GPS Survey Accuracy using Virtual Reference Station (VRS) Outside the Malaysian Real-Time Kinematic Network (MyRTKnet) Services

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Abstract
Real Time Kinematic (RTK) positioning approach needs a reference station to transmit observation correction to the rover receiver via data communication link such as radio modem or cellular phone. By using single reference station, distance between reference station and rover station is limited to 10km.Virtual Reference Station (VRS) is a solution to overcome this limitation of RTK positioning. By using VRS, the distance between reference station and rover station can be extended to 40km. The Malaysian Real-Time Kinematic Network (MyRTKnet) has been developed to facilitate RTK positioning in Malaysia. This study was conducted to test the practical accuracy of the VRS RTK positioning and VRS Static positioning with rover points outside the reference network. In this study, four points outside the MyRTKnet network were observed in VRS RTK and VRS Static modes. Distances between rover station and the nearest physical reference station are 1km, 10km, 20km and 30km. The preliminary results show that the VRS generated using MyRTKnet is suitable for centimeter level accuracy requirement even if the positions of the rover stations are outside the MyRTKnet.

1. Introduction

Real Time Kinematic (RTK) GPS has become a popular technique in conducting precise positioning applications such as surveying, high accuracy GIS mapping, highway construction and others. Current RTK positioning can be delivered with accuracies up to centimeter level by combination of observation from a minimum of two GPS receivers. At least one of the receivers serves as a base station or reference stations with known coordinates and the other serves as a rover station in which the coordinates of the position are to be determined relative to the base station. In classical RTK GPS measurements, one reference station within 10km to 15km is required to ensure the accuracy of the position to reach up to centimeter level (Talbot et al., 2002 and Hu et al., 2002). High ionospheric and troposphere activity will influence the distance from the reference station limiting it to be less than 10km (Vollath et al., 2001 and Rizos, 2003). The solution of the limitation in the distance between the rover and the reference station is the technique of Virtual Reference Station (VRS). This can be done by linking together several continuously observing reference stations to form the network. Virtual Reference Station (VRS) is an efficient method for transmitting corrections from the reference network to the rover positioning (Hu et al., 2002). The concept of Virtual Reference Station (VRS) allows us to perform RTK positioning inside the reference networks with distance of up to 40km (Vollath et al., 2002). This concept has been tested and applied in certain countries such as Australia, Italy, Finland, Japan, and Singapore. Many research groups have done their research on VRS concept, algorithm, performance, accuracy and method of transmitting the correction to the rover (Wanninger, 1999, Vollath et al., 2000, Cannon et al., 2001and Euler, 2002). In 2004, the Department of Survey and Mapping Malaysia (JUPEM) under the Eight Malaysian Plan (RMK-8) established a RTK project called Malaysia Real Time Kinematic Network (MyRTKnet). Up to now, there are 78 RTK stations in the MyRTKnet covering the whole of Malaysia including Sabah and Sarawak (51 stations in Peninsular Malaysia and 27 stations in Sabah and Sarawak). Since the use of the RTK GPS has become more widespread in Malaysia, it is considered important to study the quality of VRS generated by MyRTKnet. Until now, no study has been conducted on the quality of VRS generated by MyRTKnet, especially on the quality of VRS outside the network. In Peninsular Malaysia, ARAU is the most northern reference station in MyRTKnet system. There is an area of around 30km radius in the northern part of Peninsular Malaysia that is not covered by the network. The critical issue is the quality and the accuracy of GPS survey using VRS RTK and Static technique in that area. Thus, the main objective of this study is to examine the accuracy of GPS survey using VRS for RTK and static surveying techniques under the influence of rover stations' distance outside the network density.

1.1 Virtual Reference Station Workflow

The VRS concept was developed and commercialized by Trimble (Trimble, 2008). The basic concept of the VRS is given in the following overview:

a) Data are observed continuously at the existing references network and transferred to the control center. A computer at the control center continuously collecting and storing the information from all receivers.
b) All the data from the control network are continuously analyzed with regard to the following parameters:
   - Multipath errors
   - Ionospheric Errors
   - Tropospheric Errors
   - Ephemeris Errors
   - Carrier Phase Ambiguities for L1 and L2
c) The carrier phase ambiguities are fixed for the network baselines.
d) Interpolation models are used to predict the errors at the user location.
e) A Virtual Reference Station is generated near the user locations based on the analyzed reference station data.
f) The Virtual Reference Station is transmitted to the user in the standard formats (RTCM or CMR).

