ACCURACY ANALYSIS OF GNSS (GPS, GLONASS AND BEIDOU) OBSEVATION FOR POSITIONING

Khomsin[1,*], *Ira* Mutiara Anjasmara[1], *Danar* Guruh Pratomo[1], and *Wahyu* Ristanto[1]

[1]Geomatic Engineering Department, ITS Surabaya, Indonesia

Abstract. Global Navigation Satellite System called GNSS is a term used for the entire global navigation that already operate or are in the planning for the future. Some of the satellite that can be used are GPS (Global Positioning System) operated by USA, GLONASS (Global Navigation Satellite System) operated by Rusia and BeiDou/Compass operated by China. Many errors and biases that occur when measuring with GNSS in the field. Theoritically, there are some errors and biases that can be eliminated or subtracted by strength of satellite geometric. One factor to get a good satellite geometric is to increase the number of satellites received by receiver. In general, the more number of satellites received, the better the geometric satellites received by receivers. The development of receiver technology is currently able to capture GPS, GLONASS and BeiDou signals at one time. Thus the receiver can receive many satellites and finally the shape of geometric satellite becomes better. HiTarget V30 is one of the latest GNSS technology on the market today. This receiver is capable of receiving GPS signals, GLONASS and BeiDou at one time of observation. This research will compare the accuracy of positioning using GPS, GLONASS and BeiDou satellite.

1 Introduction

Recently, the technology of satellite navigation is continuously increasing in number of new applications. A few decades ago, many applications that were just a dream are becoming reality today and the potential applications coverages has grown significantly over the last few years. The unprecedented social, economic, technological and environmental benefits to be gained through these applications are becoming very clear [1].

Global Navigation Satellite System called GNSS is a term used for the entire global navigation satellite system that already operate or are in the planning [2]. Some of which are GPS, GLONASS, Galileo, BeiDou, IRNSS, dan QZSS satellite system. The use of GNSS make the extraterrestrial survey easier and will give better precision. GNSS can not only be used world-wide, all weather and all times but also can be used to determine precise position to all manner of user especially for surveying and geodetic applications [3].

A GNSS receiver calculates position based on data received from satellites. However, there are many sources of errors that, if left uncorrected, cause the position calculation to be inaccurate. Some of these errors, such as those caused by the refraction of the satellite signal as it passes through the ionosphere and troposphere, multipath, cycle slip, orbit, satellite clock and receiver noise [4]. The accuracy of positioning from a GNSS survey will generally depend on 4 (four) factors, namely: the accuracy of the data used, the observation geometry, the observation strategy used, and the data processing strategy. The accuracy of the data used will basically depend on three factors, namely: data type (pseudo range or phase), the quality of the receiver, and the level of error and bias affecting the observation data [5].

The observation geometry includes the observer geometry (network) and satellite geometry that depends on the number of satellites, locations, and distribution of satellites received. Theoretically, the more satellites received, the better satellite geometry [2][6]. The evolving receiver technology can overcome the error of less satellite geometry when retrieving data.

According to [7], GNSS signal combination which is between BeiDou signals (B1 and B2) and GPS signals (L1 and L2) has produced x, y, and z coordinates with better accuracy and precision. The combination of GPS signals and GLONASS signals [6] can increase accuracy up to millimeter order for short baselines and order centimeters for long baselines. In this research we will analyze the use of three combinations of GPS, GLONASS and BeiDou satellites using Hi-Target V30 receiver. With the use of more satellites it will get more data which expected to increase the accuracy of GNSS surveys.

* Corresponding author: khomsin95@yahoo.com

2 Data and Method

2.1. Data

Locating a suitable area for conducting this research is Surabaya City, East Java. The survey location and the design of baseline survey can be seen in Figure 1 below.

