ISSN 1330-3651 (Print), ISSN 1848-6339 (Online)
UDC/UDK [528.088.3:621.391.812.7]:629.783.058.6

SIGNAL MULTIPATH IN HIGH PRECISION GPS SURVEYS

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Original scientific paper
The aim of this paper is to show that GPS signal multipath can significantly influence the accuracy of the results of a GPS survey. For this purpose, Ashtech Z Max GPS receiver, which is the next generation survey solution from Magellan, is used in the obstructed area and investigates the achievable accuracy and repeatability under the same satellite configuration and site condition near a bridge environment. Z tracking and Advanced Multipath Mitigation Technologies (Enhanced Strobe Correlator (ESC)) and Ashtech Max-Trac GPS Antenna) of the Ashtech Z Max ensure the strongest centimetre level position even under weak signal conditions. All of the measurements were performed near a bridge in the two consecutive days. In the analysis, the coordinates of the point, which is located near a bridge, obtained from the same solutions of the ambiguities in the two consecutive days were compared with each other. On the other hand, the results of Ashtech Z Max GPS receiver testing were compared against results from Total Station surveying as a further quality check. The results show that Ashtech Z Max Technology is more stable for the horizontal and vertical coordinates. Positioning accuracy on the centimetre level (1 ÷ 2 cm) can be routinely achieved when observing sufficient number of satellites in the multipath environment.

Keywords: *GPS (Global Positioning System), multipath, RTK (Real-Time Kinematic)*

Višestazni signal kod vrlo točnog GPS mjerenja

Izvorni znanstveni članak
Cilj je ovoga rada pokazati da višestazni GPS signal može značajno utjecati na točnost rezultata GPS mjerenja. GPS prijemnik Ashtech Z Max, najnovije rješenje za mjerenje iz Magellana, rabljeno je u tu svrhu u ometanom području kako bi se ispitalo kolika je točnost i ponavljanje rezultata kod iste konfiguracije satelita i pod istim uvjetima u okolišu premosnika. Z satelitsko praćenje i Advanced Multipath Mitigation Technologies (Enhanced Strobe Correlator (ESC)) i Ashtech Max-Trac GPS Antenna) prijemnika Ashtech Z Max daju najveću točnost u centimetarskoj rezoluciji čak i u uvjetima slabog signala. Sva su mjerenja izvršena u okolišu mosta tijekom dva uzastopna dana. Analizom su uspoređene koordinate točke, locirane u blizini mosta, dobivene istim rješenjima višeznačnosti tijekom dva uzastopna dana. S druge strane, rezultati testiranja GPS prijemnika Ashtech Z Max usporedili su se s rezultatima mjerenja s Total Station kao dodatna provjera kvalitete. Rezultati pokazuju da je Ashtech Z Max tehnologija sigurnija za horizontalne i vertikalne koordinate. Točnost pozicioniranja u centimetarskoj rezoluciji (1 ÷ 2 cm) može se rutinski postići kad se prati dovoljan broj satelita u uvjetima višestaznog prostora.

Ključne riječi: *GPS (sustav za globalno pozicioniranje), RTK (kinematika u realnom vremenu), višestazni*

