# Comparison of the Horizontal Positional Accuracy of Single-base and Network RTK within the Mega-Manila Sub-Network

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**Abstract** – *Real Time Kinematic (RTK) Global Navigation Satellite System (GNSS) survey is a reliable and efficient survey method that has been used in applications that require centimeter level positioning in real time since the late 1900s. Two methods are commonly used for RTK positioning namely single-base RTK (SBRTK) and network RTK (NRTK). This research assessed the horizontal positional accuracy of SBRTK and NRTK with respect to derived positions using static positioning method. The Philippine Active Geodetic Network (PageNET) stations of the National Mapping and Resource Information Authority (NAMRIA), specifically the stations belonging in the Mega-Manila sub-network, were used as reference stations. Five (5) points with increasing distance from PTAG station were tested for this study in SBRTK method. Three techniques in NRTK were also experimented, namely: Virtual Reference System (VRS), Master Auxiliary Concept (MAC) and Flächen-Korrektur Parameter (FKP).*

*The coordinates of the test points measured using RTK were evaluated by comparing with the coordinates of the same points observed in static mode. The results showed that NRTK techniques excepting MAC that is giving inconsistent results are better than SBRTK in distances more than 10 km from the base station PTAG. The FKP and VRS gave average coordinate differences of 5.64 cm and 5.63 cm, respectively, compared with the 6.61 cm coordinate difference of SBRTK for the five test points. The FKP NRTK and SBRTK provide the fastest initialization time of less than 30 seconds in most of the test sites. The VRS method gave almost similar coordinate difference average as the FKP method; however, the latter method had a faster initialization time with an average of 54 seconds as against 138 seconds for the former. The results also show the distance dependency of the accuracy of the SBRTK technique. The results ranged from 2.3 cm to 11.2 cm for distance range of 5.2 km to 23.3 km, respectively. Thus, NRTK is a better alternative to SBRTK because of this. However, SBRTK can provide faster initialization than other NRTK techniques.*

*The accuracies of the different RTK techniques were also assessed with respect to the geodetic control specifications of the Philippine Reference System of 1992 (PRS92) mandated as the standard reference system for all surveys in the Philippines in Executive Order No. 45, series of 1992, as amended. From the results, all RTK techniques gave less than 10 ppm linear error, which is the allowable error for first-order geodetic control survey. Therefore RTK techniques can supplant the use of Static post-processing (PP) method for first-order and lower accuracy surveys where productivity is a prime requirement.*

*Keywords—FKP, GNSS, MAC, Real-Time Kinematic, Single-base RTK, Network RTK, VRS*

## I. INTRODUCTION

The Philippine Active Geodetic Network (PageNET) stations by the National Mapping and Resource Information Authority (NAMRIA) is a network of permanently-installed, continuously operating geodetic reference stations that utilize signals from Global Navigation Satellite Systems (GNSS) to provide real-time, high-precision geographic position data to users via the Internet. Importantly, these stations provide continuous link to the International Terrestrial Reference Frame (ITRF). To date there are 30 operating stations installed all over the country [1].

Since its establishment in 2008 to present, no study has yet been conducted comparing the accuracy of Real-Time Kinematic (RTK) Global Positioning System (GPS) or Global Navigation Satellite System (GNSS) survey method in network and single-base modes in the Philippines. Although the establishment of the PageNET stations was intended for the highest order geodetic survey (e.g., zero-order geodetic control) for the whole country, the maximization of this resource entails other uses such as lower-order geodetic surveying, GIS and mapping, engineering applications, hydrographic surveying and transportation monitoring applications. The latter use should be given emphasis since mobile positioning, particularly in Metro Manila, is starting to gain popularity with some cars (private and public) now being equipped with GPS/GNSS receivers. With the Land Transportation and Franchising Regulatory Board (LTFRB) directing the installation of GPS receivers on board all public utility buses (PUBs) [2] the PageNET stations will play an important role in mobile transport applications.

Accurate positioning using GNSS receiver depends on many factors such as baseline distance and duration of observation. High-accuracy GNSS positioning sometimes requires a longer observation time; but, most often this translates to less productivity. With RTK, this is not anymore the case; RTK can provide accuracy comparable to static method in seconds of observation time. Furthermore, the availability of a network of continuously operating reference stations introduced a new method called network RTK or NRTK. Its main advantage is the removal of limited reference-to-rover range in RTK which is usually from 10 to 20 km [3].

This research assessed the accuracy of GNSS positioning in horizontal directions in RTK mode using PageNet stations and the Leica SpiderNET RTK software in the NAMRIA Master Control Station (MCS). A post-processed GNSS solution derived from static observations was computed to serve as reference values for assessment. All resulting coordinates were given in International Terrestrial Reference Frame (ITRF) 2008 [4]. As NAMRIA is now shifting to a geocentric datum, the results of this research will also serve as an initial test in GNSS positioning in the said datum.

