Reprocessing the Western Australian S*tatefix* Geodetic GPS Network Using Commercial Software

AGUSTAN and W. E. FEATHERSTONE, Indonesia

Key words: commercial GPS software, accuracy, adjustment, baseline

SUMMARY

There are two types of GPS data processing software, first is scientific GPS data processing software and the other is commercial GPS data processing software. It is usually believed that scientific GPS data processing software is better than commercial software, in terms of accuracy and precision of coordinate results especially in large areas. However, continual improvements in commercial GPS data processing software may enable people to achieve the same result as the scientific software. This paper describes the performance of the GPS commercial software in processing GPS baseline data in large areas. For that instance, Trimble Geomatics Office, one of GPS commercial software is used to reprocess STATEFIX GPS data. STATEFIX is GPS geodetic network in Western Australia, which is processed by using in-house software developed by Geodesy Group Laboratory, Curtin University. The coordinate results will be compared with STATEFIX coordinates. The results found that the quality indicator of GPS data processing such as RMS and precision can achieve centimeter level. The mean RMS of GPS baseline processing is 0.0117m for 205km mean baseline length. Point absolute error is around 1.5cm in horizontal and 4.3cm in vertical. However, the differences between coordinate results and STATEFIX coordinates are quite big, around 3cm in horizontal and 15cm in vertical.

Reprocessing the Western Australian S*tatefix* Geodetic GPS Netwok Using Commercial Software

AGUSTAN and W. E. FEATHERSTONE, Indonesia

1. INTRODUCTION

A geodetic network is defined by Kuang (1996) as being any geometric configuration of three or more terrestrial survey points that are connected either by geodetic measurements made among themselves, such as horizontal direction, angles, azimuths, spatial distances, etc., or by astronomical or space techniques; for instance, the NAVSTAR Global Positioning System (GPS), or both. One purpose of geodetic network measurement is to achieve an optimal solution for determining coordinates of new point locations from some control points. In this term, optimal solution means a high accuracy from data processing.

The GPS baseline data processing for large areas with high precision usually uses specific software that can handle specific conditions. The specific software, usually software developed in house, can be customized to make it more flexible and easy to modify if one wants to apply new algorithms or advanced modelling. This type of software is called scientific software that originates from developments at scientific institutions (Seeber, 1993). Examples are: Bernese, GIPSY. GAMIT, SWAG and Micro Cosm.

Usually the kinds of software are used to process GPS data for scientific research and high-level accuracy such as BERNESE for determining crustal motion (e.g. Rossikopoulos *et al.*, 1998; Michel *et al.*, 2001; Lowry *et al.*, 2001; Pan *et al.*, 2001) and GIPSY for determining 3-D displacement (Scherneck *et al.*, 1998).

Another type of GPS processing software is commercial software, which can be defined as software packages that can be easily found in market and produced by software or hardware companies to be used in common GPS projects. Usually, every GPS receiver manufacturer also develops GPS software that is compatible with its particular receivers. Commercial software is adequate for everyday surveying work and can be operated easily enough by personnel with an average background in engineering and GPS technology (Seeber, 1993). Examples are: GPSurvey, Trimble Pathfinder Office and Trimble Geomatics Office from Trimble Company, SKI-System from Leica Company, Solution System from Ashtech Company.

Gili *et al*, (2000) conducted a research in landslide monitoring using GPS techniques. They used Trimble Total Station 4000 SSi model with dual-frequency receivers. The observation method is fast static and real time kinematic for baseline in the range 1-1.5km. GPS data were processed by using GPSurvey and achieved 30-40mm planimetric error and 46-62mm elevation error.

Wylde and Featherstone (1995) evaluated some stop and go kinematic GPS observation by using Trimble 4000SSE receivers. The lengths of all baselines were less than 2.5km and processed by GPSurvey and GeoLab. This research found the horizontal accuracy was better than 19mm and 24mm in vertical, but there were several outliers that were detected using separate control.

Kenyeres (1999) established third-order levelling loop in Hungary by using Trimble SST series in small network. GPS data observations were processed by using GPSurvey and Bernese as a comparison. The results shown that the accuracy of GPS heighting is 5mm and can fulfill third-order levelling tolerance.

From the above references, it seems that commercial software usually used in surveying and engineering fields, which have short or medium baseline length. However, Kulkarni and Save (1999) conducted geodynamics research with long baselines (from 64km to 770km) and successfully estimated the movement in millimeter level by using GPSurvey software.

In 1996, The Western Australian Department of Land Administration (DOLA) established STATEFIX, a high precision GPS network. This is a densification of the Australian National Network (ANN) in Western Australia with baseline lengths ranging from 45 km to 450 km (Stewart, 1998).

