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RESEARCH ARTICLE

ACCURACY COMPARISON BETWEEN GPS ONLY AND GPS PLUS GLONASS IN RTK AND STATIC METHODS

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ABSTRACT

Today, with the quick development and changing of the space geodesy and satellite techniques, opportunities for choosing and using GNSS increased, many satellite systems are available and ready to use. At present using Differential Global Navigation Satellite System (DGNSS) for different purposes are so common and attracts many users, especially for surveying and mapping applications. Therefore, comparing the use of GPS only and combined GPS + GLONASS for RTK and static methods in accuracy is important. The aim of this study is to compare Global Positioning System GPS only and GPS+GLONASS when using Real Time Kinematic (RTK) and static methods. For this purpose, a field work was performed with 14 test points using RTK method and 3 test points using rapid static method. Measurements were performed for both GPS only and GPS + GLONASS. Finally, the position qualities were compared. Leica Geo office software was used for data processing, and Leica Viva GS15 was used as instrument. Also the benefits and challenges of a combined GPS and GLONASS system for post-processed static and RTK methods were identified.

INTRODUCTION

Global Navigation Satellite System (GNSS) is a common term that defines a satellite system that provides independent geo-spatial positioning with a worldwide coverage. At present, there are two popular operational GNSSs: GPS and GLONASS. GPS which is developed by the United States of America (USA), and its satellites were first launched in February 22, 1978. GPS was available only for military, but later in 1983 a decision made for extending GPS to civilian, and GPS is presently operating at full capability, with 31 satellites operational in orbits compare to GLONASS which reached full coverage in Russian territory by 2010, and in 2011 reached full operational capability with the full orbital constellation of 24 satellites (Jeffrey, 2015; Anonymous5, 2017). Today, opportunities for choosing or using GNSS increased, many satellite systems are available and ready to use, and now the direction goes towards combining signals from multiple GNSSs to maintain greater availability, higher performance, especially while using DGNSS, which is a differential correction technique that enhances the quality of location data, gathered utilizing GNSS receivers. Differential correction can be applied in real-time directly in the field or when post-processing data in the office. Although both methods are based on the same principles, each accesses different data sources and achieves different levels of accuracy.

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Combining both systems provides flexibility during data collection and improves data integrity(Morag Chivers, 2017).Availability of GLONASS satellites, when combined with GPS, should bring two significant advantages. First, there is an increase in the number of available satellites (and measurements) at any time in comparison to a single system, so it can provide better satellite geometry and redundant information allowing users to compute more accurate and precise positions, especially in cases of obstructed areas. Secondly, the solution from GLONASS could be used as an independent verification of the GPS solution, thus improving quality control (Choy *et al*, 2013). Combining GPS +GLONASS has a better performance in terms, accuracy, satellite availability and reliability, avoiding signal loss (Alkan, 2015; Pirti, 2013; Choy *et al*, 2013). Many groups and researchers tested and showed the benefits of combining GPS+GLONASS as for Precise Point Positioning (PPP) technique, RTK method, navigation…etc. In this study the benefits of combining GPS+GLONASS while using RTK and static methods for engineering purpose like land surveying and mapping, data collection in the field, establishing control points will be discussed. Main objective in this study is to assess the differences in position quality for both RTK and static GPS, RTK and static GPS+GLONASS, particularly when the area is obstructed due to signal blockage with trees or buildings. Thisstudy starts with fundamental of RTK and static methods. Then discussing the advantages of combining GPS+GLONASS while using DGNSS for RTK and static methods. Subsequently numerical tests that comparing and evaluating RTK method and static method in both cases of GPS only and GPS+GLONASS. Finally, the results are discussed.

RTK and Static GPS, RTK and Static GPS+ GLONASS Techniques

Today DGNSS has a wide using in the world, using RTK and static methods in the daily field work been so common, while RTK refers to a stop-and-go method where the coordinates of points are available in real time. In this method, a radio communication link is maintained between the base and rover receivers, and the base receiver supplies the pseudo-range and carrier phase measurements to the rover receiver, which in turn computes its position, and display the coordinates (Figure 1). The rover keeps updating coordinates as it moves as long as the lock on satellites is maintained (Leick, 2013; Anonymous2, 1999; Mwangi, 2009; Anonymous4, 2011). Dual frequency LI and L2 GNSS receivers are essential to RTK surveying. The GNSS receivers are free to move from point to point except one of them which are installed over a known point. A radio connection and a processor or data collector are required when performing the survey in real time. The radio link is used to transport the raw data from the reference station to the rover (Anonymous4, 2011).