## II. GNSS SURVEYING METHODS

The GNSS is a collective term for different satellite navigation system constellations. These include GPS of the United States of America [5], Global Navigation Satellite System (GLONASS) of Russia [6], Galileo of European Union [7], Beidou of China [8], Quazi-Zenith Satellite System (QZSS) of Japan [9] and Indian Regional Navigation Satellite System (IRNSS) of India [10]. These are designed to be interoperable, hence, multi-GNSS antennas can actually receive signals from these different navigation satellites. The increasing number of satellites is an added benefit to GNSS signal users because it provides satellite availability at any given time of observation. The different GPS/ GNSS surveying methods used in this research are discussed below.

### *2.1 Static*

Static GPS observation was the first method used in satellite positioning using GNSS. It still continues to be the primary technique used in the field today [11]. This method requires observations acquired from receivers that are stationary. For positioning that requires high accuracy, static GPS observation is the method used. The data logged from receivers are downloaded later for post-processing of carrier phase measurements using special software to eliminate observation errors. Observation sessions ranging from 30 minutes to 2 hours can vary depending on length of baseline, number of available satellites, and required accuracy.

### *2.2 Real-Time Kinematic (RTK)*

RTK is an instantaneous GNSS positioning method that delivers high accuracy for short observation of time. This is achieved through the determination of corrections from reference/base stations and transmitted to the rover via radio or internet. Thus, the positions are determined immediately. There are three (3) important components of RTK: (1) reference receiver, (2) rover receiver and (3) data link [12]. The following are short discussions on two (2) methods employed mostly for RTK.

#### *Single-base RTK*

Single-base RTK (SBRTK) basically needs two receivers: a base station (with known position) and a rover. The carrier phase observations from GNSS are measured simultaneously by the two receivers [12]. These raw observations from the base station are sent by radio link to the rover that combines the data and performs carrier phase differential GNSS [13] in real time to compute the coordinates of the rover. Distances between base station and rover are often limited to 10-20 km. Figure 1 illustrates this concept.

*Network-based RTK (NRTK)*

The processing and correction dissemination of NRTK is based on a tiered system of networks, clusters and cells [14]. A cluster is defined as a sub-network of stations that are processed together to achieve a common ambiguity level [15]. It is also possible that the network processing software may choose a subset of stations from a network or clusters based on certain criteria to be the optimal set of stations to provide corrections to the rover. The sub-network consisting of seven (7) PageNET stations (see Table 1 and Annex 1) with master control station located in NAMRIA, Taguig City is called the Mega-Manila cluster.

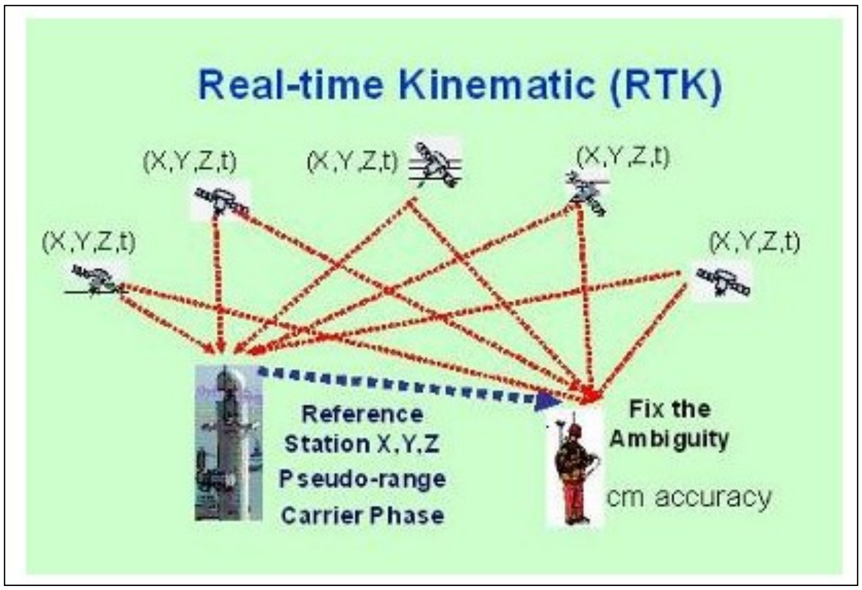


**Figure 1.** Single-base RTK [12]

NRTK provides high accuracy GNSS positioning results through the measurement of GNSS signals, modeling of the distant-dependent systematic errors and computation of the real-time corrections for roving GNSS receivers [16]. The transmissions of these real-time corrections are typically in the standard Radio Technical Commission for Maritime Services (RTCM) format via radio, mobile phone or wireless internet [14]. The advantage of NRTK over single-base RTK is the expansion of coverage to a wider area. While single-base RTK distance is limited to a maximum of 20 km [17], NRTK can be extended up to 100 km [16].