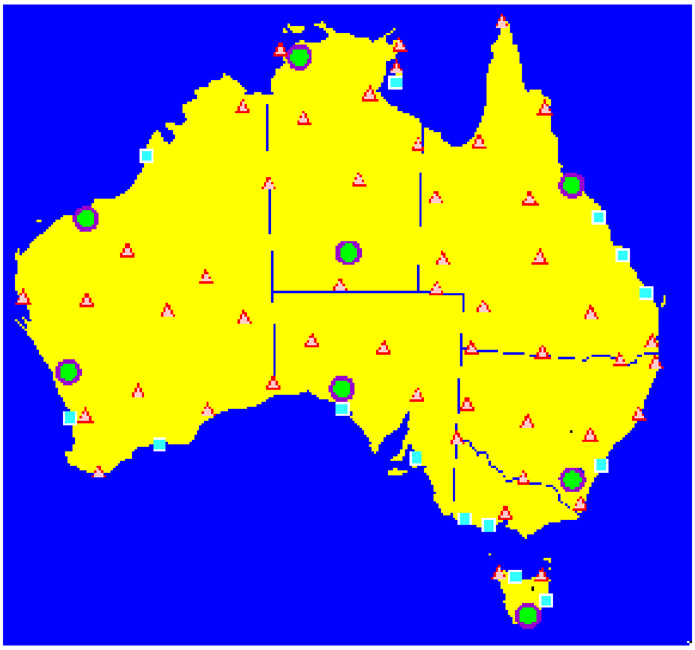
The GPS data were processed using in-house software developed by the Geodesy Group, Curtin University called SWAG (South West Australian GPS Software) (Stewart, *et al.*, 1997). The accuracy (95% confidence) of the adjusted STATEFIX coordinates is approximately 30 mm in plan and 50 mm in height (Stewart, 1998) with respect to the ANN. This in-house software applied some models and methods such as: using IGS precise orbits, Earth-body-tide modelling, antenna phase centre modelling, atmospheric modelling, ambiguity resolution and rigorous adjustment of simultaneously observed baselines. This software allows the user to take more control of the data and also provides advanced processing and modelling algorithms, which are not usually available in commercial software.

However, continual improvements in commercial GPS data processing software may enable people to achieve the same result as from scientific software under certain circumstances. Therefore, it is necessary to conduct research about the ability of GPS commercial software in processing long baseline data and determining positions with a high level of accuracy. This article will describe the ability of commercial software in processing long-baseline GPS data with high accuracy for regional geodetic networks. For that instance, Trimble Geomatics Office (TGO), one of the commercial GPS post-processing developed by Trimble Corporation, is used to reprocess STATEFIX GPS data in Western Australia. The results of the TGO data processing will be compared with existing results from STATEFIX project to analyse the ability of this commercial GPS software to process long-baseline GPS data.

2. THE STATEFIX OVERVIEW

In 1996, the STATEFIX geodetic network was established to provide high-accuracy control points by using GPS techniques in Western Australia, and represents the densification of the

Australian Fiducial Network (AFN) and Australian National Network (ANN). For more clearly, the AFN and ANN can be seen in Figure 1.



AFN station

ANN station

Figure 1: Distribution of AFN and ANN
(*taken from http://www.auslig.gov.au/geodesy/argn/afngiff.htm*)

The STATEFIX was observed between March and November in 1996. In that year, the ionospheric disturbance was minimum due to the low in 1996 of the eleven-year sunspot cycle. This fact supports the best condition to avoid ionospheric observation bias. It consists of 228 baselines and because the vast area (over 2,500,000km^2), it is divided into 9 cells for the purposes of observation and processing. The diagram of the STATEFIX can be seen in Figure 2.

The STATEFIX GPS data were processed at Curtin University using the in-house software called SWAG (South West Australian GPS) GPS processing software suite, and GEOLAB for the network adjustment**.** The results of are classified into two groups, horizontal and vertical. The relative horizontal or plan error (95% confidence) for all baselines is at the sub-cm level, indicating excellent internal precision for all the individual cell adjustments. On the other hand, vertical error in general, has magnitude of the mean height error is 1-3cm for smaller cells, but between 4 and 9cm for cells with longer baselines and the accuracy of the adjusted STATEFIX station coordinates within the ANN can achieve approximately 1cm in horizontal and 3cm in vertical using 95% confidence level (Stewart, *et al.*, 1997).