In RTK the Achievable accuracies typically equal or exceed 10 mm (Manual, 2003).Distances between the reference receiver and the rover are quite short which is ideally less than 3 km. Baselines above 5 km should be avoided if possible, and satellite geometry should be strong it means minimum 5 satellites should be available if possible 6 or more satellites (Anonymous2, 1999). So using GPS only if comparing with GPS + GLONASS for RTK method, obtains a lower number of satellite availability, lower accuracy in centimeters, lower position quality, and in obstructed areas also losing signals will be so common. But performing RTK method using GPS+GLONASS provides a better quality, accuracy, increasing satellite availability, reliability, improved the code measurements, reduced the code noise level, and improves ionospheric and tropospheric propagation models especially in obstructed areas. The most obvious advantage of a combined system is the availability of twice as many satellites of the total of 48 satellites; at least 12 satellites will be visible anywhere at any time. (Alkan, 2015; Kleusberg, 1990; Pirti 2013; Choy *et al*, 2013).

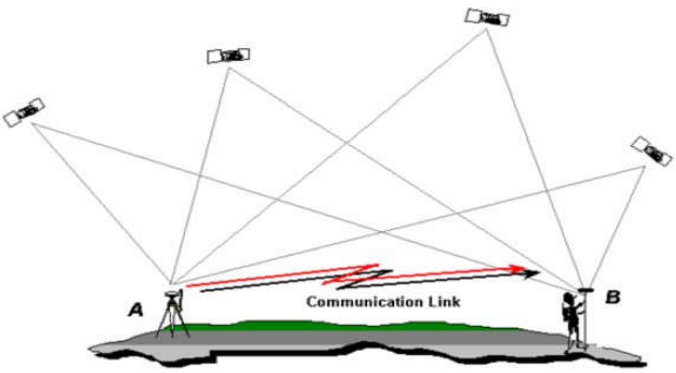

Figure 1. RTK communication

Static GPS survey procedures allow various systematic errors to be resolved when high-accuracy positioning is required. Static procedures are used to produce baselines between stationary GPS units by recording data over an extended period of time during which the satellite geometry changes. In this method, each receiver at each point logs data continuously for a pre-planned length of time. Fast Static GPS surveys are similar to static GPS surveys, but with shorter observation periods (approximately 15 to 30 minutes) (Anonymous1, 2012; Anonymous3, 2000; Anonymous4, 2011; Mwangi, 2009). While using static method, Pairs of GNSS receivers are set up in both known and unknown position stations. In most cases, one of the GNSS receivers is positioned over a location whose coordinates are well known (have been carried forward as on a traverse).

The second receiver can also be positioned over a location whose specific coordinates are unknown. This technique desires to know the coordinates of the second receiver. Depending on the precision and conditions of observation required, it is mandatory for the two GNSS receivers to receive signals from the four or more similar satellites for a specific length of time. This period ranges from a few minutes to many hours. CORS stations are mostly regarded as the best base station since they are able to continuously make observations (Mwangi, 2009; Anonymous4, 2011), but in cases where the CORS stations are completely unavailable, a specific point will make a suitable base station (Figure 2).

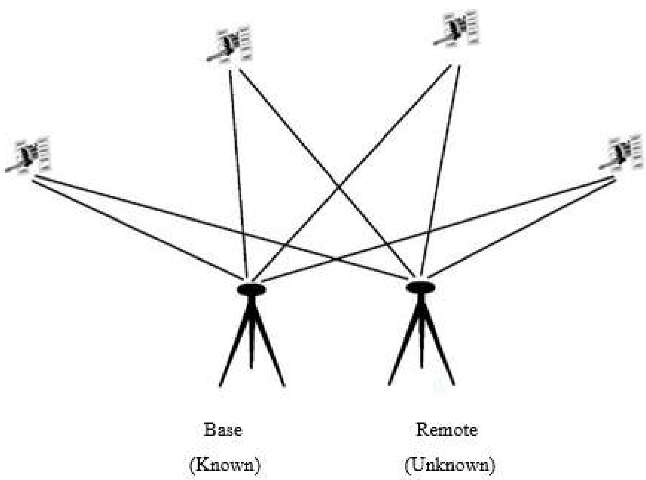

Figure 2. Static method using a known point as a base station

In terms of accuracy and productivity, measuring short baselines (example 5 km) from various temporary references is more advantageous compared to measuring long baselines (example 15 km) from a specific central point .

