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# Validation of GNSS processing results from some commercial software packages under un-advantageous conditions

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**Abstract**

We have analyzed the processed results of 67 GNSS independent baselines less than 12km in Hai Duong province, Vietnam by using various commercial software packages. These baselines are collected from 30 sessions with 2-4 GNSS receivers. Under un-advantageous conditions such as poor satellite constellation, strong multipath and ionospheric effects, some of baselines have errors of decimeter level although they still have good quality indicators: fixed ambiguity status and RMS values of baselines at centimeter level. Our further examinations show that even checking closure errors on these baselines is not sufficient to detect the baseline biases. There are some ways to minimize risk are recommended in conclusion.

*Keywords:* GNSS; Validation; Commercial software packages;

## 1. Introduction

In order to validate results from processing GNSS, the Vietnam national technical specification for establishing cadastral map in 2014 [1] has claimed that:

- The acceptable single baseline processing results must be fixed solution, RATIO ≥ 1.5 and RMS ≤ 20mm+4ppm.
- Relative closure errors $f_S/\Sigma S \leq 10$ppm

Where $f_S = \sqrt{f_{\Delta X}^2 + f_{\Delta Y}^2 + f_{\Delta Z}^2}$, $f_{\Delta X} = \sum_{i=1}^{n} \Delta X_i$, $f_{\Delta Y} = \sum_{i=1}^{n} \Delta Y_i$, $f_{\Delta Z} = \sum_{i=1}^{n} \Delta Z_i$

$\Delta X_i$, $\Delta Y_i$, $\Delta Z_i$ are the i[th] baseline components of the checking polygon

According to the Vietnam technical measuring and processing GPS data in engineering surveys in 2012 [2]:

- The acceptable single baseline processing results must be fixed solution, RATIO ≥ 2.0.
- Relative closure errors must be less than the values given in the table below

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Table 1. Allowable relative closure errors

| n | D, km | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 0.1 | 0.15 | 0.20 | 0.50 | 1.00 | 2.00 | 3.00 | 4.00 |
| 3 | 1:8 160 | 1:12 200 | 1:16 300 | 1:16 300 | 1:80 000 | 1:151 600 | 1:210 000 | 1:255 000 |
| 4 | 1:9 430 | 1:14 100 | 1:18 800 | 1:46 900 | 1:92 400 | 1:175 000 | 1:242 500 | 1:294 500 |
| 5 | 1:10 500 | 1:15 800 | 1:21 000 | 1:52 400 | 1:103 400 | 1:195 700 | 1:271 200 | 1:329 200 |
| 6 | 1:11 500 | 1:17 300 | 1:23 000 | 1:57 400 | 1:113 200 | 1:214 400 | 1:297 000 | 1:360 700 |

Where:
D - is the medium length and
n - is the number of baselines in the checking polygon

Most recently, the Vietnam technical specification for topographic surveying published in 12/2015 [8] has confirmed that:

- The acceptable single baseline processing results must be fixed solution.
- Relative closure errors must be less than the values given in the table below

Table 2. Allowable relative closure errors

| $\Sigma S$ (km) | 5-10 | 10-25 | 25-50 | >50 |
|---|---|---|---|---|
| $f_S/\Sigma S$ (ppm) | 100/7 | 100/10 | 100/15 | 100/30 |

In general, validation of a GNSS solution is usually bases on three factors: solution status, root-mean-square value of carrier phase measurement residuals (RMS) and relative closure errors. RATIO denotes the ratio between squared norms of ambiguity residuals of the second-best and the best integer solution respectively. RATIO is usually used because it is implemented in some Trimble software packages which are the most popular in Vietnam. These technical requirements are also similar to other countries around the world.

Under normal conditions, by using commercial software packages a GNSS solution, which passes all of the four above tests, should be considered a reliable solution. However, under adverse conditions such as poor satellite constellation, strong multipath and ionospheric effects, some of the baselines which still give good quality indicators have errors of decimeter level. This is a dangerous situation, since it affects the whole network and can cause a bias at decimeter level in point position.

In this paper, we demonstrate the mentioned cases on a specific network and finally recommend some solutions to reduce the risk.

## 2. Data collection and processing

Our testing data are 67 independent GNSS baselines from Hai Duong cadastral network (figure 1) within 9 days in 2014. The baseline length varies from 2.2km to 11.3km. In the campaign, four Trimble R8 receivers were used for baseline measurement. The interval of 15 seconds is set up for all the receivers and the session length is approximately 1.5 hours.