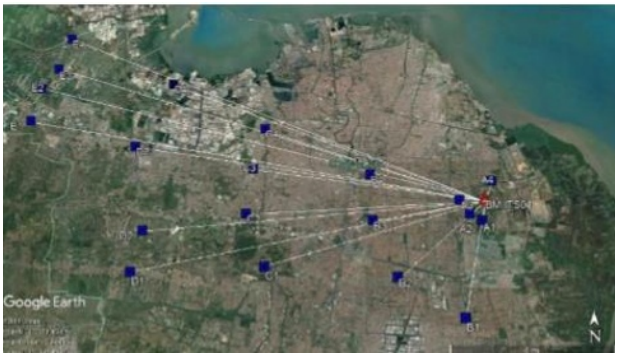

Figure 1. Survey Location and baseline survey plan

2.2 Instruments

The study used GNSS receiver Hi-Target V30 to observe the baseline from base to other points (rovers). The instrument specifications and visualizations can be seen in Table 1 and Figure 2.

Table 1. GNSS receiver Hi-Target V30 Specification [8]

Measurement	220 channels
Satellite signal tracked simultaneously	GPS (L1C/A, L2C, L2E, L5)
	Glonass (L1C/A, L1P, L2C/A)
	BeiDou (B1 and B2)
Static and Fast Static	H: 2.5 mm x 0.5 ppm D
	V: 5.0 mm x 0.5 ppm D
RTK Surveying	H: 8.0 mm x 1.0 ppm D
	V: 15.0 mm x 1.0 ppm D

Figure 2. GNSS receiver Hi-Target V30

2.3 Method

The first step taken in this research is planning a survey that includes the baseline design and field orientation. In this case, we plan some baselines with distance of 1 km, 5 km, 10 km 15 km and 20 km from a base station. In addition, each baseline distance categories have four baselines (points), so that total observations in this case are twenty baselines. After that is the field orientation to check the location of the points to be measured whether the location meets the requirements or not by looking at multipath and other obstacles.

The next step is the GNSS survey was carried out in accordance with the designs previously made using two V30 Hi-Target GNSS Receivers where one receiver as a base and another as a rover. The observation method used is static with an hour observation and only radial observation with BM ITS-01 as a base and other points as rovers.

After the all of observations are complete, the observation data are downloaded and then to be processed with 6 strategies:

- 1st strategy is GPS, GLONASS and BeiDou signals are processed simultaneously
- 2nd strategy is both of GPS and GLONASS signal are processed simultaneously
- 3rd strategy is both of GPS and BeiDou signals are processed simultaneously
- 4th strategy is both of GLONASS and BeiDou signals are processed simultaneously
- 5th strategy is only GPS signal is processed
- 6th strategy is only GLONASS satellite signal is processed

We could not process only BeiDou signal because the GNSS receiver Hi-Target V30 just received two satellite of BeiDou, namely B1 and B2. Finally, this research will compare coordinate results between one strategy and other strategies.

3 Result and Discussion

3.1 BM Referenced

The GNSS observation in this case was carried out by static positioning and radial methods which were tied at the BM ITS – 01 as referenced point. This BM is located in front of the ITS Rectorat building in Sukolilo Campus – Eastern of Surabaya (Figure 3). The coordinates of BM ITS-01 can be seen at Table 2.

Figure 3. BM ITS – 01 and its location

Table 2. BM ITS-01 coordinate as referenced point

Coordinate	
Easting (m)	698.076.449
Northing (m)	9194686.012
Latitude (S)	7°16'55.123"
Longitude (E)	112°47'38.956"
Ellipsoid Height (m)	36.056

The condition of BM ITS - 01 is relatively still strong and sturdy, and generally the location is free from multipath and other obstacles. Even though there is a little multipath from the surrounding trees, but it can still be reduced by 15^0 mask angle observation.

3.2 Length of baseline observation

In this research, the GNSS observation is divided to five categories of length of baselines: 1 km (A), 5 km (B), 10 km (C), 15 km (D) and 20 km (E) from the base station. Each category has four measured points, so that a total of twenty points are measured (Table 3). The Table 3 below shows that the baseline distance at each point. The length of the baseline obtained cannot be fixed with the planning carried out, because only estimates and location conditions do not make it possible to take measurements so that it must be shifted. However, in general the conditions of GNSS observations are still the same as the planned.

