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Multipath and Multipath Reduction in the Urban Environments (Especially for L1 Signal Processing)

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ABSTRACT. The multipath is a serious of error source in both the static and the kinematic GPS measurements. The positioning accuracy is being degraded due to multipath signal. The multipath detection depends on the difference of carrier to noise (C/NO) between the reference station and the rovers. It is focused on signal strength fading due to reflection and masking by surrounding objects such as trees and buildings. This paper shows the method to detect multipath and the example to improve the positioning accuracy by using the L1 signal processing in the different multipath environments.

Keywords: GPS, urban environment, static and kinematic processing, accuracy.

1. Introduction

Urban areas are known as difficult environments for GPS based positioning: deep streets mask GPS signals or create multipath effects that result in degraded accuracy or lacks of coverage. In the urban environment, most received signals were clear line-of-sight signal and blocked signals. In case of shadowing mostly due to trees, most signals were clear signals and shadowed signals. The fading due to tree was several dB. In this case, the satellites could still be tracked. With the increase of elevation, the percentage of clear signals increased and the percentage of shadowed and blocked signals decreased because there was more open sky when the elevation was higher.

Multipath is one of the major error sources in GPS. The signal travels away from the transmitter in various paths and usually encounters various natural and

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man-made phenomena such as buildings, trees, surfaces of water etc. prior to reaching the receiving antenna. Whenever these phenomena are encountered, the GPS signal is absorbed, attenuated, refracted and reflected. The receiver antenna then becomes the point of convergence for the direct and multipath signals. Depending on the situation, the multipath signal can reach the GPS antenna at the same time or after the direct signal. The direct or true signal is that one that is transmitted from the GPS satellite and received at the GPS receiver without any multipath. GPS is a radio ranging and positioning system, it is imperative that the GPS receiver signal reception from each satellite be direct line of sight. Anything other than the true signal will bias the range measurements and thus induce an error in the calculated position. In effect, multipath signals give a false impression of where you are. The true magnitude of the error varies and is dependent on how much multipath is present (Hoffmann 2000), (Misra 2001), (Rizos 1997).

The term of multipath is derived from the fact that a signal transmitted from a GPS satellite can follow a “multiple” number of propagation ‘paths’ to the receiving antenna. This is possible because the signal can be reflected back to the antenna off surrounding objects, including the earth’s surface. The following important characteristics of multipath are enumerated (Towsend 2000):

i) The multipath signal will always arrive after the direct path signal because it must travel a longer propagation path.

ii) The multipath signal will normally be weaker than the direct path signal since some signal power will be lost from the reflection. It can be stronger if the direct path signal is hindered in some way.

iii) If the delay of the multipath is less than two PRN code chip lengths, the internally generated receiver signal will partially correlate with it. If the delay is greater than 2 chips the correlation power will be negligible.

Measurement and positioning errors occur in part when GPS receivers cannot distinguish direct signals from indirect signals, reflected off objects. These indirect signals are known as multipath, and the ability to reject them is known as multipath mitigation. The delay is measured in C/A code chips (1 millisecond = 1 chip). The C/A code with a chip length of T_C = 293.05 m is available on both carriers. Therefore, for path delays greater than T_C, the multipath error is zero. Receivers referred to as C/A code receivers monitor only the L1 signal, and search for the C/A code pattern by generating a copy of the pattern and attempting to correlate it with the received signals. Since the signal transmitted by the GPS satellites takes some time to travel from the satellite to the receiver, the pattern received from any satellite will be delayed in time from when it was transmitted by an amount related to the distance between the satellite and receiver. The amount of time, it is delayed, is determined in the C/A code receiver by having the internally generated pattern shifted in time until a match is found, and then determining how that time shift relates to the receiver’s internal clock. This time shift is called the pseudorange errors, since it is related to the actual range, but also contains several other elements including a factor due to receiver’s clock not exactly matching GPS time. The ability of a receiver to measure this time precisely is related to the period of pattern it is matching, and usually can be done down to some tenths of a percent, or from one to a few parts in 1000. Since the C/A code has a period of about 1 μsec, the C/A code receiver is generally able to resolve the time to some number of nanoseconds. The maximum phase error due to carrier multipath is directly related to the carrier wavelength. Thus, assuming identical attenuation factors α, carrier multipath on L1 is smaller than on L2 maximum phase errors occur for a multipath signal which is reflected without being attenuated ($\alpha = 1$). In this (worst) case, the phase error due to multipath does not exceed a value of $\lambda/4$ ($\sim$ 4.8 cm for L1 and $\sim$ 6 cm for L2). The power of the L1 ranging signal is twice that of the corresponding L2 signal, the cross correlation of the L1 and the L2 signal leads to an improvement of 3 dB compared to the squaring of the L2 signal. However, compared to the code correlation technique, an SNR degradation of 27 dB occurs (Irsigler 2003), (Hoffmann 2000), (Misra 2001), (Rizos 1997).

