

# **The efficiency and effectiveness of the VRS technology as a densification to the RTK - Single Base technique for GPS/GNSS surveys in South Africa**

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## **Abstract**

*GPS/GNSS measurements have become an essential part of the global geospatial community and in South Africa there has been a continuous introduction and/or advancements of techniques introduced to improve on the efficiency and effectiveness of the traditional RTK GPS/GNSS measurement technique.*

*There has been uncertainty among professionals in the geospatial community; surveyors in particular on whether the Virtual Reference Station (VRS) concept improves the accuracy of GPS measurements as some studies have suggested, however there has been other studies differing with these findings which is the subject matter in this study.*

*The paper aims to demonstrate the accuracy comparisons of GPS/GNSS survey techniques in South Africa and to an extent; the efficiency and reliability of the Virtual Reference Station (VRS) technology; as a densification to the GPS/GNSS Real Time Kinematic (RTK) technique. The analysis in the study was specifically chosen to ensure the reciprocal comparison of the GPS/GNSS measurement techniques and the findings presented at the end of the paper will prove whether the VRS technology improves the accuracy of GPS/GNSS measurements and if the viability of the VRS concept varies by location or not and whether the VRS concept can be declared to be a substitute for classic RTK except for the time and cost saving elements.*

## **Keywords**

Reciprocal, GPS, GNSS, TrigNet, RTK, VRS, SB

## **1. Introduction**

As part of the global Continuously Operating Reference Station (CORS) networks which contains more than 1,900 stations established by over 200 public and private organizations in different countries; TrigNet; established and maintained by the Chief Directorate: National Geospatial Information office; forms part of the network as a densification to the current positioning methods available to the geospatial community in South Africa. The integration of TrigNet into

GPS/GNSS surveying techniques has proven to be useful for users requiring centimetre accuracy levels especially surveyors; however the use of TrigNet services requires knowledge of the measurement technique used and the expected accuracy levels associated with each technique.

The GPS error measurement is computed in Parts Per Million (PPM) where 1PPM is equal to 1 mm per km and this is correlated to the baseline distance; measured at the 95% level of confidence, i.e. 95 out of 100 measurements are within the specified tolerance

Since its establishment, RTK has reliably provided GPS users; particularly surveyors with centimetre level accuracies within a specific range, due to the correlation of certain GPS errors with distance. This method of surveying has proved to be reliable for small scale surveying projects however with the establishment of a network of active GPS/GNSS base stations; covering the whole country; streaming real time corrections, surveyors and other professional in the geospatial community now have the option of either using the traditional Real Time Kinematic (RTK) for small scale projects or benefit from the use of the Virtual Reference Station (VRS) or Single Base (SB) technique when carrying out positioning tasks, depending on the application and levels of accuracy demands.

First discusses the GPS/GNSS positioning principles, then the incorporation and/or correlation of TrigNet on GPS/GNSS survey methods, particularly VRS and Single Base then finally discusses the different survey methods and their positioning and ambiguity resolution techniques.

## **2. GPS Positioning Principles**

All GPS satellites broadcast two carrier waves in the L-Band of the spectrum. These carrier waves are derived from the fundamental frequencies; namely the L1 and L2.

- L1: 1575.42 MHz

The L1 carrier wave has two codes modulated upon it i.e. the Coarse Acquisition (C/A) code and the encrypted precision (P(Y)) codes, plus the L1 civilian (L1C) and military (M) codes on future Block III satellites.

- L2: 1227.60 MHz

The L2 only has the P(Y) code, plus the L2C and military codes on the Block IIR-M and newer satellites.

These L-Band frequencies are used to transmit data from satellites to ground based stations or receivers. These ground based stations and GPS receivers then use the different codes to distinguish

between satellites. These codes can also be used as a basis for making pseudo-range measurements and therefore calculate a position on the ground.

