GPS Antenna Height and Its Influence on Pseudorange Multipath

Gilad EVEN-TZUR and Doron SHAKED, Israel

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SUMMERY

The GPS antenna is the connecting component between the GPS satellite and the GPS receiver. Its function is to transfer the satellite signal propagation to the receiver with minimum interruption. A satisfactory process is expected to result in an accurate and reliable performance of the GPS receiver. Multipath error is a dominant error source connected with GPS positioning. Mitigation of such errors can be achieved by improving signal processing and a better antenna design.

When the geometry between the GPS satellite and the receiver remains unchanged, a comparison study between antenna types set up in different height is possible since the pseudorange multipath pattern is repeated every sidereal day. Such a multipath comparison was carried out for three types of pseudorange, the C/A code and the P-code modulated on the L1 and L2 carrier phase. The multipath pseudorange from several satellites with different elevation angles was used in the assessment of the multipath effects. The method of comparison and the test are also presented.

This paper attempts to examine the effects of the antenna height on pseudorange multipath in a variety of GPS antenna types, and compares the multipath mitigation capabilities of different antenna types set up at different heights. The effects of different height positioning of the GPS antenna on the pseudorange multipath are examined, as determining the desirable height at which a GPS antenna should be positioned can assist in reducing pseudorange multipath effects. The data obtained in this research proves that the optimal height for positioning the GPS antenna in order to reduce pseudorange multipath is at ground level.

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1. INTRODUCTION

A multipath effect occurs when GPS signals arrive at an antenna via multiple paths due to reflections from nearby objects, such as the ground, buildings, vehicles, trees, etc. Multipath distorts the C/A-code and P-code modulations, as well as the carrier phase observations. Multipath is considered a major source of error connected with GPS positioning (Weill, 1997). Positioning the antenna away from nearby objects whenever possible can minimize the multipath effect. The impact of multipath signals on the pseudorange and carrier phase observation is dependant upon a variety of factors: the distance of the reflecting object from the antenna, the antenna attenuation characteristics and the capacity of the receiver to mitigate multipath. Carrier-phase multipath effects typically display sinusoidal characteristic with the theoretical maximum amplitude of a quarter of the observed wavelength (about 5cm for GPS L1 and 6cm for L2). The multipath frequency is proportional to the perpendicular distance of the reflectors. Pseudorange multipath behaves similarly to that of carrier phases, except that the variation is larger by several orders of magnitude (Leick, 1995). Pseudorange multipath is a function of the length of the code. The maximum expected multipath is limited by the chipping rate, the higher the chipping rate, the lower the maximum multipath. The expected multipath on the P-code is smaller than for the C/A-code. More extensive review on theoretical aspects of multipath effects is given by e.g. van Nee (1995).

Partial multipath rejection can be built into the antenna by shaping the gain pattern. Multipath arising from below the antenna can be reduced by using ground planes. Improved multipath resistance can also be achieved with choke rings (Leick, 1995). A choke ring antenna can be used to mitigate multipath signals reflected from objects below the antenna. However, it has no effect on multipath signals reflected from objects above the antenna (e.g. tall buildings or trees). The majority of current GPS receivers use right circularly polarized microstrip patch antennas due to their compact size and low cost when compared to choke ring antenna. The disadvantage of a microstrip antenna is that it cannot reject multipath signals. Therefore, multipath-resistant GPS receiving microstrip antennas are designed with ground planes to reject the multipath signals resulting from low elevation angles near the horizon. Usually, the microstrip antenna includes a radome to protect it from environmental extremes.

There is ample research in the filed of carrier phase multipath. For example, Lau and Cross (2007) describe the basis of a model for the GPS carrier phase multipath process using ray-tracing and identifies the key factors that can contribute to carrier-phase multipath errors. Satirapod and Rizos (2005) apply a wavelet decomposition technique to extract carrier phase multipath from GPS observations. The extracted multipath signature is then applied directly to the GPS observations to correct the multipath effects.