2. MyRTKnet Concept

The MyRTKnet consists of 78 permanent GPS stations as reference stations. 51 of the stations are located in peninsular Malaysia and 27 stations are located in Sabah and Sarawak as shown in Figure 1. The distances between reference stations are in the range of 30 km – 150km. All of the reference stations were established in GDM 2000 new geodetic datum through classical static GPS surveying technique. Geodetic receivers with geodetic antenna collect dual-frequency carrier and pseudorange observations at all reference stations. The concept of MyRTKnet Network Solution is based on having a network from all GPS reference stations continuously connected via Internet Protocol Virtual Private Network (IP VPN) to Control Centre and create a living database of Regional Area Corrections. A central facility was set up to model the spatial errors that limit GPS accuracy through a network solution and generate corrections anywhere inside the network with accuracy better than a few centimeters (VRS RTK GPS) to a few decimeters (DGPS) in real time. At the same time, Virtual RINEX also can be downloaded from the DSMM website. Virtual RINEX data can be used for post processing differential solution to get the highest positioning accuracy. The following describes the way the system works (Figure 2).

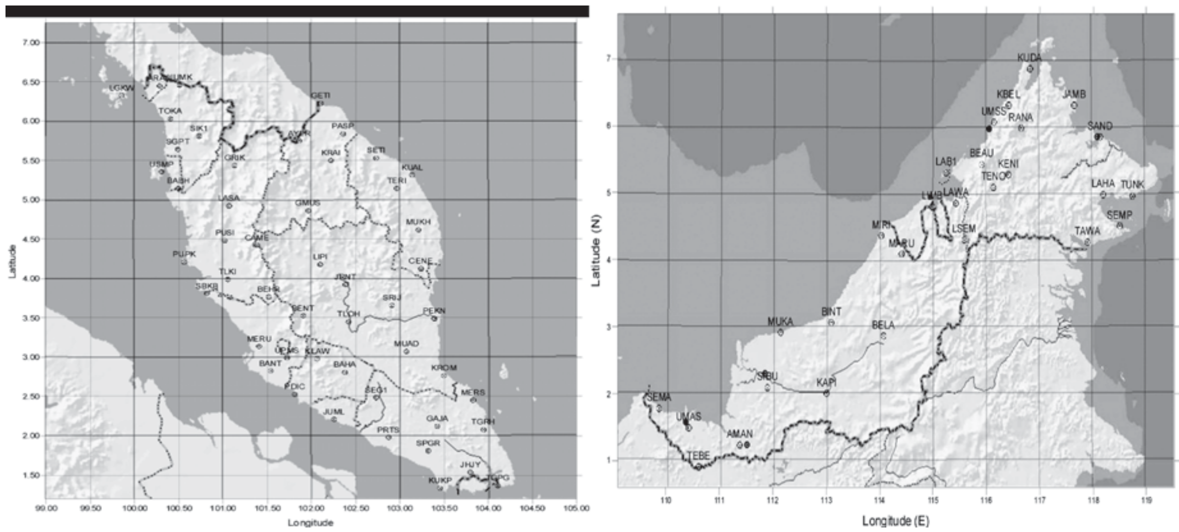


Figure 1: Malaysia MyRTKnet Stations (DSMM, 2005)