In GPS positioning, there are three receiver types available in today's marketplace for different applications and accuracy demands and several types of positioning techniques. Each of these receiver types and/or positioning techniques offer different levels of accuracy, and has different requirements to obtain those accuracies.

The three types of GPS receivers are namely

## **2.1 Coarse Acquisition (C/A code) receivers**

C/A Code receivers typically provide 1-5 meter GPS position accuracy with differential correction. C/A Code GPS receivers provide a sufficient degree of accuracy to make them useful in most GIS applications and can provide 1-5 meter GPS position accuracy with an occupation time of 1 second. Longer occupation times (up to about 3 minutes) will provide GPS position accuracies consistently within 1-3 meters. Recent advances in GPS receiver design will now allow a C/A Code receiver to provide sub-meter accuracy, down to 30 cm.

## **2.2 Dual Frequency receivers**

Dual-Frequency receivers are capable of providing sub-centimeter GPS/GNSS position accuracy with differential correction. Dual-Frequency receivers provide "survey-grade" accuracies often not required for GIS and other civilian applications. Dual-Frequency receivers receive signals from the satellites on two frequencies simultaneously. Receiving GPS signals on two frequencies simultaneously allows the receiver to determine very precise positions.

## **2.3 Carrier Phase receivers**

Carrier Phase receivers typically provide 10-30 cm GPS/GNSS position accuracy with differential corrections and they provide the higher level of accuracy demanded by certain GIS applications. Carrier Phase receivers measure the distance from the receiver to the satellites by counting the number of waves that carry the C/A Code signal. This method of determining position is much more accurate; however, it does require a substantially longer occupation time to attain 10-30 cm accuracy. Initializing a carrier phase GPS/GNSS receiver on a known point requires an occupation time of about 5 minutes and about 30 – 40 minutes on an unknown point.

Additional requirements, such as maintaining the same satellite constellation throughout the job and the need to be very close to a base station, limit the applicability of Carrier Phase GPS receivers to many GIS applications. The next section discusses the carrier phase positioning method.

### 2.3.1 Carrier Phase Positioning Overview

The carrier phase receivers determine positioning using either one or a combination of the sine wave signals that is created by the satellite and encoded on the L-Band frequencies, i.e. the L1 or L2. The L1 carrier is generated at 1575.42MHz, the L2 carrier at 1227.60MHz.

The carrier phase positioning technique is used because it can provide a much more accurate measurement to the satellite than using either the P-code or the C/A code. The L1 carrier wave has a wavelength of 19.4 cm. If you could measure the number of wavelengths (whole and fractional parts) there are between the satellite and receiver, you have a very accurate range to the satellite. The next page discusses the relative carrier phase positioning and absolute carrier phase positioning techniques.

#### (i) Absolute Carrier Phase Positioning / “Point” Positioning

By definition: “Absolute Positioning is a mode in which a position is determined with respect to a well-defined coordinate system, commonly a geocentric system” (i.e., a system whose point of origin coincides with the center of mass of the earth). This type of positioning involves the use of only a single passive receiver at one station location to collect data from multiple satellites in order to determine the station’s location. It is not sufficiently accurate for precise surveying or hydrographic positioning uses. It is, however, the most widely used military and commercial GPS positioning method for real-time navigation and location.

#### (ii) Relative Carrier Phase positioning also known as “Differential GPS” - DGPS

In differential or relative positioning, one receiver is at location A, whose absolute coordinates ( $x_A, y_A, z_A$ ), are known and another receiver is at point B, whose position ( $x_B, y_B, z_B$ ) is to be determined. Both receivers observe the same satellites, and the observation data collected at both sites is then used to compute the position of B; *relative* to A. This technique of relative positioning can remove or reduce most of the biases common to two receiver sites, thus resulting in a higher positioning accuracy.

