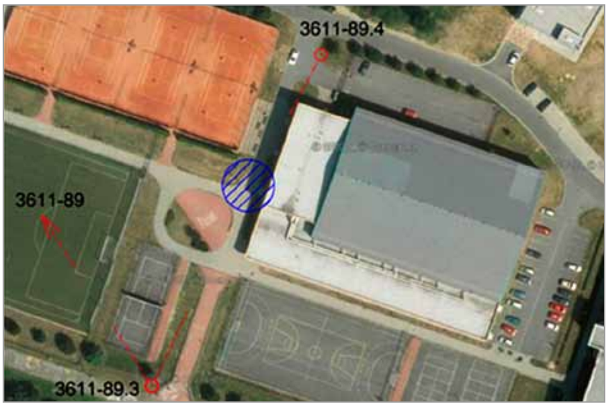

Fig. 1. Location of multipurpose sports hall VSB-TUO + the geometrical base

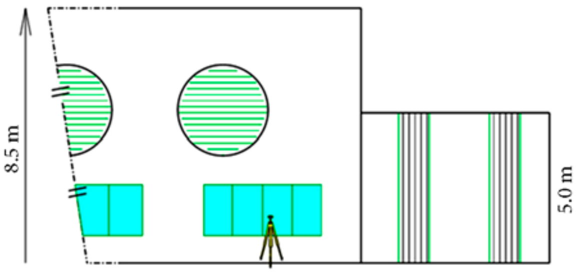

Fig. 2. Draft of the situation – the sports hall multipath

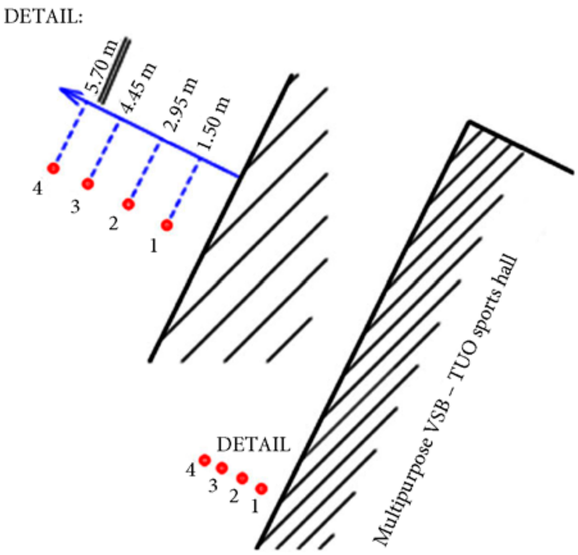

Fig. 3. Observed points – VSB – TUO sports hall

2. Stabilization of points for the measurement and the applied instruments

Four points were proposed for observation of the multipath effect in this position. Point No. 1 was stabilized in the immediate vicinity of the multipurpose sports hall, approximately only 1.5 m from the wall. Other points followed at an average interval of 1.4 m between the points. The measurement points lie approximately on a line perpendicular to the reflective surface. The individual distances of the stabilized points (survey pins) are shown in Figure 3 (Mikoláš *et al.* 2013).

The following instruments were used in the research: Leica GPS System 1200 (antenna ATX 1230 GG), total station Leica TCR 1202+ with accessories.

3. The tested method, measurement methodology and the procedure

Monitoring of the multipath effect was based on measurement using a rapid static method. It involved the execution of at least two independent observations by means of GNSS technology. The measurements were thus divided into two working stages. In the first working stage, which proceeded on 11th February 2015, the first observations were executed in the individual points.

The second stage of measurements was executed with more than a two-week delay, thus satisfying the demand for independence of repeated observations. Independence of repeated observations requires that the repeated measurement be executed in a distribution of satellites different (independent) from the first measurement. It allows for the so-called „dangerous" time interval for repeated measurements related to the first measurement (Staňková, Černota 2013).

Independence of the measurements was purposefully observed only during observation in points 1 and 2. Observations in points 3 and 4 were executed at times which purposefully depended on the first observation with their constellation. The reason was comparison of the observation outcomes while ignoring the specified period. The time intervals of the observations and the calculated dangerous or unsuitable periods for repetition of the measurements are summed up in Table 1.