2. Description of the GPS Experiment

The experiment was performed in Ortakoy Region of Istanbul, Turkey (Figure 1). A local geodetic network consisting of 4 stations (P1, P2, P3 and P4) was surveyed using GPS and terrestrial measurement methods, see Figure 2. To study the GPS multipath effects on a static baseline, the two stations (P1 and P4) were situated under the tree environments and one station (P3) was situated at distance $\sim$ 1 m near a building in the urban area, see Figures 3 and 4.

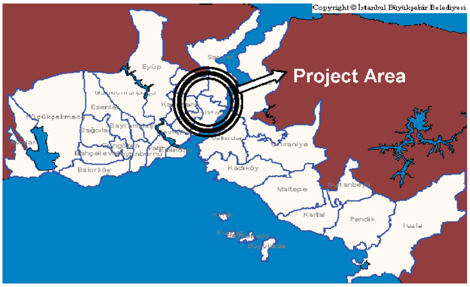


Fig. 1. *Project area.*

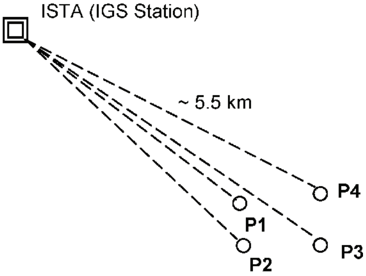


Fig. 2. *GPS network.*

The GPS data was collected on P1, P2, P3 and P4 using the same GPS receivers (two Ashtech Z Max receivers on 23 October 2005). The minimum elevation cut-off angle was 10 degrees; the data was collected for $\sim 2^h$ with a sampling rate interval of 10 s for the line P1-P2 (10:15-11:40 hours) and P3-P4 (08:10-10:00 hours). The purpose of the experiment was the identification of signal multipath at GPS sites close to building and tree environments.

3. Data Processing and Analysis

3.1. Static Processing

Static data collection is stationary in nature. The GPS systems simultaneously collect raw data from all available satellites while remaining stationary on their respective points. Data collection continues at these locations for an amount of time dependent upon several factors including the distance between the receivers, the satellite geometry, and obstruction conditions at the data collection locations (for example, trees or building blocking some of the sky). Some objects such as buildings can completely block the satellite signals. Other objects such as trees can partially obstruct or reflect/refract the signal. In some cases, enough signals can be observed to compute a rough position, but in virtually every case, the signal is not clean enough to produce centimetre level positions. This is not to say that GPS surveying systems can only be used in areas with wide-open view of the sky. The trick is to be able to observe, at any given time, enough satellites to accurately and reliably compute a position. At any given time and location, 6-10 satellites may be above the horizon and available for use, although GPS system does not require this many satellites to function. Accurate and reliable positions can be determined with five satellites properly distributed throughout the sky. Therefore, an obstructed location is surveyed if at least five satellites can be observed. Static data collection produces the most accurate and reliable results due to the amount of data collected during each observation. The disadvantage is in productivity. Long observations at each point reduce the number of points that can be collected in a day (Hoffmann 2000), (Misra 2001), (Rizos 1997).