Further work in the filed of pseudorange multipath includes Hilla and Cline (2004), who evaluated the amount of pseudorange multipath at hundreds of sites in the CORS network in order to identify the most affected and least affected sites in the network. Even-Tzur (2007) examined the effects of the pseudo-range multipath in a variety of GPS antenna types and compared the ability of different antenna types in mitigating multipath. Park et al. (2004) designed and constructed a prototype antenna and multipath calibration system to determine site dependent errors such as antenna phase-center variations and multipath.

This paper attempts to examine the effects of the antenna height on pseudorange multipath in a variety of GPS antenna types.

2. THE MULTIPATH COMPUTATION

The GPS receiver provides pseudorange data on L1 (C1 and P1) and pseudorange data on L2 (P2), in addition to the L1 and L2 carrier phase data (Φ_1 and Φ_2). Computation of pseudorange multipath can be carried out by isolating the multipath component from the code and by using phase linear combination observation equations. Using pseudorange and carrier phase data enables eliminating the effects of station clocks, satellite clocks, tropospheric delay, and ionospheric delay. The pseudorange multipath can be derived by using the following equations (Ge et al., 2002; Estey and Meertens, 1999; Langley, 1998):

$$\begin{aligned} MP_{P1} &= P1 - 4.0915\Phi_1 + 3.0915\Phi_2 + \left[4.0915(\lambda_1 N_1 + MP_{\Phi_1}) - 3.0915(\lambda_2 N_2 + MP_{\Phi_2})\right] \\ MP_{P2} &= P2 - 5.0915\Phi_1 + 4.0915\Phi_2 + \left[5.0915(\lambda_1 N_1 + MP_{\Phi_1}) - 4.0915(\lambda_2 N_2 + MP_{\Phi_2})\right] \end{aligned} \quad (1)$$

The terms in the square brackets are functions of the multipath carrier phase, MP_{Φ_1} and MP_{Φ_2}, and the unknown integer ambiguities, N_1 and N_2, where λ_1 and λ_2 are the L1 and L2 carrier phase wavelength respectively. All terms except the integer ambiguities are expressed in meters. The impact of the multipath on the carrier phase is insignificant in comparison to the multipath pseudorange, and can therefore be ignored. Hence, those terms are biases that are assumed to be constant if there is no cycle slip in the carrier phase data, and can therefore be removed. The results, MP_{P1} and MP_{P2}, are the pseudorange multipath mixed with the receiver noise, which can be seen as a series of residuals with metric unit values.

In this work the TEQC software was used to compute the pseudorange multipath. The inputs used were RINEX observation files and the constant part of the MP_{P1} and the MP_{P2} was removed by averaging the data over 50 epochs (Estey and Meertens, 1999).

The TEQC software computes the pseudorange multipath using the P1 observation (MP_{P1}) as a default. If P1 is unavailable TEQC will use the C1 in equation (1) instead, which enables the calculation of MP_{C1}. Some receivers (Ashtech Z family receivers for example) collect three types of pseudorange observations: the C/A code on L1 (C1), the P code on L1 (P1) and the P code on L2 (P2). When using these receivers the C1 pseudorange multipath can be calculated in addition to the P1 pseudorange multipath, when removing all P1 observations from the RINEX file.

3. COMPARISON OF PSEUDORANGE MULTIPATH

When the geometry between the GPS satellite and the receiver (positioned at the same place) remains unchanged, the pseudorange multipath pattern is repeated every sidereal day (Even Tzur, 2007, Ge et al, 2002). This enables checking the effect of the pseudorange multipath on a variety of GPS antenna types set up in different heights. However, there are differences between successive pseudorange multipaths, originating from changes in uncorrelated noise from day to day, as well as differences caused by the time difference between the GPS satellite orbit periods and the mean solar day. On average, the offset Δt of the time of two complete satellite revolutions from one mean solar day equals approximately 240 seconds (see also Wanninger and May, 2000). A correct reduction of the Δt from the time axis in each day enables obtaining a common time scale for the representation of the pseudorange multipath. Examination of the multipath pattern over successive days in a permanent GPS station showed that the repeatability of the pseudorange multipath is at the level of 75%-80% due to changes in uncorrelated noises between days (Even Tzur, 2007).