Table 1. Observation times and intervals unsuitable for repetitive measurement

1. Measurement 11.2.2015			2. Measurement 27.3.2015		Dangerous interval pursuant to 31/1995 Coll		Independence observed Yes/No
Point No.	From	To	From	To	From	To	
1	11:25	11:40	12:51	13:01	9:21	11:21	YES
2	11:45	11:57	13:19	13:29	9:45	11:41	YES
3	12:00	12:10	12:10	12:21	9:56	11:56	NO
4	12:12	12:22	12:30	12:42	10:08	12:08	NO

The first and second observations were separated by 16 days. If we use only the American NAVSTAR GPS navigation system, as in this case, the orbital period of the navigation satellites is decisive for calculation of the dangerous time of the second measurement. It is 11 hours 58 minutes. It means that the American navigation satellites fly around the Earth more than twice in 24 hours. Thus, they get ahead of the Earth. For our case of sixteen days, the same constellation of the satellites related to the first measurement will occur 1 hour 04 minutes earlier than in the first observation. If we add the determined minimum distance of the measurement (±1 hour), we will obtain intervals which we should avoid during repetitive measurements. If we receive signals from both systems, the independence should conform to the configuration of both the GPS and GLONASS systems. Photographs from the second observations are shown in Figure 4.

Fig. 4. Observed points – VSB – TUO sports hall

Together with the second stage of observation using GNSS technology, the points were measured terrestrially. We also applied a classic polar method in which, as mentioned above, the geometric base was provided by aiming points of the trigonometric point 3611-89.

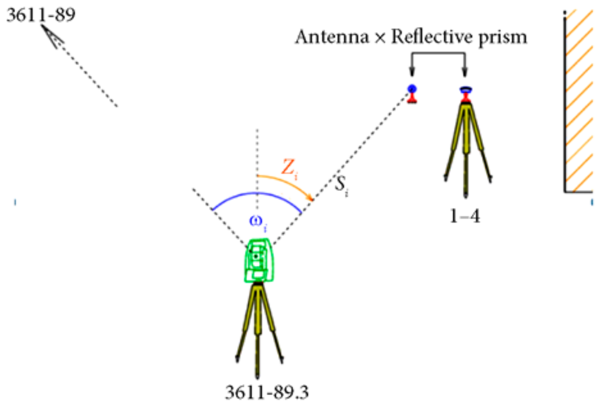

Fig. 5. Terrestrial measurement of the points

The chart given in Figure 5 shows the terrestrial measurement. Points 1–4, which are the subject of the evaluation, were measured together with the GNSS observations. As soon as observation using the rapid static method was finished, the antenna was replaced with a reflective prism and a measurement was executed. This eliminated repetitive centring, which also improved the weight of terrestrial measurement for the subsequent evaluation of the GNSS outcomes (Labant, Weiss 2013).

A five-second interval with 10° elevation was used as a recording interval for the GNSS observation using the rapid static method. A permanent station called VSBO (CZEPOS) was used as reference. The VSBO reference station is located on the roof of the A building, VSB – TUO. In our case, it created a very close reference (the position between the measurement and the reference station was about 200 m) (Staňková, Černota 2010).

In the first measurement stage, both the American NAVSTAR GPS navigation system and the Russian GLONASS system were used for observation. The second observation proceeded only with NAVSTAR GPS. This option has its reasoning. The question was how dual reception would reflect on the resulting accuracy. Thus, the observations were first executed with reception from both systems and the second only from the American. The subsequent comparison then involved calculations of the first stage with the GPS data and then GPS + GLONASS.

4. Results of the observations

The difference between the first and second measurement (see Table 2) suggests, in line with the expectations, the highest scatter in points 1 and 2. Positionally, the results differ from 6 to almost 9 cm. In the height, the results also show a relatively high uncertainty (up to one centimetre). Relatively good results as regards agreement of the double observation come from measurement in points 3 and 4, where the difference between the positions of the determined double-measured points is less than 1 cm. Surprisingly, the heights of points 3 and 4 do not diverge, but converge up to 1 cm.

Table 2. Difference between the 1st and 2nd measurements

Point No.	Δ*y* [m]	Δ*x* [m]	Δ*H*[m] (Bpv)	Δ*P* [m]
1	−0.043	−0.044	−0.017	0.061
2	−0.085	−0.012	−0.093	0.086
3	0.009	0.002	0.008	0.009
4	0.002	0.000	0.004	0.002

In practice, this comparison of the results is frequently the only check of measurement using GNSS technology. The geodesist would probably exclude results showing differences approaching 10 cm and use a different method or add another observation. It certainly is a certain control mechanism. It is probably sufficient in practice, but even the relatively favourable difference in points 3 and 4 does not guarantee that the results are in order for the particular purpose (Mikoláš *et al.* 2013).