Firstly, the approximate two hours of GPS data for P1, P2, P3 and P4 was processed using the Ashtech Solution 2.60 Processing Software. In the adjustment procedure, the ITRF 2000 coordinates of ISTA (IGS Station, $\varphi_{\mathrm{ITRF}} = 41° \; 06' \; 16''.011252$, $\lambda_{\mathrm{ITRF}} = 29° \; 01' \; 09''.625728$, $H_{\mathrm{ITRF}} = 147.240$ m) were taken fixed. The distance from ISTA to the points in the project area is approximately 5.5 kilometres, see Figure 2. In engineering geodesy, the distances between the GPS sites are usually short, e.g., below 10-20 km. Most of the linear combinations are (only) useful with longer distances, and many precise applications can be realized using L1 only, or L1 and L2 phase observations without linear computing combinations other than DD. This is because the software can compare the effects of the ionosphere on the L1 to the effects on the L2 signal and for all intents, compute an ionospheric free solution. For single frequency receivers, the GPS satellites transmit a prediction model for the ionosphere that could compensate for 50% of the ionospheric error but in times of high ionospheric activity, this may not suffice. After processing the GPS network, the results of the coordinates of the four points and the baselines P1-P2 and P3-P4 in 23 October 2005 measurements were examined. In addition, a terrestrial survey was carried out to obtain an independent result of the position for assessing the accuracy of the GPS results. In Table 1 shows the coordinates and standard deviation values for the points of P1, P2, P3 and P4 for L1 static processing. In Table 2 shows the coordinates and standard deviation values for the points of P1, P2, P3 and P4 for L1 & L2 static processing. In Tables 1 and 2, the coordinates and standard deviations of P2 and P3 points are different from each other. The coordinates and standard deviation values of the two points (P1 and P4) are equal to in both L1 (Table 1) and L1&L2 (Table 2) processing. The causes of the situations are explained the following sections.

Table 1. *The results of the L1 static processing the GPS network.*

Point	φ_{ITRF}	**Std(m)**	λ_{ITRF}	**Std (m)**	**h_{ITRF} (m)**	**Std (m)**
P1	41° 03′ 22″.06395	0.004	29° 01′ 22″.57845	0.005	54.055	0.022
P2	41° 03′ 20″.24139	0.014	29° 01′ 22″.59060	0.018	52.821	0.019
P3	41° 03′ 19″.14309	0.018	29° 01′ 25″.98806	0.016	63.013	0.018
P4	41° 03′ 21″.14296	0.005	29° 01′ 26″.64061	0.005	67.118	0.010

Table 2. *The results of the L1 & L2 static processing the GPS network.*

Point	φ_{ITRF}	**Std(m)**	λ_{ITRF}	**Std(m)**	**h_{ITRF} (m)**	**Std(m)**
P1	41° 03′ 22″.06401	0.004	29° 01′ 22″.57836	0.005	54.044	0.011
P2	41° 03′ 20″.24205	0.004	29° 01′ 22″.59102	0.005	52.818	0.010
P3	41° 03′ 19″.14150	0.006	29° 01′ 25″.98183	0.006	63.113	0.010
P4	41° 03′ 21″.14301	0.005	29° 01′ 26″.64064	0.005	67.110	0.009

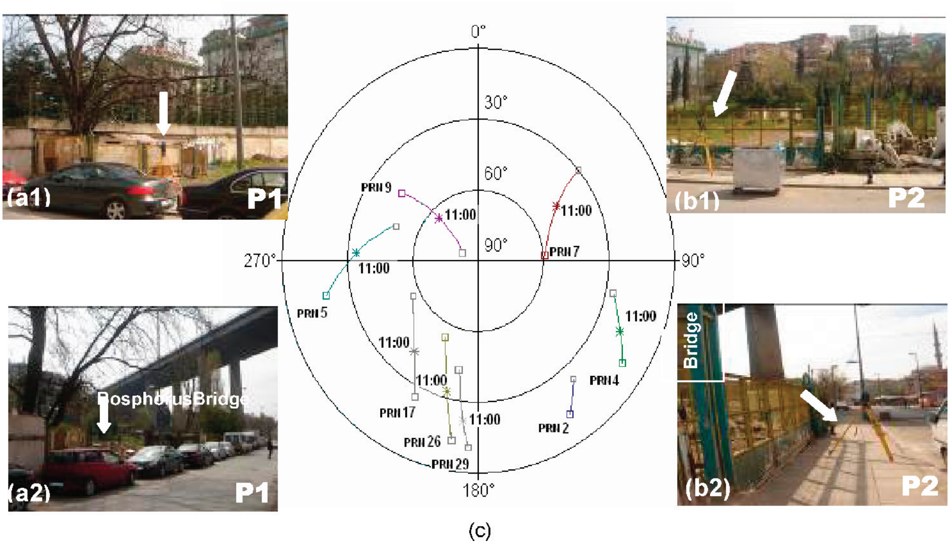


Fig. 3. *Point 1(P1) under a tree (a1 and a2) and Point 2 (P2) near a bridge (b1 and b2), sky plot at P1 and P2 (c), 10:15-11:40 hours, strong obstruction by the tree and bridge.*