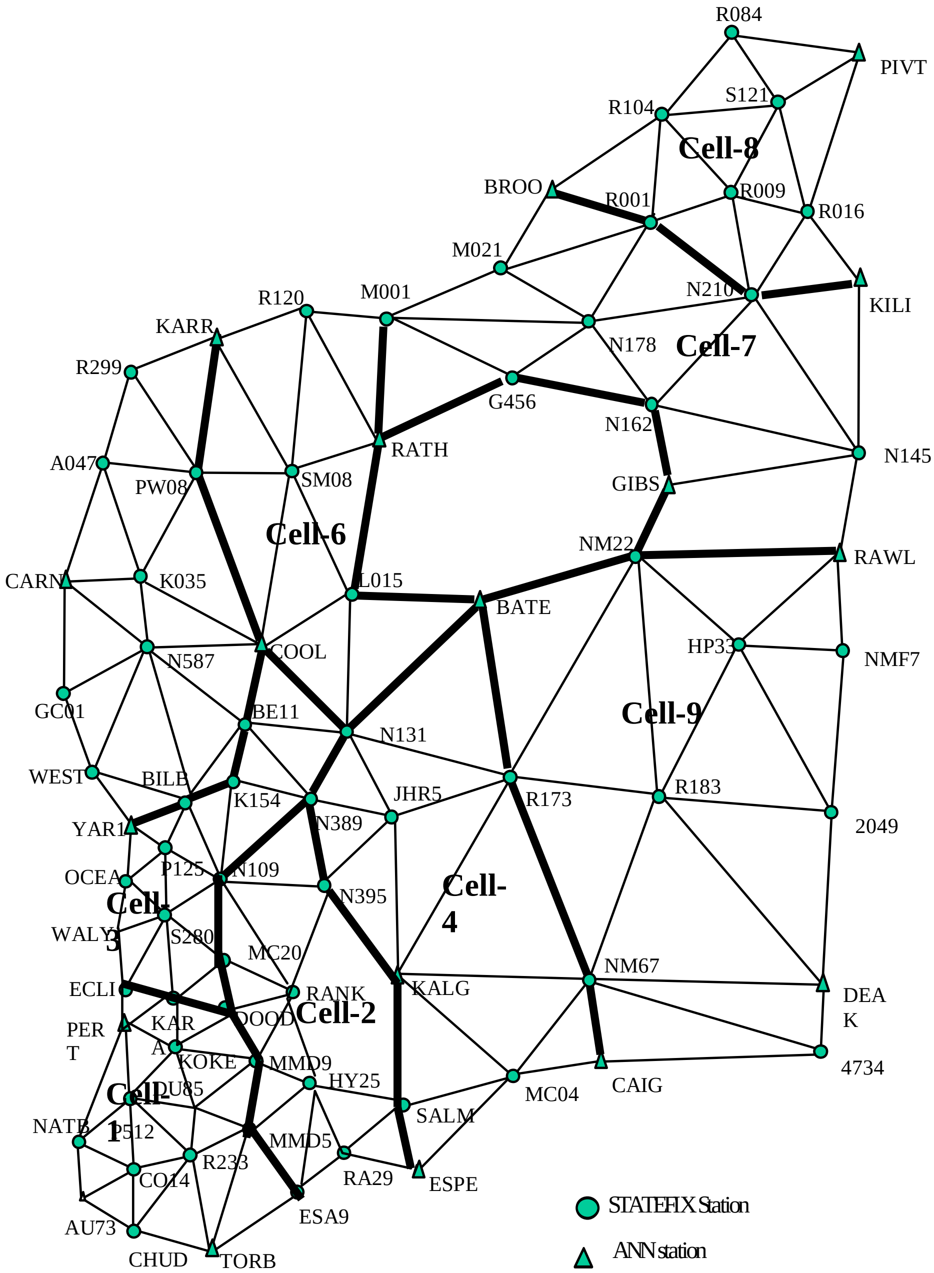


Figure 2: The STATEFIX Network Diagram

3. METHODOLOGY

In reprocessing the STATEFIX GPS data using commercial GPS data processing software, some methods and procedures are applied such as:

- Individual cell processing (cell by cell)
- Use precise ephemeris from IGS (International GPS Service) file to achieve better quality (Heroux and Kouba, 1995).
- Use antenna phase centre values from STATEFIX data documentation

- Define and choose only independent baseline that will be processed.
  The STATEFIX project occupied minimum three receivers simultaneously, and it means there are a total R(R-1)/2 possible baselines with R = number of receiver, and (R-1) independent baselines. It is applied to avoid baseline correlation, whereas commercial GPS cannot handle this problem (e.g. Han and Rizos, 1995).
- Configure GPS baseline processing styles.
  The configurations of baseline processing styles are:
  - Elevation mask is set to 15 degrees
  - Using fixed solution (ionosphere free) with wide-lane frequency type
  - The wide lane frequency type is a combination of L1 - L2 and has long wavelength (around 86cm) that suitable for long baseline and the ambiguity is easily resolved. Since, ionospheric biases are still present, an ambiguity-fixed solution must be conducted (Rizos, 1999).
  - Apply Saastamoinen model for the tropospheric correction and set default value of 2 hours interval for zenith delay estimation from observed meteorology data.
- Configure network adjustment styles, by choosing a 95% confidence level and 2mm set-up errors for antenna height error and centering error.
- Network adjustment strategy is minimally constrained to one control point for each cell.
- Check quality indicator, such as RMS for observation residuals, number of rejected observations, residual statistical test, and variance and covariance matrix solution (Rizos, 1999).

4. GPS BASELINE PROCESSING RESULTS

After individual cell baseline processing follows the procedures and methods above, GPS baseline processing summary results can be seen in Table 1 and summary of GPS loop closures can be seen in Table 2.

	No. of Baseline	Baseline Length (km)			RMS (m)			Mean Ratio	Mean Ref. Variance
		Mean	Max	Min	Mean	Max	Min		
Cell-1	34	117.672	212.526	45.371	0.0105	0.019	0.006	26.1540	0.9692
Cell-2	24	155.077	246.492	90.455	0.0095	0.015	0.005	29.0395	0.7662
Cell-3	25	153.669	283.687	87.060	0.0120	0.025	0.008	12.0800	1.0930
Cell-4	21	231.845	381.085	108.115	0.0138	0.038	0.007	20.5176	1.9710
Cell-5	28	201.419	284.170	116.005	0.0116	0.018	0.006	54.4183	1.1816
Cell-6	17	244.913	331.835	164.468	0.0092	0.023	0.006	24.9939	0.8030
Cell-7	24	268.960	402.626	124.522	0.0100	0.031	0.005	56.4265	1.0949
Cell-8	21	232.269	331.937	137.025	0.0156	0.056	0.006	13.1936	3.1717
Cell-9	27	285.693	393.750	101.597	0.0136	0.031	0.006	15.4829	1.7822