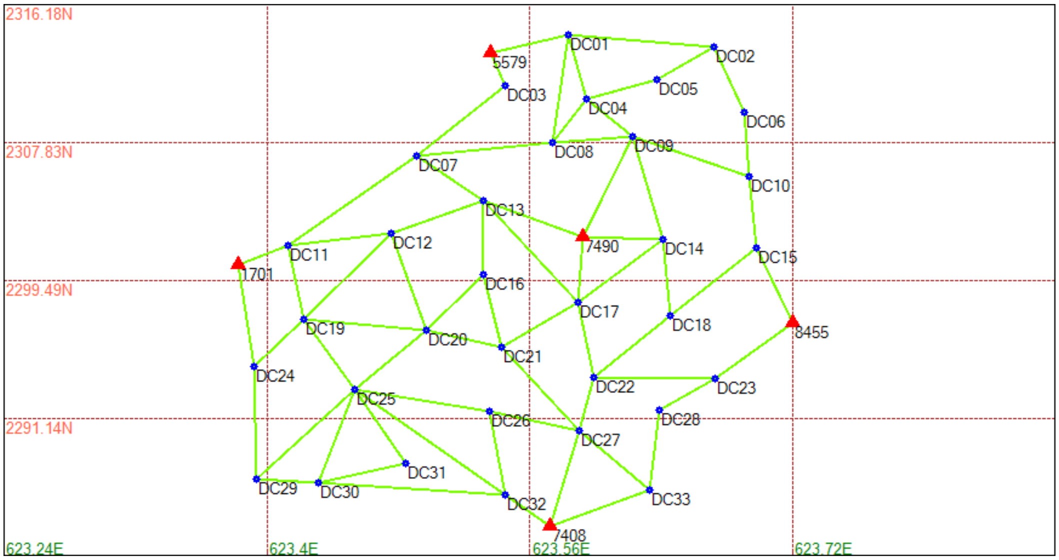


Fig. 1. Hai Duong GNSS cadastral network

For processing, we used two commercial software packages: Trimble Business Center V2.00 (TBC) [6] and Leica Geomatics Office V5.0 (LGO) [7], and one scientific software package GAMIT [3]. The GAMIT results are considered as ‘precise’ to check the results of the other software packages. Some processing options are given in table 3

Table 3. Setting up some processing options

| Contents | Values |
|---|---|
| Observation type used in the processing | Carrier phase L1 |
| Elevation cutoff angle | 10° |
| Satellite systems | GPS+GLONASS (GPS only for GAMIT) |
| Atmospheric delay estimation | Does not apply |
| Satellite ephemerides | Broadcast ephemerides |

### *2.1. TBC processing results*

In comparisons between TBC and GAMIT single baseline results we found 3 baselines which have deviations of more than 1 dm in absolute or 10ppm in relative terms. DC13-DC16 and DC13-DC17 are in the same session. Comparison between TBC and GAMIT on these baselines is given in table 4.

Table 4. Comparison between TBC and GAMIT on baselines with large deviations

| Baseline | ΔX | ΔY | ΔZ | ΔN | ΔE | ΔU | Solution | RMS | RATIO |
|---|---|---|---|---|---|---|---|---|---|
| DC13-DC16 | -0.316 | +0.001 | +0.013 | -0.018 | +0.303 | +0.088 | L1 Fixed | 0.014 | 2.093 |
| DC13-DC17 | -0.348 | +0.012 | +0.002 | -0.035 | +0.331 | +0.103 | L1 Fixed | 0.018 | 2.412 |
| DC12-DC20 | -0.082 | +0.028 | -0.014 | -0.030 | +0.071 | +0.042 | L1 Fixed | 0.012 | 2.217 |

In table 4, we can see these baselines have good quality indicators. However, they have large deviations from the GAMIT results. Especially, DC13-DC16 and DC13-DC17 have similar deviations (~0.3dm in East component).

We continue checking closure errors of the network. For polygons containing only one of the above baselines, we easily detect because of their large values of closure errors (for example, the second line of table 5). The closure error of polygon containing both of DC13-DC16 and DC13-DC17 is within allowable value and no sign for including gross error (the third line in table 5).

