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GNSS Accuracy Analysis for Efficiency of Ground Control Point (GCP) Measurement

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***Abstract*—Nowadays, the Global Navigation Satellite System (GNSS) has a significant role in the field of surveying and mapping, especially in determining the coordinates of ground control points for rectifying aerial photography, satellite imagery and airborne lidar. Each of these rectification processes requires a different coordinate accuracy from 5 to 20 cm. This research will conduct GNSS measurement with radial method and observation length to see how far the required accuracy will be fulfilled. This research examined ten Ground Control Points (GCPs) using the GNSS receiver in Surabaya. Each GCP was observed for 2 hours with 15" epoch and then they were processed with an interval of 15 minutes such as 15', 30', 45', 60', 75', 90', 105' and 120' with the radial method. In general, the results showed that the longer the GNSS observation the more accurate coordinates from 0.923 m (15 minutes) to 0.011 m (120 minutes) will be achieved. Measurement of GCPs for aerial photogrammetry, High-Resolution Satellite Image (HRSI), and airborne LIDAR needs 15' observation both of radial and network method for less than or equal 10 km of baseline. For 10 – 20 km, the radial method needs 90' observation for photogrammetry, 75' observation for HRSI, 45' GCPs observation of airborne LIDAR, but for network methods need 45' observation for photo and HRSI and 30' observation for Airborne LIDAR.**

***Keywords*— GCP; GNSS; radial method; rectification.**

I. INTRODUCTION

Global Navigation Satellite System (GNSS) is a term used to cover all global navigation satellite systems that are already operating or are in planning. GNSS emits navigation signals positioning to users that are controlled from control stations on earth. The basic concept of GNSS positioning is resection with distance, by distance measurement simultaneously to several GNSS satellites. Positioning can be determined with a minimum of 4 (four) satellites (see Fig 1), which are based on longitude, latitude, altitude and time [1], [2].

Theoretically, if the receiver receives more satellites, the better the shape of the geometry, and it will ultimately produce better accuracy [2]. One of the most popular GNSS satellites is the Global Positioning System (GPS). At this time, GPS systems have been widely used by people around the world. GPS has been widely applied, especially those related to applications that demand information about positions [3]. All systems in GNSS such as GPS, GLONASS, Galileo and also Compass have almost the same principle with GPS to get positions. Compared to other positioning systems and methods, GPS has many advantages and offers more benefits, both in terms of operational and quality of the position given [4].

Many activities require the implementation of GNSS observations [2], [3]. The first non-military applications of GNSS technology were in surveying and mapping. Today, GNSS is being used for commercial applications in agriculture, transportation, unmanned vehicles, machine control, marine navigation, and other industries where efficiencies can be gained from the application of precise, continually available position and time information. GNSS is also used in a broad range of consumer applications, including vehicle navigation, mobile communications, entertainment, and athletics. As GNSS technology improves and becomes less expensive, more and more applications will be conceived and developed.

One of GNSS applications in Indonesia today is for Ground Control Point (GCP) measurements. GCP is a tie point for the process of giving coordinates to an image such as aerial photogrammetry, satellite imagery, airborne LIDAR and other imageries. This process can be called a georeferencing that aims for geometric correction. The accuracy of GCP depends significantly on the type of GPS used and the number of GCP samples on the location and time of collection [4]. The ideal location when taking GCP [5]–[7] is the intersection, the corner of the road, the intersection of the pedestrian road, the area that has a striking color, the intersection of the railroad with the road and objects/monuments/buildings that are easily identified or known. It is necessary to avoid trees, buildings, and electric poles in addition to being difficult to identify, because of their high similarity [6] and multipath [3], [8].

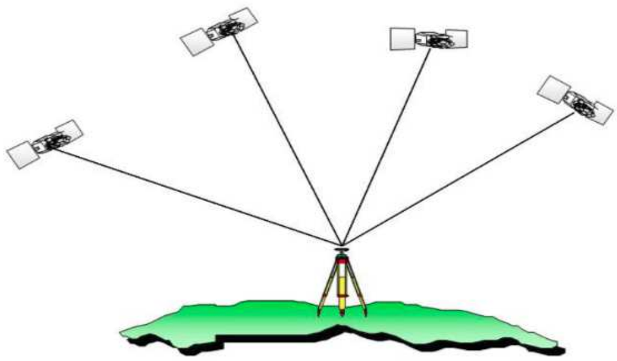

Fig 1. GNSS principle (resection with distance) [2]

The GCPs used for geometric correction must have accurate coordinates according to needs [5], [7], and this will be used to geometric corrections in aerial photography, high-resolution satellite images (HRSI) and LiDAR. GCP measurements can be done using radial or network methods with static methods. The comparison of the baseline [6], session and measurement time between network and radial modes is the radial mode requires a smaller number of baselines, sessions and less measurement time (56 %) when compared to network mode.