Table 1: Summary of GPS Baseline Processing Results

	Number of Loops	Average Length (m)	Delta Horizontal (m)			Delta Vertical (m)		
			Average	Best	Worst	Average	Best	Worst
Cell-1	20	351577.936	0.010	0.001	0.019	0.003	0.000	0.035
Cell-2	13	478307.012	0.006	0.001	0.010	0.002	0.000	0.071
Cell-3	7	491553.977	0.015	0.001	0.035	-0.011	0.002	-0.072
Cell-4	11	718436.416	0.003	0.027	0.088	0.009	0.002	0.103
Cell-5	14	639023.875	0.013	0.001	0.042	0.003	0.001	0.374
Cell-6	9	726740.507	0.014	0.002	0.040	-0.026	-0.002	-0.127
Cell-7	11	842350.268	0.011	0.003	0.028	-0.003	-0.001	-0.360
Cell-8	10	677211.387	0.046	0.002	0.293	-0.058	0.002	-0.279
Cell-9	12	851934.252	0.029	0.003	0.085	-0.001	0.000	-0.077

Table 2: Summary of GPS Loop Closures

The relation of baseline length and RMS value can be seen in Figure 3.

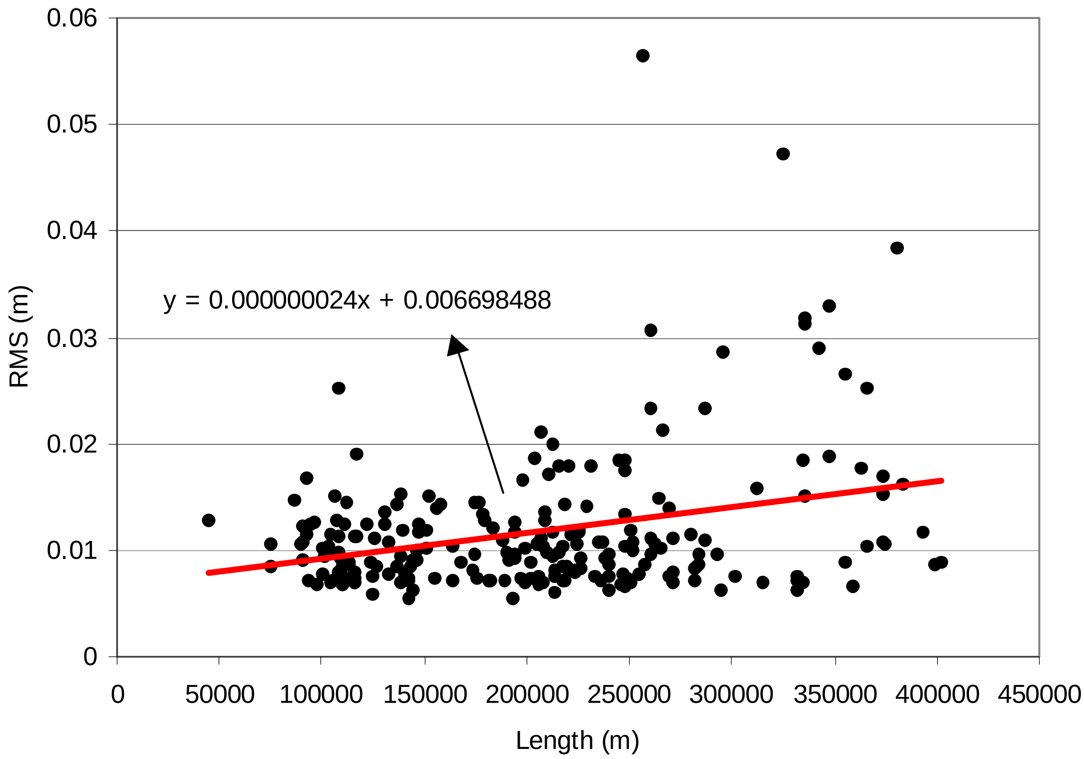


Figure 3: Baseline Length and RMS Value

As can be seen in Figure 3 above, baseline length range is roughly between 50km and 450km with RMS value between 0.005m and 0.06m. The mean of baseline length and RMS value is 205km and 0.0117m respectively. The RMS expresses the accuracy of baseline measurement. It is the radius of the error circle within which approximately 70% of position fixes are found. It can be said that based on Trimble Geomatics Office software, the STATEFIX GPS observation is reliable. It is accepted if RMS value below 0.1 cycles (Rizos, 1999). In this project, widelane observable is applied and the wavelength becomes 86cm, therefore it means

8.6cm is the tolerance value. The only way to improve the quality of GPS baseline processing in Trimble Geomatics Office is by editing the satellite observations data. The fact is by disable some information from certain satellites usually increase reference variance. However it can reduce RMS value if it is applied to right data such as to eliminate multipath and cycle slips.

5. GPS NETWORK ADJUSTMENT

The result of STATEFIX network adjustment using Trimble Geomatics Office is varying in precision, however, all points have precision in centimeter levels. The interesting point in this project is the error ellipse seems like a circle and it means the precision is equal and comparable in both (North and East) directions and the geometric network is well developed. Figure 4 illustrates the graph of point plan absolute error using 95% confidence level.