3.1 Experiment description

In this experiment the same antennas was set in three successive days at the same time over the same point, and each day the antenna phase center was positioned at different heights: about 1.60m in the first day, 0.9m in the second day and 0.2m in the last day. The selected station was located on a flat open field, with no obstacles in a radius of hundreds of meters. Thus, the only reflected object was the ground (see figure 1). Three types of GPS antennas were examined in this study, Ashtech DM Choke Ring (ASH701945C_M), Ashtech Geodetic L1/L2 (ASH700578) and AeroAntenna Geodetic L1/L2 (AERAT2775_42). They are all dual frequency (L1/L2) antennas. The antennas were set up with 15-20m between them (see figure 1). Three Ashtech Z-Surveyor receivers were used in all the experiments, in order to eliminate the receiver noise factor.

The GPS data observations were made from GPS day 301 to day 303 in the year 2007. The observations were measured during the same time every day (between 6:20 to 9:00 UT). Measurements were collected at 5 second intervals. The observation types collected were C1, P1 and P2 pseudoranges and L1 and L2 carrier phase data, when P1 and P2 refer to the Y-code. Table 1 summarizes the antennas height phase center (L1) for each day.

Table 1 – The antennas height phase center, in meter, for each day.

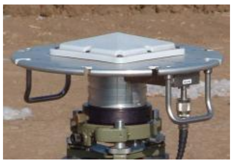
GPS day	Antenna Type		
	Ash. DM Choke Ring 	Ash. Geodetic L1/L2 	Aer. Geodetic L1/L2 
301	1.56	1.55	1.64
302	0.97	0.92	0.91
303	0.20	0.12	0.19

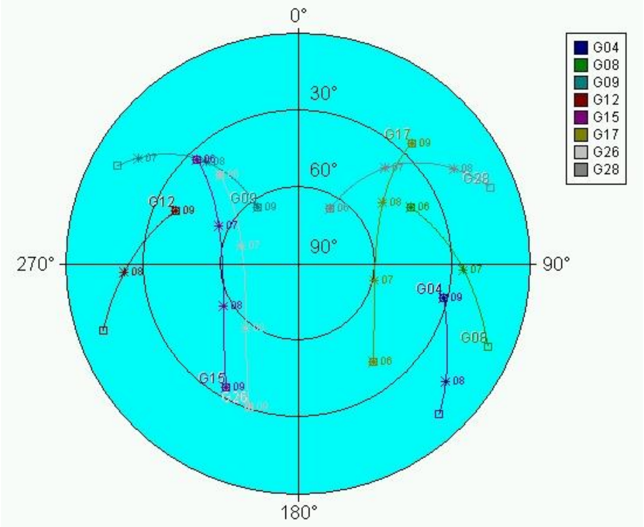
Figure 1 – GPS day 301, three GPS antenna types set up on a flat open field at a height of approx. 1.6m.