1 Introduction

The objective of this paper is to investigate and evaluate the performance of the latest advances in Ashtech Z Max technology in the multipath environment. GPS stations very often have to be placed on slopes and/or near trees, buildings, metal surfaces. In addition to the expected signal distortion effects are caused by these effects. The main signal distortion scenarios considered here are multipath and diffraction defined as follows; multipath signals arrive at the antenna by means of reflection. The multipath is the phenomenon of the GPS signal reflection and/or diffraction from some objects and reaches the receiver antenna indirectly. It may cause signal interference between the direct and reflected or diffracted signal and cause error in the user position calculation. Multipath signals will be always received to the antenna after line-of-sight signals because of the longer travel paths caused by reflection and diffraction. Multipath can introduce both negative and positive error on the pseudorange measurement depending on the phase of the multipath signal with respect to the direct path signal. The direct and multipath signals will superimpose to produce the composite received signal and in turn affect the correlation property of the C/A code. The multipath signal will normally be weaker than the direct path signal since some signal power will be lost from the reflection and diffraction. Therefore, there is big difference in the value of the C/NO between the reference at the multipath-free environment and the rover at multipath environment. Note that anything which acts as a signal attenuator – e.g., antenna, cables, atmosphere, obstacles – usually weakens the signal and the noise entering, and adds the thermal noise to the signal and noise leaving. It therefore reduces the C/N, and consequently the C/NO. Usually, an attenuator also causes a path delay. Under the same environment, the presence of multipath errors can be verified using a day-to-day correlation (or similarity) of the estimated residuals. GPS satellites have an orbital period of about 23 hours 56 minutes. Therefore, nearly the same multipath effects repeat every sidereal day on the same satellite phase observations. Multipath error is indicated by a rise and fall (or scalloping) of the lower frequency curve, inconsistent with the remainder of the curve. Analyses of multipath can also be performed by examining the associated C/NO ratio as a function of elevation angle for each satellite and time. A noticeable scalloping effect coinciding with a sharp drop in C/NO is an indication of multipath. Furthermore, multipath errors in the undifferenced pseudorange measurements can be identified if dual frequency observations are available. A good general multipath model is still not available, mainly because of the variant satellite-reflector-antenna geometry. There are, however, several other options to reduce the effect of multipath. The straightforward option is to select an observation site with no reflecting objects in the vicinity of the receiver antenna. Another option to reduce the effect of multipath is to use a receiver that takes advantage of multipath mitigation techniques. Multipath affects both the carrier phase and pseudorange measurements; however, its size is much larger in the pseudorange measurements. With the new advances in signal processing and receiver technology, actual pseudorange multipath is reduced dramatically. Examples of such technologies include narrow correlator, strobe correlator techniques. The first major breakthrough in pseudorange multipath mitigation came with the introduction of the so called "Narrow Correlator" design. The primary difference in this correlator compared to its predecessors is that it employs narrow spacing between the "early" and "late" arms, compared to the standard wide spacing correlator. The latter employs "early" and "late" arms with a spacing of 1 C/A code chip or nearly 1 microsecond whereas a narrow spacing correlator has arms with a typical spacing of only 0,1 C/A code chip or nearly 100 nano seconds. The reduction in correlator spacing not only makes the pseudorange measurements 10 times more accurate but multipath error due to long delay replicas. To take advantage of this narrow spacing, the intermediate frequency (IF) bandwidth is also increased from about 2 MHz in standard correlator to more than 10 MHz in a Narrow Correlator. The narrow spacing correlator significantly reduces the long delay multipath but provides no relief to the short delay multipath. Further, the long delay multipath is not completely eliminated. Another type of correlator that makes use of the additional two arms is the "Strobe Correlator", which employs a double delta discriminator. In this correlator, there are two pairs of "early" and "late" correlator arms, with each pair spaced at typically 0,1 and 0,2 of a C/A code chip. Typically in a receiver the early-minus-late correlation value is used as an input for the code tracking loop. In the Strobe Correlator, however, the differences of the early-minus-late correlation values between the two pairs of correlators are used in the code tracking loop. The strobe correlator achieves discriminator function shaping by combining two different narrow correlator discriminators. A further improvement in the Strobe Correlator technology is achieved in the Advanced Strobe Correlator such as Enhanced Strobe Correlator [2, 4, 6, 8, 10].

2 Methodology

Receiver manufacturers have invented various multipath mitigation schemes with varying degree of success. In general, more research work has been done to mitigate pseudorange multipath errors than those associated with the GPS carrier phase. The Ashtech Z Max receiver implements the latest advances in Ashtech Multipath rejection Technology: the Enhanced Strobe Correlator (ESC). The method implements a C/A code and C/A carrier phase multipath error rejection especially for performing in RTK GPS technique. This correlator schemes are such as standard (1-chip) correlator spacing or narrow (1/10 chip) correlator spacing. The ESC works well in any kind of multipath environment specular as well as diffuse, regardless of the number of multipath signals present, its ability to track is not significantly impacted in low signal-to-noise ratio (SNR) environment. The ESC is a digital signal processing technique implemented in the hardware and software of the Ashtech Z Max receiver that removes multipath errors almost entirely for reflected signals. The multipath sensitivity range for the code and carrier phase is approximately 24 metres, with a maximum tracking error approximately 3,5 metres. It is clear that ESC performance is much better, almost totally cancelling any multipath with a delay of more than 24 m. This means improved accuracy and greater reliability in RTK GPS applications. The specifications in Ashtech Z Max GPS receivers are Z Tracking (to mitigate the effects of Anti-Spoofing and provide dual frequency performance, the unit provides up to a 13 dB signal-to-noise ratio advantage over competing technologies, such as cross correlation, and also allows users the ability to track weaker satellite signals. The result is reliable, cm-level positions you can count on for all of your high productivity GPS applications) and advanced multipath mitigation technologies ensure the strongest centimetre-level position in weak signal conditions. The accuracy specifications in static mode are 0,005 m + 0,5 ppm and 0,010 m + 0,5 ppm horizontal and vertical, respectively. In addition, the Ashtech Max-Trac GPS Antenna (highly sensitive, multipath resistant antenna for strong signal tracking and quality data) module contains the GPS antenna which allows the Ashtech Z Max receiver to track signals from the GPS satellites. This geodetic quality antenna tracks accurately and consistently satellites above the horizon and provides good multipath rejection for signals reflection from intermediate surfaces such as the ground. Ashtech Z Max performance values assume minimum of five satellites, following the procedures recommended in the product manual. High multipath areas, high PDOP values and periods of severe atmospheric conditions may be degrading performance [8, 9]. In the analysis of these two following tests in the experiment the Ashtech Z Max GPS measurement results were compared with the measurement results obtained from Total Station.