3.3 Coordinate accuracy analysis of baseline processing

This GNSS data processing used Hi-Target Geomatics Office (HGO) software to convert format data from Hi-Target format to RINEX (Receiver Independence Exchange) format and Topcon Tools 8.2.3 software to perform a baseline (differential positioning) processing. Table 4 to Table 9 shows the accuracy of coordinate results for category A, B, C, D, and E with 1st strategy to 6th strategy. There are two accuracies, namely horizontal accuracy and vertical accuracy.

Table 3. Length of Baseline observation

Base	Category	Point	Distance (m)
BM ITS - 01	1 km	A1	915.584
		A2	1123.152
		A3	960.171
		A4	968.860
	5 km	B1	5022.564
		B2	4957.415
		B3	6518.977
		B4	5561.453
	10 km	C1	10061.730
		C2	10096.420
		C3	10513.090
		C4	9778.561
	15 km	D1	14847.860
		D2	14648.180
		D3	14597.480
		D4	14242.440
	20 km	E1	20628.960
		E2	20492.890
		E3	20848.130
		E4	20860.360

Table 4 shows that the 1st strategy processing using GPS + GLONASS + BeiDou signals together produce horizontal and vertical accuracy less than 1 cm for length of baseline ≤ 5 km. For the length of baseline from 10 km to 20 km, this strategy resulted less than 2 cm for horizontal accuracy and 2.5 cm for vertical accuracy. These accuracies can be used as ground control point measurements for high resolution satellite image, airborne photogrammetry and complete land registration.

In the 2nd strategy used GPS + GLONASS signals together to process the data, it can be seen in Table 5 that all baselines have the same horizontal and vertical accuracy with the 1st strategy. It means that BeiDou satellite signals namely B1 and B2 has no significant to improve GPS + GLONASS accuracy. Therefore, all the 2nd strategy coordinates accuracies can be used as ground control point and independent check point measurements for high resolution satellite image and airborne Lidar and photogrammetry rectification and orthorectification process. In addition to these accuracies can also be used as control points for surveying and mapping and complete land registration project.

Table 4. Coordinate accuracy from GPS + GLONASS + BeiDou processing (1st Strategy)

Category	Point	Horizontal RMS (m)	Vertical RMS (m)
1 km	A1	0.2	0.5
	A2	0.3	0.6
	A3	0.5	0.8
	A4	0.3	0.4
5 km	B1	0.3	0.5
	B2	0.3	0.4
	B3	0.4	0.8
	B4	0.3	0.5
10 km	C1	1.1	2.0
	C2	1.4	2.3
	C3	1.9	1.4
	C4	0.7	1.2
15 km	D1	0.8	1.1
	D2	0.7	1.2
	D3	0.8	1.3
	D4	0.8	1.3
20 km	E1	1.3	1.5
	E2	1.0	2.3
	E3	1.5	1.5
	E4	1.3	2.0

GPS + BeiDou signal processing in the 3rd strategy can be seen in Table 6. This table describes that in general, the horizontal accuracies for all baselines have almost the same accuracy with the 1st and 2nd accuracies but C3 and E3 have accuracy more than 1.5 cm that is 3.3 cm and 1.7 cm for C3 and E3 respectively. The vertical accuracies for length of baselines ≤ 5 km has the same value with the 1st and 2nd strategies, however many baselines have more 2 cm accuracies for 10 – 20 km baselines.

Coordinate accuracy obtained from the 4th strategy, ie GLONASS + BeiDou Satellite signal processing can be seen in the Table 7. Horizontal accuracies for 1 – 5 km baseline length are less than 1 cm and vertical accuracies are less than 1.5 cm. Generally, the horizontal accuracies for 10 – 20 km baseline are less than 20 cm, although some points have more than 20 cm such as C1 (44.5 cm) and E3 (30.4 cm). Vertical accuracies in these baselines almost have similar accuracy with horizontal accuracies. Some points have accuracy more than 20 cm, namely C1 (38.0 cm), E2 (25.4 cm) and E3 (28.3 cm).