Three network RTK principles currently available today are Flächen-Korrektur Parameter (FKP) or area correction parameters method [15], Virtual Reference System (VRS) [18] and Master Auxiliary Concept (MAC) [3,15]. These techniques are briefly described below and illustrated in Figure 2.

The FKP method is the oldest Network RTK method and was developed by Geo++ GmbH in Germany. It does not require the RTK rover to send its current position to the network central server. It is the server that models the distance-dependent errors and sends RTK data from one reference station within the network to the rover. The FKP method creates area correction parameters represented as simple planes that are valid for a limited area around a single reference station [19].

The widely used VRS concept is a technique that creates GNSS reference station data for an invisible or virtual, unoccupied station near (just a few meters) a roving receiver [20]. This virtual reference station provides network RTK corrections interpreted by the rover as coming from a single, real reference station [18]. Three (3) reference stations are required in the implementation of the VRS technique connected to a network server and the rover communicating via a two-way scheme [14].

The MAC principle is a relatively new concept introduced by Euler et al. (2001). The basic concept of MAC is to provide, in compact form, as much of the network information and the errors it is observing to the rover [3,21]. The phase ranges from raw code and phase data collected from different reference stations are reduced to a *common ambiguity level* in the processing facility [22]. Two reference stations are said to be on a common ambiguity level if the integer ambiguities for each phase range (satellite-receiver pair) have been removed (or adjusted) so that when double differences are formed the integer ambiguities cancel. The network corrections are generated from a subset of stations in the network/clusters that gives the best solution for the rover [21]. These corrections are termed master-auxiliary corrections (MAX) transmitted in a highly compact message format [22] through a two- way or broadcast communication mediums. The rover then uses the information to determine the dispersive and non-dispersive errors at its location and subsequently resolves its ambiguities and determines its position.

Conceptually, the main difference between MAC and VRS is that it shifts some of the intelligence from the reference station software onto the rover [21]. Since VRS requires two-way communication it can theoretically limit the number of simultaneous users [14].

