Accuracy Assessment of the Network Real-Time Kinematic Techniques for Geodetic and Plane Coordinates

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Virtual Reference Station (VRS), Master-Auxiliary Corrections (MAX) and Individualised Master-Auxiliary Corrections (IMAX) are among the Network Real-Time Kinematic (NRTK) techniques supported by Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) in rendering network-based solution to users. However, different network corrections have different limitations due to different manufacturers hence offering varieties output. Therefore, this study was conducted to assess the accuracy of VRS, MAX and IMAX for geodetic and plane coordinates. Three (3) techniques were implemented to observe points at Universiti Teknologi Malaysia (UTM) and cadastral lot in Johor Bahru. The results were analysed based on assessment with known values and baseline lengths. The findings showed that the accuracy of all techniques ranged from 0.16 to 3.61 cm (horizontal) and 2.86 to 6.20 cm (vertical) for geodetic coordinates. For plane coordinates, the values varied from 0.3 to 4.22 cm (horizontal) and 2.1 to 8.26 cm (vertical). IMAX provided the worst accuracy compared to others due to incompatibility of Radio Technical Commission for Maritime Services (RTCM) format. Moreover, the accuracy decreases as the baseline length between rover and reference station increases. In conclusion, VRS and MAX yielded acceptable accuracy and can be safely chosen rather than IMAX. Furthermore, the baseline length for applications involving high accuracy measurement should also be considered.

Keywords: Network RTK techniques; MyRTKnet; VRS; MAX; IMAX

I. INTRODUCTION

Accurate and precise measurements are of utmost important to many surveying and mapping applications. Network Real-Time Kinematic (NRTK), one of the most commonly used techniques for various applications was introduced in mid-1990 (Wubbena *et. al.*, 2001; Wanninger, 2008; Kim & Bae, 2015). This method was applied in practices through the approaches of Virtual Reference Station (VRS), Flachen Korrektur Parameter (FKP) and Master-Auxiliary Concept (MAC) with the aim to provide an immediate and well accurate positioning information around the clock (Ogutcu & Kalayci, 2016; Park, 2008; Takac & Zelzer, 2008; Janssen, 2009) while reducing an investment cost required to start a Real-Time Kinematic (RTK) positioning service (Wanninger, 2008). The NRTK technique along with the approaches of VRS, FKP and MAC have been widely implemented in countries such as Japan, Korea, China, Turkey and Europe by utilising existing communication services covering their respective regions (Wanninger, 2008; Bae & Kim, 2018; Chan & Ben, 2007; Cina *et. al.*, 2015; Gumus & Selbesoglu,

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2019). In Malaysia, Department of Survey and Mapping Malaysia (DSMM) has developed Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) since 2004 to facilitate fast and accurate surveys by introducing the NRTK technique, which models the spatial and temporal errors that affect Global Navigation Satellite Systems (GNSS) signals. MyRTKnet offers several NRTK services including two (2) of the most commonly used services which are VRS and MAC with its Master-Auxiliary Corrections (MAX) and Individualised Master-Auxiliary Corrections (IMAX) approaches.

The central concept of NRTK is to improve the long-range ambiguity resolution by generating reliable error models that can mitigate dispersive (ionosphere related) and non-dispersive (troposphere-related and orbit related) signals components. Ambiguity resolution is an analytical procedure to determine the integer cycle of the GPS phase observations (Shariff *et al.,* 2009). Due to the aforementioned fact, ambiguity resolution is essential, in which failure or incorrect resolution could lead to the degradation of the quality of solution (Lim *et al.,* 2020). It is for this reason that NRTK has been accepted widely as a capable technique in providing highly accurate coordinate from GNSS measurement.

This NRTK technique is made up by permanent GNSS receivers' network that continuously transmit observation of the satellite to a central server. The concept of network-based positioning involves three (3) basic processes: i) data processing from master to reference station, ii) network corrections generation and iii) data processing on user side. In order to support NRTK users, all computation must be performed as fast as possible. Figure 1 illustrates the concept of NRTK positioning.
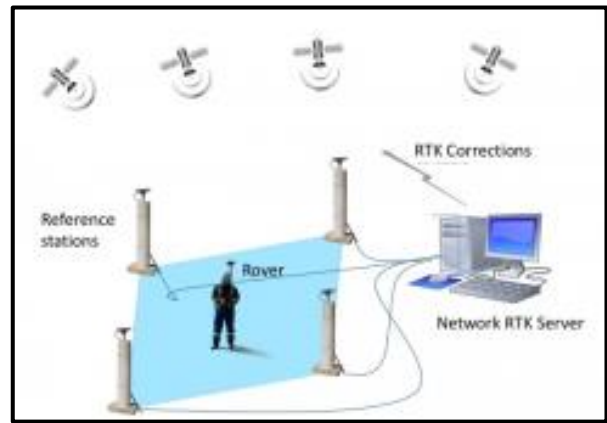

Figure 1. The concept of NRTK positioning (Canadian Geodetic reference System Committee, 2020)

A. Virtual Reference Station (VRS)

The concept of VRS which has been proven and broadly employed is an approach of generating GNSS reference stations data for an imaginary reference station, located near to the initial rover position (refer Figure 2). It is a combination approach of modelling the network and representing the network corrections for users. The VRS approach necessitates at least three (3) reference stations linked to a network server, which requires two-way communication (Inal *et al.,* 2018).