Table 5. Coordinate accuracy from GPS + GLONASS processing (2nd Strategy)

Category	Point	Horizontal RMS (m)	Vertical RMS (m)
1 km	A1	0.2	0.5
	A2	0.3	0.6
	A3	0.5	0.8
	A4	0.3	0.4
5 km	B1	0.3	0.5
	B2	0.3	0.4
	B3	0.4	0.8
	B4	0.3	0.5
10 km	C1	1.1	2.0
	C2	1.4	2.3
	C3	1.9	1.4
	C4	0.7	1.2
15 km	D1	0.8	1.1
	D2	0.7	1.2
	D3	0.8	1.3
	D4	0.8	1.3
20 km	E1	1.3	1.5
	E2	1.0	2.3
	E3	1.5	1.5
	E4	1.3	2.0

Table 8 shows that the accuracy of the 5th strategy (only GPS processing). It can be seen that the horizontal accuracies for the baseline length less than or equal 5 km are ≤ 1.0 cm and baseline between 10 km and 20 km have accuracies less than 2.0 cm. Except A3, the vertical accuracies for baseline 1 – 5 km are ≤ 1.0 cm and for baseline 10 – 20 km have accuracies less than 6.0 cm.

Finally, the 6th strategy used only GLONASS satellite signal describes that the horizontal accuracies for less than or equal 5 km baseline have ≤ 1.0 cm and their vertical accuracies are less than 1.5 cm. Some points in the baseline length between 10 and 20 km have accuracies more than 30 cm both horizontally and vertically. Therefore, GLONASS data cannot be used to observe ground control point for high resolution satellite image, lidar and airborne photogrammetry. In addition, this strategy also cannot be used to observe ground control points for land surveying and mapping.

Table 6. Coordinate accuracy from GPS + BeiDou processing (3rd Strategy)

Category	Point	Horizontal RMS (cm)	Vertical RMS (cm)
1 km	A1	0.2	0.4
	A2	0.4	0.7
	A3	1.0	1.9
	A4	0.5	0.9
5 km	B1	0.3	0.5
	B2	0.4	0.5
	B3	0.5	1.0
	B4	0.3	0.5
10 km	C1	1.0	2.4
	C2	1.5	2.3
	C3	3.3	5.3
	C4	0.6	1.1
15 km	D1	0.8	1.2
	D2	0.8	1.6
	D3	0.9	1.3
	D4	0.9	1.9
20 km	E1	1.3	1.6
	E2	1.1	2.8
	E3	1.7	2.7
	E4	1.4	1.8

Table 7. Coordinate accuracy from GLONASS + BeiDou processing (4th Strategy)

Category	Point	Horizontal RMS (cm)	Vertical RMS (cm)
1 km	A1	1.0	1.4
	A2	0.5	1.0
	A3	0.6	0.8
	A4	0.4	0.4
5 km	B1	0.6	1.0
	B2	0.5	0.5
	B3	0.5	1.0
	B4	0.7	1.2
10 km	C1	44.5	38.0
	C2	8.8	17.8
	C3	1.6	1.1
	C4	1.8	4.6
15 km	D1	1.3	1.8
	D2	1.7	1.9
	D3	1.3	2.1
	D4	5.1	6.4
Category	Point	Horizontal RMS (cm)	Vertical RMS (cm)
20 km	E1	5.6	11.3
	E2	17.8	25.4
	E3	30.4	28.3
	E4	2.2	2.5

Table 8. Coordinate accuracy from only GPS processing (5th Strategy)