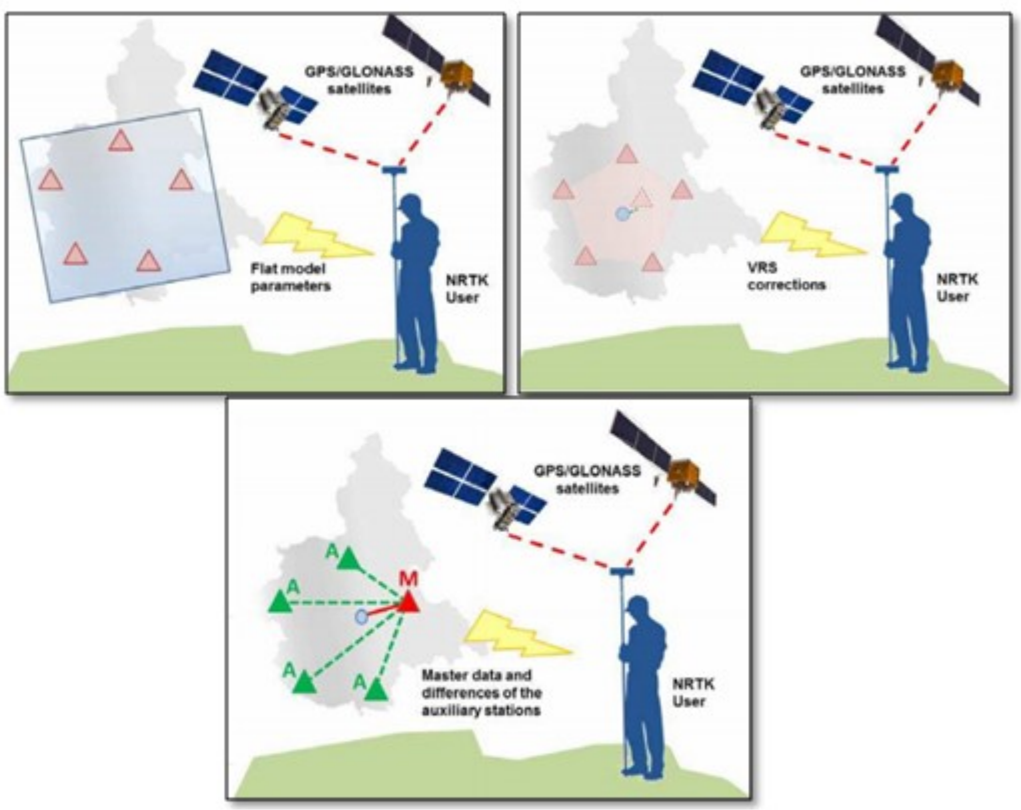


**Figure 2.** The FKP (a), VRS (b) and MAC (c) principles [23]

## III. METHODOLOGY

*3.1 Instruments and software used*

The instrument used as rover for this research was the Trimble SPS985 GNSS receiver with TSC-3 data collector installed with SCS900 software. The base station PTAG is equipped with Leica GR5 that is capable of receiving GPS and GLONASS signals only. The remaining reference stations were all equipped with Leica receivers except for station PMRV which was equipped with a Trimble NetR9 receiver (see Annex 1).

The Master Control Station at NAMRIA employs the Leica GNSS Spider software for network processing solutions. For post-processing, ConverttoRINEX, RTKLib, GNSS Solution and Trimble Business Center were used. The online processing service of AUSPOS was also availed for checking the point positions from static observations.

*3.2 Identification of study area*

The area covering Metro Manila was identified as the site for testing the RTK survey due to its accessibility and internet connection consideration. As shown in Figure 3 the area is located at the center of the network of seven (7) PageNET stations comprising the Mega-Manila sub-network. Table 1 lists these stations and their locations. Descriptions of these stations are given in Annex 1.

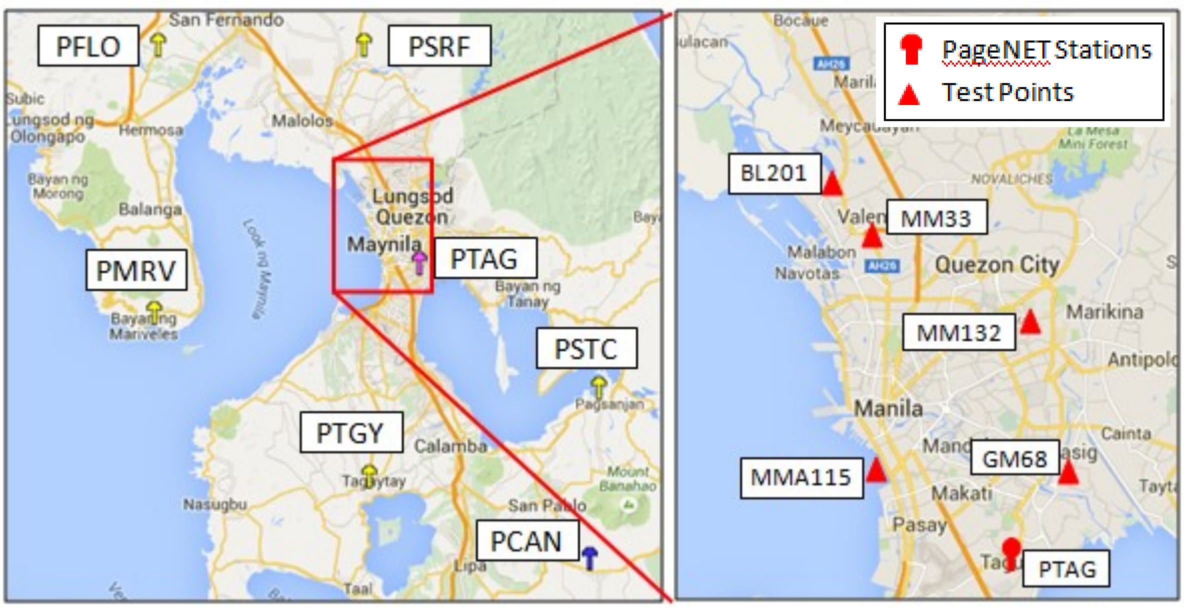


**Figure 3.** Mega-Manila sub-network and location of test points.

*3.3 Selection of test points*

The study initially included the assessment of the vertical accuracy of the test points which all included existing bench marks (BM). The main reason for excluding the heights for assessment is because the accuracy of the Philippine Geoid Model that will be used to convert ellipsoidal heights to orthometric heights was placed at +/- 30 cm during the time of the experiment. The test points were selected based on the designed distances of approximately 5, 10, 15, 20 and 25 km from station PTAG. Descriptions of the test points are given in Annex 2. Only PTAG was selected as reference/base station for the single-base RTK due to the proximity of the selected test points. The test points are also shown in Figure 4. Table 2 identifies their locations and distances from station PTAG.