3.2 The data analysis process

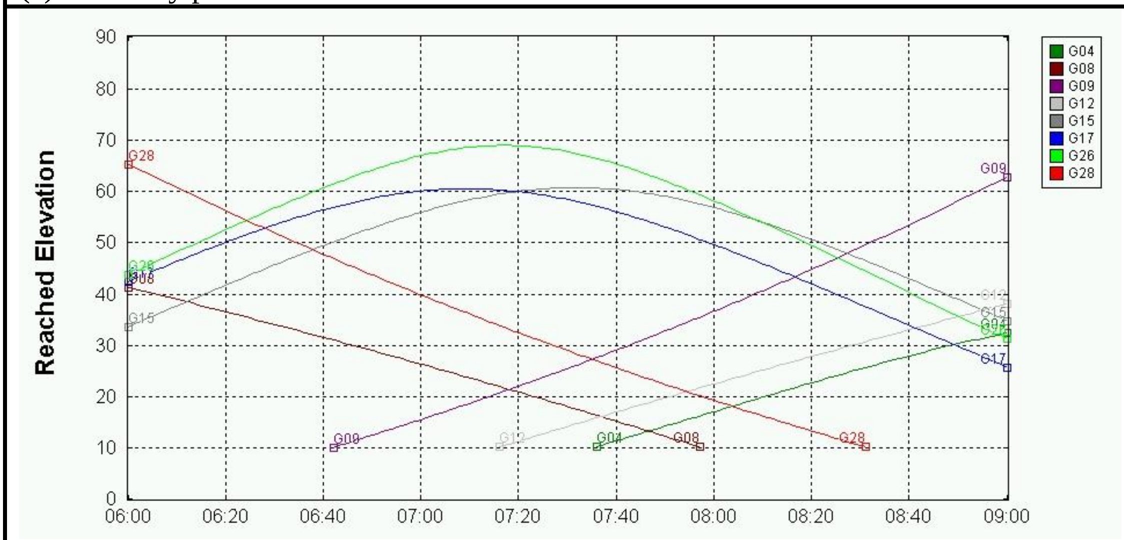
The analysis was carried out on RINEX files using TEQC software. The TEQC output is a file summarizing the pseudorange multipath residual for each satellite in each measured epoch. Three types of pseudorange multipath were calculated: MP_{C1}, MP_{P1} and MP_{P2}, for each of the satellites in view. To produce a common time scale pseudorange multipath day 303 was used as the basis and the other pseudorange multipath from earlier days were shifted by 4 minutes per day. The common time for the pseudorange multipath was 152 minutes.

One can present the total effect of pseudorange multipath by using the quadratic form, $\varphi = \sum (MP_{P1})^2$. Since the pseudorange multipath is a series of residuals, it is possible to quantify the multipath by φ. As φ becomes smaller the effect of the pseudorange multipath on the code observations is reduced, and vice versa, as φ becomes greater the effect of the pseudorange multipath on the code observations is increased. Testing the quadratic form of the same satellite in the same time on different days enables a numerical comparison of the pseudorange multipath effects.

During the experiment 12 satellites were in the sky above an elevation cut-off angle of 10 degrees. Four satellites that were above the horizon less then one hour and reached a maximum elevation of 30 degrees were eliminated from data processing. The sky plot of the 8 satellites that were used for the experiment is shown in Fig. 2a. The satellites elevation angels are displayed in Fig 2b.



(a) - The sky plot



(b) - The satellites elevation angels

Figure 2 - 8 satellites and their constellations that were used for the experiment at point $(N32^{\circ}46', E35^{\circ}03')$ for GPS day 303 between 6:00 and 9:00 UT.

4. RESULTS AND DISCUSSION

Figure 3 presents the pseudorange C/A code multipath on two GPS satellites (PRN26 and PRN28) during three successive days in a common time scale. An Ashtech DM Choke Ring antenna was used and set up at the same point and the antenna phase center was positioned at three different heights. PRN26 is a high elevation satellite, starting with an elevation of 50 degrees and going up to 69 degrees and then down to 31 degrees. On the other hand, PRN28 starts with a high elevation of 58 degrees and goes down to 10 degrees. From Figure 3 it is easy to see that pseudorange multipath residuals grow smaller as the GPS antenna height decreases, especially when satellite elevation is low. Multipath effects are highest at lower elevations and lowest at higher elevation. It happens because the direct signal arrive at lower elevations is entering the antenna at a point where the gain is relatively low, and the reflected signal is entering the antenna where the gain is relatively high. Therefore, the ratio of the amplitude of the reflected signal to the direct signal is high (Schupler et al., 1994). For the most part, high satellite elevation does not have much of an effect on the multipath, even at different antenna height set ups. A choke ring antenna is intended to mitigate multipath reflected from objects below the antenna. However, it seems that the antenna mitigates signals arriving through multipath at high elevation angles more efficiently. Reducing the distance between the antenna and the ground improves the mitigation ability, especially for signals with low elevation angles.