Baseline Lengths Observation and Times are dependent on:

- Number of satellites
- Ionosphere
- Baseline length
- Satellite geometry

Disturbance of ionospheric varies with day/night, time, year, month and earth's surface position at that particular period. According to (Anonymous6) a good rule of thumb is 5 minutes per kilometer of baseline length with a minimum of 15 minutes. Table 1 shows a guide to observation times and baseline lengths.

Table 1. Relation between baseline length and approximate time observation requires (Anonymous6)

Baseline Length	Occupation Time
1 km	15 min
2 km	15 min
3 km	15 min
4 km	20 min
5 km	25 min
6 km	30 min
7 km	35 min
8 km	40 min
9 km	45 min
10 km	50 min
>10 km	> 60 min

Using GPS + GLONASS in static method increases the position accuracy for static, and also increasing the number of satellite availability, and better satellite geometry. And also reduces multipath error and signal loss problems. Using GPS + GLONASS in static method is better than GPS only with some millimeters when the observation performed in the same time.

Testing RTK and Static GPS, RTK and Static GPS+GLONASS Techniques

Test Description

For testing RTK and static GPS, RTK and static GPS+GLONASS Techniques, a field work was performed and carried out in April 2017, in Erbil city of Iraq, which locates at lat. 36.191113 degree, long. 44.00916 degree. The study area is near Shanadar Park in the city center of Erbil city. This area is selected because in spite of open sky, also obstructed sky were available because of trees and buildings (Figure 3 and Figure 4). Leica viva GS15 dual-frequency GNSS receiver was used for measuring 14 points with RTK method, and 3 points for static method. The Leica viva GS15 GNSS receiver has 120 channels, and this dual frequency receiver is capable of receiving GPS signals: L1, L2, L2C, L5 and GLONASS signals: L1, L2 together. Accuracy of the receiver can be summarizing as follows: single baseline (rms) for RTK are Horizontal: 8 mm + 1 ppm (rms) and for Vertical: 15 mm + 1 ppm (rms), and for rapid static (phase) Horizontal: 3 mm + 0.5 ppm (rms) Vertical: 5 mm + 0.5 ppm (rms). The reference point ER01, which is an official reference point in the country, used as a base station for both RTK and static, the point was established on WGS84 datum.

For RTK, 14 points were established and measured in the area (Figure 5). Occupation times for each point was 5 seconds and simple rate or epoch was 1 second, and elevation cut-off angle was 15° for normal RTK process, WGS84 was used as a datum, and L1 and L2 signals were received. Each point measured two times; First, points were measured with GPS + GLONASS mode which the receiver will receive signals from GPS and GLONASS satellites together. Second, measuring the same points using GPS only mode that the receiver will only receive signals from GPS satellites. In the same area, also a rapid static method was performed and 3 points (BM1, BM2, BM3) were established with GPS + GLONASS in open sky, 15 minutes' observation accepted for each point, because of having short baselines of about 100 m. Then data processing started using Leica Geo office software for the RINEX data, which contains GPS + GLONASS signals. Later by using the Leica Geo Office software the GPS signals was exported from the combined RINEX, a new RINEX file made that contains GPS only signals. After data processing for the GPS only RINEX file also, the coordinates and standard deviations of points were obtained. Since the baseline is too small in rapid static, so observations will be in the same ionospheric condition. WGS84 used as a datum, after that the data is projected to UTM at zone 38 of north. Table 2 shows the selected processing parameters for post processing. Tests under an obstructed sky were not performed for static, because in static method we are about establishing control points, which always requires the maximum accuracy possible, and always better satellite availability and more suitable locations will be more preferred. It doesn't make sense to put control points under an obstructed area, in case if you have another choice, because when an accuracy with millimeters is requires, choosing the best location for receiving signals and satellite availability needs to be chosen first, and also points must be well located which provide a good visibility for the project. So in case of performing a test like static in obstructed area, the results will not be that useful for the users, because normally users should not put it under the closed sky.