Table 5. Closure errors of some polygons

| Polygon | $f_{\Delta X}$ | $f_{\Delta Y}$ | $f_{\Delta Z}$ | $f_S$ | ΣS (m) | $f_S/\Sigma S$ |
|---|---|---|---|---|---|---|
| DC13-DC17-DC11-DC13 | +0.331 | +0.050 | +0.028 | 0.336 | 18800.1 | 1/55965 |
| DC13-DC16-DC21-DC17-DC13 | +0.069 | +0.033 | +0.020 | 0.079 | 22832.9 | 1/288816 |

### *2.2. LGO processing results*

When using L1 observations, there were some single baselines processing results with floating status. Hence we turned to use L1+L2 option which gives us more fixed solutions. In comparisons between LGO and GAMIT single baseline results, we found 9 baselines which have deviations of more than 1 dm in absolute or 10ppm in relative terms. Where, we emphasize, 7490-DC14 and 7490-DC17 are in the same session. Comparison between LGO and GAMIT on these baselines is given in table 6.

Table 6. Comparison between LGO and GAMIT on baselines with large deviation

| Baseline | ΔX | ΔY | ΔZ | ΔN | ΔE | ΔU | Solution | RMS |
|---|---|---|---|---|---|---|---|---|
| 1701−DC24 | -0.316 | +0.233 | +0.073 | -0.036 | -0.392 | +0.064 | L1+L2 Fixed | 0.008 |
| DC19−DC24 | -0.139 | -0.162 | +0.080 | -0.147 | -0.157 | +0.076 | L1+L2 Fixed | 0.004 |
| DC02−DC06 | +0.094 | +0.345 | -0.111 | -0.338 | 0.000 | +0.162 | L1+L2 Fixed | 0.004 |
| DC06−DC10 | +0.018 | +0.367 | +0.013 | +0.239 | -0.195 | +0.200 | L1+L2 Fixed | 0.010 |
| DC28−DC33 | -0.059 | +0.034 | -0.171 | +0.124 | +0.007 | -0.136 | L1+L2 Fixed | 0.006 |
| DC13−DC16 | -0.011 | +0.017 | +0.143 | -0.082 | +0.007 | -0.119 | L1+L2 Fixed | 0.013 |
| 7490−DC14 | +0.200 | +0.154 | +0.139 | -0.044 | +0.110 | -0.263 | L1+L2 Fixed | 0.007 |
| 7490−DC17 | +0.250 | +0.177 | +0.125 | -0.011 | +0.122 | -0.307 | L1+L2 Fixed | 0.006 |
| DC24−DC29 | +0.060 | +0.240 | +0.012 | -0.032 | -0.243 | +0.035 | L1+L2 Fixed | 0.006 |

In table 6, all of the baselines also have good quality indicators. Especially, 7490-DC14 and 7490-DC17 have similar deviations of baseline components.

We continue checking closure errors of the network. For polygons containing only one of the above baselines, we easily detect because of their large values of closure errors (for example, the second line of table 7). The closure error of polygon containing both of 7490-DC14 and 7490-DC17 is within allowable value and no sign for including gross error (the third line in table 7).

Table 7. Closure errors of some polygons

| Polygon | $f_{\Delta X}$ | $f_{\Delta Y}$ | $f_{\Delta Z}$ | $f_S$ | ΣS | $f_S/\Sigma S$ |
|---|---|---|---|---|---|---|
| 7490-DC17-DC13-7490 | +0.236 | +0.202 | +0.161 | 0.350 | 18799.8 | 1/53714 |
| 7490-DC17-DC14-7490 | +0.046 | -0.032 | -0.092 | 0.108 | 15187.4 | 1/140627 |

## 3. Analyzing the problem

Under adverse conditions such as poor satellite constellation, strong multipath and ionospheric effects, some commercial software packages do not always give GNSS solution with the correct solution status. Positioning accuracy is typically achieved from mm-cm for fixed solutions and dm-m for floating solutions (figure 2). With an error of decimeter level, the baseline solutions in table 4 and table 6 cannot be of fixed status. However, this “wrong fixed” situation unfortunately cannot be detected by checking RATIO or RMS values.