The receiver antenna of P1 was situated under a tree in the urban area; see Figures 3(a1) and 3(a2). The antenna of P2 was situated near a bridge and some buildings, see Figures 3(b1) and 3(b2). The problem shown by the sky plot of 10:15 –11:40 hours is typical for the whole day: several satellites were shaded by the tree, bridge and buildings, but were still tracked by the receivers. As can be seen from the sky plot P2 (Figure 3(c)) the receiver tracked satellites PRN 7 and PRN 9 continuously, at a high elevation in the obstructed area of the sky. PRN 2, PRN 4, PRN 5, PRN 17, PRN 26 and PRN 29 satellites were shaded in the obstructed areas. Strong signal distortion may therefore be expected because these six satellites have a medium to low elevations at this period for P1 and P2. Their maximum elevations are about 50 degree; see Figure 3(c). The signal scatter is partially due to the low elevation. This effect occurs due to multipath caused by bridge, building and tree environments.

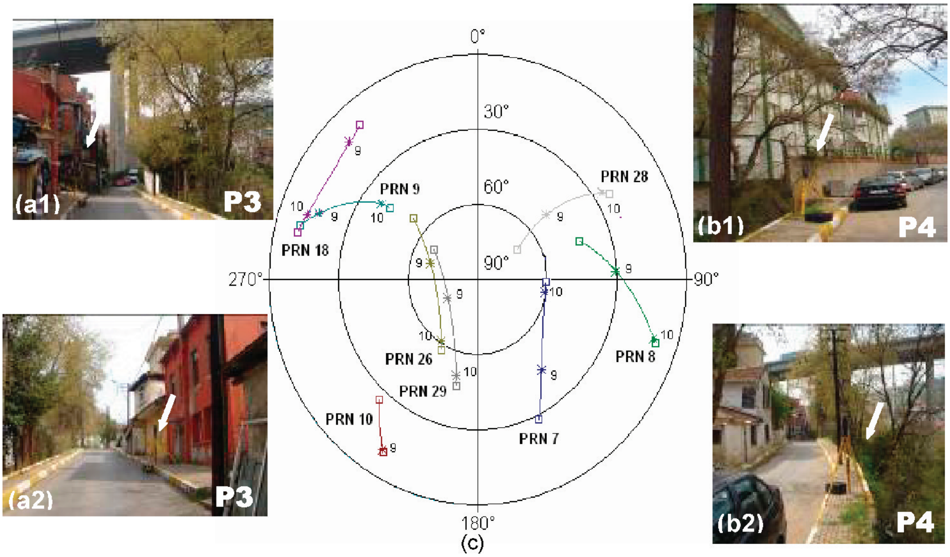


Fig. 4. *Point 3 (P3) under a tree, close to buildings (a1 and a2) and Point 4 (P4) very close to the buildings (b1 and b2), sky plot at P3 and P4 (c), 8:10-10:00 hours, strong obstruction by the trees and buildings.*

As stated above, P3 and P4 stations are close to trees and buildings in the urban environment, which totally obstructs the direct signal from some satellites. The receiver therefore tracks the satellite even while it is not directly visible, and only indirect signals arrive at the antenna during this period. Diffraction is indicated by a drop of the C/NO values below their expectation, and by an increase of the signal path length. The diffraction effect is indicated by the changes in the C/NO values see Figure 5. The value of the C/NO is actually related to the signal quality of certain observations. The C/NO values obtained at P3 and P4 indicate signal distortion, see Figures 5(a) and 5(b). The diffraction effect caused by the trees and buildings reduces the C/NO values of some satellites. The C/NO information provides a possibility to detect these errors, since biased phase observations will