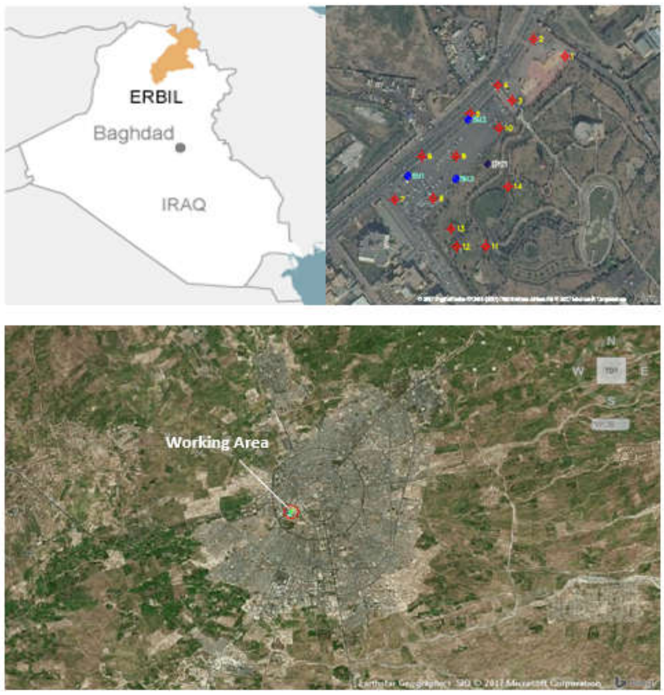

Figure 3. Satellite Images of Working Area (Erbil City, Iraq)

After the results of coordinates are obtained the position qualities are obtained also from the elements of the variance-covariance matrix of the horizontal coordinates and elevations of any point can determine standard deviations of *easting, northing, elevation,* and position quality.

Variance-covariance matrix,

$$C = \begin{bmatrix} Q_{11} & Q_{12} & Q_{13} \\ Q_{21} & Q_{22} & Q_{23} \\ Q_{31} & Q_{32} & Q_{33} \end{bmatrix} \qquad \text{.................(1)}$$

Standard deviation of *easting*,

$$\sigma_E = M_0\sqrt{Q_{11}} \qquad \text{..................(2)}$$

Standard deviation of *northing*,

$$\sigma_N = M_0\sqrt{Q_{22}} \qquad \text{..................(3)}$$

Standard deviation of *elevation,*

$$\sigma_z = M_0\sqrt{Q_{33}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4)$$

Position quality of coordinates,

$$\sigma_p = \sqrt{\sigma_E^2 + \sigma_N^2 + \sigma_Z^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

Obstructed Area

Open Sky

Figure 4. Working area for open sky and obstructed sky

Table 2. Selected processing parameters for post processing

Parameters	Selected
Cut-off angle:	15°
Ephemeris type:	Precise
Solution type:	Automatic
GNSS type:	GPS + GLONASS
Frequency:	L1 + L2
Fix ambiguities up to:	80 km
Min. duration for float solution (static):	5' 00"
Sampling rate:	Use all
Tropospheric model:	Hopfield
Ionospheric model:	Automatic
Use stochastic modelling:	Yes
Min. distance:	8 km
Ionospheric activity:	Automatic

Test Resultsfor RTK Method

The results show that for RTK method the position quality or accuracy was about 1 cm when using GPS + GLONASS, and near 1 cm better than using GPS only in unobstructed area, including points 1—10 (Figure 5). However, in obstructed area the position quality was about 2—3 cm for GPS + GLONASS and near 3 cm better than GPS only, as it can be notice from points 11—14 which locates in the obstructed area (Figure 5). The coordinate differences, standard deviations and position qualities of the points are shown in Table 3 and Table 4, and also see Figures 6, 7, 8, and 9. Generally, in RTK method the combining system showed a better accuracy, better position quality and provided a better satellite availability. With cut of angle 15°, the maximum 8 satellites were available when using GPS only in unobstructed area, and in obstructed areas the satellite number for GPS only was about only 4—5 satellites, while more than 14 satellites were available when using GPS + GLONASS in unobstructed area and at least 8 satellites were available in obstructed area. Combined GPS + GLONASS reduced the chances of signal loss and multipath, and less observation time was required by providing a better satellite geometry because of increasing the number satellite availability.