VRS allows the complex modelling of atmospheric effect in the server by taking into account the full network information (Janssen, 2009). In other words, no complex computations are involved at the rover. However, there are constraints to the kinematic application, specifically when rovers pass across wide areas with one dial-in time. If the rover travels further from the initial VRS, a new VRS needs to be decided.
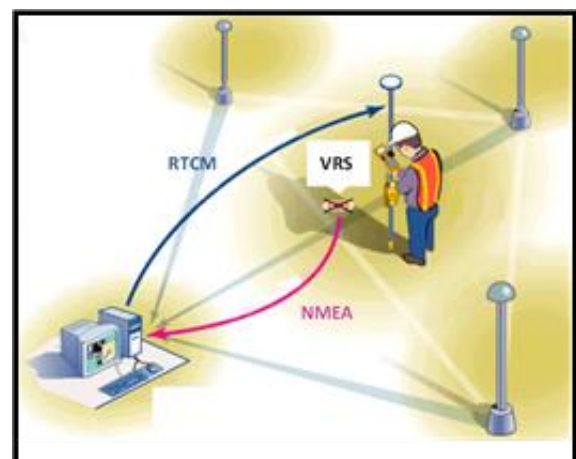

Figure 2. The principle of VRS (Landau *et al.,* 2002)

B. Master Auxiliary Correction (MAX)

The transmission of MAX is utilised based on the MAC principle (Euler *et al.,* 2001) as well as depending on a tiered system of networks, cluster and cell (Janssen, 2009). In contrast to VRS, this concept can be either two-way or one-way communication, as illustrated in Figure 3. Therefore, it is important to note that for two-way communication, the process occurs automatically through the receiver transmitting its approximate position; otherwise, the master station is predetermined by the user manually. The interpolation of this network correction is achieved using the full information of the network by the rover that supports Radio Technical Commission for Maritime Services (RTCM) 3.1 network messages.

The complete information about the prevailing sources of error is made accessible to the rover through RTCM; permitting more intelligent positioning algorithms to be used at the rover to determine the position (Janssen, 2009). According to Janssen (2009), if there are no network corrections obtainable (e.g., due to insufficient pairs between satellite and receiver with fixed ambiguity), then correction will not be transferred and user must adapt a single-based solution.
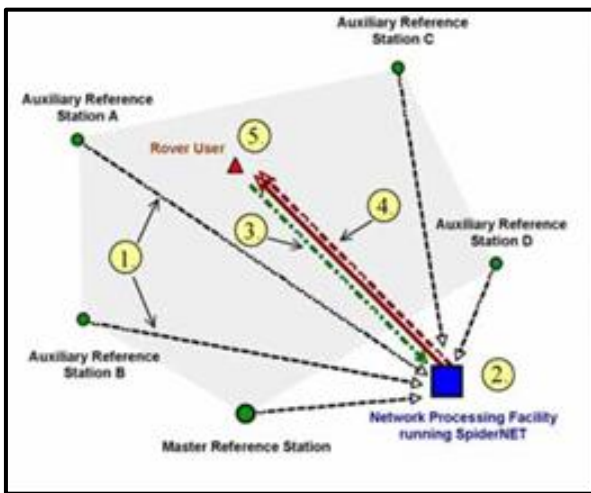

Figure 3. The MAX principle (Brown *et al.,* 2005)

C. Individualised Master-Auxiliary Correction (IMAX)

IMAX was developed at the same time as MAX to support older receivers that cannot interpret the RTCM 3.1 network messages. The IMAX and VRS techniques are similar; both are classified as individualised corrections involving the rover to send its approximate position to the server. The important processes in the uses of IMAX are equivalent to MAX, with the exemption that the network server will calculate and implement network corrections for the rover to the master station. Contradict to VRS, for each rover, IMAX provides individual RTK corrections based on a real reference station.

Every rover must generate its approximate position for the system to identify the closest reference station (Jensen, 2017), meaning that two-way communication must be established either by telephone or over the internet (Garrido *et al.,* 2011). The concept of IMAX approach is demonstrated in Figure 4.
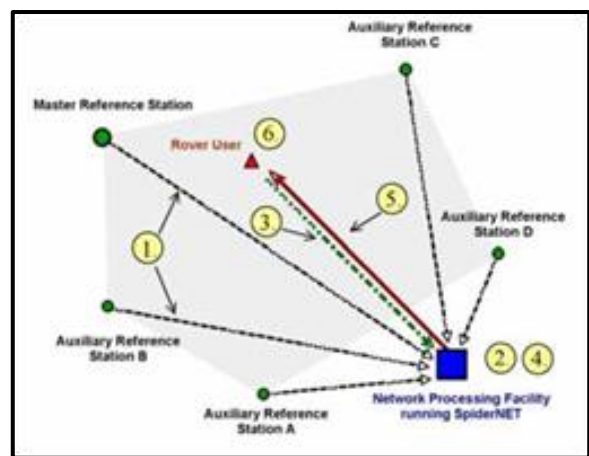

Figure 4. The IMAX principle (Brown *et al.,* 2005)

Therefore, this study presents an effort to assess the accuracy of NRTK techniques for geodetic and plane coordinates, focussing only on the approaches of VRS, MAX and IMAX as implemented by DSMM. In order to realise the aim, a few points at Universiti Teknologi Malaysia (UTM) and nearby cadastral lot in Johor Bahru have been observed. Comparisons of the results were divided into two (2) cases of geodetic and plane coordinates: i) with known values and ii) between baseline lengths. In addition, this study intends to highlight NRTK techniques by comparing their significance and accuracy that could be beneficial to MyRTKnet users by identifying the best technique that provides the highest precision in positioning (geodetic coordinates) and mapping (plane coordinates) as well as maintaining the accuracy as required. However, it should be noted that each of the NRTK techniques is unique in their principles, with different concepts and implementations that could result in different outcomes and accuracies. Each of the characteristics of VRS, MAX and IMAX are summarised in Table 1.

Table 1. Summary of the characteristics of VRS, MAX and IMAX techniques (Janssen, 2009; Cina *et. al.,* 2015; Berber & Arslan, 2013)

VRS	MAX	IMAX
• Generation of GNSS reference stations data for an imaginary reference station. • Two-way communication. • Complex modelling of atmospheric effects in the server – no complex computations involved at the rover. • Mimicking conventional single based RTK. • Limited for kinematic applications.	• Transmission of all relevant correction data from Continuously Operating Reference Station (CORS) to the rover. • Two-way communication. • Complete information on the error correction • Need more bandwidth in the data communication link due to the amount of data to be transmitted. • Advantages for kinematic applications. • Only available for a rover that supports RTCM 3.1.	• Similar interpolation concept as MAX with the exemption that network server calculates and apply the correction to master station. • Two-way communication. • Similar with VRS - both are classed as individualised. • Involved physical reference station. • Correction is regularly updated based on the rover movement. • Support the old receiver that unable to interpret the RTCM 3.1.