Table 2 shows the quadratic form φ of the multipath residuals on the C/A and P codes in common time scale for the eight satellites. The quadratic form of the multipath residuals on the C/A code for PRN26 and PRN28 provides numerical proof to the same conclusions received from Figure 3. When viewing Table 2 there is a noticeable minor reduction in φ between higher and lower antenna set ups for PRN26 and a dramatic reduction of φ between higher and lower antenna set ups for PRN28. Table 2 shows the clear influence of GPS antenna height on pseudorange multipath residuals without correlation to the antenna type. For all codes, the multipath residuals level grows smaller when the antenna height is lower. Sometimes there is a minor difference between high and medium antenna heights, but a dramatic difference is always achieved when comparing higher vs. lower antenna heights.

Three types of GPS antennas were examined in this experiment. The first was an expensive choke ring antenna (ASH701945C_M) designed to mitigate multipath efficiently. This kind of antenna is a standard in permanent GPS sites. The second type was a geodetic microstrip patch antenna (ASH700578) with a medium size ground plane, typically used for GPS base stations and for geodetic surveying. The third was a geodetic antenna (AERAT2775_42) with a small sized ground plane, typically used for RTK surveying. Table 2 shows, as expected, that the choke ring antenna had the best performance for C/A and P codes. The choke ring antenna mitigated multipath signals reflected from the ground in a better way, relative to the two other antennas, especially for signals arriving at high elevation angles. For high and medium antenna heights the RTK antenna had the poorest performance out of the 3 antennas examined. For the high antenna height the quadratic form φ for the RTK antenna is 3 to 4 times greater then for the choke ring antenna, and about 2 times greater then the geodetic antenna. For the medium antenna height the gap between the antennas performance decreased. But for the low antenna height the RTK antenna performance, surprisingly, was equal to that of the choke ring and geodetic antennas. At low antenna heights there are no big differences in antenna performances.

Since pseudorange multipath behaves very much like that of the carrier phases, we can conclude that carrier phase multipath is affected by the antenna height, similarly to pseudorange multipath. But in their work from 1995 Johnson et al. came to the conclusion that GPS antennas should not be placed near the ground because the multipath phase error is of low frequency and can be mismodeled as a tropospheric delay for low elevation satellites. The phase multipath error correlates strongly with a tropospheric signal since for low elevation satellite the multipath effects are highest and the tropospheric signal is strongest.

