Investigation into Various Factors Influencing the Achievable Accuracy of Kinematic GNSS Height Observations for Road Surveys

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Abstract

In South Africa, road maintenance and construction are the responsibility of the South African National Roads Agency Limited (SANRAL), which only accepts tenders for topographical road surveys carried out by conventional methods, in accordance with the Technical Methods for highways (TMH 11) guidelines. The aim of this paper is to investigate the height accuracies achievable under various conditions for GNSS observations and whether these can be used for topographical road surveys. To investigate the achievable accuracy of GNSS height observations, a 1km test bed consisting of 500 precisely leveled points was established along a road, which served the basis for all fieldwork. Each point was occupied for more than 10 epochs, observing GPS+GLONASS satellites at a 0° elevation cut-off angle in Real Time and Post Processing Kinematic mode. The above mentioned observations allowed for the analysis of the effect of GPS-only and GPS+GLONASS observations on height accuracy. It further made provision to investigate the effect of the number of epochs per point observation. Both GPS-only and GPS+GLONASS results illustrate an achieved RMS of 14mm with more than 90% of its observations within 25mm accuracy among all observation sessions for GPS and GPS+GLONASS. To acquire the best possible results using GNSS, the base station should be set up close to the test site, within 1 km of the road been surveyed unless provision is made for geoid modeling. GNSS height observations can provide an accuracy level that is similar to heights established by conventional methods such as total station, which are in accordance with TMH 11 specifications.

1. Introduction

The advances of Global Navigation Satellite Systems (GNSS) in modern day surveys have become more precise and reliable in establishing 3-dimensional (3D) co-ordinates in real time such that centimetre-level accuracy is achievable. The determination of heights using GNSS techniques is known to be less accurate than the determination of planimetric (y, x) co-ordinates.

In South Africa, GPS is generally used for surveying purposes. Advances in satellite receivers have given rise to the development of receivers that have the function of observing a combination of
GPS and GLONASS satellites, which result in an increased number of satellites to fix a 3D point. There are various factors which have an impact on the accuracy of GNSS height kinematic observations.

This article focuses on the use of differential carrier phase kinematic GPS and GPS+GLONASS observables in context of general surveys where single base real time kinematic (RTK) GNSS will be used. It involves the investigation on the effect of observation interval (epoch) on achievable height accuracies using RTK GPS+GLONASS observations and the effect of achievable height accuracies using GPS and GPS+GLONASS observations at various observation intervals (epoch) in determining point heights. The effect of the geoid was not considered in this article.

2. Height Measurements using GNSS

In 2008, the use of VRS GPS for road surveys was investigation by Robert Owen. In his research, he explores the creation of digital terrain models (DTM) by both VRS GPS and total station and makes a comparison between the two methods. Calibrated points were then placed using the VRS GPS survey method. The impact of these calibrated points on the established DTM was then assessed. A comparison between GPS and total station height accuracy was also analysed over a test field of 88 points. This was achieved by obtaining height observations of the 88 points by precise levelling, VRS GPS and total station. The levelled heights were taken as reference heights an observations from the total station and VRS GPS where compared to the levelled heights. He concluded that the observations taken by GPS and total station were of the same magnitude (Owen, 2008).

In South Africa, the South African National Road Agency (SANRAL) is responsible for the maintenance and construction of roads. A practicing surveyor needs to tender for a topographical road survey on behalf of SANRAL, which is the body that allocates and approves the survey of South Africa’s roads. On the approval of a tender, SANRAL follows the guidelines of the THM 11 documents (Desai, 2010).

The surface of the Earth is represented by the geoid, which by definition is referred to as “that equipotential surface of the Earth’s actual gravity field which on average coincides with mean sea level” (Merry, 2010). The gravity potential along an equipotential surface is constant. The geoid is a mathematical model which is used as a reference surface for heights.
Figure 1: Relationship between the physical surface, geoid and ellipsoid.
(priabroy.files.wordpress.com/2010/01/geoid-ellipsoidal-orthometric_height.jpg)

As illustrated in the Figure 1, we can see that the geoid is expressed as been between the physical surface (terrain) and the ellipsoid. The geoid and mean sea level depart from each other by less than or equal to 2 metres, due to the effect of forces such as wind, pressure and ocean currents. The physical surface and the geoid are separated by no more than 8km, whereas the ellipsoid and the geoid are separated by as much as 120m. In general, height above the geoid, also known as the orthometric height, is used for surveying applications, but when using GNSS, heights above the ellipsoid are achieved. Thus, the reference surface for vertical heights when using GNSS techniques is given above the ellipsoid (Merry, 2010).

3. Methodology

A 1km stretch of road was selected as the test site upon which all fieldwork was to be conducted. Permanent and clearly defined points along the road were precisely levelled between Town Survey Marks (TSMs) and this served as the standard to compare the GNSS observations in order to make a valid comparison for accuracy. Figure 2 below defines the procedure followed in carrying out this article.