II. DATA AND METHODS

From this study, there are two (2) main purposes conducted and analysed based on different points and areas which are i) geodetic (positioning) and ii) plane (mapping) coordinates. For positioning purpose, the area of interest was at UTM, whereas for mapping purpose, the study was carried out at Kg. Melayu, Johor Bahru, Johor. Figure 5 shows the locations of three (3) arbitrary chosen geodetic markers among the points established in UTM meanwhile, Figure 6 shows three (3) Cadastral Reference Mark (CRM) points with known coordinates within the same cadastral lot located at Kg. Melayu, Johor Bahru. Both areas were chosen due to the accessibility of the location. Besides, any information on cadastral lot (for mapping) can be easily obtained from the Land Office (LO) within the region.
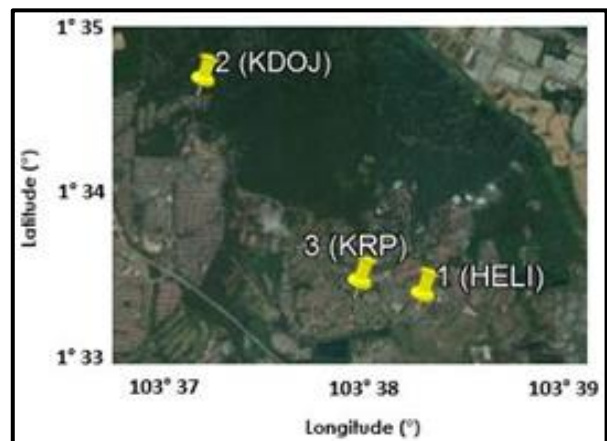

Figure 5. Location of the geodetic markers at UTM for positioning (source: Google Earth)

Figure 6. Location of the CRM points at Kg. Melayu, Johor Bahru, Johor for mapping (source: Google Earth)

In this section, VRS, MAX and IMAX methods are assessed based on two (2) classifications, namely i) comparison with known values and ii) between baseline lengths. The main idea of these assessments is to evaluate the accuracy of the observation points' position according to the NRTK techniques involved.

A. Comparison of Geodetic Coordinates with Known Values (Positioning)

Each result from the NRTK techniques at the observed points is compared to the true coordinate obtained from static GNSS observation. This comparison allows the reliability assessment of each NRTK techniques. From the comparisons, the accuracy (represented by Root Mean Square Error (RMSE)), precision (represented by standard deviation), magnitude and direction were calculated and tabulated. The formulas involved in deriving the RMSE, standard deviation, magnitude and direction are shown per Equations (1) to (4) below (Howell 1998; Ghilani, 2010):

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(p_i - a_i)^2}{n}} \qquad (1)$$

where,

p_i : coordinates from each network correction technique

a_i : coordinates from static GNSS observation or CRM

n : number of observation

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(xi - \mu)^2}{N-1}} \qquad (2)$$

where,

σ : sigma/standard deviation

N : size of data

xi : each data values

μ : mean of data

$$Magnitude\ (D_{AB}) = [(E_B - E_A)^2 + (N_B - N_A)^2]^{1/2} \qquad (3)$$

$$Direction\ \emptyset_{AB} = \tan^{-1}\left|\frac{E_B - E_A}{(N_B - N_A)}\right| \qquad (4)$$

where,

A and B : two (2) different techniques

E and N : coordinates of observed points

B. Comparison of Plane Coordinates with Known Values (Mapping)

CRM is a monument that is often used as control or datum for the cadastral survey. In Malaysia, the cadastre system is managed by two (2) main agencies, namely DSMM and LO. Both of these agencies are responsible for the cadastral spatial information and the cadastre attribute information, respectively (Hassan *et al.,* 2008). Therefore, the observations for this section took place on the three (3) CRM points located at Kg. Melayu, Johor Bahru, Johor. The location of the three (3) CRM points at Kg. Melayu, Johor Bahru, Johor is illustrated in Figure 6. The same formulas (1) to (4) were used to compute the values of RMSE, standard deviation, magnitude and direction between the observed and known coordinates.

C. Baseline Lengths

In general, NRTK technique is made up by permanent GNSS receivers' network that continuously transmits observation of the satellite to a central server, combines the data and produces corrections within the area covered by the reference stations while interpolating those corrections to the rover position (Ogutcu & Kalayci, 2017). The software on the server will automatically choose the closest MyRTKnet station to the rover. The master station is always selected as the closest to the rover, while auxiliary stations are chosen from the surrounding stations (Janssen, 2009).

In this case, the accuracy of NRTK was accessed by taking into account the baseline lengths between the nearest MyRTKnet station and the rover. Therefore, JHJY station was chosen as it was the closest station located to the points of interest. JHJY station served as a guide in classifying points for short and long baseline lengths. For the short baseline, the observed point is located at Kg. Melayu, Johor whereas for long baseline, the point is located at UTM. Figure 7 displays the location of the observed points according to baseline lengths.
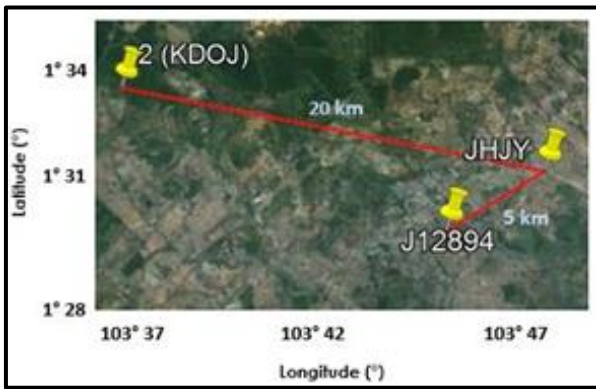
Figure 7. Location of observed points for the evaluation of baseline lengths (source: Google Earth)

D. Data Acquisition and Processing

In order to acquire the known coordinate of the observed points in geodetic coordinate, a static GNSS observation of 8-hours was conducted using Topcon GR-5 dual-frequency receiver on 12th February 2019. The GNSS data was processed using Trimble Business Centre (TBC) post-processing software that can compute coordinate solution accurately within few centimetres level (Soko, 2018). The three-dimensional (3D) control networks were tied to three (3) MyRTKnet stations, namely JHJY, KUKP and SPGR.