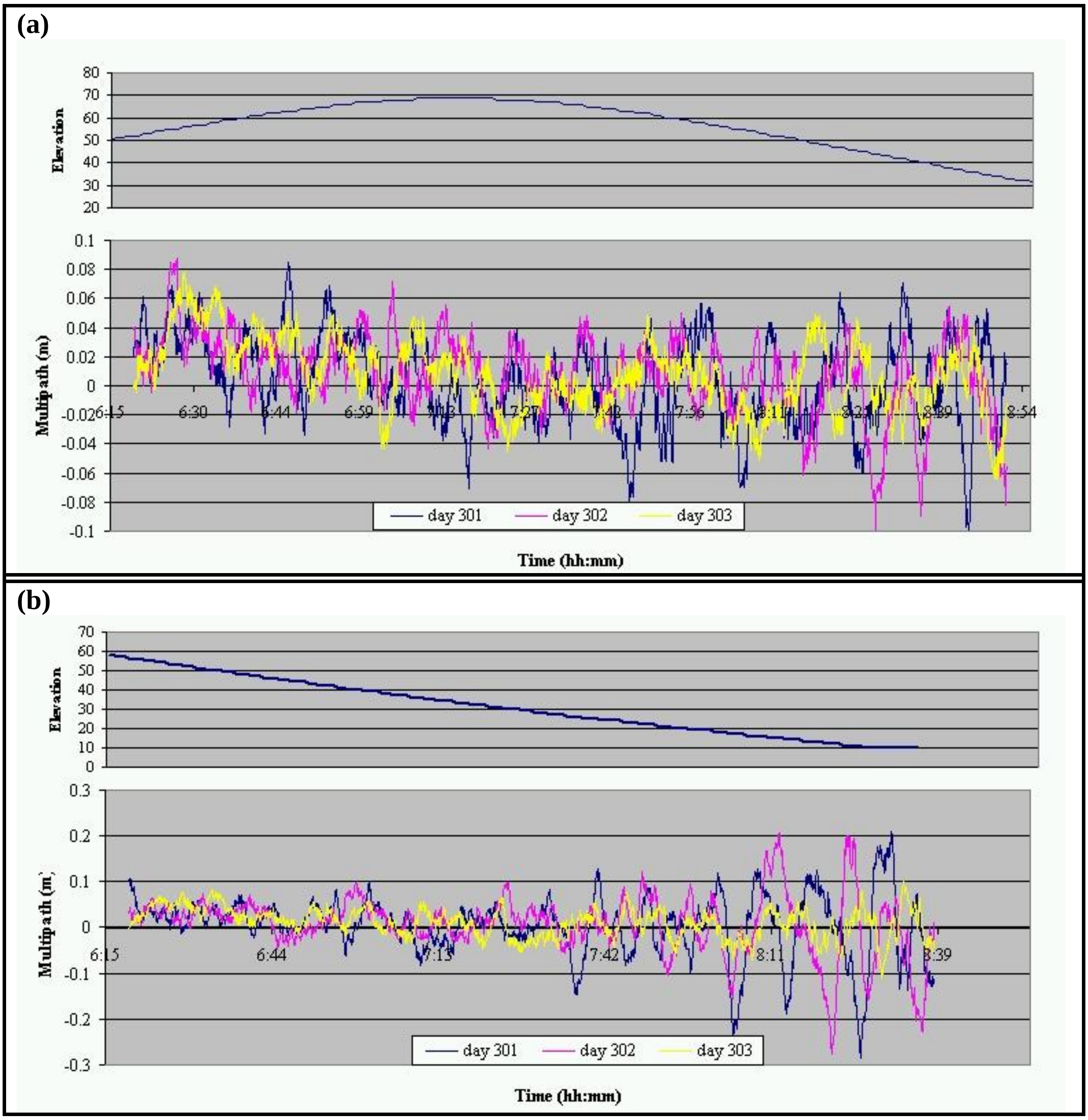


Figure 3 - Pseudorange C/A code multipath on (a) the GPS satellite PRN26 and (b) PRN28, during three successive days (GPS day 301 to day 303 in 2007), in common time scale relative to GPS day 303, at the same point, while the antenna phase center was positioned at three different heights: 1.56m at day 301, 0.97m at day 302 and 0.2m at day 303. The point was located on a flat open field and equipped with an Ashtech Z-Surveyor GPS receiver and an Ashtech Dorne-Margolin (DM) choke ring antenna. The satellite elevation angle is presented on top of each figure.

Table 2- The quadratic form of the multipath residuals on the C/A and P codes for eight GPS satellites in common time scale, in square meter units. The same antennas were set on three

successive days, (GPS day 301 to day 303 in 2007) at the same time over the same point, and the antenna phase center was positioned at three different heights: 1.6m, 0.9m and 0.2m.