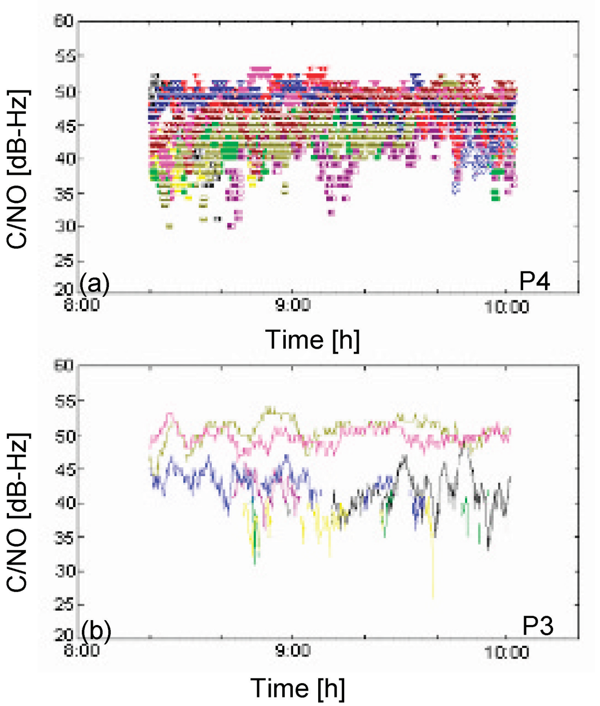


Fig. 5. *L1 and L2 C/NO values measured simultaneously at two GPS sites (P3 and P4), equal antenna/receiver combination.*

yield much lower C/NO values compared to unaffected satellite signals at the same elevation. The path delay and the DDR may increase to a theoretically unbound value on such an occasion, depending only on the additional path length of the indirect signals. Practically, with large the C/NO drops below the acquisition threshold, once the direct line-of-sight to the obstructed satellites are far from the edges of the object. The satellites can not be tracked any longer then. C/NO value is a key parameter in analyzing GPS receiver performance and directly affects the precision of the receiver's pseudo range and carrier phase observations occurs (Irsigler 2003), (Hoffmann 2000), (Misra 2001), (Rizos 1997).

P3 antenna was situated close to the building and tree environments and P4 antenna was situated under a tree environment. As obstacles, the buildings and trees mainly caused shading of satellites, see Figure 4(c), multipath and diffraction. Satellite PRN 26, PRN 28 and PRN 29 for P3 and P4 are initially tracked at a high elevation in the unobstructed area of the sky; see Figure 4(c). From the sky plot, we see that the receiver tracked satellites. Furthermore, the receiver looses lock to the satellite signals several times because the signal strength drops below the acquisition threshold, see Figure 5. So the satellite is tracked for several very short periods, and simultaneously subject to signal distortion. We may expect ambiguity fixing problems for these satellites. Subsequent investigations refer to the L1 and L1&L2 processing of the baselines P1-P2 and P3-P4.

Table 3. *The loop closure for L1 static processing of the GPS network.*

	Vectors in Loop	**Loop Length (m)**	**X Misclosure (m)**	**Y Misclosure (m)**	**Z Misclosure (m)**	**Length Misclosure (m)**
Loop 1	ISTA-0004	10943.671	0.008	-0.034	0.019	0.040
	ISTA-0003					
	0003-0004					
Loop 2	ISTA-0001	10863.373	-0.021	-0.024	0.074	0.081
	ISTA-0002					
	0001-0002					

Table 4. *The loop closure for L1& L2 static processing of the GPS network.*

	Vectors in Loop	**Loop Length (m)**	**X Misclosure (m)**	**Y Misclosure (m)**	**Z Misclosure (m)**	**Length Misclosure (m)**
Loop 1	İSTA-0004	10943.991	0.008	-0.223	-0.343	0.409
	İSTA-0003					
	0003-0004					
Loop 2	İSTA-0001	10863.436	0.060	0.313	-0.060	0.325
	İSTA-0002					
	0001-0002					

On the other hand, the loop closures for L1 and L1 & L2 static processing are compared with each other. The value of the loop closure for L1 processing is 4 cm and 8.1 cm in Table 3. However, the value of the loop closure for L1& L2 processing is ~ 41 cm and 32.5 cm. These results show that the accurate coordinates are obtained by using L1 processing technique in this experiment.