3 Data capture GPS observations and site condition

The experiment was carried out to investigate the accuracy and repeatability assessment of the Ashtech Z Max GPS receivers in the severe multipath environment, see Figs. 1 and 2. For this purpose, two tests were performed and two points (P1 and P2) were located in the project area (Samandıra region of Istanbul, see Fig. 1). The reference point (P1) was mounted by no obstructions in the vicinity and set up at a distance of about 65 m from the bridge, see Figs. 1 and 2a. However, the rover point (P2) was mounted close to a concrete bridge, which could cause multipath effects. The bridge caused severe obstruction of almost 50 % of the sky, see Figs. 1b and 2b. The static GPS survey for determining the coordinates of the two points was conducted in the project area on two days (23 ÷ 24 July 2005). In the first and second tests two Ashtech Z Max receivers and Ashtech Max-Trac GPS Antennas were used at both the reference and rover station on two days. The length of the observation session was approximately 7 hours (UTC Time: 7:00-14:00 hour), at a sampling rate 10 s and elevation cut-off angle was 10°. In addition, a terrestrial survey was performed to obtain an independent result of position for assessing the accuracy of the GPS results in the multipath environment.

The ITRF 2000 coordinates of the reference point (P1) were determined using data from the nearby IGS permanent station ISTA (IGS Station, φ_{ITRF} = 41° 06' 05",337, λ_{ITRF} = 29° 01' 09",626, h_{ITRF} = 147,237 m), and the observations were collected on Day 1 (23 July 2005) and Day 2 (24 July 2005) of the two tests. These coordinates of P1 were then introduced as known during a dual frequency; it is only one baseline processing for the two days. The solution was computed using Bernese Software; the output is given in Tabs. 1 and 2. The other processing was performed by using Ashtech Solution 2,60 GPS Software (static and epoch-by-epoch processing not really kinematic). Reference point (P1) was held fixed in the processing of the rover point (P2) by using Ashtech Solution 2,60 GPS Software. Due to short distances (~65 metres) the low height differences (~6,55 metres) between the reference and rover site, atmospheric propagation effects are largely reduced by double differencing. Furthermore, the double difference residuals (DDR) were almost free of antenna effects, since the same antenna type was used on the two sites, and all antennas had the same orientation.

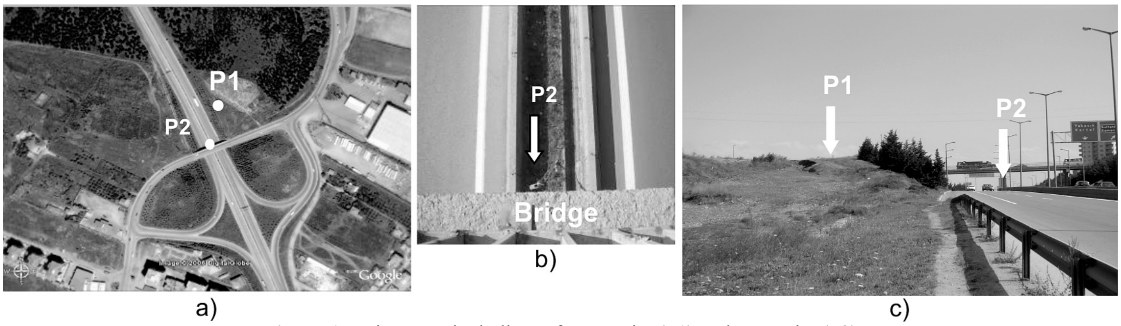

Figure 1 Project area including reference site (P1) and rover site (P2)