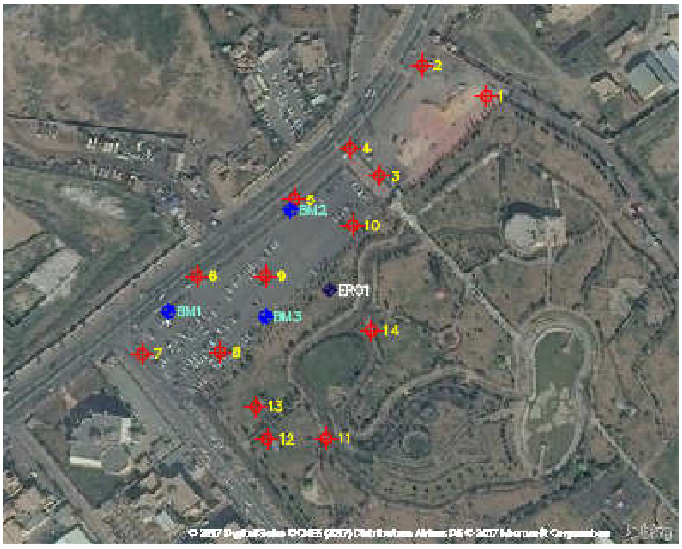

Figure 5. Satellite image of working area (Erbil City, Iraq, Shanadar Park)

Table 3. Coordinate differences between GPS + GLONASS and GPS only in RTK method [m]

Points	ΔX	ΔY	ΔZ
1	0.0099	0.007	-0.0156
2	0.0036	0.004	-0.012
3	0.0013	0.006	-0.0185
4	0.0048	0.006	0.0034
5	0.0042	-0.001	-0.008
6	0.0043	0.001	-0.0047
7	-0.0006	0.004	-0.0072
8	0.0009	0.004	-0.0056
9	0.0024	0.006	0.0312
10	-0.0034	0.008	0.0393
11	-0.016	0.02	0.016
12	-0.043	0.01	0.029
13	-0.137	0.106	0.078
14	-0.011	-0.024	0.005

According to the results as shown in Table 3 and Table 4, and Figures 6, 7, 8, 9 below, from points 11—14 a lower accuracy can be notice if compares with the points from 1—10 in both GPS only and GPS + GLONASS cases, this difference between them is because of that the points 11—14 locates in an obstructed area, which causes a lower number of satellite availability which is about 4—5 satellites for GPS only and 8 satellites for GPS + GLONASS, also chances for multipath and signal loss was higher because of having many high trees inside the park, while in the open sky the number of satellites are increased to 8 satellites for GPS only and more than 14 satellites for GPS + GLONASS, and also chances of multipath and signal loss was extremely low because the area was open and number of satellites was higher.

Finally using GPS + GLONASS is so important to obtain a better quality and to avoid multipath and losing signal problems, especially in obstructed area because it increases the satellite numbers and provides a better satellite geometry.

Table 4.Standard deviations and position qualities of points in RTK method [m]

	GPS + GLONASS				GPS only			
Points	σ_E	σ_N	σ_Z	P.Q	σ_E	σ_N	σ_Z	P.Q
1	0.00568	0.00514	0.00765	0.0108	0.00661	0.00619	0.00821	0.0122
2	0.00637	0.00523	0.00845	0.0118	0.00712	0.00831	0.0124	0.0165
3	0.00581	0.00622	0.00819	0.0118	0.00716	0.00821	0.0128	0.0168
4	0.00562	0.00674	0.00793	0.0135	0.00842	0.00879	0.00983	0.0156
5	0.00495	0.00484	0.00846	0.0109	0.00814	0.00829	0.0112	0.0161
6	0.00539	0.00547	0.00734	0.0106	0.00842	0.00876	0.0131	0.0179
7	0.00653	0.00679	0.00967	0.0135	0.00751	0.00814	0.0143	0.0180
8	0.00586	0.00593	0.00869	0.0120	0.00803	0.00812	0.0152	0.0191
9	0.00541	0.00568	0.00828	0.0114	0.00915	0.00946	0.0123	0.0180
10	0.00684	0.00695	0.00978	0.0138	0.00821	0.00907	0.0131	0.0179
11	0.01324	0.01385	0.01623	0.0251	0.02046	0.01915	0.02413	0.0370
12	0.01638	0.01454	0.01751	0.0280	0.02358	0.02658	0.02974	0.0463
13	0.01127	0.01236	0.01623	0.0233	0.03943	0.03841	0.04982	0.0742
14	0.01473	0.01396	0.01659	0.0262	0.03297	0.03284	0.04023	0.0615