Each image produced requires a control point with precise accuracy. Aerial photography of 10 cm resolution requires a minimum horizontal accuracy of 5 cm. Based on the spatial planning validation module of the Geospatial Information Agency [7], high-resolution satellite imagery requires horizontal accuracy ≤ 20 cm. In other regulations, LiDAR requires horizontal accuracy ≤ 30 cm.

To meet these requirements, basic provisions have been established regarding the length of observation and the method used. Measurement of CSRT and LiDAR GCPs refers to SNI 196724-2002 [9] regarding Horizontal Control Networks which need to be observed for 2 hours with a maximum baseline distance of 10 km using the network method., GCP observations of aerial photographs took 20 minutes by a radial method [10], [11]. When measuring GNSS in the field, it is often constrained by unexpected conditions such as multipath and cycle slip effects, which causes a discrepancy between observational times during planning and implementation in the field. Therefore, it is necessary to research the minimum time required for GCP measurements using GNSS based on the radial and network method and length of the observation. Then the results of this study are expected to be a reference and alternative in order to measure GCPs with an efficient time but still get accurate results.

II. Materials and Method

The data used in this research were in situ GNSS observation distributed in Surabaya City, East Java, on 24 February - 5 March 2018 (see Fig 2). There were 10 GCPs measured using radial (see Fig 3) and network method (see Fig 4) method where each observation was carried out for 2 hours observation.