Comparison of the terrestrial measurement with the results of the first and second observations and deviations in the individual points 1–4 was recorded in tables 3 and 4. If we go back to the differences between the first and second observation, points 3 and 4 showed a relatively high agreement in position and height (see Table 2). In contrast to the GNSS observation, the difference in the polar measurements in point 4 is only in millimetres in both stages. In the height, the situation is significantly worse (see Tables 3, 4). Despite the fact that comparison of the two observations showed no significant divergence in the height, the results show that both observations are strongly affected by the multipath factor as regards determination of the height element. The agreement between the first and second observation was probably caused by the fact that in both cases, the multipath effect was manifested by the same proportion (similar load with a systematic error – the direction as well as the size).

Table 3. Comparison of results (GNSS vs. terrestrial) – 1st observation

GNSS deviations (1st measurement vs. terrestrial)				
Point No.	Δ*y* [m]	Δ*x* [m]	Δ*H* (Bpv) [m]	Δ*P* [m]
1A	−0.004	−0.017	−0.048	0.018
2A	−0.014	0.009	−0.081	0.016
3A	−0.005	0.018	−0.070	0.019
4A	−0.001	0.008	−0.082	0.008

Table 4. Comparison of results (GNSS vs. terrestrial) – 2nd observation

GNSS deviations (2nd measurement vs. terrestrial)				
Point No.	Δ*y* [m]	Δ*x* [m]	Δ*H* (Bpv) [m]	Δ*P* [m]
1B	0.038	0.026	−0.031	0.047
2B	0.071	0.020	0.012	0.074
3B	−0.014	0.016	−0.078	0.021
4B	−0.003	0.008	−0.087	0.008

Larger differences in the position, but not so bad to be excluded from the geodetic practice (e.g., in the land registry), were obtained in the first stage in points 1 to 3. These points showed deviations against the terrestrial measurement within 2 cm (see Table 3). As regards the height evaluation, the situation is similar; the accuracy moves from almost 5 cm to 9 cm. Interestingly, deviations in the height component had the minus sign at observation in point 2 during the second measurement. The resulting heights thus show values lower than the reality. This can be explained by a longer wave route in case of a reflection from the building, which can be manifested by a longer distance between the satellite and the antenna, thus a lower height value.

A much larger positional divergence can be noticed in the second observation in the 2B point. It reached values that would affect the subsequent measurement (e.g., if we used the results as a geometric base for a detailed measurement) and might reduce the relevance of the resulting work. The position of the 2B point against the position in a terrestrial measurement is deviated by more than 7 cm.

Let us concentrate on observation in point 2. A significant variance in accuracy of the point‘s positioning is more noticeable than in any other observations. The first observation provided relatively reliable results. The second observation, however, is affected by the multipath effect more than the first.

Let us apply the general geometric assumption that signals received from low-flying satellites (lower elevation) are more sensitive to the multipath effect than signals from higher-elevation satellites. Figure 6 describes what can happen during the observations (Hofmann-Wellenhof *et al.* 2008).

The example in Figure 6 describes a geometric model of the multipath effect during observation in the vicinity of the VSB-TUO multipurpose sports hall. The chart proportionally corresponds to the reality (the height of the antenna vs. height of the building). To confirm the assumption of higher sensitivity to reflections with lower elevation, we chose two examples. The red mark shows reception of a signal from a satellite with an elevation of 30°. According to the law of reflection, the signal does not reach the receiver only directly, but also along a longer path caused by reflection at the same angle. The blue lines show reception of a signal at 70° elevation. It is apparent from the chart that a signal from a lower-situated satellite is more sensitive to reflections. In theory, signals arriving at an angle of 70° should not be affected by the multipath effect in case of reflection from the wall.

Even if they were reflected by the top part of the building, they would reflect at the same angle at which they reached the wall, thus missing the antenna (see Fig. 6). This chart corresponds to observation in point 2 (the distance from the building is 2.95 m). The chart in Figure 6 is simplified; in reality, the problem is more complicated. The reflections illustrated in Figure 6 are valid if the transmitted signals reach the reflective surface perpendicularly. The law of wave reflection says that the angle of reflection equals the angle of incidence and the reflected wave remains in the plane of the incidence. During measurements, signals coming from various directions at various elevations fall on potential reflective surfaces (smooth materials, water surface, steel structures, land surface, etc.). Description of the wave behaviour in the real environment is thus complicated (Sládková, Kapica 2013).