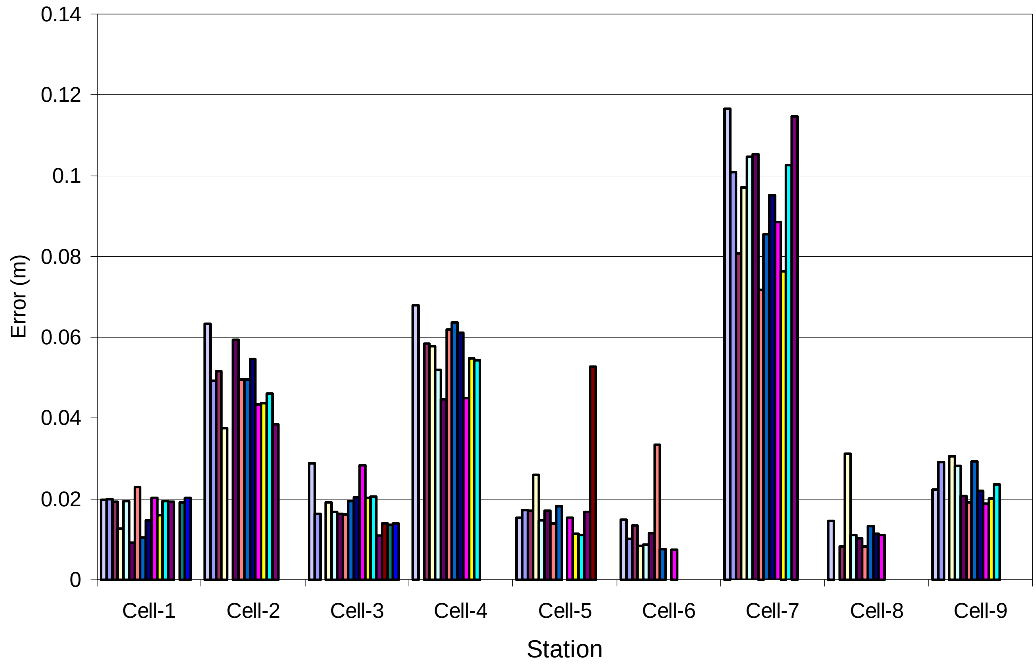


Figure 4: Point Plan Absolute Error (95% Confidence Level)

As can be seen in Figure 4, the maximum point error in horizontal is 0.12m and the mean value is 0.0275m with 95% confidence level. The higher point errors are found in Cell-7, but the rest of point errors seem relative good and under 8cm in precision. In ellipsoidal height, the maximum absolute error is 0.273m an the mean is 0.0635m. The distribution of point height absolute error can be seen in Figure 5.

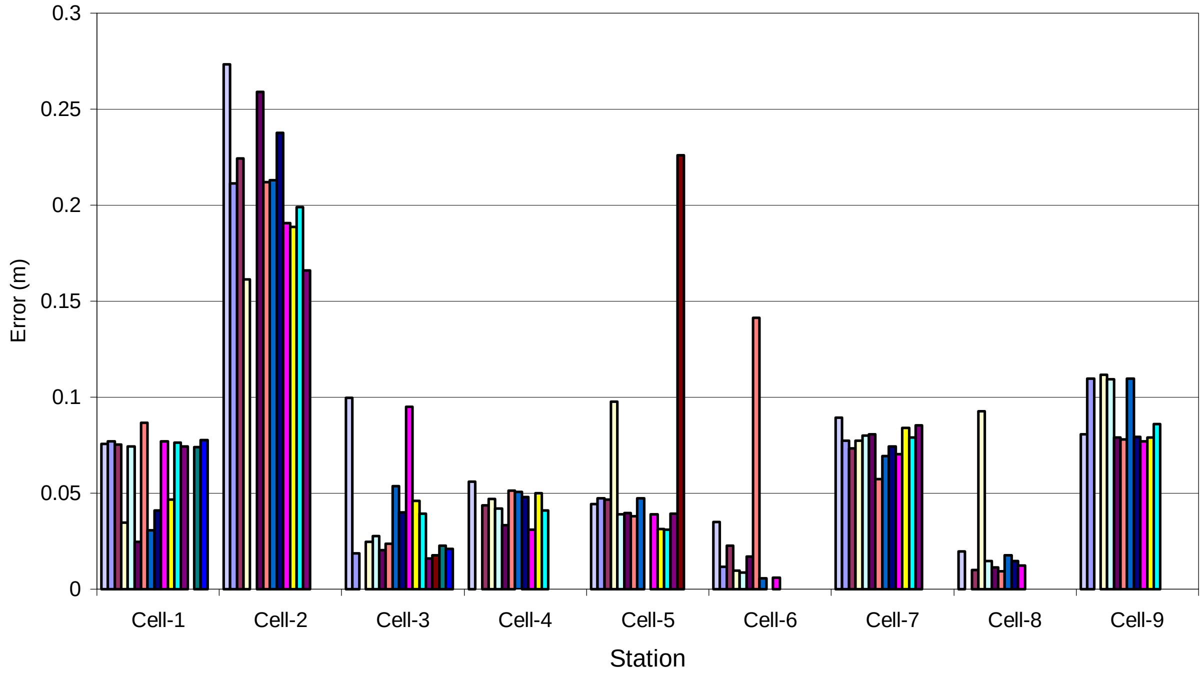


Figure 5 Point Height Absolute Error

Another consideration in this project is whole network adjustment. The mean horizontal error is 0.015m and 0.043m for vertical; therefore 0.0455m for slope distance. The absolute error of whole network adjustment is better than absolute error of individual cell adjustment. However, the results of whole network adjustment come from weighting strategy that scaling the network reference factor by different scalar.