PRN		GPS day									common time
		301	302	303	301	302	303	301	302	303	
	height	1.6m	0.9m	0.2m	1.6m	0.9m	0.2m	1.6m	0.9m	0.2m	
	Ant.	Ash. DM Choke ring			Ash. Geodetic L1/L2			Aer. Geodetic L1/L2			[minutes]
4	C/A code	3.64	2.99	1.10	3.74	3.10	0.90	16.36	8.45	1.41	79
8		10.18	2.41	1.77	6.44	6.55	1.72	13.10	5.89	2.13	99
9		8.60	4.14	1.92	8.29	6.67	1.16	14.72	9.39	2.44	123
12		4.05	2.69	1.47	11.10	7.53	1.61	17.26	6.54	1.54	92
15		1.41	1.23	1.36	3.04	3.18	1.88	2.42	2.19	0.88	149
17		1.22	1.58	1.25	2.77	2.25	1.41	4.95	2.52	1.45	152
26		1.70	1.45	1.26	3.40	3.44	1.76	5.32	2.94	1.16	152
28		7.58	7.18	1.94	11.73	11.67	2.30	18.62	9.47	1.83	139
4	P1 code	5.22	5.01	3.44	6.72	3.05	2.62	21.33	7.01	4.22	79
8		11.08	3.91	1.95	6.84	7.08	2.18	19.14	6.85	2.25	94*
9		6.20	4.99	2.21	11.01	8.07	1.17	21.85	12.35	1.11	123
12		5.87	3.58	1.34	12.11	8.01	1.16	19.13	6.26	1.11	92
15		1.67	1.22	1.11	3.15	2.76	1.43	5.95	3.36	0.55	149
17		1.42	1.49	1.08	4.83	4.50	1.43	10.06	5.37	1.04	152
26		1.98	1.36	1.24	3.74	3.39	1.58	6.86	4.34	0.77	152
28		7.51	6.10	2.49	18.70	10.51	2.62	19.21	10.56	2.96	139
4	P2 code	8.35	6.26	5.00	12.67	8.28	4.54	13.46	10.49	6.79	79
8		9.38	4.24	2.21	9.41	5.56	2.33	10.71	3.95	2.13	94*
9		10.95	3.65	2.48	23.70	15.05	1.12	15.13	9.97	1.65	123
12		6.51	3.35	1.40	24.15	16.42	1.93	21.02	5.37	1.50	92
15		1.49	1.24	1.07	3.92	3.42	1.88	5.21	3.04	0.74	149
17		1.68	1.57	1.37	4.16	4.15	1.88	7.62	5.45	1.11	152
26		1.54	1.61	1.16	3.08	3.08	1.58	4.78	2.92	0.82	152
28		7.79	4.79	2.93	20.42	11.57	2.99	19.33	11.22	3.42	139

* Due to error in the P code data, 5 minutes of observation were omitted.

5. SUMMARY AND CONCLUSIONS

A comparison study on the influence of GPS antenna heights on pseudorange multipath is presented above. This comparison includes three types of antenna set ups on a flat open field with no objects in radius of hundreds of meters, and was carried during three successive days. Each day the antennas were set up at different heights of approximately 1.6m on the first day, 0.9m on the second day and approximately 0.2m on the last day. This experiment examined three types of GPS antennas, a high cost choke ring antenna, a geodetic microstrip patch antenna and an antenna typically used for RTK surveying.

The pseudorange multipath pattern is repeated every sidereal day. The repeatability of the pseudorange multipath is at the level of 75%-80% due to changes in uncorrelated noises between days. This enabled checking the different effect of the pseudorange multipath in a variety of GPS antenna types, set up at different heights.

The multipath comparison was carried out for three types of pseudo-range: the C/A code and the P-code modulated on the L1 and L2 carrier phase. The pseudo-range multipath was computed using the TEQC software. The multipath pseudo-range from several satellites with different elevation angles was used in the assessment of the multipath effects.

The satellites elevation angels shown in Figure 2 along with the data from Table 2 highlight the well known relationship between the satellite elevations and the pseudorange multipath effect caused by signals reflected from the ground. Satellites with a low elevation angle are more prone to the effects of the pseudorange multipath. When the satellite elevation is increased the effects of the pseudorange multipath are decreased, both on the C/A and the P codes.

Table 2 shows the clear influence of GPS antenna height on the pseudorange multipath residuals, with no correlation to the antenna type. For all codes, the multipath residuals level grows smaller as the antenna height decreased.

As expected, the choke ring antenna had the best performance in mitigating multipath signals reflected from the ground. For high and medium antenna heights, the RTK antenna had the worse performance among the antennas examined. But for the lower antenna height the RTK antenna performance equaled that of the choke ring and geodetic antennas. At the lower antenna height there were no big differences between the antennas' performance.

Differences in the capability of the antennas to reduce the pseudorange multipath were detected depending on the antenna height above the ground. It is shown that placing the antenna close to the ground assists in the mitigation of pseudorange multipath effects.

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CONTACTS

Gilad Even-Tzur
Mapping and Geo-Information Engineering,
Faculty of Civil and Environmental Engineering
Technion - Israel Institute of Technology
Technion City, Haifa 32000
ISRAEL
Tel. +972-4-8293459
Fax +972-4-8295708
Email: eventzur@technion.ac.il