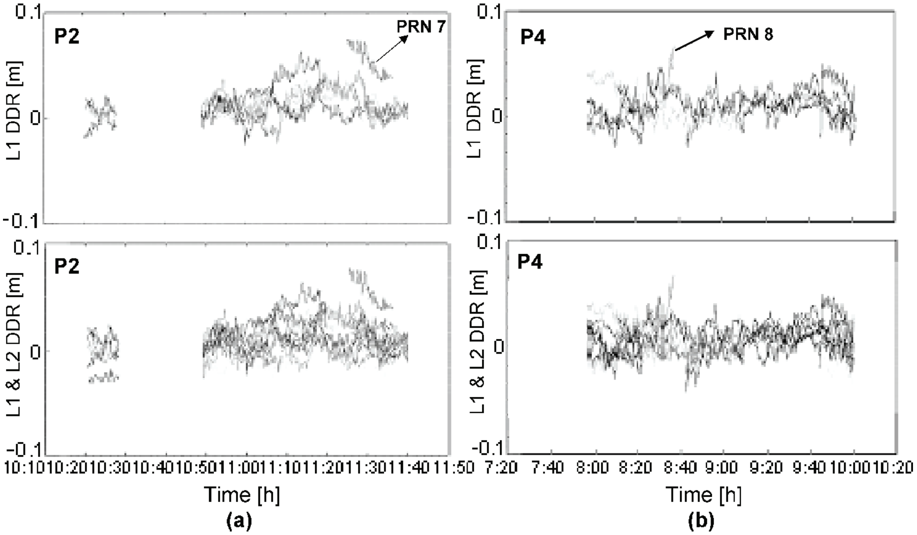
To compare the results of GPS measurements with those of independent measurement method, the distances were measured between the points using a total station. The terrestrial measurements were performed using a Leica TC 605 (angle accuracy: ± 5”, distance measurement accuracy: 3 mm + 3ppm) and a Topcon DL 102 digital level. A barcode rod was used for the height differences. Distance and height measurements were taken (3 series) and the mean values of all measurements were calculated. The quality of the GPS results can be assessed by comparison with the spatial distances determined by the terrestrial measurements. The GPS distances were calculated from the coordinates obtained from the GPS measurements and compared with the distances obtained using the total station, see Table 5. The height differences obtained by using the digital level were also compared to ellipsoidal height differences obtained from the GPS, see Table 5.

Herein, the variation of the geoid was neglected since the distances are very short. It appears from this comparison of the results in GPS with terrestrial measurements at the Ortakoy Region that the variations are greater in height differences and smaller in distances.

Table 5. *The results of the terrestrial and GPS measurements.*

	S [Distance – m]			**Δh [Height Difference – m]**		
Line	L1	L1 & L2	Total station	L1	L1 & L2	Topcon DL –102 Digital Levelling
P1-P2	56.238	56.220	56.255	1.234	1.226	1.270
P3-P4	63.680	63.756	63.693	4.105	3.997	4.132

The signature of the obstructing bridge, buildings and trees for P2 and P4 is shown by the DDR time's series of all satellites, see Figures 6(a) and 6(b). Satellite PRN 7 is initially tracked at a high elevation in the unobstructed area of the sky for P2; see Figure 3(c). Figure 6(a) shows the DDR L1 and DDR L1&L2 of all satellites, for P2. Satellite PRN 7, which is not obstructed by the building and bridge at between 10:50-11:05 hours; see Figure 3(c), serves as an example of the highest signal quality attainable at P2 site. When the satellite starts disappearing behind the bridge and buildings between 11:05-11:40 hours, its DDR indicate increasing bias. Once the satellite is deeply behind the bridge and buildings, its DDR show strong fluctuations. These are irregular signal distortion affected by the bridge and buildings. The maximum bias is of the order of ~ 8 cm; see Figure 6(a). Between 10:28 and 10:48 hours for P2, there are no satellites visible by the receiver, see Figure 6(a).