**Table 1.** AGN Stations in Mega-Manila sub-network.

| PageNET Stations | Geographic Coordinates | | Year Established | Location |
|---|---|---|---|---|
| | Latitude | Longitude | | |
| PCAN | 13°55' 56.241" | 121°23'48.423" | 2008 | Quezon |
| PFLO | 14°58'58.401" | 120°29'57.713" | 2008 | Pampanga |
| PMRV | 14°26'09.438" | 120°29'24.813" | 2012 | Bataan |
| PSRF | 14°58'54.741" | 120°55'39.502" | 2013 | Bulacan |
| PSTC | 14°16'53.780" | 121°24'52.254" | 2012 | Laguna |
| PTAG | 14°32'07.432" | 121°02'26.783" | 2008 | Taguig City |
| PTGY | 14°06'00.851" | 120°56'17.858" | 2008 | Cavite |

**Table 2.** Location of test points.

| **Test Points** | **Distance from Base Station PTAG (km)** | **Location** |
|---|---|---|
| MMA115 | 8.6 | Manila City, Metro Manila |
| MM132 | 14.5 | Quezon City, Metro Manila |
| MM33 | 19.4 | Valenzuela City, Metro Manila |
| BL 201 | 23.3 | Marilao, Bulacan |

*3.4 Reconnaissance*

Before the actual observation, reconnaissance survey was conducted to determine the status of the selected BMs. Since most of these are located along major roads and highways, the possibility of their being disturbed due to road widening, utility rehabilitation and construction is quite high. Reconnaissance survey also provides information on the actual conditions surrounding the selected test point. To achieve maximum efficiency of the GNSS survey, an overall assessment of obstructions in the site is needed. This helps the surveyor decide whether to select alternative test points or measure offsets from test points with less obstructions.

*3.5 GNSS observation on test points*

Actual observations on test points were conducted using three (3) GNSS survey techniques: 1) Static (post processed); 2) SBRTK and 3) NRTK. Below is a short description of the process.

*Static observation for post-processed survey*

The purpose of the static GNSS observations in this research was to provide reference values for assessing the performance of the RTK technique. The coordinates of the test points determined from the post-processed data observed using static technique will were compared with the coordinates of test points determined by the RTK technique. A minimum of one (1) hour per session was done over each test point for post-processing. Since the PageNET stations used as reference were continuously logging, there was no problem with the data required for post-processing.

*Single-base RTK (SBRTK)*

During the SBRTK observation, the setting was set to PTAG as reference station. Distances for SBRTK ranged from 5.2 to 23.3 km. This research extended the distance to more than 20 km to determine the effect of distance, if any, on the degradation of the accuracy of GNSS positioning using this technique. Communication between station PTAG and the rovers was established through internet using a pocket Wi-Fi. To connect with the base station an IP address, Port number, Mountpoint, Username and Password were provided by NAMRIA. The duration of observations depended on the speed of the resolution of the carrier phase ambiguity.

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*Network Based RTK (NRTK)*

Unlike SBRTK, NRTK requires three or more reference stations. The Mega-Manila sub-network consists of seven (7) PageNET stations as given in Table 1. The basic principle of NRTK involves sending to the rovers corrections computed from the network of reference stations in real-time [24]. This research experimented on FKP, VRS and MAC techniques. All of these approaches are provided by NAMRIA to its end users through the PageNET web service http://pagenet.namria.gov.ph.

### *3.6 Post-processing*

After the observations, the raw data were downloaded and converted to RINEX format using the ConvertoRINEX software. The static observations were post-processed using RTKLib and also uploaded in AUSPOS for online processing. The RINEX data for the base station were provided by NAMRIA during the post-processing stage. The GNSS Solution and Trimble Business Center software were sometimes used for a more detailed viewing of the processing results.

## IV. RESULTS AND DISCUSSIONS

### *4.1 Processed data points*

During the survey, the number of satellites observed ranged from 7 to 17 and the monitored Position Dilution of Precision (PDOP) values were mostly less than 2. At least three (3) sets of observations were conducted on the test points and used to analyze the results of the processed points. The decision to relocate some of the points to open areas was based on the pre-analysis of the results of the post-processing. However, even with the relocation, for test points MMA115 and GM68 no positions were obtained using the MAC technique despite two attempts.

The processed test points from the static observations were projected on Zone 51 of the Universal Transverse Mercator (UTM) projection in the World Geodetic System WGS84 datum, which was also the setting during the RTK observations. Table 3 summarizes the coordinates of the test points using the different GNSS surveying techniques.