For the plane coordinate, coordinates of the CRM points were downloaded from the DSMM website known as JUPEM2U Johor. These coordinates were treated as the ground truth value for the assessment of coordinates from the NRTK techniques. Both true coordinates of points located in UTM (latitude, longitude, ellipsoidal height (h)) and CRM points (northing (N), easting (E), ellipsoidal height (h)) are tabulated in Table 2.

Then, the NRTK techniques were observed at the same 8-hours observation points (25th March 2019) and CRM points (19th March 2019) using Topcon HiPer HR using three (3) different MyRTKnet services which were VRS, MAX and IMAX. For each observation, five fixed solution epochs were collected concurrently with a 1-second sampling rate, and the average of these five (5) epochs was recorded as a single measurement. In total, twenty-five (25) measurements were obtained for each technique from five (5) different initialisations. The mean coordinate from the NRTK techniques was then compared to the known values obtained from static observation. Table 3 summarises the processing parameters and strategies implemented in the TBC post-processing software followed by Figure 8, illustrating the data collection at UTM and Kg. Melayu, Johor, Johor Bahru.

Table 2. True values for geodetic and plane coordinates

Geodetic Coordinates			
Points	Latitude	Longitude	h (m)
1 (HELI)	1° 33' 29.60131"	103° 38' 13.35441"	42.0900
2 (KDOJ)	1° 34' 34.50924"	103° 37' 12.39913"	52.2720
3 (KRP)	1° 33' 33.64825"	103° 37' 56.67691"	33.2620
Plane Coordinates			
CRM Points	N (m)	E (m)	h (m)
J12892	-58600.7340	21364.7480	28.9660
J12893	-58620.3720	21465.8040	33.8080
J12894	-58571.4740	21589.8360	30.9200

Table 3. Processing strategy for post-processed using TBC

Processing Parameters	Processing Strategies
Elevation mask	10°
Processing interval	10 s
Orbit/clock	Broadcast
Type of solution	Fixed

Figure 8. GPS data collection at UTM (left figure) and Kg. Melayu, Johor Bahru, Johor (right figure) using Topcon GR-5 dual-frequency receiver and Topcon HiPer HR, respectively.

III. RESULTS AND DISCUSSION

The interpretation, analysis and discussions are presented in this section. Results and discussion comprise of all research

methodology from geodetic to plane coordinates. Analyses were made in terms of the achievable RMSE (accuracy), standard deviation (precision), magnitude and direction of output from each NRTK technique.

A. Comparison of Geodetic Coordinates with Known Values (Positioning)

The comparisons between the true coordinates and the coordinates obtained from the NRTK techniques of each observed point along with their standard deviations were calculated and tabulated in Table 4. Following that, the result from those comparisons was used to compute the RMSE for northing, easting and ellipsoidal height (h) (refer Table 5). The magnitude and direction of output from each NRTK technique are presented in Tables 6 to 8.

Table 4. Mean coordinates and standard deviation of NRTK techniques

Points	NRTK	Mean Coordinates		
		Latitude	Longitude	h (m)
1 (HELI)	VRS	1° 33' 29.60221"	103° 38' 13.35429"	41.9860
	MAX	1° 33' 29.60254"	103° 38' 13.35429"	42.0078
	IMAX	1° 33' 29.60234"	103° 38' 13.35500"	41.9515
2 (KDOJ)	VRS	1° 34' 34.51060"	103° 37' 12.39889"	52.2080
	MAX	1° 34' 34.51030"	103° 37' 12.39869"	52.1652
	IMAX	1° 34' 34.50659"	103° 37' 12.39666"	52.3652
3 (KRP)	VRS	1° 33' 33.64884"	103° 37' 56.67727"	33.1448
	MAX	1° 33' 33.64839"	103° 37' 56.67788"	33.1284
	IMAX	1° 33' 33.64956"	103° 37' 56.67613"	33.1630
Points	NRTK	Standard Deviation		
		Latitude (cm)	Longitude (cm)	h (cm)
1 (HELI)	VRS	0.36	0.50	0.62
	MAX	0.77	0.29	1.53
	IMAX	0.98	2.67	4.69
2 (KDOJ)	VRS	0.61	0.35	1.00
	MAX	0.36	0.79	1.83
	IMAX	14.99	9.09	23.77
3 (KRP)	VRS	0.86	0.38	1.17
	MAX	1.59	2.68	2.85
	IMAX	0.61	3.03	3.81

Table 5. RMSE of NRTK techniques

Points	NRTK	Latitude (cm)	Longitude (cm)	h (cm)
	VRS	1.23	0.20	4.65
1 (HELI)	MAX	1.68	0.17	3.68
	IMAX	1.43	0.82	6.20
	VRS	1.87	0.34	2.86
2 (KDOJ)	MAX	1.48	0.62	4.78
	IMAX	3.61	3.44	4.17
	VRS	0.80	0.47	5.24
3 (KRP)	MAX	0.16	1.33	5.97
	IMAX	1.80	1.09	4.43

Table 6. Magnitude and direction of Point 1 (HELI)

NRTK	Magnitude (m)		Direction	Remarks
	Horizontal	Vertical		
VRS	0.0279	-0.1040	350° 56' 31.56"	North-West
MAX	0.0378	-0.0822	354° 13' 44.76"	North-West
IMAX	0.0369	-0.1386	29° 53' 56.04"	North-East

Table 7. Magnitude and direction of Point 2 (KDOJ)

NRTK	Magnitude (m)		Direction	Remarks
	Horizontal	Vertical		
VRS	0.0425	-0.0640	169° 41' 42.72"	South-East
MAX	0.0360	-0.1068	157° 25' 45.12"	South-East
IMAX	0.1116	0.0932	223° 37' 13.80"	South-West

Table 8. Magnitude and direction of Point 3 (KRP)

NRTK	Magnitude (m)		Direction	Remarks
	Horizontal	Vertical		
VRS	0.0207	-0.1172	30° 46' 26.40"	North-East
MAX	0.0300	-0.1336	83° 06' 42.12"	North-East
IMAX	0.0470	-0.0990	148° 44' 37.32"	South-East

As shown in Table 5, the RMSE for all observed points using three (3) dissimilar techniques varies from 0.16 to 3.61 cm for northing, 0.17 to 3.44 cm for easting and 2.86 to 6.20 cm for height. The RMSE for the height component is the biggest compared to other components. Based on the study conducted by Berber *et al*. (2012), the vertical accuracy of GNSS is in the order of 2 to 3 times worse than the horizontal component (northing and easting) due to the reason that satellite configuration is better for horizontal determination, which were also proven by Zulkifli *et al*. (2019) and Ramachandran *et al*. (2019) in their studies.

