Impact of Baseline Distance and Interstation Height Difference On the Accuracy of GPS-Derived Station Coordinates

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Abstract. This paper investigates the accuracy comparison of scientific and commercial GPS processing software for varying length of baselines and interstation height differences. European Reference (EUREF) Permanent Network Stations were used for the processing. GAMIT/GLOBK research GPS processing software (version 10.6) and Leica Geo Office (version 8.4) commercial GPS processing software were chosen for the experiment. TUBO EUREF GPS station was taken as a known station whose three-dimensional (3D) published coordinates are precisely known and the other stations were taken as unknown points whose 3D coordinates are calculated after the processing. In this way, minimally constrained adjustment was performed for each unknown station within the EUREF network and their coordinates were calculated w.r.t. TUBO station with using each software. Only independent (non-trivial) baselines are processed between known station and unknown stations. Processing was conducted for 10 different days with 24 hours rinex data of the stations. When choosing the GPS stations, we consider the interstation height difference and baseline distance between the chosen GPS stations. Baseline distances varying from 131 km to 495 km. Interstation height differences varying from 4 m to 1620 m. After the processing, differences between the calculated 3D Cartesian coordinates of the stations whose coordinates were assumed unknown and the published true coordinates of these stations were transformed to topocentric coordinates (north, east, up) to observe the error component in 3D space. Results show that vertical accuracy obtained from commercial software is significantly low and not consistent comparing with the scientific software. There is no significant difference observed for horizontal accuracy between the software but the horizontal accuracy obtained from the scientific software is slightly better than the commercial one. There is no strong correlation found between the baseline distance and the accuracy for each software but this is not the issue for interstation height differences. Regarding the interstation height differences, it is observed that height difference between station pairs effect the accuracy in up component. As height difference between baseline points grow vertical, error becomes larger, especially for commercial software.

1. Introduction

The Global Positioning System technique becomes ubiquitous for surveyors. Determination of three-dimensional coordinates with this system based on the determination distance between satellites and receiver. Static relative positioning technique generally carried out for measurements requires high accuracy and precision. Static relative positioning employs at least two GPS receivers (base receiver
and roving receiver) simultaneously tracking the same satellites to determine the baseline components between the points. Base receiver remains stationary at a site with accurately known coordinates while the remaining receivers occupy the points whose coordinates are unknown [1]. Generally, carrier phase measurements are used for precise static relative positioning [2, 3]. GPS carrier phase processing can be performed with commercial and research software. 3D accuracy obtained after the processing depends on several factors. These factors can be summarized as follows:

- Baseline distance between the known and unknown points.
- Height difference between the baseline points.
- Antenna types between the baseline points.
- Length of observation session.

In this paper, varying length of baselines are processed with using commercial and scientific GPS processing while considering height difference between the baseline points. 36 stations were chosen within the EUREF network. Table 1 shows the baseline length and height difference between the TUBO station whose 3D coordinates assumed unknown and the other stations whose published 3D coordinates are known as increasing order w.r.t the height differences.

10 different days (from March 03 to March 16 in 2015) were chosen to conduct the experiment. Due to the data shortage of some stations, 4 consecutive days between March 08 and March 13 cannot be processed. Constrained adjustment is quite common in the processing of GPS data enables a new survey can be aligned to existing control points datum. In general, unknown parameters in the constrained adjustment are the coordinates of points. It is generally necessary to fix coordinates of at least one point to determine the coordinate of unknown point w.r.t. the control point [4]. When only one point used as a fix station for the adjustment, this is called minimally constrained adjustment. In this experiment, minimally constrained adjustment is performed while fixing the TUBO station as a control point. When more than one point is used for fixed stations, it should be considered as a source of systematic error due to the uncertainty of the location of the fixed stations [5]. After the processing, difference between 3D coordinates of the unknown points obtained from the adjustment and published true coordinates of these points were calculated in order to investigate accuracy analysis.