Table 1 The coordinates of the two points (P1 and P2) in the project area (23 July 2005)

Point	φ_{ITRF}	*Std* / m	λ_{ITRF}	*Std* / m	H_{ITRF} / m	*Std* / m
P1	40° 58' 9",9931	0	29° 13' 4",0119	0	205,240	0
P2	40° 58' 7",9420	0,001	29° 13' 3",2578	0,001	198,688	0,001

Table 2 The coordinates of the two points (P1 and P2) in the project area (24 July 2005)

Point	φ_{ITRF}	*Std* / m	λ_{ITRF}	*Std* / m	H_{ITRF} / m	*Std* / m
P1	40° 58' 9",9931	0	29° 13' 4",0119	0	205,240	0
P2	40° 58' 7",9416	0,001	29° 13' 3",2578	0,001	198,682	0,001

Figure 2 Reference point (P1) and rover point (P2) close to the bridge

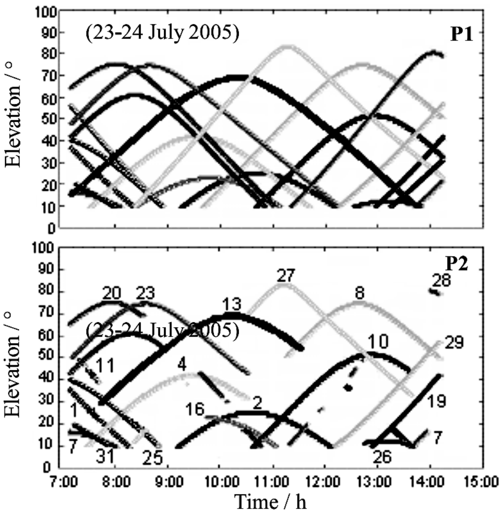

Figure 3 Elevation angles of satellites tracked at reference point (P1) and rover point (P2) during 7:00 ÷ 14:00 hour on two days (23 ÷ 24 July 2005)

Fig. 3 (top-bottom) shows the number of satellites tracked at stations P1 and P2 along with the tracking length for each satellite on 23 ÷ 24 July 2005, respectively. However, the elevation cannot indicate errors, because it does not carry any information about obstacles. As mentioned before, the value of the C/NO is actually related to the signal quality, while elevation is not. An easier approach would be to compare directly the C/NO values between the reference (P1, no obstacle) and the rover point (P2, obstacle). The multipath detection depends on the difference of the C/NO between the reference station and the rover station.

3.1 No obstacle

On Day1 and Day 2, there was no obstacle in the vicinity of any antennas for reference point (P1), and no obstruction above an elevation of 10 degrees, see Fig. 2a. So, in a favourable environment -no obstacles in the signal path- the C/NO mainly depend on the antenna gain pattern and on the amount of signal attenuation by the atmosphere, both of which are approximately a function of elevation. This is confirmed by Fig. 4 (top-bottom), site P1 is a favourably located reference site while site P2 is affected by an obstacle which degrades the quality of certain observations, see Fig. 5 (top-bottom).

The C/NO values obtained at P1 change slowly with elevation only. Correspondingly, the quality of the data collected on Day 1 and Day 2 for reference point (P1) was exceptionally high, see Fig. 4 (top-bottom). Satellite PRN 13 is perfectly representative of the tracked satellites for reference point (P1) on Day 1 and Day 2 in Fig. 3 (top). Fig. 4 (top-bottom) shows the C/NO values and the time of satellite PRN 13 for the reference point (P1) on both days. The C/NO values show scattering effects at low elevation during the initial and end period of the session on both days, but very high data quality at high elevations, see Figs. 3 (top-bottom) and 4 (top-bottom).