Additionally, from Table 4, IMAX at Point 2 has the largest standard deviation with the values of 14.99 cm for northing, 9.09 cm for easting and 23.77 cm for ellipsoidal height. It is considered the worst compared to others that only range between 0.36 to 4.69 cm for all components. This could be due to the wrong interpretation of the RTCM messages by the receiver. The IMAX technique was originally introduced to support the older receivers that cannot interpret the RTCM 3.1 network messages (Janssen, 2009). However, it should be noted that during the observation, RTCM 3.1 network messages format was used, which most likely to induce the inconsistent result as seen in Table 4. RTCM

format 3.1 was chosen in order to synchronise the network messages used for all the three (3) NRTK techniques. Since RTCM 3.1 was developed to be more efficient compared to the older versions supported by IMAX technique, there would be some conflicts when the versions were mixed up (different messages types have different compatibility), which might affect the final positioning solution (Brown *et. al.*, 2005; Janssen, 2009; SmartNet North America, 2021).

For northing and easting components, the standard deviation is generally in the order of millimetres level except for IMAX at Point 2 and MAX at Point 3 which are in the range of 1.59 to 14.99 cm. As expected, the standard deviation for the vertical component are much worse than horizontal and typically range from 0.62 to 23.77 cm.

Overall, the magnitude of all the three (3) techniques deviate between 2.07 to 11.16 cm and 6.40 to 13.86 cm for horizontal and vertical component, respectively. Meanwhile, for the direction of points, specifically Point 3, VRS and MAX have the same direction towards the known value (north-east) meanwhile, IMAX shows the direction towards south-east.

Generally, if the accuracy of IMAX technique is excluded into consideration, the values of RMSE for both components (horizontal and vertical) remain within the allowable values, which are 2 cm for horizontal and 6 cm for vertical. 2 cm accuracy is the allowable horizontal tolerance for most of the precise applications such as property boundary analysis, engineering works and change detection, whereas, for

vertical tolerance, the information from the GPS measurement is determined maximum three (3) times worse than the horizontal, with the value of 6 cm (Berber *et. al.*, 2012; Amirrudin *et al.*, 2021). Jamil *et al.* (2010) have also stated in their study of MyRTKnet in 2010 and beyond, that the accuracy in the horizontal and height component were 1 cm and between 5 to 7 cm, respectively for areas within 30 km from the network using VRS technique. In terms of standard deviation obtained from the repetition of measurements, by excluding the NRTK of IMAX technique, there are changes within the maximum values of 2.68 cm for horizontal and 2.85 cm for vertical components and this output aligns with the research conducted by Baybura *et al.* (2019), showing almost similar values which are ± 1.5 (N and E measurement) and ± 4 cm (up).

B. Comparison of Plane Coordinates with Known Values (Mapping)

In this part, comparisons between the known CRM coordinates and the coordinates from NRTK techniques were assessed at each CRM point in Cassini Soldner geocentric representing the plane coordinates. The values of standard deviation are tabulated in Table 9. Then, the result from those comparisons was used to calculate the RMSE in northing, easting and ellipsoidal height, as shown in Table 10. The magnitude and direction of output from each NRTK techniques are presented as well in Tables 11 to 13.

Table 9. Mean coordinates and standard deviation of NRTK techniques

Points	NRTK	Mean Coordinates		
		N (cm)	E (cm)	h (m)
	VRS	-58600.7408	21364.8018	28.8862
CRM (J12892)	MAX	-58600.7544	21364.7828	28.8970
	IMAX	-58600.7694	21364.8424	28.7812
	VRS	-58620.4120	21465.8742	33.7442
CRM (J12893)	MAX	-58620.4068	21465.8640	33.7542
	IMAX	-58620.4198	21465.8552	33.8684
	VRS	-58571.4970	21589.8530	30.8730
CRM (J12894)	MAX	-58571.4982	21589.8820	30.8664
	IMAX	-58571.4964	21589.8516	30.8484
Points	NRTK	N (cm)	E (cm)	h (cm)
CRM (J12892)	VRS	0.47	0.33	1.44

	MAX	0.42	0.33	0.54
	IMAX	3.72	7.46	11.80
	VRS	0.32	0.29	1.33
CRM (J12893)	MAX	0.18	0.51	1.44
	IMAX	0.37	0.43	2.24
	VRS	0.43	0.10	1.26
CRM (J12894)	MAX	0.19	0.47	0.34
	IMAX	0.15	0.61	1.03

Table 10. RMSE of NRTK techniques

Points	NRTK	N (cm)	E (cm)	h (cm)
	VRS	0.30	2.41	3.57
CRM (J12892)	MAX	0.91	1.56	3.09
	IMAX	1.58	4.22	8.26
	VRS	1.79	3.14	2.85
CRM (J12893)	MAX	1.56	2.68	2.41
	IMAX	2.14	2.29	2.70
	VRS	1.03	0.76	2.10
CRM (J12894)	MAX	1.08	2.06	2.40
	IMAX	1.00	0.70	3.20

Table 11. Magnitude and direction of CRM J12892

NRTK	Magnitude (m)		Direction	Remarks
	Horizontal	Vertical		
VRS	0.0542	-0.0798	277° 12' 12.96"	North-West
MAX	0.0403	-0.0690	300° 22' 44.76"	North-West
IMAX	0.1008	-0.1848	290° 33' 21.60"	North-West

Table 12. Magnitude and direction of CRM J12893

NRTK	Magnitude (m)		Direction	Remarks
	Horizontal	Vertical		
VRS	0.0808	-0.0638	299° 40' 28.20"	North-West
MAX	0.0694	-0.0538	300° 06' 49.32"	North-West
IMAX	0.0700	-0.0604	310° 01' 58.80"	North-West

Table 13. Magnitude and direction of CRM J12894

NRTK	Magnitude (m)		Direction	Remarks
	Horizontal	Vertical		
VRS	0.0286	-0.0470	323° 31' 50.88"	North-West
MAX	0.0520	-0.0536	297° 44' 53.88"	North-West
IMAX	0.0273	-0.0716	325° 08' 43.80"	North-West

As shown in Table 10, the RMSE for all the observed points using the three (3) different techniques range from 0.30 to 2.14 cm for northing, 0.70 to 4.22 cm for easting and 2.10 to 8.26 cm for ellipsoidal height. The result for the height component is the biggest of all. As previously mentioned, error in vertical component is always significantly worse than the horizontal.