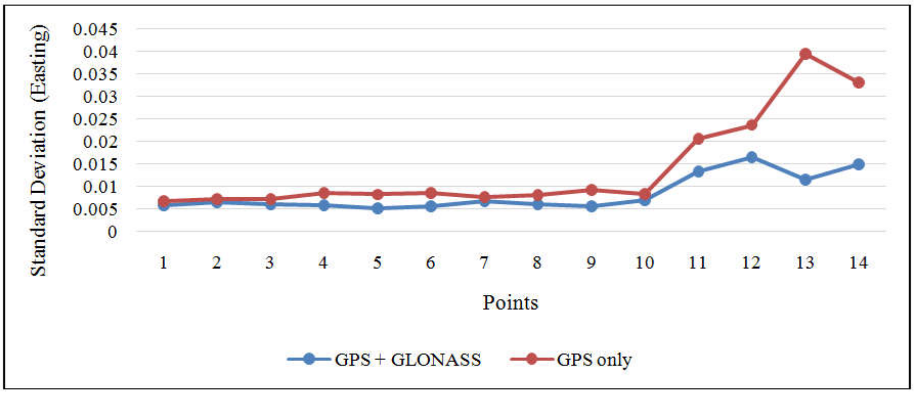

Figure 6.Standard deviations of easting in RTK method [m]

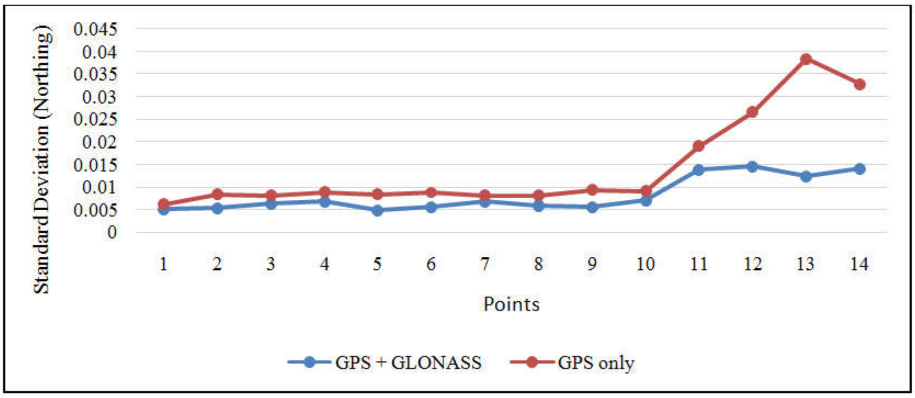

Figure 7. Standard deviations of northing in RTK method [m]

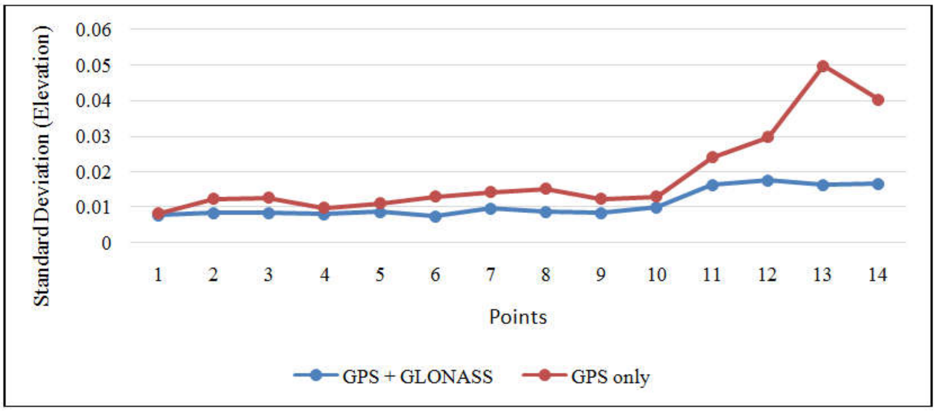

Figure 8.Standard deviations of elevation in RTK method [m]