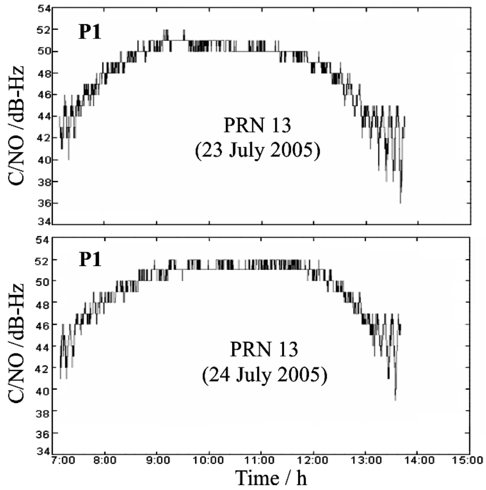

Figure 4 L1 C/NO values of PRN 13 at reference station (P1) on two days

3.2 Obstacle

The C/NO values at P2 depart significantly from those at P1 and vary without respect to the change in elevation due to the concrete bridge. On the other hand, both stations are equipped equally and separated by about 65 metres, i.e., the satellite elevations are equal at P1 and P2, so, the C/NO values should be equal. The low values observed at rover point (P2) consequently indicate signal distortion on both days; see Fig. 5 (top-bottom). The test concept and investigations employed the day-to-day repeatability of the multipath effects. Therefore, comparing C/NO values of the same satellite (PRN 13) measured with the same GPS receivers. The rover station (P2) is close to a concrete bridge, which totally obstructs the direct signal from PRN 13 during the period (10:00-11:30 hour). The impact of the bridge on the signal quality during this period is clearly seen from Fig. 5 (top-bottom) which shows the C/NO values of PRN 13 on both days. The receiver therefore tracks the satellite PRN 13 even while it is not directly visible, and only indirect signals arrive at the antenna during this period. Between 11:30 and 14:00 hour on both days for rover point (P2), satellite PRN 13 was also completely obstructed by the bridge and is not tracked by the receiver; see Fig. 3 (bottom) and Fig. 5 (top-bottom). Satellite PRN13 is tracked for several very short periods only at the end of the session on both days, and is simultaneously subject to signal distortion, see Fig. 5. Furthermore, the receiver loses lock to the satellite signals several times, because the signal-strength drops below the acquisition threshold. The multipath effect is indicated by the changes in the C/NO values, see Fig. 5 (top-bottom). The C/NO values of PRN 13 are expected to be around 52 dB-Hz during 10:00-11:30 hour, see Fig. 4 (top-bottom). However, the multipath effect caused by the bridge reduces the C/NO values of this satellite to the much smaller value of about 36 dB-Hz during 10:00-11:30 hour, see Fig. 5 (top-bottom). Beside the C/NO values also the double difference residuals (DDR) display the multipath effect in this period on two days, see Fig. 6 (top-bottom). Therefore, comparing double difference phase residuals (DDR) of the same satellite (PRN 13) measured with the same GPS receivers (Ashtech Z Max) and the same satellite geometry. The signature of the obstructing bridge is shown by the DDR time series of satellite PRN 13 for the baseline P1-P2 on 23-24 July 2005, in Fig. 6 (top-bottom).

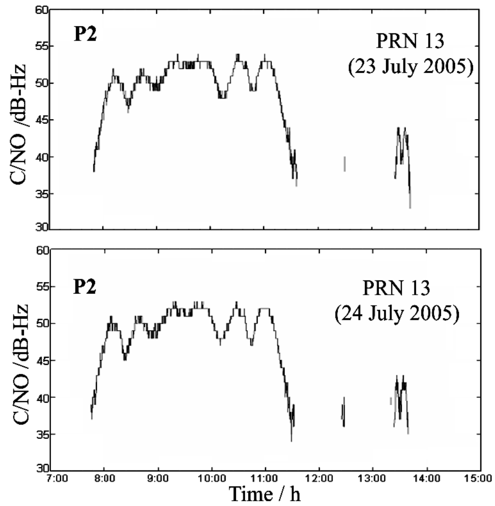

Figure 5 L1 C/NO values of PRN 13 at rover station (P2) on two days

For the same satellite PRN 13 at the same time (10:00-11:30 hour) on both days, we see a characteristic case of carrier phase multipath, see Fig. 6 (top-bottom). Notice, the roughly sinusoidal value of the tracking error is shown in C/NO and DDR plots on two days, as expected (see Figs. 5 and 6). Satellite PRN 13 is initially tracked at a low elevation (about 30 degrees) for the rover point (P2), when the satellite PRN 13 starts to disappear behind the bridge at about 10:30 hour, its DDR indicate increasing bias, its signals are subject to multipath.