(a) (b)

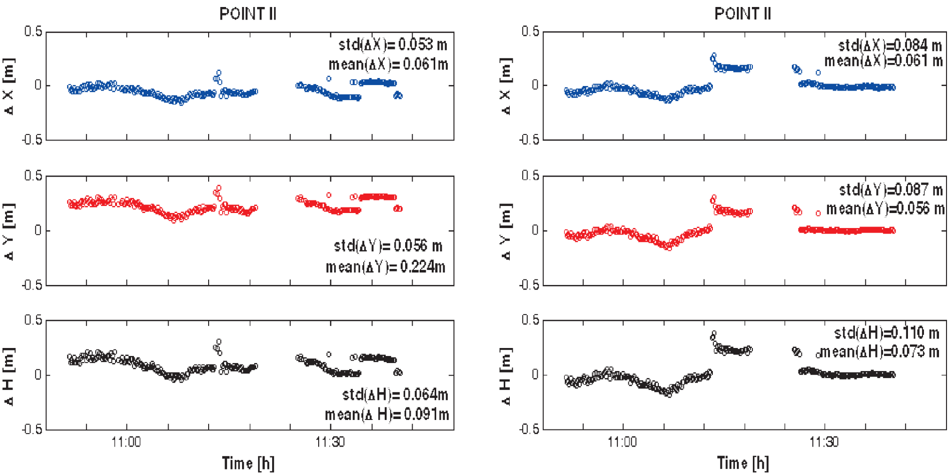
Fig. 6. *L1 DDR and L1&L2 DDR of all satellites for P2 and P4.*

The signature of the obstructing trees for P4 is shown by the DDR times of satellites in Figure 6(b). PRN 8 is initially tracked at a medium elevation (~ 45 degree) in the unobstructed area of the sky for P4; see Figure 4(c). When the satellite starts disappearing behind the tree at about 08:30 hour, its DDR indicates increasing bias; see Figure 6(b). These are due to irregular signal diffraction effects by foliage and branches of the trees. The maximum bias is of the order of ~ 7 cm.

In this experiment the same receiver and antenna hardware is used in the obstructed environments, this shows the impact of the nearby trees and buildings on the overall tracking capability of the receiver. The multipath error largely cancels if the session result is calculated using data from a sufficiently long session, e.g., more than 30-60 minutes. For short sessions, multipath may completely corrupt kinematic session results, where the estimated position may be based on the observations of a single epoch, in the extreme case.

3.2. Kinematic Processing

Although kinematic data collection has the advantage of high productivity, it has some disadvantages. Accuracy is not as well as with static data collection. In addition, the rover system must maintain lock on GPS satellites as it moves around the project area. Loss of satellites requires from the user to re-initialize the receiver. Generally, the results of these sessions are much worse than those of sessions with all ambiguities fixed. Generally, float solutions should never be accepted for short sessions, if there is no evidence that they are accurate. The impact of the bad signal quality on the positioning results is naturally worse for kinematic positioning than for static processing occurs (Irsigler 2003), (Hoffmann 2000), (Misra 2001), (Rizos 1997).

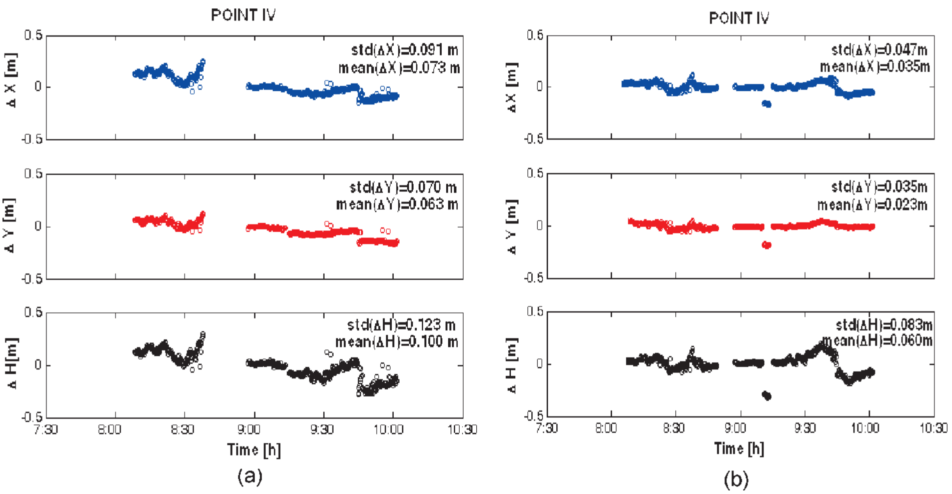


(a) (b)