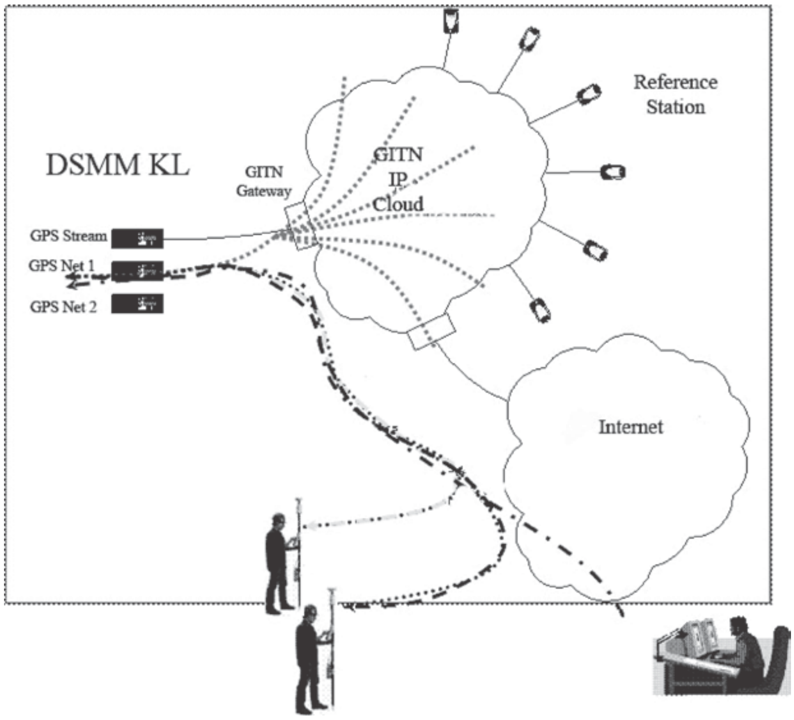


Figure 2: MyRTKnet System (DSMM, 2005)

- All reference station data will stream into the GITN IP cloud via 64k leased line.
- From the GITN cloud, all reference station data are immediately sent to Geodesy Section in Kuala Lumpur over a 1M leased line.
- Remote users connect by getting onto the internet using GPRS or GSM to ISP and selecting the IP address of the GITN Internet Gateway 202.7.44.54 port 8080
- The GITN Internet Gateway forwards request on ports 8080 to the GPSstream computer on which the NTRIP server is running.
- Upon receipt of the NMEA GGA string from the particular user, the system will begin to stream RTK corrections to the user.
- Other users can also access the webserver at 202.7.44.154 for access to customizable RINEX files for post-processing and other applications.

3. Study Area

The study area is located in the northern region of Peninsular Malaysia just a few kilometers from the Thailand border. The northern region network which consists of TOKA, ARAU, LKGW and UUMK reference stations were selected for this study as shown in Figure 3. A total of four control points were chosen outside the network covering evenly the distance of 1 km to 30 km away from the ARAU reference station.

All observations were made with Trimble 5700 dual frequency receiver with geodetic antenna.

4. Field Test Set Up

In order to study the accuracy of the VRS system, two basic considerations in choosing the test points were set.

a) Surrounding obstruction of the points should not rise above 15 degrees.

b) Reflecting surfaces in the vicinity of the antenna and nearby electrical installation are not allowed to avoid signal disturbances (Hofmann et al., 2001).

The following set-ups were used to examine the accuracy of VRS RTK and Static VRS in comparison with the true position of control points. All control points done by 3 hours conventional static observation using geodetic receiver, antenna and processing technique.

a) *VRS RTK*: Observation of each point was conducted in continuous mode for 1 hour using geodetic receiver and geodetic antenna with 1 second epoch. Horizontal and vertical precisions acceptable are 0.020m and 0.040m respectively.

b) *Static VRS*: Each point was observed on static mode. Occupation times of each point are 3 minutes, 5 minutes, 10 minutes, 30 minutes, 40 minutes and 50 minutes with 5 second epoch. The VRS RTK corrections are generated by Department Surveying and Mapping Malaysia using RTKnet software and the corrections are delivered using RTCM 2.3. For the Static VRS, reference point observations were computed in post processing mode.

5. Results and Discussions

To recall, the main objective of this study is to examine the accuracy of GPS survey using VRS for RTK and Static mode of observations. More specifically, the evaluation of the results is based on the differences in coordinates between VRS RTK, VRS static and the known coordinates initially obtained from the static observation with geodetic accuracy.

5.1 Accuracy of VRS RTK

The real time position of the test points were observed under certain conditions to make sure the result can be achieved at centimeter level. Minimum of five initialized satellites can be received with maximum geometry dilution of precision value (GDOP) value not more than 6 and sky view must be obstacle free for at least 15 degrees from the horizontal. Figure 4 shows the scatter plot for horizontal positions errors of point 1km to 30km outside the network. For the points located at 1km and 10km from the physical reference station, northing component is more accurate than the easting component as shown in Figure 4(a) and (b). The accuracy of points located at 20km and 30 km from the physical reference station suggest that the easting component is more accurate than the northing component as shown in Figure 4 (c) and (d).This could be due to the constellation and satellite geometry during the observation periods. For the results in Figure 4 (a) and (b), during the observation, more satellite signals were originated for the north area rather than the east area. For results in Figure 4(c) and (d); more satellite signal were actually coming from the east area rather than the north area. Figure 5 shows the average error of vertical component of VRS RTK for points 1km to 30km from the physical reference station. According to Figure 5, the RMS errors of the points are increased based on the distance from the physical reference station. The maximum and minimum error of vertical components for all test points is in the range of 0.050m and 0.010m. Normally, because of the satellite geometry, accuracy of the vertical component would be two times less than horizontal component. From these results, the accuracy of the VRS RTK positioning using MyRTKnet correction is generally ranged from 1cm – 6cm in horizontal position. The height accuracy is in the range of 1cm-8cm. The results from this study proved that the MyRTKnet can provide centimeter level accuracy for RTK even if the required positions are outside and far from the MyRTKnet reference stations.