This effect is due to multipath caused by the bridge environment, and is then tracked by the receiver. During 10:00-11:30 hour PRN 13 satellite reaches an elevation of 70 degrees shown in Fig. 3 (top-bottom). Nevertheless, its strongly fluctuating DDR show a typical multipath pattern due to the bridge environment. The bias shown by the DDR reaches about 50 mm during 7:00-14:00 hour on 23-24 July 2005, and is caused by the additional path length of the indirect signals. The root mean square error (rms) of the DDR of PRN 13 is 9 mm and 8 mm between 7:00 and 14:00 hour on Day 1 and Day 2, respectively.

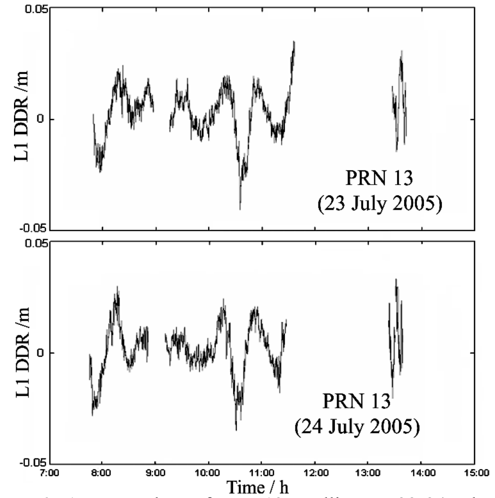

Figure 6 L1 DDR values of PRN 13 satellites on 23-24 July 2005 during 7:00-14:00 hour

4 Results and analysis
4.1 Epoch-By-Epoch GPS Processing Results

All subsequent investigations refer to L1 and L2 processing of the baseline P1-P2 only. The coordinates of the reference point (P1) were fixed in all computations by processing Ashtech Solution 2.60 GPS Software. The rover point (P2) was coordinated in the ITRF 2000 system. The data of the P1-P2 baseline was processed in the GPS kinematic mode to investigate the epoch-to-epoch variations of the coordinates. Next, the multipath effects on the coordinate results will be investigated. The three components results are displayed in Fig. 7. It shows the epoch-to-epoch coordinate results of P2 by using Ashtech Solution 2.60 GPS Software minus the coordinate results of P2 by using Ashtech Solution 2.60 Software (static L1 and L2) on both days. Fig. 7 shows a significant multipath effect on the bridge environment and the impact of this effect on the epoch-to-epoch horizontal and vertical components on two days. The characteristic feature of GPS multipath effects is the day-to-day repeatability of almost the same phase variations due to the repetition of the same satellite geometry, as long as the GPS antenna does not move relative to the environment [10].

Fig. 7 gives the average differences and standard deviations of the coordinate differences for the rover point (P2). The north and height components were however less consistent, and sometimes differed up to 10 cm at certain times on two days. The only possible explanation could be traced to the original GPS data. Between 10:00 and 11:45 hour for rover point (P2), the satellite windows were not good for both tests, where the number of satellites observed ranged between 4 ÷ 7 satellites but six satellites (PRN 2, PRN 10, PRN 16, PRN 20, PRN 24, PRN 28) were tracked at low elevation (between 10 and 30 degrees), and the recorded PDOP average values were 2,1 and 9,1 for the first and second tests. The multipath effect appears in the coordinate results of the two days observations during this period, see Fig. 7. For the other epochs, height and north differences were as little as a few centimetres.