However, IMAX at CRM J12892 has the largest standard deviation, which is 3.72, 7.46 and 11.80 cm for northing, easting and height, respectively (refer Table 9). It is considered the worst compared to other techniques that only range between 0.18 to 1.44 cm for all components. The values show better precision compared to the standard deviation values computed by Baybura *et al.* (2019) which were ± 1.5 and ± 4 cm for horizontal and vertical component, respectively.

In addition, the magnitude of all techniques generally range from 2.73 to 10.08 cm for horizontal and 4.70 to 18.48 cm for vertical (refer Tables 11 to 13). Meanwhile, for the direction, VRS, MAX and IMAX project the same direction towards the known values.

Interestingly, the magnitude is bigger compared to the acceptable value, which is 2 cm for horizontal position and 6 cm for vertical position, specifically for cadastral works (Jabatan Ukur dan Pemetaan Malaysia, 2009). However, since the comparison was made between NRTK and static techniques, the accuracy of NRTK technique would contribute to error in the solution with the magnitude differences up to 5 cm for horizontal and 7 cm for vertical components due to short period of data in modelling distance-dependent errors (Baybura *et al.*, 2019). Besides, it should also be noted that the observation took place in an urban area, thus there could be errors from the multipath (Deep *et al.,* 2018) and interference from the elevation mask as well.

C. Baseline Lengths

This section discusses the accuracy and precision of NRTK techniques in terms of baseline lengths between the rover and the nearest MyRTKnet station (JHJY). The distance of 5 km between JHJY and J12894 represents the short baseline length, whereas the Point 2 (KDOJ) symbolises the long baseline length with the distance of 20 km from JHJY station. All results are tabulated and plotted in Table 14 and Figure 9.

Table 14. Standard deviation of Point 2 and J12894

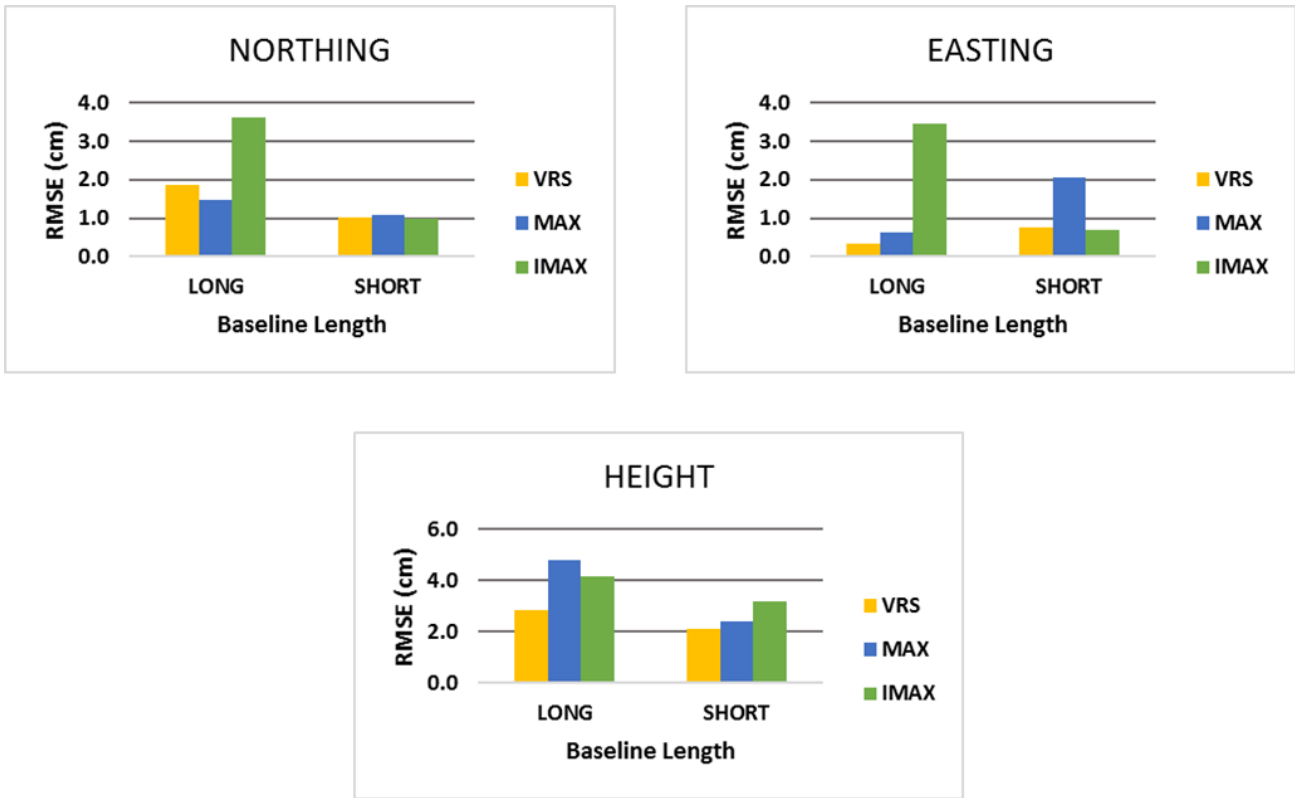| Points	NRTK	Latitude/N (cm)	Longitude/E (cm)	h (cm)
2 (KDOJ)	VRS	0.61	0.35	1.00
	MAX	0.36	0.79	1.83
	IMAX	14.99	9.09	23.77
CRM (J12894)	VRS	0.43	0.10	1.26
	MAX	0.19	0.47	0.34
	IMAX	0.15	0.61	1.03

Figure 9. RMSE of northing, easting and height components

Based on Table 14, the baseline length between the rover and the nearest MyRTKnet station does affect the horizontal and vertical components. From the comparison, it shows that the long baseline has the highest RMSE value for all components compared to the short baseline. This might probably happen due to the effect of distance-dependent errors (Musa, 2007). Apart from that, if there are high ionospheric and tropospheric activities, the 15 km distance might become less than 10 km because dispersive and non-dispersive errors swiftly changed from the base station to the rover side (Hu *et al.,* 2002). Furthermore, referring to Baybura *et al.* (2019), they observed the differences between NRTK-static and in east coordinates were at a maximum of 2 cm based on 5 km baseline and this value was estimated to be increased when moving away from reference station. In terms of RMSE (refer Figure 9) for northing and easting components of long baseline, IMAX at Point 2 has the greatest values compared to others, which are 3.61 and 3.44 cm, respectively. Nevertheless, MAX has the lowest value of northing which is at 1.48 cm and VRS has the lowest values for easting and height, which are 0.34 cm and 2.86 cm, respectively.