**Table 3.** Test point in UTM Coordinates: Northings (N) and Eastings (E) in units of meter

| **Test Points** | **Distance from PTAG (km)** | | **NRTK Technique** | | | **SBRTK** | **Static PP** |
|---|---|---|---|---|---|---|---|
| | | | **FKP** | **MAC** | **VRS** | | |
| BL201 | 23.3 | N | 1629606.401 | 1629606.409 | 1629606.378 | 1629606.412 | 1629606.308 |
| | | E | 280511.062 | 280511.033 | 280511.048 | 280511.071 | 280511.113 |
| MM33 | 19.4 | N | 1626343.630 | 1626343.693 | 1626343.687 | 1626343.646 | 1626343.646 |
| | | E | 282969.308 | 282969.266 | 282969.255 | 282969.350 | 282969.270 |
| MM132 | 14.5 | N | 1622048.360 | 1622048.407 | 1622048.375 | 1622048.373 | 1622048.335 |
| | | E | 291918.307 | 291918.268 | 291918.313 | 291918.298 | 291918.360 |
| MMA115 | 8.6 | N | 1612872.634 | No measurement | 1612872.638 | 1612872.629 | 1612872.604 |
| | | E | 281845.237 | | 281845.238 | 281845.232 | 281845.197 |
| GM68 | 5.2 | N | 1611404.853 | | 1611404.859 | 1611404.837 | 1611404.843 |
| | | E | 292641.987 | | 292641.989 | 292641.989 | 292642.011 |

*4.2 Accuracy assessment*

The coordinates obtained from the SBRTK and NRTK techniques were compared with reference values derived from the static post-processed (Static PP) method. The coordinate differences are then further compared to determine if the RTK method can achieve an accuracy comparable with that obtained using the Static PP method, and hence can replace, or be an alternative technique to, the latter method for geodetic control establishment. The coordinate differences are given in Table 4.

As can be observed from the preceding table, the results from the NRTK observations do not differ significantly from those of the SBRTK observations. In general, NRTK positions are better for distances more than 10 km (approximately) as shown in Figure 4, than the SBRTK derived positions. For the 5.2 km-distance, the SBRTK resultant is 0.023 m, while the FKP and VRS methods show 0.026 m and 0.027 m, respectively. For the 8.26 km-distance, the SBRTK resultant is 0.043 m, while the FKP and VRS methods show 0.050 m and 0.053 m, respectively. Among the three NRTK techniques, FKP and VRS gave the least differences from the reference values. The average coordinate differences (i.e., RTK derived coordinates-Static PP derived coordinates) for the 5 test points for FKP and VRS are 5.64 and 5.63 cm, respectively; while the SBRTK coordinate difference average is 6.61 cm. In this experiment, the MAC technique gave inconsistent results and had difficulty connecting to the master control station during the survey.

**Table 4.** Coordinate differences between RTK and Static PP derived positions.

| TEST POINT | DISTANCE FROM PTAG (km) | | NRTK (m) | | | SBRTK (m) |
|---|---|---|---|---|---|---|
| | | | FKP | MAC | VRS | |
| BL201 | 23.3 | dN | 0.093 | 0.101 | 0.070 | 0.104 |
| | | dE | -0.051 | -0.080 | -0.065 | -0.042 |
| | | R | 0.106 | 0.129 | 0.096 | 0.112 |
| MM33 | 19.4 | dN | -0.016 | 0.047 | 0.041 | 0.000 |
| | | dE | 0.038 | -0.004 | -0.015 | 0.080 |
| | | R | 0.041 | 0.047 | 0.044 | 0.080 |
| MM132 | 14.5 | dN | 0.025 | 0.072 | 0.040 | 0.038 |
| | | dE | -0.053 | -0.092 | -0.047 | -0.062 |
| | | R | 0.059 | 0.117 | 0.062 | 0.073 |
| MMA115 | 8.6 | dN | 0.030 | no measurement | 0.034 | 0.025 |
| | | dE | 0.040 | no measurement | 0.041 | 0.035 |
| | | R | 0.050 | --- | 0.053 | 0.043 |
| GM68 | 5.2 | dN | 0.010 | no measurement | 0.016 | -0.006 |
| | | dE | -0.024 | no measurement | -0.022 | -0.022 |
| | | R | 0.026 | --- | 0.027 | 0.023 |

dN = difference in northings; dE = difference in eastings and R= resultant.

The SBRTK results reveal distance dependency of positions assessed by comparing with reference values from post-processed static observations. The coordinate differences increased as distance from base station increased. The usual effective distance for the SBRTK technique is within 20 km. [13]. Assuming a linear relationship, the distances from the base station by which the coordinate differences of FKP and VRS from SBRTK equalize are at 10.3 km and 11.1 km respectively. The MAC technique shows inconsistencies with varying resultant differences at increasing distances. While the MAC performed better than SBRTK in the 19.4 km, same cannot be said at distances 14.5 km and 23.3 km.