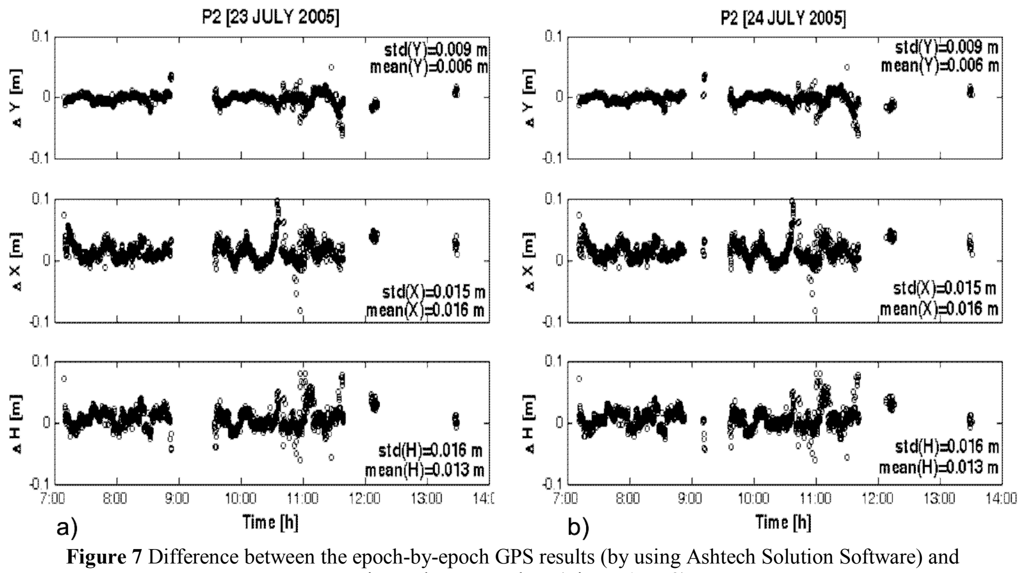

Figure 7 Difference between the epoch-by-epoch GPS results (by using Ashtech Solution Software) and static results on two days (Line: P1 – P2)

During 8:55-9:15 hour, not enough satellites were tracked to fix the ambiguity value for the rover point (P2) on both days, see Figure 3 (bottom) and Figure7. In this period, PDOP value was very high and the ambiguity fixing problem occurred. At the end of the session (11:45-14:00), not enough satellites were tracked to fix the ambiguity value, see Figure7. The number of tracked satellites was between 5 and 8 but four satellites (PRN 2, PRN 7, PRN 13, and PRN 19) were tracked at a low elevation (between 10 and 20 degrees) during this period, see Figure 3 (bottom). This means that fewer satellites were available to the receiver and the satellite signal scatter was partially due to the low elevation. In this period, generally PDOP values were very high. It is obvious that Dilution of Precision (DOP) increases, with a corresponding loss of accuracy. In marginal conditions, DOPs were beyond the specific limits, or four satellites were not available for position computation. This means that the field operator must wait for more satellite signal (or a better satellite geometry) and therefore production is down. As a result of this situation, if the extreme signal obstruction occurs, GPS surveying becomes impossible at certain times of the day [1].

4.2 Comparisons with terrestrial methods

Fig. 8 shows an example of the epoch-to-epoch changes of the distance between a reference and rover station estimated with GPS phase observations. To compare the results of the GPS measurements with the results of terrestrial measurements the distances between the points were measured using the Leica TC 605 total station (measurement accuracy for angles and distances ±5" and 3 mm + 3 ppm, respectively). Height differences were also compared using a Topcon DL 102 digital level with a barcode rod (with a measurement accuracy of 1,5 mm/km). The GPS distances were calculated from the coordinates obtained from the GPS measurements and compared with the distances obtained using the total station. The height differences obtained by using the digital level also compared ellipsoidal height differences obtained from the GPS. Here the variation of the geoid was neglected since the distance between P1 and P2 is very short.

In Fig. 8 the standard deviation of the distance differences (ΔS) for the line P1-P2 was ±14 mm on the first day and ±14 mm on the second day. The mean value of the distance difference for P1-P2 was 15 mm on the first day and 15 mm on the second day. In Fig. 8 the standard deviation of the height difference (ΔH) variations for P1-P2 was ±16 mm on the first day and ±16 mm on the second day. The mean value of the height difference for P1-P2 was 15 mm on the first day and 15 mm on the second day. The differences of the GPS and the terrestrial survey results were generally smaller than ±2 cm, except at the positions of the peaks where the difference between both methods reached about 10 cm due to multipath caused by the bridge, see Fig. 8. On the other hand, the satellite geometry plays an important role for the attainable GPS accuracy for kinematic and even for short-static GPS applications.

Our experience shows that bad multipath propagation exists but that perfectly multipath-free ones can hardly be found. Still, careful site selection, whenever possible, is one of the best remedies against multipath effects. Receiver technology and special design of antennas help to reduce the impact of multipath. Nevertheless, if mm-level accuracies are required using short site occupation times, multipath propagation is perhaps the major concern. It was shown that the accuracy in GPS surveys is significantly affected if the satellite signals are distorted by the obstructions [7, 10]. In this experiment, the errors can occur up to 10 cm in the horizontal and the vertical position at certain times on two days. The concrete bridge, in particular, was harmful to GPS positioning, as it frequently blocked the signals of the satellites.