The test site selected needed to meet certain criteria in order to make valid comparisons. The criteria used to select the test site are the following:

- Situated in an area with low traffic activity throughout the day.
- The 1km stretch of road must have no overhead obstacles along its extent, which may limit satellite signals.
- Both horizontal and vertical control is needed in the vicinity of the test site. These include Town Survey Marks (TSM) and Beacons for setting out further control where necessary.
Fieldwork involved the setting up of a single dense test site of 500 well-established and distributed (height) reference points along a 1 km stretch of road. The height of points in the test site will then be determined using both precise leveling and RTK GNSS observations. These observations will then be compared to each to make the necessary accuracy conclusions of RTK GNSS. The RTK GNSS observations will then undergo post-processing to model other variables as discussed. Figure 3 below illustrates the setup of the test bed.

Figure 2: A flowchart illustrating the procedures carried out in the completion of this research project.

Figure 3: Pictorial view of the structure of points within the test bed.
4. Results and Analysis

4.1 RTK GNSS Observations

Once an orthometric height had been established for each point in the test bed, RTK (GPS+GLONASS) observations were observed and recorded using a RTK single base station method (Position and Height fixed to a known point). The elevation cut-off angle was set to zero degrees and GPS+GLONASS satellites were observed from both the base station and rover. These observations included all points in the test bed and at benchmarks. Three individual sessions, of varying observation interval (epoch in seconds), were observed. This included two sessions of 4 second epochs and a single session of 10 second epochs. The base station setup was established on the same known point for all three sessions and each point in the test bed and all benchmarks were observed to obtain a height observation for each point. During observations in the field, the geometric dilution of precision (GDOP) was kept to a minimum to ensure accurate observations were taken. Observations at both the base station and rover where recorded and stored during all fieldwork to allow for the processing of post processing kinematic (PPK) observations in the office.

RTK (GPS+GLONASS) GNSS height observations compared to precisely levelled points, which served as a standard for evaluating the achievable accuracy and precision of RTK GNSS. The 10 Epoch session was then used in post-processing mode (PPK) to further analyse the achievable height accuracies of both GPS and GPS+GLONASS observations at 5 levels of observation interval (1, 2, 3, 5 and 10 Epochs). Figure 4 below illustrates occupation of a point in the test bed.

![Observing points along the test bed using RTK GNSS.](image)

The observations of 3 RTK (GPS+GLONASS), 5 PPK (GPS+GLONASS) and 5 PPK GPS will be analyzed.
4.2 RTK (GPS+GLONASS) Observations

3 RTK GPS+GLONASS observation sessions were observed in the field, which served the basis for analysis. Table 1 below illustrates the number of points observed per session, minimum number of GNSS satellites observed at one given time per session and the maximum number of satellites observed overall within a session.

Table 1: Total number of Points and satellites observed per GNSS session.

<table>
<thead>
<tr>
<th>Session</th>
<th>Total Number of Observations</th>
<th>Minimum GNSS satellites observed at once</th>
<th>Maximum number of GNSS satellites observed over entire session</th>
</tr>
</thead>
<tbody>
<tr>
<td>Session 1 4 Epochs (1)</td>
<td>519 points (10 benchmarks)</td>
<td>11 GNSS (6 GPS and 5 GLONASS)</td>
<td>19 GNSS (14 GPS and 5 GLONASS)</td>
</tr>
<tr>
<td>Session 2 4 Epochs (2)</td>
<td>519 points (10 benchmarks)</td>
<td>11 GNSS (6 GPS and 5 GLONASS)</td>
<td>20 GNSS (14 GPS and 6 GLONASS)</td>
</tr>
<tr>
<td>Session 3 10 Epochs</td>
<td>519 points (10 benchmarks)</td>
<td>11 GNSS (7 GPS and 4 GLONASS)</td>
<td>28 GNSS (19 GPS and 9 GLONASS)</td>
</tr>
</tbody>
</table>

Each RTK (GPS+GLONASS) observation session was observed independently from each other as discussed previously. Both the 4 Epoch (1) and 4 Epoch (2) datasets present similar distribution patterns with an average height difference of -0.002m and a RMS of 0.009m as illustrated in Figure 5. This would illustrate that on two different occasions, under different conditions, similar statistical results where achievable. The 10 Epoch distribution has an average height difference of -0.001m and a RMS value of 0.010m as illustrated in Figure 5.

Figure 5: A graph illustrating RMS and MEAN statistical measures for each RTK Observation Interval using GPS+GLONASS.
This would illustrate that observing over a longer observation interval decreased the average height difference by a value of 0.001m, but not the RMS value. Thus, increasing the observation interval increases the probability of achieving better results but does not increase the variation within the sample of data observed in the field.

![A Graph illustrating the Threshold Percentage Levels for RTK GNSS (GPS+GLONASS) Observations](image)

Figure 6: Threshold Percentage Levels for RTK (GPS+GLONASS) Observations

Both 4 Epoch samples illustrated the best percentage of observations falling within 1.0cm accuracy with a percentage value of 84.01% and 99.23% of observations falling within a threshold of 2.5cm. The 10 Epoch sample had a percentage value of 81.31% within 1.0cm accuracy and 98.84% within 2.5cm. This illustrates that the probability of obtaining accuracy within 2.5cm is achieved above 90.0% of the time using RTK (GPS+GLONASS) with various observation intervals. This is illustrated in Figure 6.