	Individual Cell Network Adjustment		Whole network Adjustment	
	Horizontal (m)	Vertical (m)	Horizontal (m)	Vertical (m)
Mean	0.0288	0.0457	0.0156	0.0427
Minimum	0	0	0	0
Maximum	0.1166	0.2260	0.0212	0.0584
Std. Deviation	0.0278	0.0366	0.0029	0.0067

Table 3: Comparison of Statistic Values of Point Absolute Error

6. COMPARISON TO THE STATEFIX COORDINATES

The STATEFIX true coordinates are compared to the result of this project. The maximum value of horizontal differences is 0.0569m; mean is 0.0374m with and standard deviation is 0.0102m. On the other hand, the maximum value of height differences is 0.2293m, mean is 0.1534 and standard deviation is 0.0392m. After calculation, the coordinate differences between STATEFIX and whole network adjustment in this project can be seen in Table 4

	Horizontal (m)	Height (m)	Slope Distance (m)
Mean	0.0380	0.1534	0.1587
Minimum	0.0065	0.0000	0.0065
Maximum	0.0610	0.2293	0.2348
Std. deviation	0.0100	0.0392	0.0378

Table 4: Descriptive Statistics of Coordinate Differences between STATEFIX and The Project Results

The horizontal and height differences can be seen in Figure 6 and Figure 7.