In summary:

At least 2 receivers are required:

- One Over Known Position “Base” or “Reference” station
- Another receiver over Unknown Position “Rover”
- Both base and rover receive same Space Vehicles (SV) range data
- Base receiver measures vector difference between received position data and known position, works out the correction and applies it to the rover.

- Positioning can be obtained either using either Real-Time (RTCM format) or Post-Processing

In the geospatial community, particularly surveying; where centimeter or better accuracy is required, the type of position determination technique deployed is the carrier phase in its relative mode; commonly known as DGPS and in the following sections, the survey methods and/or GPS densification techniques discussed utilize this type of position determination.

### **3. TrigNet**

Since its establishment, the Chief Directorate: National Geospatial Information (CD: NGI) office in Mowbray, Cape Town is mandated to “*establish and maintain a national survey network*” for South Africa which consists of a passive network of approximately 20 000 town surveys and 29 000 trig beacons. As part of the global technological evolution in the geospatial community, to keep up with the developments; in recent years dating back to 1999, the CD: NGI commenced with the installation of a network of active GPS/GNSS base stations known as TrigNet. By definition, TrigNet is a network of continuously operating GNSS base stations that are highly precise with respect to each other. These base stations cover the whole of South Africa and are managed and controlled by a single control centre situated in the offices of National Geospatial Information (NGI).

These stations form part of the established global real-time CORS network used to provide real-time and/or post-processing positioning services to GPS/GNSS users. The TrigNet network currently consists of 63 full operational stations with more awaiting either construction or connection. These stations are typically 40km – 300km apart with one control station at the CD: NGI. This network of stations log dual frequency GPS/GNSS data and computes a “*network solution*” from which their observation errors and corrections are computed at the central control station and broadcast to GPS/GNSS users. These TrigNet stations are in the same coordinate and reference system and are highly precise with respect to one another and there is therefore no substantial difference in their positional accuracy and streamed corrections; provided that they are operational during data collection.

All data products and services from the CD: NGI are free of charge. For post-processing, data is made available for download on TrigNet’s ftp website (<ftp://ftp.trignet.co.za>) in the Receiver Independent Exchange (RINEX) format and for real-time users; data is made available in the Radio Technical Commission for Maritime Services (RTCM) format using cell phone connections to the internet while in the field as explained below. Both formats are independent of the GPS/GNSS receiver manufacturer used to collect data and it is provided to GPS/GNSS users in the following formats:

### **3.1 Post processing in RINEX format:**

- 1 sec L1, L2 1 hourly data available within 30 minutes after the hour;
- 1 sec L1, L2 24 hourly data;
- 5 sec L1 24 hourly data; and
- 30 sec L1, L2 24 hourly data.

### **3.2 Real Time data via Networked Transport of RTCM via Internet Protocols (NTRIP):**

- DGPS - (approx. 0.35m accuracy) all stations countrywide;
- RTK - (approx. 0.05m accuracy) within 30-40kms of each station using a single base technology; and
- Network RTK - (approx. 0.03m accuracy) within the Gauteng, Western Cape and KwaZulu-Natal VRS clusters.

## **4. GPS/GNSS Survey Methods**

### **4.1 Real Time Kinematic (RTK)**

RTK is a GPS/GNSS satellite dependent technique of surveying used in the geospatial community for position determination. This method of surveying uses a single static reference station (refer to Fig. 1) referred to as the base station; with known coordinates to compute corrections between its known coordinates/position and its real-time satellite determined position/coordinates. The resulting solution is a vector (differential corrections) in position determination of the base-station i.e. ( $\Delta Y$ ,  $\Delta X$ ,  $\Delta Z$ ) which is then transmitted to the rover via radio communication (Fig. 2) which will in turn transmit its position relative to the base station to the survey controller via Bluetooth to calculate the position of the rover.