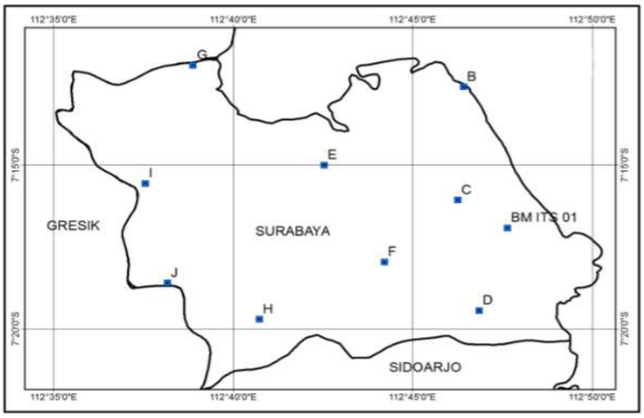

Fig 2. GCPs distribution in Surabaya City

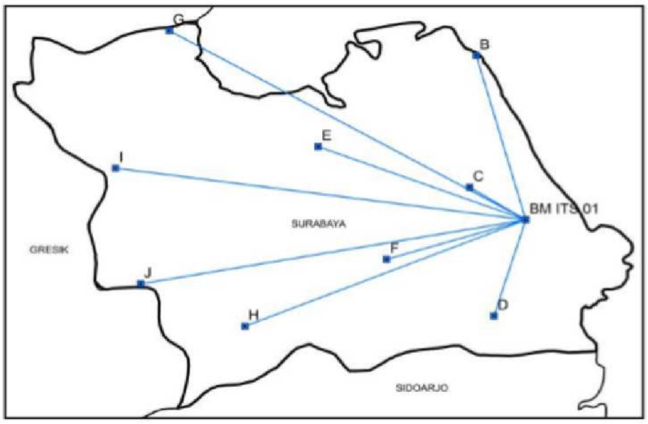

Fig 3. Baseline design of GCPs measurements

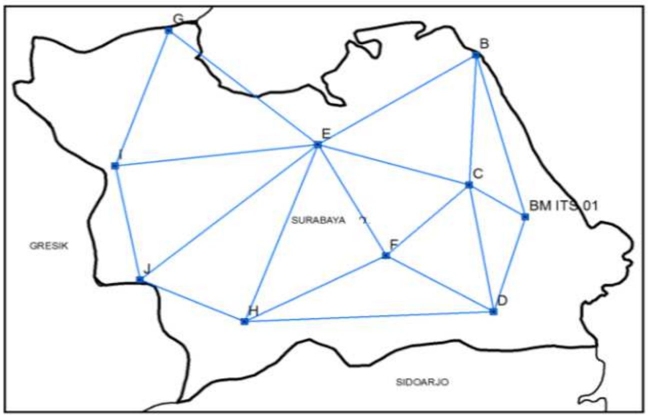

Fig 4. Network design of GCP measurements

The GNSS positioning methods can be categorized as absolute and relative. Absolute positioning [2], [3] means that the point coordinate on which the receiver is set up is determined. The absolute positioning or point positioning means that to determine the point position using only the measurement made at that point without reference station. On the other hand, in relative positioning [2], [3], the coordinates of one or more points are determined according to a point with known coordinates. In other words, the base vector between two points is determined in relative positioning or differential positioning. Simultaneous code or phase observations are conducted with the same satellites using two receivers set up at two different points for differential positioning. Differential positioning achieves a much better accuracy [12] than absolute positioning; it varies between 0.001 and 100 ppm depending on the receiver type ephemeris information (broadcast or sensitive), measurement time, observed satellite geometry, number of satellites, (P coded, P codeless) and that is used. Differential positioning conducted using phase observations is applied in static and kinematic modes. The measurement methods can be categorized [3] as static, fast static, iterative, stop-and-go, and kinematic according to the base length, measurement time, and evaluation method.

In this study, the GNSS GCPs positioning were measured using the differential positioning method, where one point as the base station and others as rovers. The measurement was s conducted using a Topcon Hiper SR and Sokkia GRX01 dual-frequency signals (L1 & L2) geodetic GNSS receiver and Hi-Target V30 can also receive BeiDou signals. The shortest baseline (the distance between the referenced point and a GCP) is 2.992 km and the most extended baseline is 18.694 km. The software used is commercial software, i.e., Topcon Tools v8.2.3. All GNSS observations will be tied on BM ITS 01 with coordinates X = 698075.011 m, and Y = 9194686.033 m. This coordinate refers to the Universal Transverse Mercator (UTM) zone 49S (see Fig. 2).

The methodology used in this study is as follows: Firstly, pre-survey is a planning design for GCP measurement with radial methods. The minimum observation time is 2 hours. The following step is data processing, which explained in the following fields: 1. Parameter configuration, i.e., the initial step of project processing, is by setting the configuration and several parameters including time, datum, the projection used, and minimum accuracy required. 2. Radial method processing: observational data input for 2 hours for all points and parameters needed include antenna height and reference point coordinates (BM ITS 01). In this case, 2 (two) hours of observations were processed with interval 15 minutes, such as 15 minutes, 30 minutes, 45 minutes, 60 minutes, 75 minutes, 90 minutes, 105 minutes, and 120 minutes. The following figure (see Fig. 5) are examples of cutting signals according to the time processed by 15’ interval. Fig 5 shows that the signal satellite number received by the receiver which different by color.

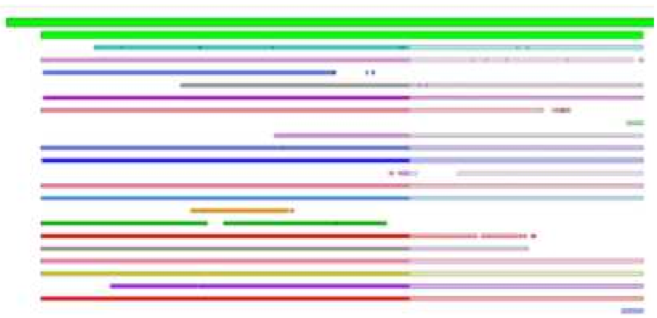

Fig 5. Cutting signal to be processed by 15’ interval

The third step is the post-processing of GNSS data observation to get the final coordinate. From these results, it can be seen whether the accuracy obtained has met the needs or not. If the accuracy does not meet the tolerance, then the signal continuity checking phase is carried out. If the continuity of the signal tends to be less good, then the elimination of the signal is then carried out again post-processing.