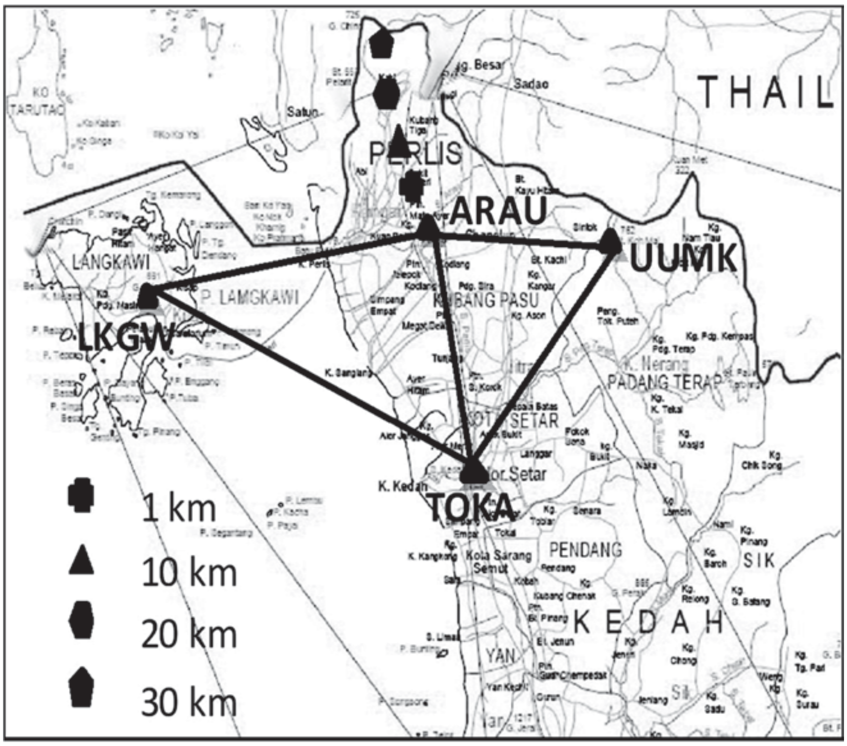
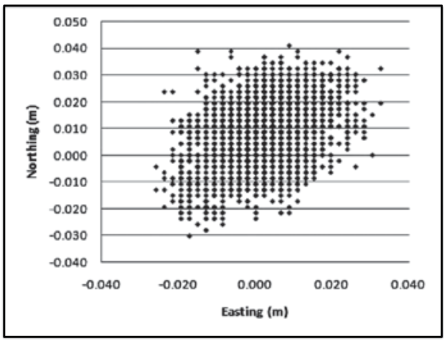
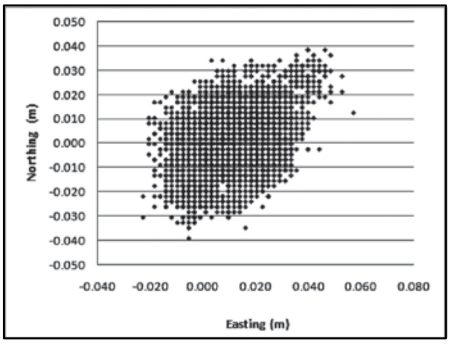


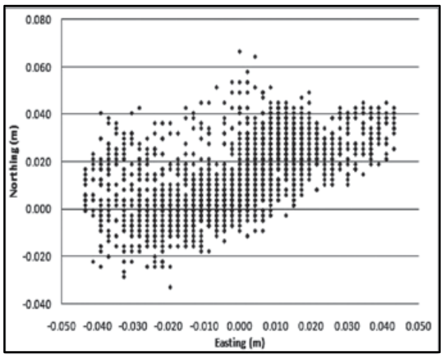
Figure 3: Test points and MyRTKnet



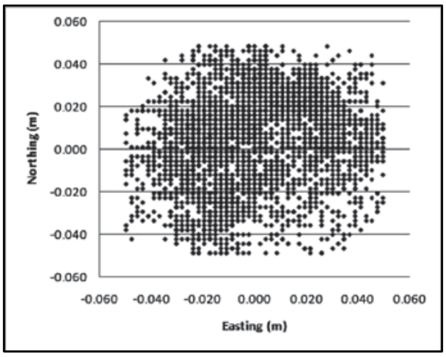
RMS $_{Northing}$ =0.006 RMS $_{Easting}$=0.011