Based on the mentioned example, it is apparent that the susceptibility to reflection depends on the particular geometrical situation in the terrain. It depends on the geometrical character of the neighbouring real world as well as the time. The momentary configuration of the satellites is essential together with the directions from which the signals arrive and the angle. The risk of the signal being reflected depends on the distance of the receiving instrument from the reflective area and the height of the antenna compared to the height of the reflective area, in our case the sports hall (Sládková, Kapica 2013).

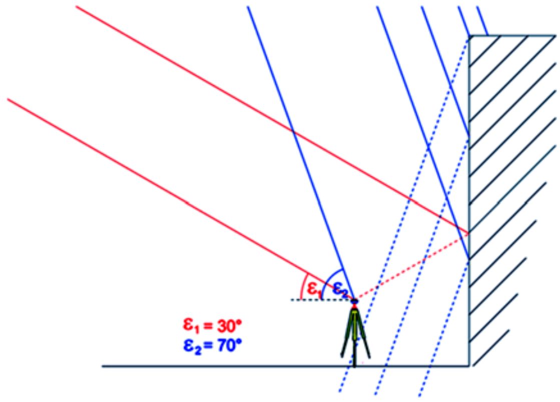

Fig. 6. Geometric model – multipath: VSB-TUO sports hall (point 2)

Determination of the elevation that should not be dangerous for observation as regards the multipath effect is illustrated in Figure 6. The chart corresponds to point No. 2, i.e. the distance from the building is 2.95 m, the height of the building is 8.5 m and the height of the tripod with antenna is about 1.7 m. Based on goniometrical functions in the rectangular triangle, we obtain relation (1). If we insert it numerically into relation (1), we will obtain the limit value for „safe elevation" 66°. (Hofmann-Wellenhof *et al.* 2008).

$$\varepsilon = \mathrm{arctg}\left(\frac{V_B - V_A}{s}\right), \qquad (1)$$

where ε – equals the satellite elevation angle; s – distance from the building; V_A – height of the antenna, V_B – height of the building.

5. Comparison of results in dual reception from NAVSTAR GPS and GLONASS

We include brief results of observations with dual reception as a matter of interest. In the first stage of measurements, the observations were executed using the American as well as Russian satellite system. For comparison, the calculation included firstly only the NAVSTAR GPS data and then the GLONASS data. Table 5 shows differences in the position and height of the points compared to the terrestrial measurement in cases when only the GPS data were used and then a GPS + GLONASS combination. The symbols next to the position and height deviations illustrate whether the accuracy increased, decreased or did not change by application of GLONASS.

Table 5. Difference in the obtained accuracy (GPS vs. GPS + GLONASS) – 1st stage

Point No.	NAVSTAR GPS		NAVSTAR GPS + GLONASS				
	ΔP [m]	ΔH (Bpv) [m]	ΔP [m]		ΔH (Bpv) [m]		
1	0.018	–0.048	0.014	⬀	–0.060	⬂
2	0.016	–0.081	0.024	⬂	–0.105	⬂
3	0.019	–0.070	0.021	⬂	0.078	⬂
4	0.008	–0.082	0.008	⇨	0.089	⬂

Conclusions

As regards the resulting position of the points, the first observations provided relatively satisfactory results. The position deviation did not exceed 2 cm compared with the terrestrial measurement. The method would suffice for standard geodetic practice without the need for high accuracy. The results of the second observations are worse as regards the position, especially in point 2. The heights of the monitored points show large ambiguity.

The observation can be seriously deteriorated by a multipath effect of the signal. However, we cannot generally declare that, disregarding other factors, the closer the instrument is to the potential reflection area, the greater the multipath effect will be. It always depends on the particular situation, the geometrical parameters of the given location, orientation of the reflective area and the current constellation of the satellites. Each observation needs to be approached individually.

In practice, we try to reduce the risk of potential signal reflection as much as possible. If we really need to perform an observation in areas where the risk of multipath is generally higher, we should observe the distance from buildings, water surfaces, high natural elements, etc., but also plan the time of the measurement, evaluate the configuration, etc. It also seems suitable to use higher adjustment of the elevation mask during the observation. In this way, we can reduce the risk of signal reflection of very low-flying satellites. A relatively safe distance from the building was in points 4 (5.70 m from the building), but only for the position of the point, not the height.

Based on the data in Table 5, we can conclude that even in the case of dual reception in combination of the NAVSTAR GPS and GLONASS satellite navigation systems, the accuracy did not increase. Quite the opposite. In the height, the situation was markedly worse. It slightly deteriorated in the position of the points in two cases. The results in point 4 remained unchanged, point 1 showed slightly improved accuracy.

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