III. Results and Discussion

In this research, reference coordinates were based on the results of the data processing of the network method with an observation time of 2 hours, referring to SNI 19-6724-2002 [9] as Horizontal Control Network. (see Table 1)

TABLE I
GNSS Coordinate result with 2 hours observation as referenced

GCP	Easting (m)	Northing (m)	Hor. Std Dev (m)	Distance (km)
B	696440.508	9202756.149	0.010	8,234
C	695537.968	9196271.665	0.007	2,992
D	696603.564	9190041.459	0.008	4.872
E	688687.041	9898268.936	0.009	10.048
F	691800.578	9192801.834	0.009	6.551
G	681967.107	9203906.701	0.011	18.560
H	685337.403	9189588.876	0.010	13.720
I	679559.319	9197261.146	0.011	18.694
J	680477.744	9191355.736	0.011	17.910

Based on Table 1 above, the results of the data processing of the network method with 2 hours of observation, the horizontal standard deviation value has a minimum value of 0.007 m at point C and a maximum value of 0.011 m at point G, I and J. The shortest baseline distance is point C with 2.992 km while the longest baseline distance is point I with 18.694 km. In general, the longer the baseline observation point from the control point affects the accuracy of the coordinates of the observation point, which is decreasing [10].

In the processing of radial data produced different accuracy values for different observations. Accuracy can be expressed in numerical form by calculating RMSE (Root Mean Square Error) to determine the accuracy of the measurement data resulted. RMSE is used to calculate the accuracy between observation and the reference value (assumed true value: two hours of observation). Mathematically [13] the RMSE can be written with the formula:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(y_i - \bar{y}_i)}{n}^2} \quad (1)$$

whereas RMES is Root Mean Square Error, $\sum(yi - \bar{y}i)^2$ is the sum of squares of observation minus true value, and n is the amount of data. The following data (see Fig 6 and Table 2) are the results of accuracy for each observation period by 15’ interval (15’, 30’, 45’, 60’, 75’, 90’, 105’, 120).

In Fig 6, it can be seen that on average, there is an increase in error in 30 minutes observation. Furthermore, observations of 45 minutes to 120 minutes tend to increase accuracy. The far distance of the baseline can cause this, the existence of a cycle slip and the number of signals that can be captured in the first 30 minutes observation is not maximal. Fifteen minutes of radial observation got accuracy on an average error of coordinate value of 0.051 m and at 120 minutes, the average error value is 0.019 m. Every 15 minutes multiples changes in the average error with the range 0-0.048 m.

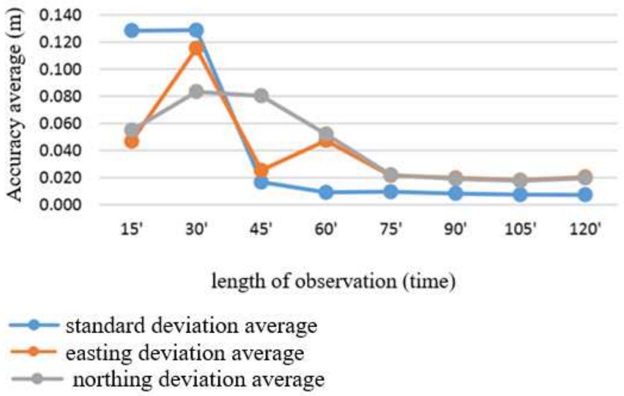

Fig 6. Standard, easting and northing deviation average

TABLE II
FINAL COORDINATED DEVIATION TO REFERENCED AS RADIAL METHOD

Length of observation Time	Results	RMSE (m)	Easting deviation from ref. (m)	Northing deviation from ref. (m)
15’	Min	0.002	0.007	0.003
	Max	0.923	0.288	0.016
	Average	0.128	0.047	0.055
30’	Min	0.003	0.003	0.006
	Max	1.017	0.815	0.550
	Average	0.129	0.115	0.083
45’	Min	0.003	0.004	0.006
	Max	0.050	0.114	0.548
	Average	0.017	0.025	0.080
60’	Min	0.002	0.008	0.004
	Max	0.015	0.274	0.296
	Average	0.009	0.047	0.052
75’	Min	0.002	0.050	0.003
	Max	0.021	0.047	0.019
	Average	0.010	0.021	0.022
90’	Min	0.002	0.003	0.005
	Max	0.021	0.047	0.019
	Average	0.008	0.020	0.019
105’	Min	0.003	0.003	0.002
	Max	0.013	0.045	0.047
	Average	0.007	0.018	0.018
120’	Min	0.002	0.003	0.004
	Max	0.011	0.050	0.047
	Average	0.007	0.020	0.020

Based on Table 2, the highest of horizontal standard deviation value lies in 30 minutes observation with the maximum value with 1.017 m, the maximum deviation of easting value to the referenced is 0.815 m, and the maximum deviation of northing value to the reference reached 0.550 m. This is due to the poor quality of the data during the first 30 minutes of observation, which is indicated by the small number of satellites and the extensive cycle slips.