2. Methodology and Data Processing

24 hour rinex data of each station was downloaded from EUREF network. GPS precise ephemerides data was downloaded from IGS (International GNSS Service). Since GAMIT/GLOBK cannot handle GLONASS observations efficiently as much as GPS observations, only GPS satellites were used for processing to keep consistency between the two software. Baseline processing was performed with using 30 second sampling rate and 15 degrees of elevation mask angle for each software. Tropospheric models used for processing are different for each software. Hopfield tropospheric model [6] and Global Mapping Function (GMT) [7] were used for Leica Geo Office and GAMIT/GLOBK software respectively. The ionospheric effect was eliminated by forming the linear combination of two carrier phase frequency for each software. The same processing steps were carried out by each software. For each baseline, assumed true ECEF (Earth Centered Earth Fixed) Cartesian coordinates of TUBO station are held fixed, then baselines between TUBO station and unknown stations were processed. Only the phase ambiguity fixed solutions are accepted from the baseline processing for each day and each software. After the baseline processing, minimally constrained adjustment was performed for each day. The obtained 3D coordinates of the unknown points after the minimally constrained adjustment are taken as final coordinates.

3. Results

With the help of calculated north east up coordinates, root mean square (rms) errors of each component was calculated as follows;

$$\text{rms}_{\text{north}} = \sqrt{\frac{\sum_{i=1}^{10} (X_{\text{north}})^2}{10}}$$ (1)
Table 1. Baseline Distance, height difference (increasing order) and antenna differences

| Baseline  | Baseline Length (km) | Height Difference (m) | Antenna  |
|-----------|----------------------|-----------------------|----------|
| TUBO-BZRG | 495                  | 4m                    | Identical|
| TUBO-KATO | 211                  | 8m                    | Different|
| TUBO-LINZ | 197                  | 13m                   | Different|
| TUBO-GSR1 | 383                  | 27m                   | Different|
| TUBO-PENC | 253                  | 33m                   | Different|
| TUBO-CPAR | 110                  | 41m                   | Identical|
| TUBO-SPRN | 169                  | 45m                   | Different|
| TUBO-CFRM | 138                  | 49m                   | Identical|
| TUBO-CRAK | 230                  | 57m                   | Identical|
| TUBO-LODZ | 351                  | 64m                   | Different|
| TUBO-ZYWI | 197                  | 88m                   | Different|
| TUBO-UZHL | 423                  | 92m                   | Different|
| TUBO-CLIB | 206                  | 124m                  | Identical|
| TUBO-WROC | 215                  | 143m                  | Identical|
| TUBO-BUTE | 265                  | 143m                  | Identical|
| TUBO-CTAB | 141                  | 171m                  | Identical|
| TUBO-JOZ2 | 449                  | 172m                  | Different|
| TUBO-BOGO | 480                  | 175m                  | Different|
| TUBO-JOZE | 449                  | 183m                  | Different|
| TUBO-OROS | 424                  | 190m                  | Different|
| TUBO-GVWL | 405                  | 197m                  | Different|
| TUBO-BOR1 | 343                  | 200m                  | Different|
| TUBO-USDL | 406                  | 206m                  | Different|
| TUBO-GRAZ | 251                  | 212m                  | Different|
| TUBO-BYDG | 448                  | 220m                  | Different|
| TUBO-POUS | 327                  | 248m                  | Different|
| TUBO-MOP2 | 105                  | 257m                  | Different|
| TUBO-GOPE | 153                  | 268m                  | Different|
| TUBO-WTZR | 271                  | 342m                  | Different|
| TUBO-VACO | 209                  | 475m                  | Different|
| TUBO-MARJ | 295                  | 580m                  | Different|
| TUBO-BISK | 131                  | 626m                  | Different|
| TUBO-TRF2 | 152                  | 768m                  | Different|
| TUBO-SBG2 | 301                  | 999m                  | Different|
| TUBO-ZOUF | 400                  | 1622m                 | Different|

\[
\text{rms}_{\text{north}} = \sqrt{\frac{\sum_{i=1}^{10}(x_{\text{north}}^2)}{10}} \tag{2}
\]

\[
\text{rms}_{\text{up}} = \sqrt{\frac{\sum_{i=1}^{10}(x_{\text{up}}^2)}{10}} \tag{3}
\]

\[
\text{rms}_{\text{3D}} = \sqrt{(\text{rms}_{\text{north}})^2 + (\text{rms}_{\text{east}})^2 + (\text{rms}_{\text{up}})^2} \tag{4}
\]
Here, $x_{\text{north}}$, $x_{\text{east}}$ and $x_{\text{up}}$, represent the topocentric coordinates of the unknown stations obtained after the minimally constrained adjustment; $\text{rms}_{\text{north}}$, $\text{rms}_{\text{east}}$ and $\text{rms}_{\text{up}}$ represent the rms error of north, east, up and three-dimensional components respectively. $10$, represents the total number of days for processing. Calculated rms errors for each station and each software w.r.t. the interstation height differences as increasing order were tabulated in Table 2.