Category	Point	Horizontal RMS (cm)	Vertical RMS (cm)
1 km	A1	2.0	4.0
	A2	4.0	7.0
	A3	1.0	1.9
	A4	0.5	0.9
5 km	B1	0.3	0.5
	B2	0.4	0.5
	B3	0.5	1.0
	B4	0.3	0.5
10 km	C1	1.0	2.4
	C2	1.5	2.3
	C3	3.3	5.3
	C4	0.6	1.1
15 km	D1	0.8	1.2
	D2	0.8	1.2
	D3	0.9	1.3
	D4	0.9	1.9
20 km	E1	1.3	1.6
	E2	1.1	2.8
	E3	1.7	2.7
	E4	1.4	1.8

Table 9. Coordinate accuracy from only GLONASS processing (6th Strategy)

Category	Point	Horizontal RMS (cm)	Vertical RMS (cm)
1 km	A1	1.0	1.4
	A2	0.5	1.0
	A3	0.6	0.8
	A4	0.4	0.4
5 km	B1	0.6	1.0
	B2	0.5	1.0
	B3	0.5	1.0
	B4	0.7	1.2
10 km	C1	36.3	62.4
	C2	58.5	35.9
	C3	1.6	1.1
	C4	1.8	4.5

15 km	D1	1.3	1.8
	D2	1.8	1.9
	D3	1.3	2.1
	D4	5.6	6.8
20 km	E1	5.3	11.1
	E2	1.8	25.4
	E3	33.8	30.1
	E4	2.2	2.5

3.3 Coordinate accuracy analysis of baseline processing

The coordinates accuracies of the data processing with the six strategies mentioned above can be categorized based on the length of the baseline. The accuracy of coordinates of each category from A (1 km) to E (20 km) can be seen in Tables 10 to Table 14.

Table 10 shows that all strategies resulted horizontal accuracy for category A (1 km baseline) ≤ 1 cm. However only the 1st strategy and the 2nd strategy produced vertical accuracies less than or equal 1 cm and other strategies have accuracy almost 2 cm for some points.

Table 10. Coordinate accuracy category A (length of baseline 1 km)

Strategy	Accuracy	A1 (cm)	A2 (cm)	A3 (cm)	A4 (cm)
1st	Horizontal	0.2	0.3	0.5	0.3
	Vertical	0.5	0.6	0.8	0.4
2nd	Horizontal	0.2	0.3	0.5	0.3
	Vertical	0.5	0.6	0.8	0.4
3rd	Horizontal	0.2	0.4	1.0	0.5
	Vertical	0.4	0.7	1.9	0.9
4th	Horizontal	1.0	0.5	0.6	0.4
	Vertical	1.4	1.0	0.8	0.4
5th	Horizontal	0.2	0.4	1.0	0.5
	Vertical	0.4	0.7	1.9	0.9
6th	Horizontal	1.0	0.5	0.6	0.4
	Vertical	1.4	1.0	0.8	0.4

All coordinate accuracies for category B (5 km baseline) can be seen on Table 11. In this case all points have horizontal and vertical accuracies less than 1.25 cm. This category has better accuracy than category A.

Table 11. Coordinate accuracy category B (length of baseline 5 km)

Strategy	Accuracy	B1 (cm)	B2 (cm)	B3 (cm)	B4 (cm)
1st	Horizontal	0.3	0.3	0.4	0.3
	Vertical	0.5	0.4	0.8	0.5
2nd	Horizontal	0.3	0.3	0.4	0.3
	Vertical	0.5	0.4	0.8	0.5
3rd	Horizontal	0.3	0.4	0.5	0.3
	Vertical	0.5	0.5	1.0	0.5
4th	Horizontal	0.6	0.5	0.5	0.7
	Vertical	1.0	0.5	1.0	1.2
5th	Horizontal	0.3	0.4	0.5	0.3
	Vertical	0.5	0.5	1.0	0.5
6th	Horizontal	0.6	0.5	0.5	0.7
	Vertical	1.0	1.0	1.0	1.2

Horizontal accuracies for the 10 km length of baseline can be seen Table 12. This table shows that horizontal accuracies are less than 2 cm for the 1st and 2nd strategies, otherwise generally other strategies have more than 2 cm accuracies. Many points have more than 35 cm accuracies such as C1 for 4th and 6th strategies and C2 for 6th strategy. The 1st and the 2nd strategies have vertical accuracies less than 2.5 cm and the 4th and 6th strategies have 38 cm and 62.4 cm for C1 and 17.8 cm and 35.9 cm for C2.