In the processing of the network method, data produced different accuracy values for different observations. The following (see Table 3) are the results of accuracies for each observation period by 15’ interval (15’, 30’, 45’, 60’, 75’, 90’, 105’, 120’). In the observation using the network method, in Table 3. it can be seen that the highest standard deviation value in the observation of 15 minutes with 0.064 m; the easting maximum difference value to the reference reached 1.614 m and the maximum difference in northing to the reference is 0.437 m. Whereas in the observation of 30 minutes the maximum coordinate error value reached 0.289 m. The details of final coordinated deviation to referenced as network method can be seen in Table 3.

TABLE III
FINAL COORDINATED DEVIATION TO REFERENCED AS NETWORK METHOD

Length of observation Time	Results	RMSE (m)	Easting deviation from ref. (m)	Northing deviation from ref. (m)
15’	Min	0.034	0.004	0.000
	Max	0.064	1.614	0.437
	Average	0.050	0.397	0.114
30’	Min	0.005	0.001	0.085
	Max	0.013	0.289	0.044
	Average	0.008	0.159	0.002
45’	Min	0.009	0.024	0.025
	Max	0.007	0.011	0.014
	Average	0.009	0.000	0.003
60’	Min	0.009	0.000	0.003
	Max	0.014	0.013	0.009
	Average	0.009	0.000	0.001
75’	Min	0.009	0.000	0.001
	Max	0.012	0.013	0.005
	Average	0.008	0.001	0.000
90’	Min	0.008	0.001	0.000
	Max	0.014	0.006	0.004
	Average	0.011	0.002	0.002
105’	Min	0.008	0.000	0.000
	Max	0.013	0.006	0.005
	Average	0.011	0.002	0.002
120’	Min	0.007	0.000	0.000
	Max	0.011	0.000	0.000
	Average	0.010	0.000	0.000

From 45 minutes to 120 minutes of observation the resulting residual values and coordinates have an accuracy of ≤ 5cm. The resulting coordinate value has a difference to the reference with a range of 0 m - 0.025 m. The 15-minute network method has an average error of 0.255 m and the observation of 105 minutes has an average error of 0.002 m. Every multiple of 15 minutes, the average error value changed by 0-0.154 m.

At 15 minutes observation, there were 2 baselines with a residual value of ≥ 5 cm; 1 baseline with a residual value of ≥ 20 cm and 5 baselines with a residual value of ≥ 30 cm. Whereas for 30 minutes observation there is 1 baseline with easting residual value 0,026 m and northing 0,073 m. So that the observations of 15 to 30 minutes cannot be used for GCP aerial photography with a 10 cm resolution and CSRT, but the LiDAR GCP measurement can use it. Residual values that exceed tolerance can be caused by points that experience cycle slips and multipath, or receivers that have not captured the satellite signal maximally during the first 30 minutes of observation.

The difference in the accuracy of the coordinate results (easting and northing) (see Table 2 and Table 3) between the radial and network methods by looking at the amount of data can be seen in Fig. 7 and Fig. 8.