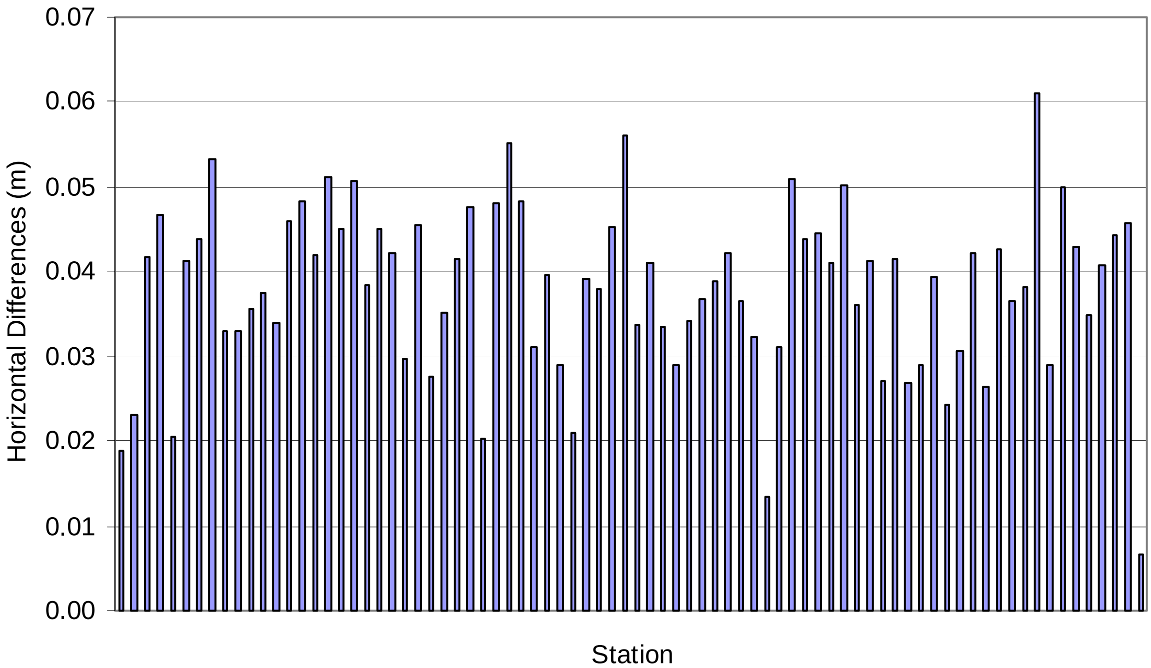


Figure 6: Horizontal Coordinate Differences

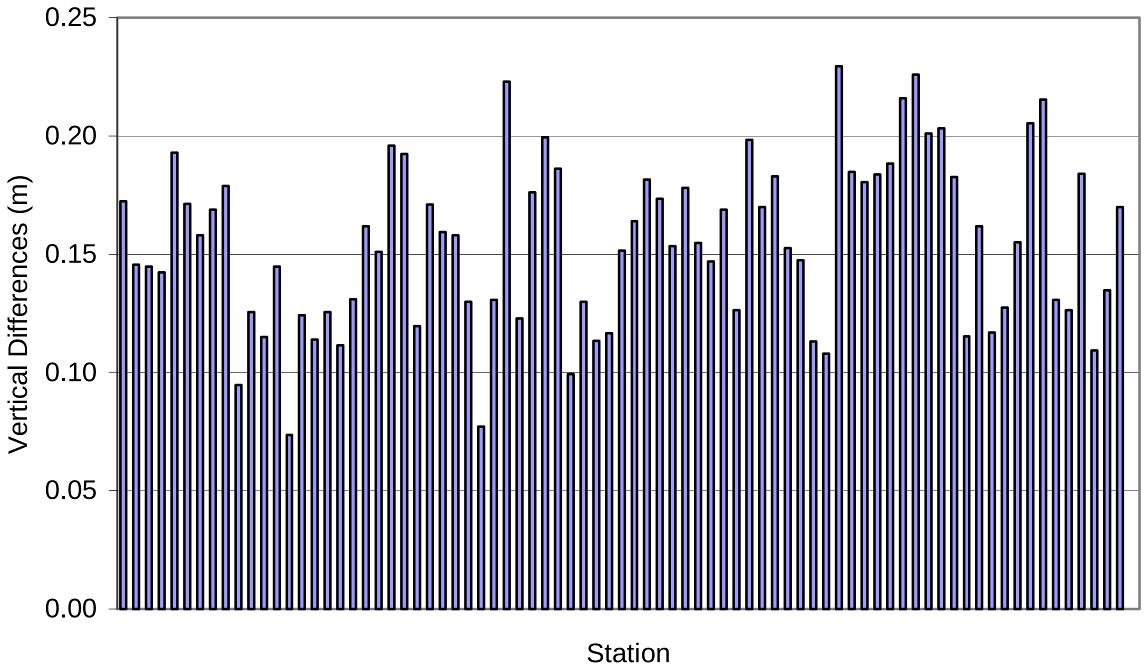


Figure 7: Vertical Coordinate Differences

7. ANALYSIS

Statistical hypothesis to determine the effectiveness of coordinate results from whole network adjustment compare to STATEFIX coordinates.

H_0 = Project coordinates is comparable to STATEFIX coordinates or Error distance $\leq \sigma^2$
H_1 = Project coordinates is not comparable to STATEFIX coordinates or Error distance $> \sigma^2$; therefore one tail test must be conducted.

The hypothesis will be tested using χ^2 (chi-squared) test, it concerns to variance of this project results whether the variance of project results is still under uncertainty tolerance, and also the error is assumed normally distributed. The confidence level is assumed 95% or $\alpha = 0.05$. There are 80 stations, so degree of freedom is 79. From the table, there is only value for sample 80 = 60.312

The formula $\chi^2 = \left(\dfrac{(n-1)s^2}{\sigma^2} \right)$;
where n = 80, s^2 = 0.00145 and $\sigma^2 = 0.03^2$ (from STATEFIX uncertainty estimation).

So, $\chi^2 = \left(\dfrac{(80-1)0.00145}{0.0009} \right)$ = 127.27; that lies in rejection area (>60.312).
The statistical test result reject H_0 or accept H_1, it means there is a significance difference between variance and STATEFIX uncertainty estimation.

8. CONCLUSIONS

Trimble Geomatics Office software with baseline processing module is proven can handle long baseline GPS data and can achieve millimeter level of sensitivity. However, there are also some weaknesses, such as: the inability to change segment type of occupation for example from Stop and Go to Static; the inability to identify baseline that is observed with Stop and Go method; and some features in the brochure such as precise earth rotation parameter, pole tide corrections and solid earth tide models cannot be found.

The results of STATEFIX data processing using GPS commercial software are: the mean RMS value is 0.0117m; mean ratio value is 28.5622; mean reference variance value is 1.3948; and the mean baseline length is 205.106km.

In network adjustment, all GPS baselines are processed with minimally constrain adjustment with 95% confidence level give quality results as mean of point absolute error is 0.0156m in horizontal and 0.0427m in vertical; and mean of point relative error is 0.009m in horizontal and 0.030m in vertical. Furthermore, point height absolute error is higher than point horizontal absolute error. Larger height error probably caused by the inability of Trimble Geomatics Office to model ocean tide loading, solid Earth tides or incorrect tropospheric modelling. Finally, reprocessing the STATEFIX geodetic network using commercial software gives a different result if compared to coordinate results by using scientific software. From statistical test, it can be said that the coordinate results from commercial software, are not comparable to STATEFIX coordinates.

REFERENCES

Gili, J. A., Corominas, J. and Rius, J. (2000) Using Global Positioning System Techniques in Landslide Monitoring, *Engineering Geology*, Vol. 55. pp. 167-192.

Han, S. and Rizos, C. (1995) Selection and Scaling of Simultaneous Baselines for GPS Network Adjustment, or Correct Procedures for Processing Trivial Baselines, *Geomatics Research Australasia*, Vol. 63, pp. 51-66.

Heroux, P. and Kouba, J. (1995) *GPS Precise Point Positioning with a Difference*, paper presented at Geomatics '95, Ottawa-Ontario, Canada, June.

Kenyeres, A. (1999) *Technology Development for GPS-Heighting in Hungary*, paper presented at the 5th International Seminar on GPS in Central Europe, Penc, Hungary, May.

Krakiwsky, E. J., Szabo, D. J., Vanicek, P. and Craymer, M. R. (1999) Development and Testing of In-Context Confidence Regions for Geodetic Survey Networks, Final Report. *Geodetic Survey Division-Geomatics Canada*, Ottawa, Canada, 24p.