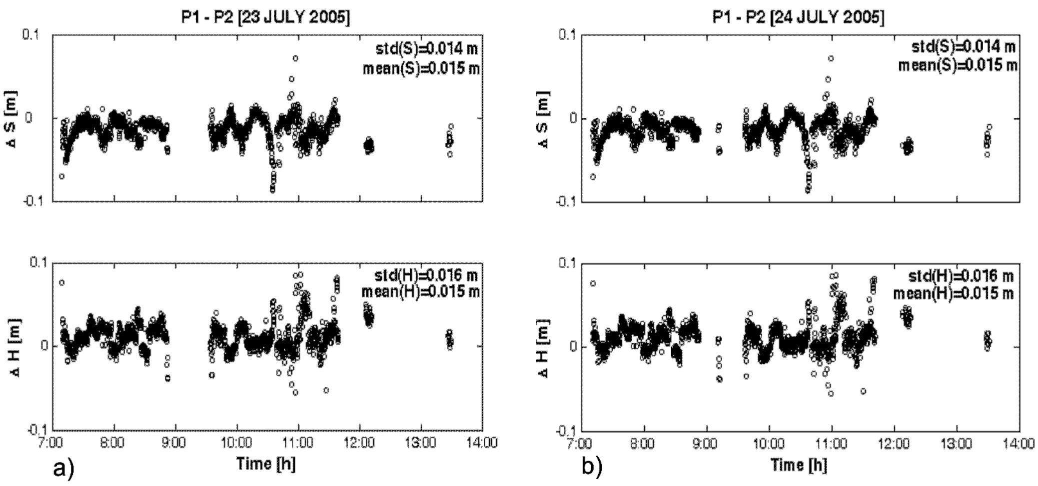

Figure 8 Difference between the epoch-by-epoch GPS results (by using Ashtech Solution Software) and Total station results on two days (Line: P1 – P2)

5 Discussions

Note that signal diffraction may last for more than a few minutes and the diffraction bias of the observation has non-zero mean. So, diffraction severely affects kinematic and short static GPS positioning. Session results using 30 minutes of data may still be biased at the cm-level. Even very long site occupation times, e.g., several hours, may not help to suppress the effect, since the risk, which more than one satellite passes behind the diffractor, increases with the session length. Signal diffraction cannot be avoided by hardware means. Therefore, appropriate site selection is the most practical way to limit diffraction effects. Due to its periodic nature, the multipath error is largely cancelled 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 only, in the extreme case. Static GPS surveying with the carrier phase measurements is the most accurate positioning system. This is mainly due to the considerable change in satellite geometry over long observation time span [1, 7, 10].

6 Conclusion

Multipath is the dominant error source in high precision GPS applications and is an important error source in non-differential applications as well. We experimentally evaluated the attainable accuracy with Ashtech Z Max GPS receiver system in the multipath environment. On 23-24 July 2005 during 8:55-9:15 hour and 11:45-14:00 hour, almost no ambiguities could be fixed in the project area due to the bridge blocking the path between the GPS receiver and the satellites. In some cases, enough signals can be observed to compute a rough position, but in virtually certain time, the signal is not clean enough to produce centimetre-level positions. The trick is to be able to observe, at any given time, enough satellites to accurately and reliably compute a position. Accurate and reliable positions can be determined with five satellites properly distributed throughout the sky.

It was shown that the accuracy in epoch-to-epoch GPS surveys is significantly affected if the satellite signals are distorted by the bridge. The major effect can be observed in the time series of the two consecutive days: The epoch-to-epoch component is affected by multipath effects repeated on the next day. The obtained accuracy in the multipath environment by using Ashtech Z Max GPS system is generally better than 2 cm in the position in this experiment for both days (epoch-to-epoch GPS processing results, see Fig. 7 and Fig. 8). However, the accuracy in the multipath environment by using Ashtech Z Max GPS system is about 1 cm in the position in this experiment for both days (in the static GPS processing results, see Tab. 1 and Tab. 2). We are continuing the investigation of these receivers and they will be compared with other types of receivers in both static and RTK GPS techniques in the multipath environment.

Acknowledgement

Fig. 1 was prepared using Google-Earth Software.

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