Similar studies [12,25,26] conducted comparing SBRTK with NRTK techniques showed favorable results of the latter. However, the study by Akyut et al.[27] showed otherwise. In this case SBRTK gave the better results than NRTK techniques but it highlighted the importance of satellite geometry in RTK measurements. Another study [28] conducted in Florida showed the consistency of the NRTK techniques by giving coordinate differences of a few centimeters from static observation results. It also emphasized that FKP is better in terms of communication link but is disadvantageous in modeling the troposphere and ionosphere errors [29]. Also, FKP technique give best result for small network [3]. It is then worth taking note that in this study FKP technique showed consistency except that at 23.3 km the resultant showed a sudden jump of more than 50% from the results attained at 19.4 km. On the one hand, VRS technique had about 20% increase for the same case.

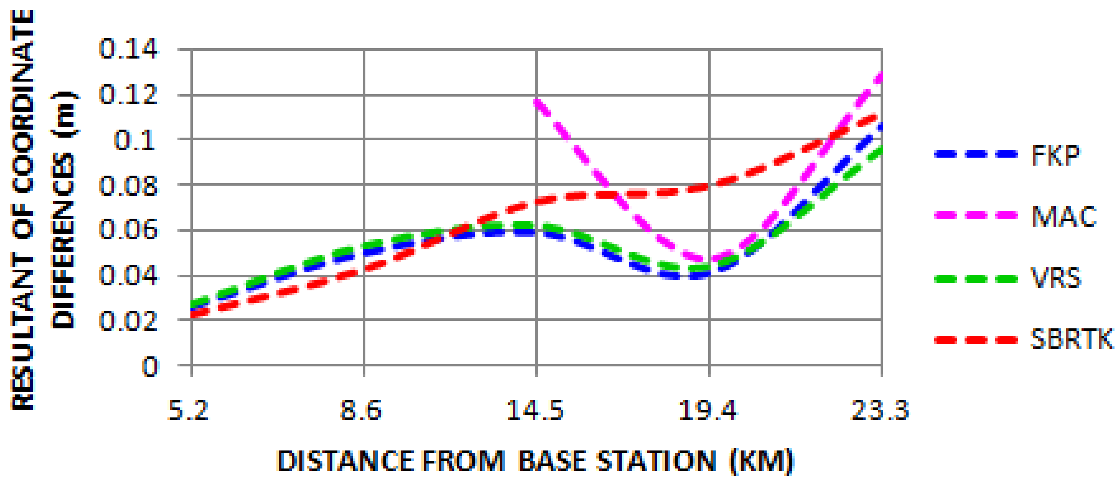


**Figure 4**. Coordinate differences between Static and RTK

In the initialization aspect, the results (Table 5) showed variations that may be due to the inconsistency of the internet connection. Internet connection may vary depending on how close or far the modem is located relative to a cell site and not on how far it is on the GNSS base station. Thus, Point 68MA, which is just 5.2 km from the base station, had around 2 to 3 minutes initialization time. The SBRTK and FKP techniques provided the fastest periods of less than 30 seconds. The longest initialization of 5 minutes was the VRS method for the station farthest from the base station (201A). Again, MAC method gave the most inconsistent results. Furthermore, considering initialization time, FKP is the better technique compared to VRS for NRTK. This could due to the fact that the FKP technique does not require two-way internet communication. Even if the initialization times of RTK techniques extended to several minutes, the observation periods using these techniques would still be much shorter than the almost one-hour observation period using the Static PP technique. In addition, the RTK technique can achieve the same, and even exceed the accuracy of the static PP technique.

**Table 5**. Initialization time for SBRTK and NRTK

| Test Point | Distance from PTAG (km) | SBRTK | NRTK | | |
|---|---|---|---|---|---|
| | | | VRS | MAC | FKP |
| 201A | 23.3 | <30s | ~300s | <30s | ~60s |
| 33 | 19.4 | ~60s | ~60s | ~120s | <30s |
| 132A | 14.5 | <30s | <30s | ~180s | <30s |
| 115A | 8.6 | <30s | ~120s | --- | <30s |
| 68A | 2.2 | ~120s | ~180s | --- | ~120s |

*4.3 Accuracy assessment based on Philippine surveying standards*

As provided in Executive Order No. 45, series of 1993 [30], issued by the Office of the President, and included in Article 7 (Survey Accuracy) of the Department of Environment and Natural Resources (DENR) Administrative Order, or DAO No. 2007-29 [31], the accuracy for first-order geodetic control in the Philippines is 1/100,000 or 10 parts per million (ppm) - equivalent to a linear error of 1 cm per km. Table 6 lists the linear error of the resulting positions from the different techniques.