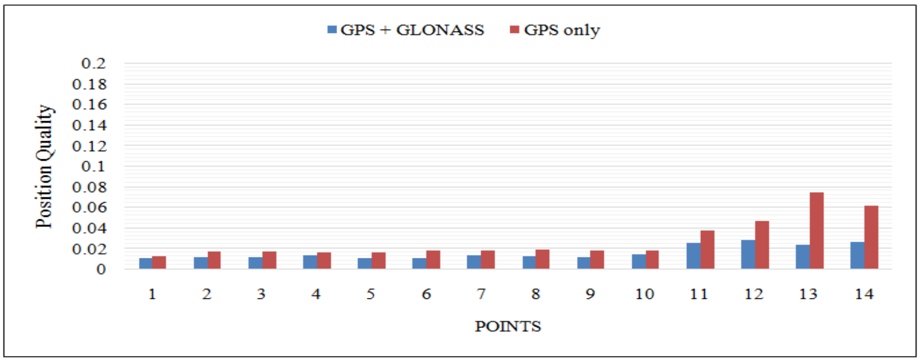

Figure 9.Position qualities of points in RTK method [m]

Test Results for Static Method

In rapid static method after processing the data results show that for points BM1, BM2, BM3, GPS + GLONASS provided a position quality of about 5 mm, which is normally 1—2 mm better than using GPS only. The coordinate differences, standard deviations and position qualities of the points are shown in Table 5 and Table 6. and also see Figures 10, 11, 12, 13

So using two GNSS systems increases the position accuracy for static, and also increasing the number of satellite visibility, and better satellite geometry. The differences between GPS only and GPS + GLONASS in static was only some millimeters, while in RTK it was about centimeters, but for static method this range must be taken seriously because in static method we are about establishing control points which higher accuracy is required.

Table 5. Coordinate differences between GPS + GLONASS and GPS only in static method [m]

Points	ΔX	ΔY	ΔZ	Position Diff.
BM1	-0.00032	-0.00027	-0.0001	-0.00069
BM2	0.00034	-0.00043	-0.00107	-0.00116
BM3	0.0005	-0.00043	-0.00131	-0.00124

Table 6. Standard deviations and position qualities of points in static method [m]

	GPS + GLONASS				GPS only			
Points	σ_E	σ_N	σ_Z	P.Q	σ_E	σ_N	σ_Z	P.Q
BM1	0.00136	0.00119	0.00473	0.00506	0.00158	0.0014	0.00525	0.00566
BM2	0.00174	0.0019	0.00518	0.00578	0.0019	0.00218	0.00588	0.00655
BM3	0.00154	0.00188	0.00411	0.00477	0.00194	0.00253	0.00542	0.00629

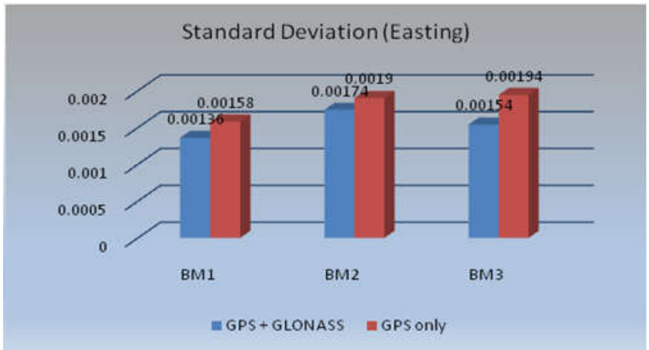

Figure 10. Standard deviations of easting in static method [m]

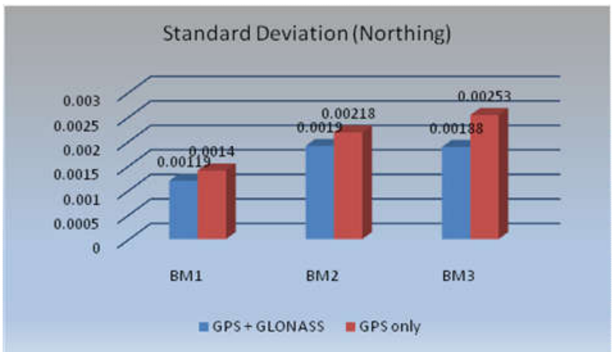

Figure 11. Standard deviations of northing in static method [m]