RMS $_{Northing}$ =0.013 RMS $_{Easting}$=0.014



RMS $_{Northing}$ =0 019 RMS $_{Easting}$=0 016



RMS $_{Northing}$ =0.022 RMS $_{Easting}$=0.022

Figure 4: Scatter plot of horizontal position errors of VRS RTK of point (a) 1km (b) 10km (c) 20km and (d) 30km outside the MyRTKnet Station

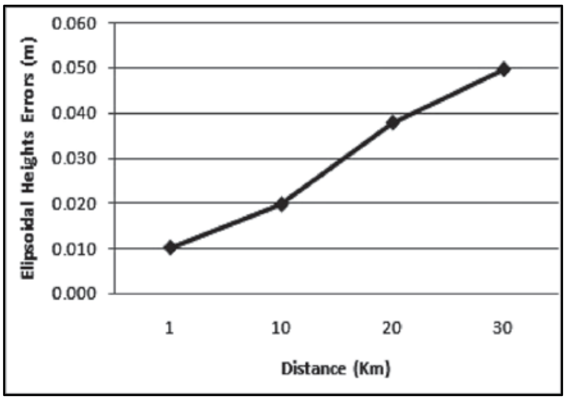


Figure 5: Average errors in vertical component for VRS RTK

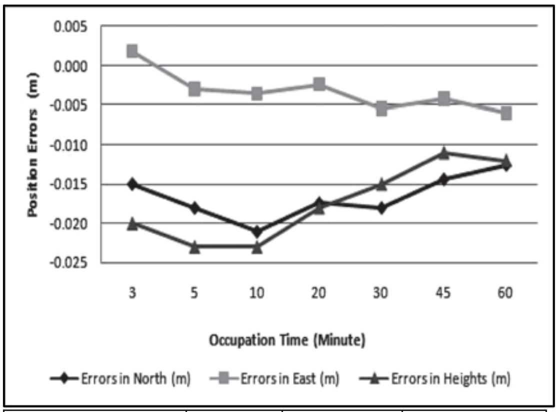
5.2 Accuracy of VRS Static

Besides the accuracy of VRS RTK, accuracy for Static measurement using VRS is also examined in this study. For the static observations, the same conditions with VRS RTK were applied. The accuracy of the static VRS were obtained by comparing the coordinates of static observation after baseline processing with VRS station with the existing value (true value) of the known points.

In baseline processing for static VRS, acceptance criteria as in Table 1 were applied for more accurate results. From the baseline processing, the result is shown in Figure 6.

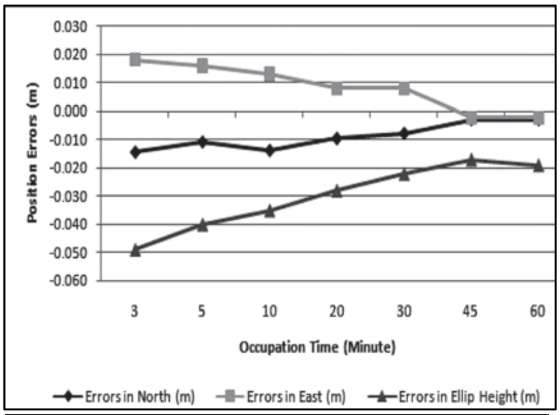
Table 1: Acceptance criteria

RMS	**Less than 0.020m**
Ratio	More than 5.0
Reference Variance	Less than 10.0



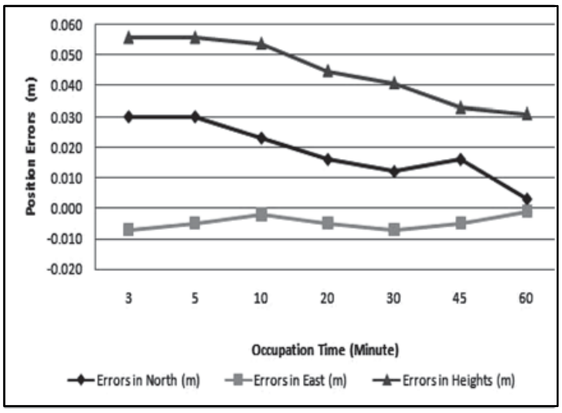
Occ. Time	RMS	Refvar	Ratio
3 minutes	0.005	1.480	20.0
5 minutes	0.005	1.808	19.6
10 minutes	0.005	1.837	13.1
20 minutes	0.006	2.014	16.5
30 minutes	0.006	2.636	16,8
45minutes	0007	2.685	21.0
60 minutes	0.007	2.632	21.7