For vertical component, the standard deviation is generally in the order of centimetres level except for MAX at CRM (J12894), which is 3.4 mm. For northing and easting, the standard deviations are at millimetres level except for IMAX of Point 2, which are 14.99 and 9.09 cm, respectively. Overall, from Table 14 and Figure 9, IMAX gives the biggest values for both standard deviation and RMSE. As stated before, this is due to the misinterpretation of RTCM messages related to GNSS equipment.

IV. CONCLUSION

In this study, the accuracy of the NRTK techniques based on VRS, MAX and IMAX approaches was successfully assessed for geodetic (positioning) and plane coordinates (mapping) in Malaysia. Due to different functions, concepts and techniques of each NRTK approach, the outcomes generated were also varied. Therefore, the significance of NRTK approaches can be seen from the comparison of their accuracies which could be beneficial to MyRTKnet users in identifying the best technique that can provide the best solution with the smallest error value in terms of geodetic and plane coordinates.

Among the three (3) techniques tested in this study, there were no noticeable differences between them except for IMAX, showing significant differences at some points. In general, the accuracy of horizontal and vertical components for both geodetic and plane coordinates were in cm level for each technique. For geodetic coordinates, the RMSE values representing accuracy ranged from 0.16 to 3.61 cm and 2.86 to 6.20 cm for horizontal and vertical component, respectively. Meanwhile, for plane coordinates, the RMSE values varied from 0.3 to 4.22 cm for horizontal and 2.1 to 8.26 cm for vertical components. Prior to the discussion in the previous section, the allowable accuracy values for horizontal and vertical components were 2 cm and 6 cm, respectively. However, if the IMAX technique is treated as an exception due to the misinterpretation of RTCM network messages, the RMSE values for geodetic and plane coordinates are both within the allowable tolerance as the biggest values for all components were derived from IMAX technique.

Furthermore, in terms of baseline length, the distance between the rover and the closest CORS station affected the horizontal and vertical accuracy as well as precision. As the rover moved farther away from JHJY station, the accuracy and precision were also deteriorated due to the errors in GNSS measurement such as ionospheric, tropospheric, signal obstruction and multipath as well as the factor of geometric configuration of satellites.

Finally, it may be concluded that any of the two NRTK techniques of VRS and MAX can be safely selected for positioning (geodetic coordinates) and mapping (plane coordinates) purposes as there was not much differences between those two techniques with regard to accuracy and precision. Nevertheless, this is not the case for IMAX since the RTCM format needs to be compatible with GNSS equipment and technique applied. For example, RTCM 3.1 network messages for MAX technique and RTCM below 3.1 network messages (older type receivers) for IMAX technique. As this study was conducted based on short observation period, further studies involving longer observation time to acquire data redundancy and increase data precision are recommended. It is also suggested to carry out observations in the same survey conditions to avoid any biases in the solutions (ionospheric and tropospheric effect, satellite geometry etc.) for all geodetic and plane coordinates points. The baseline length for specific applications that require high accuracy and precision of data should be considered as well.

V. ACKNOWLEDGEMENT

VI. REFERENCES

Amiruddin, MA, Din, AHM, Zulkifli, NA, Amat, MAC & Hamden, MH 2021, 'Assessment of the accuracy and precision of MyRTKnet real-time services', Jurnal Teknologi, vol. 83, no. 1, pp. 93-103.

Bae, TS & Kim, M 2018, 'Performance analysis of network-RTK techniques for drone navigation considering ionospheric conditions', Journal of Sensors, vol. 2018, pp. 1-8.

Baybura, T, Tiryakioglu, I, Ugur, MA, Solak, HI & Safak, S 2019, 'Examining the accuracy of network RTK and long base RTK methods with repetitive measurement', Journal of Sensors, vol. 2019, pp. 1-12.

Berber, M, & Arslan, N 2013, 'Network RTK: A case study in Florida', Measurement, vol. 46, no. 8, pp. 2798-2806.

Berber, M, Ustun, A & Yetkin, M 2012, 'Comparison of accuracy of GPS techniques', Measurement, vol. 45, no. 7, pp. 1745-1746.

Brown, N, Keenan, R, Richter, B & Troyer, L 2005, 'Advances in ambiguity resolution for RTK applications using the new RTCM V3.0 master-auxiliary messages', in ION GPS 2005: Proceedings of the 18th International Technical Meeting of the Satellite Division of the Institute of Navigation, Long Beach, 13-16 September 2005, Long Beach Convention Center, Long Beach.

Canadian Council on Geomatics, 2020, RTK and NRTK, viewed 19 March 2021, <http://cgrsc.ca/resources/gnss-augmentation/rtk-and-nrtk/>.

Chan, KK & Ben, LCH 2007, 'The Hong Kong satellite positioning reference station network (SatRef) – system configuration, applications and services', in Proceedings of FIG Working Week 2007, Hong Kong, 13-17 May 2007, Kowloon Shangri-La, Hong Kong.

Cina, A, Dabove, P, Manzino, AM & Piras, M 2015, 'Network real time kinematic (NRTK) positioning – description, architecture and perfomances', eds S Jin, in Satellite positioning – methods, models and applications, IntechOpen, London, pp. 23-45.

Deep, S, Raghavendra, S & Bharath, BD 2018, 'GPS SNR prediction in urban environment', The Egyptian Journal of Remote Sensing and Space Science, vol. 21, no. 1, pp. 83-85.