| ACCURACY ANALYSIS | GAMIT/GLOBK | LEICA |
|-------------------|-------------|-------|
|                   | $\text{rms}_{\text{north}}$ (cm) | $\text{rms}_{\text{east}}$ (cm) | $\text{rms}_{\text{up}}$ (cm) | $\text{rms}_{\text{north}}$ (cm) | $\text{rms}_{\text{east}}$ (cm) | $\text{rms}_{\text{up}}$ (cm) |
| **Baseline**       |             |       |       |             |       |       |
| TUBO-BZRG         | 0.3         | 0.2   | 0.5   | 0.6         | 0.5   | 4.8   | 4.9   |
| TUBO-KATO         | 0.1         | 0.1   | 0.3   | 0.4         | 0.2   | 0.5   | 4.4   | 4.4   |
| TUBO-LINZ         | 0.2         | 0.4   | 0.6   | 0.8         | 0.2   | 0.3   | 5.7   | 5.7   |
| TUBO-GSR1         | 0.3         | 0.2   | 0.6   | 0.7         | 0.6   | 0.4   | 5.0   | 5.1   |
| TUBO-PENC         | 0.1         | 0.2   | 0.7   | 0.7         | 0.6   | 0.7   | 4.0   | 4.1   |
| TUBO-CPAR         | 0.05        | 0.2   | 0.4   | 0.4         | 0.2   | 0.1   | 1.4   | 1.4   |
| TUBO-SPRN         | 0.3         | 0.1   | 0.3   | 0.4         | 0.2   | 0.2   | 3.0   | 3.1   |
| TUBO-CFRM         | 0.1         | 0.2   | 0.3   | 0.3         | 0.2   | 0.2   | 0.8   | 0.9   |
| TUBO-CRAK         | 0.05        | 0.2   | 0.4   | 0.4         | 0.2   | 0.1   | 1.4   | 1.4   |
| TUBO-LODZ         | 0.07        | 0.05  | 0.5   | 0.6         | 0.4   | 0.3   | 4.2   | 4.3   |
| TUBO-ZYWI         | 0.1         | 0.1   | 0.3   | 0.3         | 0.2   | 0.3   | 4.5   | 4.5   |
| TUBO-UZHL         | 0.3         | 0.1   | 0.7   | 0.7         | 0.1   | 0.8   | 3.1   | 3.2   |
| TUBO-CLIB         | 0.08        | 0.09  | 1.4   | 1.4         | 0.3   | 0.07  | 2.2   | 2.2   |
| TUBOWROC         | 0.1         | 0.1   | 0.2   | 0.2         | 0.3   | 0.2   | 2.2   | 2.3   |
| TUBO-BUTE         | 0.3         | 0.1   | 0.5   | 0.6         | 0.4   | 0.3   | 5.2   | 5.2   |
| TUBO-CTAB         | 0.3         | 0.3   | 0.3   | 0.5         | 0.1   | 0.2   | 2.8   | 2.8   |
| TUBO-JOZ2         | 0.2         | 0.1   | 0.4   | 0.5         | 0.4   | 0.7   | 4.2   | 4.3   |
| TUBO-BOGO         | 0.1         | 0.1   | 0.8   | 0.8         | 0.3   | 0.5   | 4.4   | 4.5   |
| TUBO-JOZE         | 0.1         | 0.2   | 0.5   | 0.6         | 0.4   | 0.5   | 4.0   | 4.1   |
| TUBO-OROS         | 0.2         | 0.07  | 0.5   | 0.6         | 0.5   | 0.5   | 4.9   | 5.0   |
| TUBOGVWL         | 0.2         | 0.2   | 0.3   | 0.4         | 0.5   | 0.2   | 2.5   | 2.6   |
| TUBO-BOR1         | 0.2         | 0.2   | 0.9   | 0.9         | 0.4   | 0.5   | 3.6   | 3.6   |
| TUBO-USDL         | 0.09        | 0.4   | 0.4   | 0.5         | 0.4   | 0.5   | 4.6   | 4.6   |
| TUBO-GRAZ         | 0.4         | 0.1   | 0.3   | 0.5         | 0.4   | 0.2   | 2.7   | 2.8   |
| TUBO-BYDG         | 0.1         | 0.1   | 0.4   | 0.4         | 0.5   | 0.2   | 2.8   | 2.9   |
| TUBO-POUS         | 0.1         | 0.2   | 0.9   | 1.0         | 0.3   | 0.4   | 6.8   | 6.9   |
| TUBO-MOP2         | 0.3         | 0.2   | 0.7   | 0.8         | 0.3   | 0.5   | 6.6   | 6.6   |
| TUBO-GOPE         | 0.1         | 0.1   | 0.3   | 0.3         | 0.2   | 0.2   | 6.3   | 6.3   |
| TUBO-WTZR         | 0.2         | 0.2   | 0.3   | 0.4         | 0.2   | 0.3   | 4.4   | 4.4   |
| TUBO-VACO         | 0.1         | 0.2   | 0.7   | 0.7         | 0.1   | 0.2   | 7.6   | 7.6   |
| TUBO-MARJ         | 0.1         | 0.3   | 0.5   | 0.6         | 0.2   | 0.3   | 8.2   | 8.2   |
| TUBO-BISK         | 0.2         | 0.2   | 0.6   | 0.7         | 0.2   | 0.3   | 7.1   | 7.1   |
| TUBO-TRF2         | 0.2         | 0.2   | 2.4   | 2.4         | 0.4   | 0.2   | 9.4   | 9.5   |
| TUBO-SBG2         | 0.1         | 0.3   | 1.3   | 1.4         | 0.4   | 0.4   | 10.0  | 10.1  |
| TUBO-ZOUF         | 0.6         | 0.1   | 0.7   | 0.9         | 0.3   | 0.2   | 8.3   | 8.4   |
Figure 1. 3D RMS errors w.r.t. the interstation height differences (a) and baseline distances (b)