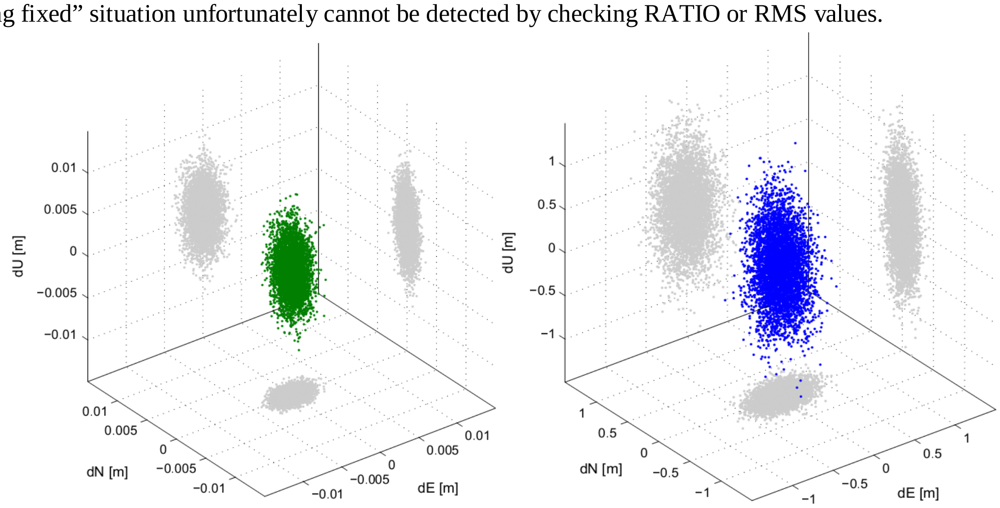


Fig. 2. Positioning accuracy for fixed solutions (left) and floating solutions (right), accepted from [4]

One of the most popular ways to address this problem is judging by the closures of the spatial polygons formed by independent baselines for each component of dimensional coordinates. However, this way is only effective when baselines forming the polygon are measured from different sessions or in the same session without common point (right part of figure 3). The common point of problems mentioned in section 2 is to check polygons containing bad baselines from the same point in the same session (left part of figure 3). At that, even where a closure error is close to zero, the possibility of bad or even gross mistakes cannot be excluded when determining the baseline parameters.

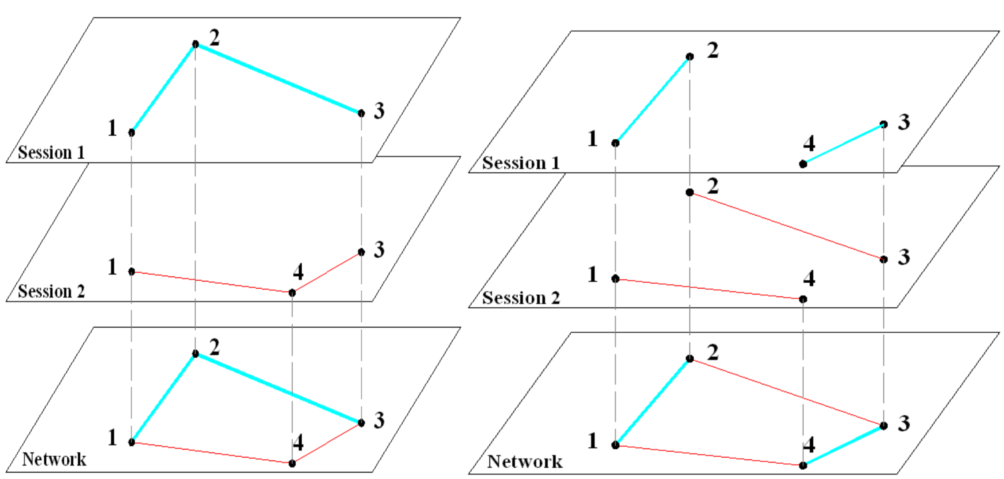


Fig. 3. Demonstration of undetectable (left) and detectable (right) cases when checking closure errors

To explain the problem, we consider the linearized double difference carrier phase equations as following [5]:

$$y = Bb + Aa + e \tag{1}$$

where:
y - is the vector of observed minus computed double difference carrier phase measurements
b - is the vector contains the *u* baseline coordinates $b \in R^u$
a - is the vector of n double difference ambiguities $a \in Z^n$
B - is the m×u design matrix for the baseline coordinates
A - is the m×n design matrix for the ambiguities
e - is the vector of unmodelled effects and measurements noise

The variance-covariance matrix of observables y is $Q_y$, that is symmetric and positive definite

By using the least squares method, we receive the estimates $\begin{pmatrix} \hat{b} \\ \hat{a} \end{pmatrix}$ and the variance-covariance matrix as

$$\begin{pmatrix} Q_{\hat{b}} & Q_{\hat{b}\hat{a}} \\ Q_{\hat{a}\hat{b}} & Q_{\hat{a}} \end{pmatrix} = \begin{pmatrix} B^T Q_y^{-1} B & B^T Q_y^{-1} A \\ A^T Q_y^{-1} B & A^T Q_y^{-1} A \end{pmatrix}^{-1} \tag{2}$$