Euler, HJ, Keenan, CR, Zebhauser, BE & Wübbena, G 2001, 'Study of a simplified approach in utilizing information from permanent reference station arrays', in ION GPS 2001: Proceedings of the 14th International Technical Meeting of the Satellite Division of the Institute of Navigation, Salt Lake City, 11-14 September 2001, Salt Palace Convention Center, Salt Lake City.

Garrido, MS, Giménez, E, Lacy, MCD & Gil, AJ 2011, 'Testing precise positioning using RTK and NRTK corrections provided by MAC and VRS approaches in SE Spain', Journal of Spatial Science, vol. 56, no. 2, pp. 169-184.

Ghilani CD (eds) 2010, Adjustment computations: spatial data analysis, 5th edn, Wiley, New Jersey, United States.

Gumus, K & Selbesoglu, MO 2019, 'Evaluation of NRTK GNSS positioning menthods for displacement detection by a newly designed displacement monitoring system', Measurement, vol. 142, pp. 131-137.

Hassan, MI, Ahmad-Nasruddin, MH, Yaakop, IA & Abdul-Rahman, A 2008, 'An integrated 3D cadastre–Malaysia as an example', The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, vol. 37, no. B4, pp. 121-26.

Howel, DC (eds) 1998, Statistical methods for psychology, 7 edn, Cengage Wadsworth, Belmont, Canada.

Hu, GR, Khoo, VHS, Goh, PC & Law, CL 2002, 'Internet-based GPS VRS RTK positioning with a multiple reference station network', Journal of Global Positioning Systems, vol. 1, no. 2, pp. 113-120.

Inal, C, Bulbul, S & Bilgen, B 2018, 'Statistical analysis of accuracy and precision of GNSS receivers used in network RTK', Arabian Journal of Geosciences, vol. 11, no. 227, pp. 1-8.

Jabatan Ukur dan Pemetaan Malaysia, 2009, Garis panduan amalan kerja ukur kadaster dalam persekitana eKadaster, Pekeliling Ketua Pengarah Ukur dan Pemetaan bilangan 6 tahun 2009, Kuala Lumpur.

Jamil, H, Mohamed, A & Chang D 2010, 'The Malaysia Real-Time Kinematic GNSS Network (MyRTKnet) in 2010 and beyond', in FIG Congress 2010, 11-16 April 2010, Sydney, Australia.

Janssen, V 2009, 'A comparison of the VRS and MAC principles for network RTK', in International Global Navigation Satellite Systems Society Symposium 2009, Queensland, 1-3 December 2009, Holiday Inn Surfers Paradise, Queensland.

Jensen, ABO 2017, High accuracy GNSS positioning, KTH Space Center, viewed 3 June 2020, <https://gidec.abe.kth.se/GEOWEB/docs_mostar/jensen.pdf>.

Kim, MH & Bae, TS 2015, 'Preliminary analysis of network-RTK for navigation', Journal of the Korean Society of Surveying, geodesy, Photogrammetry and Cartography, vol. 33, no. 5, pp. 343-351.

Landau, H, Vollath, U & Chen, X 2002, 'Virtual reference station systems', Journal of Global Positioning Systems, vol. 1, no. 2, pp. 137-143.

Lim, S, Musa, TA & Rizos, C 2020, Modelling of dispersive and non-dispersive effects on network-based real-time kinematic positioning, viewed 3 June 2020, <https://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.588.729&rep=rep1&type=pdf>.

Musa, T A 2007, 'Analysis of residual atmospheric delay in the low latitude regions using network-based GPS positioning', PhD thesis, University of New South Wales, Sydney, New South Wales.

Ogutcu, S & Kalayci, I 2017, 'Investigating Precision of Network Based RTK Techniques: Baseline Length Is Concerned', World Journal of Research and Review, vol. 5, no. 1, pp. 1-3.

Ogutcu, S, & Kalayci, I 2016, 'Investigation of network-based RTK techniques: a case study in urban area', Arabian Journal of Geosciences, vol. 9, no. 99, pp. 1-12.

Park, B 2008, 'A study on reducing temporal and spatial decorrelation effect in GNSS augmentation system', PhD thesis, Seoul National University, Seoul, Korea.

Ramachandran, D, Din, AHM, Omar, AH & Ibrahim, SA 2019, 'Real-Time Precise Point Positioning (RT-PPP) for positioning and mapping', eds B Pradhan, in Lecture Notes in Civil Engineering, Springer, Singapore, pp. 891-913.

Shariff, NSM, Musa, TA, Ses, S, Omar, K, Rizos, C & Lim, S 2009, 'ISKANDARnet: a network-based real-time kinematic positioning system in ISKANDAR Malaysia for research platform' in 10th South East Asian Survey Congress 2009, Bali, 4-7 August 2009, Bali International Convention Center, Bali.

SmartNet North America 2021, What are the different correction formats & mountpoints that you offer?, viewed 19 March 2021, <https://support.smartnetna.com/hc/en-us/articles/360000869388-What-are-the-different-correction-formats-Mountpoints-that-you-offer->.

Soko, M 2018, 'Validity and reliability of free GPS post-processing services for the southern region of Peninsular Malaysia', Master thesis, Universiti Teknologi Malaysia, Johor Bahru, Johor.

Takac, F & Zelzer, O 2008, 'The relationship between network RTK solutions MAC, VRS, PRS, FKP and i-MAX', in ION GNSS 2008: Proceedings of the 21st International Technical Meeting of the Satellite Division of The Institute of Navigation, Savannah, 16-19 September 2008, Savannah International Convention Center, Savannah.

Wanninger, L 2008, Introduction to network RTK, viewed 19 March 2021, < http://www.wasoft.de/e/iagwg451/intro/introduction.html>.

Wubbena, G, Bagge, A & Schmitz, M 2001, 'Network-based techniques for RTK applications', in GPS Symposium, 14-16 November 2001, Tokyo, Japan.

Zulkifli, NA, Din, AHM & Omar, AH 2019, 'The impact of different International Terrestrial Reference Frames (ITRFs) on positioning and mapping in Malaysia', eds B Pradhan, in Lecture Notes in Civil Engineering, Springer, Singapore, pp. 671-690.