Fig. 7. *Epoch-by-epoch coordinate results of P2 by using kinematic module (L1 processing (a) and L1&L2 processing (b)), deviation from static results.*

In this experiment, kinematic processing of the baselines of P1-P2 and P3-P4 is almost impossible. The ambiguity solution for P1 and P3 is not determined as an integer value in the entire measurement periods. The ambiguity is said to be not resolved or fixed for the baselines P1-P2 and P3-P4. In general, ambiguity fixing strengthens the baseline solution. The time is a critical component of ambiguity resolution. Since multipath is station dependent, it may be significant for even short baselines. As in the case of atmospheric and orbital errors for baselines, multipath has the effect of both contaminating the station coordinates and ambiguities.

That the buildings and trees obstruct the signal (P1 and P3) results in lack of enough satellites for a position fix and too high dilution of precision. This is shown in Figures 3(c) and 4(c), using the sessions, which are the representative of the whole day. Figure 7 and Figure 8 show the results of epoch-by-epoch kinematic processing of ~ 2 hours session for the baselines P1-P2 and P3-P4 by using Ashtech Solution 2.60. The signal scattering due to the buildings, trees and bridge causes strongly fluctuating epoch results, with ranges of more than 30 cm for the height and for the north and east components, see Figures 7 and 8. Between 10:15-10:50 hours and 11:20-11:24 hours, the satellite windows were not well at P2, where the number of satellites observed ranged between 3-4 satellites, and the recorded PDOP values between 19 and 20. At this period, it is expected that the ambiguity was not solved for some visible satellites at P2, see Figures 7(a) and 7(b).



(a) (b)

Fig. 8. *Epoch-by-epoch coordinate results of P4 by using kinematic module (L1 processing (a) and L1&L2 processing (b)), deviation from static results.*

Between 08:45-09:00 hours, the satellite windows were not well at P4, where the number of satellites observed ranged between 4-5 satellites, and the recorded PDOP values between 7 and 9. At this period, it is expected that the ambiguity was not solved for some visible satellites at P4, see Figures 8(a) and 8(b). The standard deviations and mean values of the coordinate differences for P2 and P4, using L1, L1&L2 kinematic processing technique is shown in Figures 7(a) and 7(b), in Figures 8(a) and 8(b) respectively. All of the values for P2 and P4 are very high and not acceptable in engineering geodesy. As a result, the kinematic method is best suited for wide open areas where there are few obstructions.

4. Conclusion

GPS based engineering applications are usually characterized by short baselines, high accuracy requirements and short site occupation times. Furthermore, the sites cannot be selected only according to perfect suitability for GPS positioning, but are determined by the task requirements. This means that often significant obstacles close to a GPS antenna cannot be avoided. The accuracy obtainable in engineering applications of GPS is many limited by the signal multipath effects. Multipath is a serious source of error in both the static and kinematic GPS positioning measurements. The positioning accuracy will be decreased due to multipath signal. The results presented in this study indicate that the extent of tree, building and bridge environment will have a significant effect on the accuracy, precision and the performance of GPS positions. It was shown that the accuracy in kinematic GPS surveys is significantly affected if the satellite signals are distorted by the trees and buildings. However, if mm level accuracies are required using short site occupation times; multipath propagation is perhaps the major concern. We have made the experience, that bad multipath environment exist, but that perfectly multipath free ones can hardly be found. In this experiment L1 signal processing strategies was obtained very accurate results comparing with L1 and L2 processing strategies.

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Multipath i redukcija multipatha u urbanom okolišu (posebno za obradu L1 signala)

SAŽETAK. Multipath je ozbiljan izvor pogrešaka u statičkim, kao i u kinematičkim GPS-mjerenjima. Položajna točnost je smanjenja zbog multipath signala. Otkrivanje multipatha ovisi o razlici nosač/šum (C/NO) između referentne stanice i rovera. U radu je objašnjenje fokusirano na slabljene jačine signala zbog odbijanja i prekrivanja okolnim objektima, kao što su drveće i zgrade. Ovaj rad prikazuje metodu otkrivanja multipatha i primjer kako se može poboljšati položajna točnost koristeći obradu L1 signala, i to u različitom multipath okolišu.

Ključne riječi: GPS, urbani okoliš, statička i kinematička obrada, točnost.

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