a



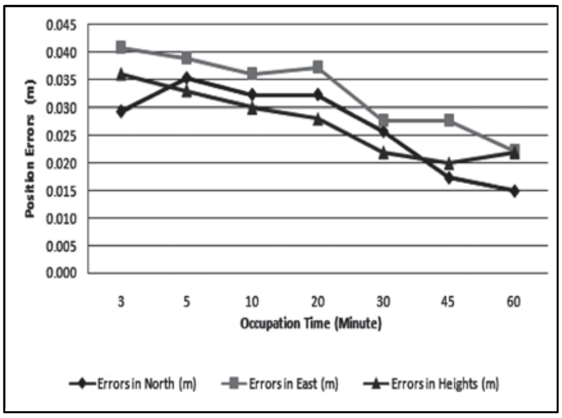
Occ. Time	RMS	Refvar	Ratio
3 minutes	0.006	2.301	10.9
5 minutes	0.007	2.809	9.9
10 minutes	0.007	3.376	8.2
20 minutes	0.007	3.375	7.7
30 minutes	0.008	2.053	8.8
45minutes	0.008	3.053	13.2
60 minutes	0.008	2.705	16.6

b



Occ. Time	RMS	Refvar	Ratio
3 minutes	0.010	4.667	8.7
5 minutes	0.009	6.116	8.7
10 minutes	0.011	7.167	8.9
20 minutes	0.011	5.420	11.1
30 minutes	0.011	5.600	9.4
45minutes	0.010	4.190	10.6
60 minutes	0.010	4.448	11.4

c



Occ. Time	RMS	Refvar	Ratio
3 minutes	0.005	1.861	8.1
5 minutes	0.007	3.293	8.3
10 minutes	0.009	4.854	8.7
20 minutes	0.010	4.695	8.7
30 minutes	0.010	4.925	7.9
45minutes	0.009	3.321	10.7
60 minutes	0.009	3.383	12.6

d

Figure 6: Error in northing, easting, ellipsoidal heights and baseline analysis of static point (a) 1km (b) 10km (c) 20km and (d) 30km outside the MyRTKnet Network with different span time observation

The result shows the differences in northing, easting and ellipsoidal height components in different occupation times of static observation. In this study, the accuracy of the points is evaluated based on the coordinates and also analyze baseline performance according to the acceptance criteria (Table1). From Figure 6, the RMS of all baselines is in the range of 0.001m to 0.012m. RMS expresses the accuracy of the observation points. Low value means that all the observation points are in accurate position. The Ratio value is the probability of correctness of the observation data. High ratio indicates that the observations data is correct. In this study the ratio for all observation is in the range of 7.0 to 22.0. This value gives us confidence that all positions are correct. Reference variance indicates how well the baseline processor estimates the expected error. The ideal value for reference variance is 1. The bigger number of reference variance means that the baseline contains more errors. In this study, the value of reference variance is below 10. These means baselines contain less errors and noise. Figure 6 also presented the accuracy of positions with different occupation time. In general, the accuracy of horizontal component is two times better than the vertical component. The major factor that affects the accuracy of vertical component is the satellite geometry. In this study, the accuracy of the point is depending on the occupation time on the points. Longer occupation point will give more accurate position in both components.

6. Conclusions

This paper has presented the results of an assessment on the practical accuracy of positioning using VRS for RTK and static surveying techniques outside the MyRTKnet network. The results indicate that the MyRTKnet network services allow the VRS RTK and VRS Static to be conducted with good accuracy even at the distance of 30km from the nearest physical reference station. In general, the horizontal accuracy of VRS RTK and VRS Static positions is in the range of 1cm to 6 cm and for vertical is in the range of 1cm to 8cm. With this range of accuracy, many high precision applications such as engineering constructions, cadastral mapping, georeferencing of remote sensing images, geodetic measurements and natural disaster monitoring can utilize the MyRTKnet services more effectively.

Acknowledgements

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