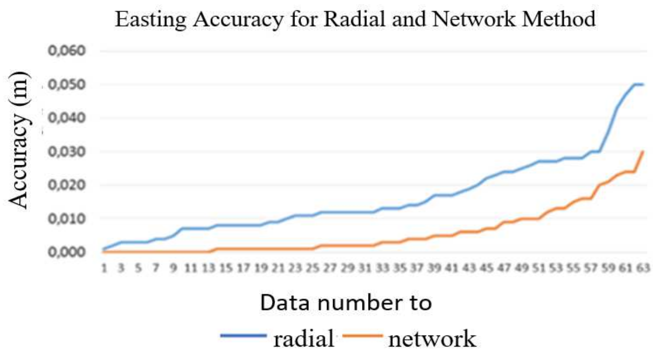

Fig 7 Comparison of easting accuracy between radial and network method

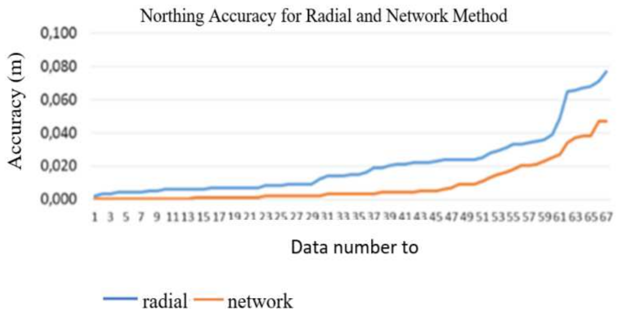

Fig 8. Comparison of northing accuracy between radial and network method

Based on Fig. 7 and Fig. 8, when compared to the coordinates of the points which have accuracy below 5 cm, it shows that the coordinate value generated by the network method is more accurate than the radial method. Overall the radial method produces coordinate values with an accuracy of 0.001 m - 0.815, while the network method produces coordinate values with an accuracy of 0 m - 0.437 m. When compared between radial and network coordinate methods, the easting difference between the two methods has a difference with a range of 0 - 1.9 m and the average has a difference of 0.100 m while the northing difference produced by the radial and network methods has a range of 0 - 0.571 m with an average difference of 0.053 m.

This study uses three types of GNSS receivers, namely Hi-Target V30, Topcon HiperPro, and Sokkia GRX01. Accuracy in determining the coordinates with these three types of receivers classified into baseline lengths less than 5 km, 5-10 km, 10-15 km, and more of 15 km can be seen in Table 4. Based on all radial measurement results, if classified according to the receiver used as in Table 4.

Based on Table 4, it can be seen that the Hi-Target V30 has better precision than Topcon Hiper SR and Sokkia GRX1. Hi-Target V30 resulted in the largest horizontal standard deviation which is 0.012 m with 18.694 km of baseline, whereas Topcon HiperPro produced the highest horizontal standard deviation value of 0.019 m (18.560 km of baseline) and Sokkia GRX1 produced the worst horizontal standard deviation of 1.017 m (13.720 km of baseline). Based on the length of the baseline, the Hi-Target V30 shows that the longer the baseline, the higher the horizontal standard deviation generated. The Topcon HiperPro receiver shows the same maximum horizontal standard deviation between points that have a baseline of 6.551 km and 18.560 km. Whereas the Sokkia GRX1 device tends to experience a decrease in the precision level from the shortest to the longest baseline. Hi-Target V30 can give more accurate than Topcon Hiper SR and Sokkia GRX01 because HiTarget V30 besides receiving GPS signals and GLONASS, it also received BeiDou signals.

TABLE IV
THE HIGHEST STANDARD DEVIATION OF GCP MEASUREMENT BASED ON RECEIVER AND LENGTH OF THE BASELINE

Receiver	GCP	Length of Baseline (km)	Highest Standard Deviation (m)
Hi-Target V30	C	3.000	0.003
	B	8.234	0.009
	I	18.694	0.012
Topcon Hiper Pro	F	6.551	0.019
	G	18.560	0.019
Sokkia GRX01	D	4.872	0.013
	E	10.048	0.046
	H	13.720	1.017
	J	17.910	0.113

However, Table 4 indicates that there is a difference at point H which reaches a horizontal deviation standard of 1.017 m caused by the measurement location near the building and cable network (see Fig 9). These locations were not good to observe GNSS signal. This is because of some multipath (some buildings) and interferences from electricity.

Fig. 9. GCPs at Point H environment

The relationship between the length of GCPs observations using GNSS receiver, radial, and network methods, and the accuracy required by rectification or geometric correction on aerial photogrammetry, high-resolution image imagery, and airborne LIDAR are as follows: Aerial photogrammetry needs ≤ 10 cm accuracies for GCPs to geometric correction for these photos [6], Sixty minutes GCPs' observation can achieve these accuracies for less than or equal 10 km of baseline with the radial method and needs 90 minutes GCPs observations for 10-20 km of baseline. By network method, it needs 15' observation for 0-10 km of baseline and 45' observation for less than the length of 20 km baseline. High-resolution satellite imagery needs ≤ 20 cm accuracy for GCPs to rectify these imageries [7]. These accuracies can be obtained by the radial method for the length of baseline ≤ 10 km needs 15 minutes observation and 10 – 20 km of baseline needs 75 minutes observation.

IV. CONCLUSIONS

In this study, the more extended GNSS observation, from 15 - 120 minutes, both radial and network methods, result in better accuracy, from 0.007 m to 0.13 m. Finally, measurement of GCPs for aerial photography (photogrammetry), HRSI, and airborne LIDAR need 15 minutes of observation, both radial and network method, for less than or equal 10 km of baseline. For 10 – 20 km, the radial method needs 90 minutes of observation for photogrammetry, 75 minutes observation for HRSI, 45 minutes GCPs observation of airborne LIDAR, but for the network, methods need 45 minutes observation for photo and HRSI and 30 minutes observation for Airborne LIDAR.

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