The ambiguity resolution is to consider $\min \left\| \hat{a} - a \right\|^2_{Q_{\hat{a}}^{-1}}$. This minimization yields the integer estimate $\breve{a}$ for the vector of ambiguities. The final solution with the fixed ambiguities is

$$\breve{b} = \hat{b} - Q_{\hat{b}\hat{a}} Q_{\hat{a}}^{-1} (\hat{a} - \breve{a}) \tag{3}$$

Assume that the ambiguity resolution of some commercial software packages is wrong. It means that vector $\breve{a}$ is biased by an amount of $\Delta\breve{a}$, so that

$$\breve{a} = \breve{a}' + \Delta\breve{a} \qquad \Delta a \in Z^n \tag{4}$$

Therefore $$\breve{b} = \breve{b}' + \Delta\breve{b} \tag{5}$$

Where $$\breve{b}' = \hat{b} - Q_{\hat{b}\hat{a}} Q_{\hat{a}}^{-1} (\hat{a} - \breve{a}') \text{ and } \Delta\breve{b} = Q_{\hat{b}\hat{a}} Q_{\hat{a}}^{-1} \Delta\breve{a} \tag{6}$$

$\Delta\breve{b}$ denotes a vector for the baseline biases due to the wrongly fixed ambiguities $\breve{a}$

Table 8. Matrices $Q_{\hat{b}\hat{a}} Q_{\hat{a}}^{-1}$ of baselines DC13-DC16 and DC13-DC17 for 15 minutes session

| Baseline name | Baseline components | PRN14-PRN22 | PRN14-PRN25 | PRN14-PRN31 | PRN14-PRN32 | PRN14-PRN16 | PRN14-PRN29 |
|---|---|---|---|---|---|---|---|
| DC13-DC16 | ΔX | -0.050 | +0.065 | -0.023 | +0.133 | +0.068 | +0.001 |
| | ΔY | +0.126 | -0.365 | +0.277 | -0.082 | -0.135 | -0.007 |
| | ΔZ | -0.075 | -0.069 | +0.136 | -0.005 | -0.080 | -0.002 |
| DC13-DC17 | ΔX | -0.058 | +0.046 | -0.008 | +0.130 | +0.067 | +0.016 |
| | ΔY | +0.150 | -0.257 | +0.199 | -0.084 | -0.113 | -0.099 |
| | ΔZ | -0.064 | -0.036 | +0.112 | -0.003 | -0.077 | -0.028 |

a) For short baselines located closely, when using the same software for processing, we will have:
- The similar values of $Q_y$, which are usually modelled following the same function of satellite elevation angles
- The same satellite combination leads to the same matrix B
- The similar relative position between satellites and receivers leads to the similar matrix A.

From the above reasoning and paying attention to (2), it finally leads to their similar values of $Q_{\hat{b}\hat{a}} Q_{\hat{a}}^{-1}$. Table 8 demonstrates this by computing $Q_{\hat{b}\hat{a}} Q_{\hat{a}}^{-1}$ of baselines DC13-DC16 and DC13-DC17.

b) Furthermore, if these baselines:
- To be measured in the same session.
- To have the common point, whose GNSS data are under adverse conditions, which may cause problems for the cycle slip reparation and ambiguity resolution. As a result, their ambiguity biases $\Delta\breve{a}$ potentially have similar values as well.

When the both a) and b) are satisfied at the same time, the baseline biases are nearly the same. Therefore, it is most likely that during processing of all or a part of baselines, obtained from one and the same observation at any of the points, repeated or similar mistakes can be made in connection with failed ambiguity resolution. In such a case, gross closure errors in baselines can go undetected.

## 4. Conclusions and recommendation

We have presented in this paper the problem of validating GNSS processing results by using some commercial software packages. By demonstration on the Hai Duong cadastral network, we have reached some conclusions:

- Under adverse conditions such as poor satellite constellation, strong multipath and ionospheric effects, some commercial software packages do not always produce GNSS solutions with the correct solution status. The "wrong fixed" solution cannot be detected by checking RATIO test or RMS values.
- Judging closures of the spatial polygons is only effective when baselines forming the polygon are measured from different sessions or in the same session without common point. Gross closure errors in baselines can go undetected when polygons containing pairs of bad baselines in the same session are from the same point.

From the above problem, we recommend some ways to reduce the risk with GNSS data measured under adverse conditions:

- Design networks to consist of as many polygons as possible. In each polygon, avoid having pairs of baselines in the same session and from the same point.
- Use some different software packages to process and compare the results against each other. Encourage the use of scientific software.

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