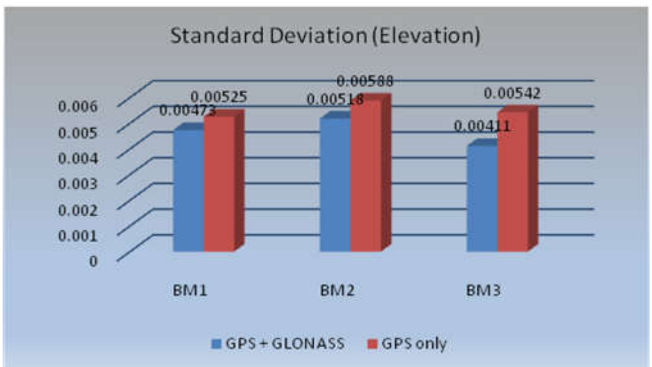

Figure 12. Standard deviations of elevation in static method [m]

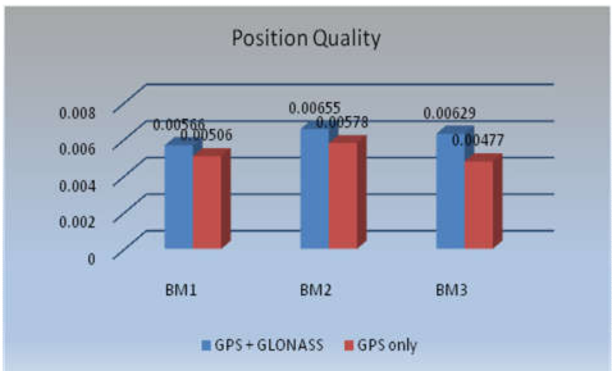

Figure 13.Position qualities of points in static method [m]

Conclusion

Combining systems from various GNSSs to maintain greater availability, higher performance, higher reliability, and higher accuracy than using only one GNSS system have been popular. In this study two tests were performed for RTK method in obstructed area and also open sky, and static method under a normal condition open sky to show the benefits of combined GPS + GLONASS in engineering sector while data collection, establishment of control points, or any other procedure required.Our tests demonstrate that for RTK system in open sky, GLONASS addition enhances the position accuracy to approximately 1 cm which is at least 1 cm better than compared to GPS signals alone. And in areas that obstructed, combining system provides 2—3 cm position quality and accuracy, which is at least 3 cm better compared to GPS signals only. In the case of static method in the open sky, a combination of GPS to GLONASS yields a position quality of around 3—5 mm, which is at least 1—2 mm millimeters better if compared to that of using GPS only. The results are similar to the tests carried out by various groups: Choy *et al* (2013),Pirti *et al* (2013), and Alkan *et al* (2015). Field experiments in operating environments points out that addition of GLONASS greatly improves availability and accuracy. In those areas that are unobstructed, GPS + GLONASS solution yields a horizontal accuracy of approximately 1 cm, and this is at least 3 cm better than a GPS only (Pirti *et al*, 2013).According to the results, the GPS + GLONASS has better performance and accuracy while using RTK and static methods as explained, using GPS + GLONASS increased quality in position, and it is important to use GPS + GLONASS in obstructed area while the area is blocked from signals. Combined system can reduce the chances of signal loss and reduces the multipath problems in closed sky, and if we compare the results in terms of standard deviation and position quality, then always the more accurate system is GPS + GLONASS. It means using multiple GNSS is more active in solving errors and reducing error problems. Normally in surveying applications or while using DGPS always it is better to avoid closed areas which causes problems for receiving signals and reduces the availability of satellites, it means always open sky is the best for any observation with single GNSS or multiple GNSS or single frequency or multiple frequency, but in case working in areas with almost closed sky or low availability by any reason, then using the multiple GNSS is so important, because according to our results the differences in accuracy between GPS only and GPS + GLONASS in obstructed area is bigger than the differences between them in open sky, the reason is in closed sky with using GPS only the satellite numbers will decrease which causes a bad satellite geometry if compares with using GPS + GLONASS.

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