4.3 GPS Vs GPS+GLONASS Observations

The following datasets were post processed using the 10 Epoch RTK (GPS+GLONASS) sample:

- 1 Epoch GPS, 1 Epoch GPS+GLONASS,
- 2 Epoch GPS, 2 Epoch GPS+GLONASS,
- 3 Epoch GPS, 3 Epoch GPS+GLONASS,
- 5 Epoch GPS, 5 Epoch GPS+GLONASS and
- 10 Epoch GPS.

These GNSS observations were then compared to the precisely levelled point heights and differences between them calculated and analyzed. A statistical comparison between the achievable
accuracies of the above analyzed in order to illustrate the effect of observation interval and GNSS type on fixing 3D co-ordinates (only the height component will be investigated).

A total of 5 observation intervals were assessed for GPS and GPS+GLONASS. The 10 epoch observation interval for GPS and GPS+GLONASS illustrates the greatest accuracy among the PPK results.

Figure 7 illustrates that as the observation interval (epoch) increases so does the accuracy of both GPS and GPS+GLONASS height observations. For GPS only, the average height difference ranges between -0.003m to -0.004m and the RMS ranges between 0.011m to 0.014m for the observation intervals investigated. For GPS+GLONASS, the average height difference ranges between -0.002m to -0.003m and the RMS ranges between 0.009m to 0.011m for the observation intervals investigated. The height accuracies achievable by GPS are similar to the height accuracies achieved by GPS+GLONASS, but the GPS+GLONASS height observations illustrate greater accuracy. The 10 epoch observation interval for GPS and GPS+GLONASS observations illustrate the greatest accuracy as expected. An RMS between 0.011m and 0.012m is achievable with GPS observations at the 5 and 10 epoch intervals, whereas a RMS of 0.009 - 0.010m is achievable with GPS+GLONASS at the 3, 5 and 10 epoch intervals.

Figure 8 illustrates the threshold levels for each GPS observation interval investigated. It can be seen that the 1 epoch represents the less accurate results whereas the 10 epoch represents the greatest accuracy at each threshold level. For each epoch interval, 76% - 80% of the height
observations are within an accuracy of 1cm and 94% - 97% are within an accuracy of 2.5cm. 97% of the observations of the 5 and 10 epoch intervals illustrate accuracy within 2.5cm.

Figure 8: Threshold Percentage Levels for RTK (GPS-Only) Observations

Figure 9: A graph illustrating the percentage of observations which fall within a certain threshold level of each PPK (GPS+GLONASS) observation interval.
Figure 9 illustrates the threshold levels for each GPS+GLONASS observation interval investigated. It can be seen that 1 epoch represents the less accurate results whereas the 10 epoch represents the greatest accuracy at each threshold level, except at the 1 epoch observation interval. A maximum of 83% of height observations are within the 1.0cm threshold level, where the 10 epoch interval is the least accurate. For each epoch interval, 97% - 99% of the height observations are within an accuracy of 2.5cm. 99% of the observations of the 3, 5, and 10 epoch intervals illustrate accuracy within 2.5cm. 90% of the observations for each observation interval observed by GPS and GPS+GLONASS are within an accuracy of 2.5cm, which is in accordance with the THM11 guidelines.

5. Conclusion

The accuracy of GPS and GPS+GLONASS height measurements are illustrated to be similar to heights established by precise leveling when using single base RTK GNSS. The RMS value for both 4 epoch sessions and the 10 epoch session are 9 millimetres and 10 millimetres respectively and each epoch session illustrates that more than 90% of its observations are within 2.5cm accuracy.

PPK GPS and PPK GPS+GLONASS observation sessions illustrate a maximum RMS of 14 millimetres with more than 90% of its observations within 2.5cm accuracy among all observation sessions.

The comparison of RTK GNSS with levelling and the acquired RMS (between 0.009m and 0.014m) values illustrate strong evidence GPS and GPS+GLONASS observations over short distances can achieve similar accuracies to conventional methods.

The main output from this article is that GPS and GPS+GLONASS can be used for road surveys, but this is highly dependent on the location of the road to be surveyed and its surroundings.

6. Recommendations

- For single base RTK GNSS, the road been surveyed should be observed in stages of 1km in distance, 500 metres on either side of the base station to ensure that heights are observed with the greatest accuracy as the effect of the geoid can be seen as been insignificant over distances less than 1 kilometre.
- Ensure sufficient control is located in the vicinity of the topographical road been surveyed, as this serves as checks to ensure the base station is correctly setup and to expose blunders within observations.
- When using GPS+GLONASS observations, a minimum of 3 epochs can be used to obtain accurate observations. When using GPS observations, a minimum of 5 epochs should be observed to obtain accurate observations.
7. References