Table 12. Coordinate accuracy category C (length of baseline 10 km)

Strategy	Accuracy	C1 (cm)	C2 (cm)	C3 (cm)	C4 (cm)
1st	Horizontal	1.1	1.4	1.9	0.7
	Vertical	2.0	2.3	1.4	1.2
2nd	Horizontal	1.1	1.4	1.9	0.7
	Vertical	2.0	2.3	1.4	1.2
3rd	Horizontal	1.0	1.5	3.3	0.6
	Vertical	2.4	2.3	5.3	1.1
4th	Horizontal	44.5	8.8	1.6	1.8
	Vertical	38.0	17.8	1.1	4.6
5th	Horizontal	1.0	1.5	3.3	0.6
	Vertical	2.4	2.3	5.3	1.1
6th	Horizontal	36.3	58.5	1.6	1.8
	Vertical	62.4	35.9	1.1	4.5

In general, horizontal and vertical accuracies for category D have better than category C. All accuracies in category D (Table 13) are less than or equal 2.1 cm. Some points have accuracies more than 5 cm such as D4 for 4th and 6th strategies.

Table 13. Coordinate accuracy category D (length of baseline 15 km)

Strategy	Accuracy	D1 (cm)	D2 (cm)	D3 (cm)	D4 (cm)
1st	Horizontal	0.8	0.7	0.8	0.8
	Vertical	1.1	1.2	1.3	1.3
2nd	Horizontal	0.8	0.7	0.8	0.8
	Vertical	1.1	1.2	1.3	1.3
3rd	Horizontal	0.8	0.8	0.9	0.9
	Vertical	1.2	1.6	1.3	1.9
4th	Horizontal	1.3	1.7	1.3	5.1
	Vertical	1.8	1.9	2.1	6.4
5th	Horizontal	0.8	0.8	0.9	0.9
	Vertical	1.2	1.2	1.3	1.9
6th	Horizontal	1.3	1.8	1.3	5.6
	Vertical	1.8	1.9	2.1	6.8

Finally, coordinate accuracies for category E can be seen in Table E. This table shows that horizontal and vertical accuracies are less than 3 cm for 1st, 2nd, 3rd and 4th strategies, however in the 4th and 6th strategies almost all points have accuracies more than 11 cm except all point in E4.

Table 14. Coordinate accuracy category E (length of baseline 20 km)

Strategy	Accuracy	E1 (cm)	E2 (cm)	E3 (cm)	E4 (cm)
1st	Horizontal	1.3	1.0	1.5	1.3
	Vertical	1.5	2.3	1.5	2.0
2nd	Horizontal	1.3	1.0	1.5	1.3
	Vertical	1.5	2.3	1.5	2.0
3rd	Horizontal	1.3	1.1	1.7	1.4
	Vertical	1.6	2.8	2.7	1.8
4th	Horizontal	5.6	17.8	30.4	2.2
	Vertical	11.3	25.4	28.3	2.5
5th	Horizontal	1.3	1.1	1.7	1.4
	Vertical	1.6	2.8	2.7	1.8
6th	Horizontal	5.3	18.0	33.8	2.2
	Vertical	11.1	25.4	30.1	2.5

4 Conclusion

Based on the results of this research, it can be concluded that:

1. The 1st (GPS + GLONASS + BeiDou) and 2nd (GPS + GLONASS) strategy have the same horizontal and vertical accuracies for all categories (1 – 20 km) whereas horizontal accuracies are less than 2 cm and vertical are accuracies less than 2.5 cm.
2. All strategies have horizontal accuracies less than or equal 1 cm and vertical accuracies less than 2 cm for baseline ≤ 5 km.

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