Kuang, S. (1996) *Geodetic Network Analysis and Optimal Design: Concepts and Applications*, Sams Publication, Illinois, 368p.

Kulkarni, M. N. and Save, H. V. (1999) *Estimation of the Drift and Deformations of the Indian Plate using GPS Repeat Measurements*, Online Resource, Available at: http://www.gisdevelopment.net/application/geology/neotectonics/geon0001pf.htm

Lowry, A. R., Hamburger, M. W., Meertens, C. M. and Ramos, E. G. (2001) GPS Monitoring of Crustal Deformation at Taal Volcano, Philippines, *Journal of Volcanology and Geothermal Research*, Vol. 105, pp. 35-47.

Manning, J. and Harvey, W. (1992) A National Geodetic Fiducial Network, *The Australian Surveyor*, Vol. 37(2), pp. 87-90.

Michel, G. W., Yu, Y. Q., Zhu, S. Y., Reigber, C., Becker, M., Reinhart, E., Simons, W., Ambrosius, B., Vigny, C., Chamot-Rooke, N., Le Pichon, X., Morgan, P. and Matheussen, S. (2001) Crustal Motion and Block Behaviour in SE-Asia from GPS Measurement, *Earth and Planetary Science Letters*, Vol. 187, pp. 239-244.

Morgan, P., Bock, Y., Coleman, R., Feng, P., Garrard, D., Johnston, G., Luton, G., McDowall, B., Pearse, M., Rizos, C. and Tiesler, R. (1996) A Zero Order GPS Network for the Australian Region, *Report ISE TR 96/60*, University of Canberra, 183p.

Pan, M., Sjoberg, L. E. and Talbot, C. J. (2001) Crustal Movements in Skane, Sweden, between 1992 and 1998 as Observed by GPS, *Journal of Geodynamics*, Vol. 31, pp. 311-322.

Rizos, C. (1999) *Principles and Practice of GPS Surveying*, Online Resource, Available at: http://www.gmat.unsw.edu.au/snap/gps/gps_survey/principles_gps.htm.

Rossikopoulos, D., Fotiou, A., Livieratos, E. and Baldi, P. (1998) A Rigorous Analysis of GPS Data To Detect Crustal Deformations. Application in the Area of The Ionian Sea, *Tectonophysics*, Vol. 294, pp. 271-280.

Scherneck, H. G., Johansson, J. M., Mitrovica, J. X. and Davis, J. L. (1998) The BIFROST Project: GPS Determined 3-D Displacement rates in Fennoscandia from 800 days of Continuous Observations in the SWEPOS Network, *Tectonophysics*, Vol. 294, pp. 305-321.

Seeber, G. (1993) Satellite Geodesy, Foundations, Methods and Applications, Walter de Gruyter, Berlin, 531p.

Spiess, F. N., Chadwell, C. D., Hildebrand, J. A., Young, L. E., Purcell Jr, G. H. and Dragert, H. (1998) Precise GPS/Acoustic Positioning of Seafloor Reference Points for Tectonic Studies, *Physics of the Earth and Planetary Interiors*, Vol. 108, pp. 101-112.

Stewart, M. P. (1998) How Accurate is the Australian National GPS Network as a Framework for GPS Heighting?, *The Australian Surveyor*, Vol. 43, No. 1, pp.53-61.

Stewart, M. P. (1998), The Application of Antenna Phase Centre Models to the West Australian State GPS Network, *Geomatics Research Australasia*, Vol. 68, pp.61-78.

Stewart, M. P., Houghton, H. and Ding, X. (1997) *The STATEFIX West Australian GPS Network*, paper presented to the IAG Scientific Assembly, Rio de Janeiro, Brazil, September.

Stewart, M.P., Ding, X., Tsakiri, M. and Featherstone, W. E. (1997) *1996 Statefix Project*, Final Report. Report Submitted to DOLA by the School of Surveying and Land Information, May

Trimble Geomatics Office, (2001) *Technical Notes*, Online Resource, Available at: http://www.trimble.com

Sun, W. and Sjoberg, L. E. (2001) Permanent Components of the Crust, Geoid and Ocean Depth Tides, *Journal of Geodynamics*, Vol. 31, pp. 323-339.

Wylde, G. P. and Featherstone, W. E. (1995) An Evaluating Some Stop and Go Kinematic GPS Survey Options, *The Australian surveyor*, Vol. 40, No. 3, pp.205-212.

Xu, G. and Knudsen, P. (2000) Earth Tide Effects on Kinematic/Static GPS Positioning in Denmark and Greenland, *Physics and Chemistry of the Earth (A)*, Vol. 25(4), pp. 409-414.

Zielinski, J. B. and Zdunek, R. (1999) GPS Orbit Accuracy and Its Influence on Large Network Solution, *Advances in Space Research*, Vol. 23(4), p. 665.

Department of Spatial Sciences, Curtin University of Technology

CONTACTS

Agustan
Research staff at Center of the Assessment and Application of Technology for Natural Resources Inventory (P3-TISDA)
BPP Teknologi, Jakarta
INDONESIA
Tel. + 62 21 316 8914 (office hour, GMT +7)
Fax + 62 21 391 8066
Email: agustan@bppt.go.id