**Table 6.** Survey accuracy of SBRTK and NRTK (in ppm)

| Test Point | Distance from PTAG (km) | NRTK | | | SBRTK |
|---|---|---|---|---|---|
| | | FKP | MAC | VRS | |
| 201A | 23.3 | 4.6 | 5.5 | 4.1 | 4.8 |
| 33 | 19.4 | 2.1 | 2.4 | 2.3 | 4.1 |
| 132A | 14.5 | 4.0 | 8.1 | 4.3 | 5.0 |
| 115A | 8.6 | 5.8 | --- | 6.2 | 5.0 |
| 68A | 5.2 | 5.0 | --- | 5.2 | 4.4 |

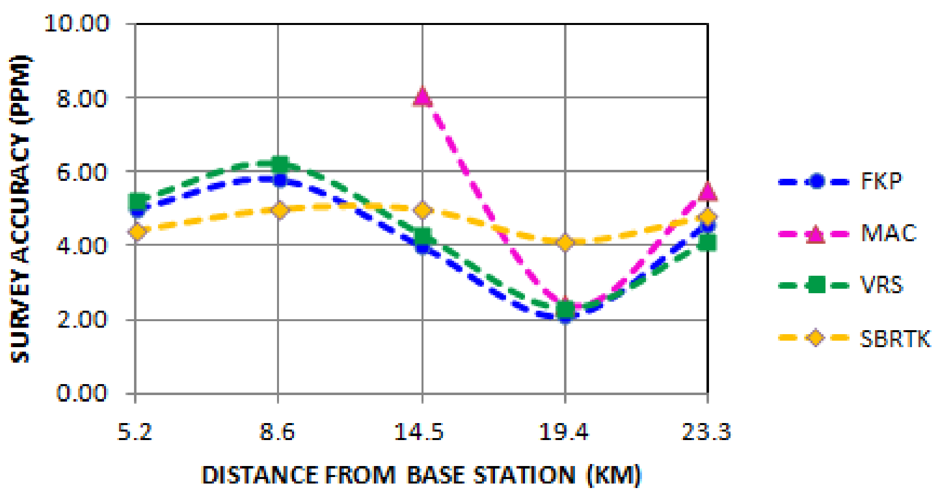


**Figure 5.** Survey accuracy of SBRTK and NRTK

Based on the results, all baseline errors for all techniques are within the allowable linear error of 10 ppm for first-order geodetic control survey. The results also indicate that the survey accuracy is independent of distances between points (Figure 5). Therefore, the RTK technique can supplant, or be an alternative method to, the Static PP technique for first- and lower-order geodetic control surveys.

## V. CONCLUSIONS AND RECOMMENDATIONS

In this study, the traditional and new techniques in GNSS surveying were assessed and compared. Static PP is the traditional technique for determining positions for high-order geodetic control establishment. New advancements in GNSS survey techniques, such as RTK, and related processing algorithms, provide for fast and reliable determination of positions. These new techniques were explored as possible options, or alternatives, for the Static PP technique. The following conclusions are derived from the results of this research.

Comparing the coordinate differences, it can be concluded that NRTK, specifically FKP and VRS, is better than SBRTK. These techniques performed better at distances 10.3 km (FKP) and 11.1 km (VRS) from the base station. For the five test points, these techniques gave average coordinate differences of 5.64 cm and 5.63 cm, respectively, compared with the 6.61 cm average coordinate difference of SBRTK relative to the Static PP method. The results show the distance-dependency of the accuracy of the SBRTK technique.

The inconsistency of the internet connection also affected the initialization times of the survey. Nevertheless, the FKP and SBRTK techniques for most of the test points provided the fastest initialization times of less than 30 seconds based on the results. Although the VRS and FKP techniques gave almost similar coordinate difference averages, the initialization time of the latter technique was faster. This is due to the fact that the FKP technique does not require two-way communication unlike the VRS technique, which is adversely affected by the relatively slow internet speed in the Philippines.

If the accuracies of the different RTK techniques used in this study are assessed with respect to the Philippine survey standard stipulated in EO No. 45, series of 1993, as amended, the baseline linear errors are within the 10 ppm linear error allowable for first-order geodetic control survey. From the results, all the RTK techniques gave less than 10 ppm linear error. Therefore, RTK techniques can supplant the use of Static PP for first-order and lower accuracy survey where productivity is a prime requirement.

Future experiments should test the accuracy of RTK techniques for longer distances. It is also recommended to verify the vertical accuracy of said techniques by conducting differential leveling from reference benchmarks to test points.

## VI. ACKNOWLEDGMENT

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