As is it seen in Figure 1, there is a trend w.r.t. the interstation height differences and 3D accuracy (mainly in up component) but there is no such a trend observed w.r.t. baseline distances and accuracy. As height difference between baseline points grow, error in up component become larger. In this study, only 24 hours rinex data was used for processing. If shorter session than 24 hours is used, error in up component would be more effected w.r.t. station height differences [8].

4. Conclusions
As it is seen from the accuracy analysis, up component accuracy of Leica commercial GPS processing software is significantly low comparing with the GAMIT/GLOBK research software especially for
growing height differences between the baseline points. It is observed that error in up component is growing for the baseline points whose interstation height differences more than 400 meters for Leica GPS processing software. Maximum error in up component was calculated 10 cm for the approximately 1000 meters’ interstation height differences between the baseline points for Leica GPS processing software and 2.4 cm for GAMIT/GLOBK GPS processing software for the approximately 770 meters’ interstation height differences. As far as baseline distances are concerned, there is no strong correlation found for the accuracy. Fluctuations in 3D accuracy are generally observed for Leica GPS processing software w.r.t the baseline distance comparing with the GAMIT/GLOBK GPS processing software. Authors are strongly emphasizing that if short session (less than 24 hours) is involved for baseline processing, error in up components would be much bigger comparing with the 24 hours processing for growing interstation height differences especially for commercial GPS processing software.

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References
[1] Berber, M., Üstün, A., Yetkin, M., 2012. Comparison of accuracy of GPS techniques. Measurement. 45: 1742-1746
[2] Teunissen, P.J.G., 2007. GPS Carrier Phase Ambiguity Fixing Concepts. GPS for Geodesy. 60: 263-335
[3] Wang, J., Satirapod, C., Rizos C., 2002. Stochastic Assessment of GPS carrier phase measurements for precise static relative positioning. Journal of Geodesy. 76: 95-104
[4] Schwarz, C.R., 1994. The Trouble with Constrained Adjustment. Surveying and Land Information Systems. 54: 202-209
[5] Freymueller, J.T., 1988. Geometry and Treatment of Fiducial Networks: Effect on GPS Baseline Precision in South America. Geophysical Research Letters. 15: 1467-1469
[6] Hopfield, H.S., 1969. Two-quartic tropospheric refractivity profile for correcting satellite data. Journal of Geophysical Research 74: 4487-4499
[7] Boehm, J., Niell, A., Tregoning, P., Schuh, H., Global Mapping Function (GMF): A new empirical mapping function based on numerical weather model data. Geophysical Research Letters. 33, 2006
[8] Hastaoglu, K. O., Sanli, D. U., 2011. Accuracy of GPS Rapid Static Positioning: Application to Koyulhisar Landslide, Central Turkey. Survey Review. 43(321): 226–240