The base station remains stationary during survey operations while the rover(s) moves around to determine the desired positions. The base station can transmit corrections to multiple rovers in its vicinity and because of the effect that the distance related errors (atmosphere and satellite orbits) have on the ambiguity resolution (initialization) and solution precision of GPS measurements; this base-rover differencing method of positioning is limited to short baselines of about 10 kilometres in open-sky areas and good satellite geometry and provides up to centimetre level accuracy position determination with a threshold of about 15-20 kilometres. The RTK surveying technique is suitable for small scale surveys because of the effect the distance related errors have on GPS measurements.

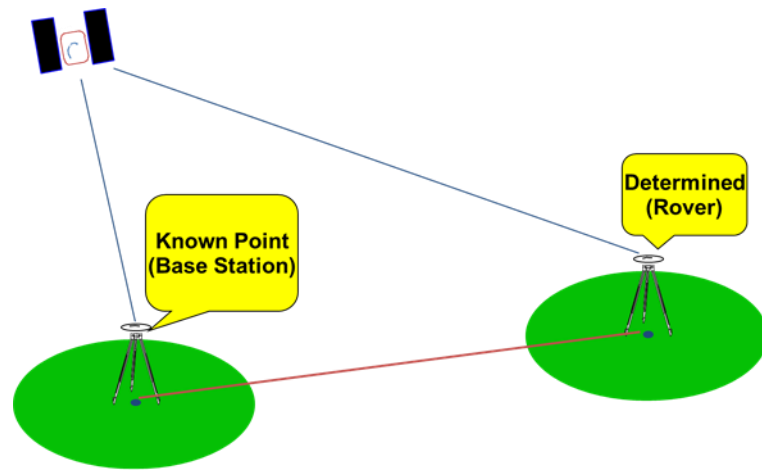


Figure 1: RTK field set-up procedure

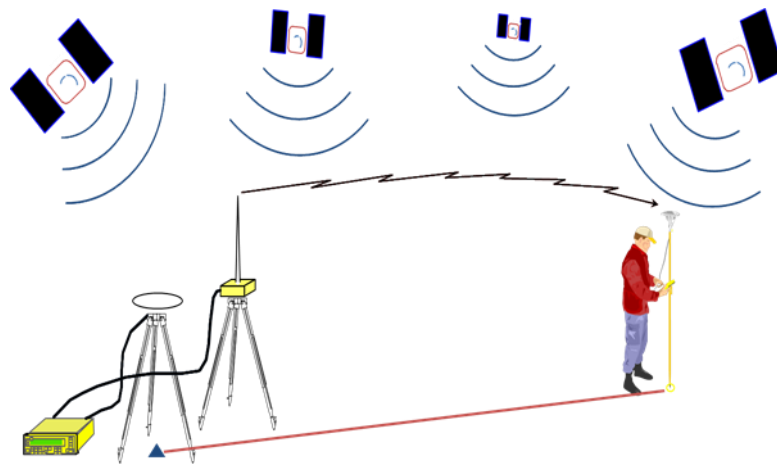


Figure 2: RTK correction streaming

#### 4.2 VRS - Virtual Reference Station

VRS is a Trimble trademark and its network is an integrated system that consists of:

- GNSS reference stations (TrigNet) spread out over a large area
- A central server at the CD: NGI in Cape Town that uses Trimble proprietary software that creates a correction model for the region covered by the network. GPS rovers communicate using a cell modem with this VRS server to receive RTK type corrections.

The Virtual Reference Station (refer to Fig. 3) technique is based on having a network of GNSS stations continuously connected via data links to a control centre. A computer at the control centre continuously gathers the information from all receivers, and creates a living database of regional area corrections. These regional area corrections are used to interpolate a mathematical model for

the ionosphere, troposphere and ephemeris distortions for the user's location enclosed by the base stations.

This mathematical model is then used to create a virtual reference station (VRS), situated only a few metres from where any rover is situated, together with the raw data, which would have come from it; i.e. the receiver is "tricked" into thinking that it's receiving corrections from a physical reference / base station close by.

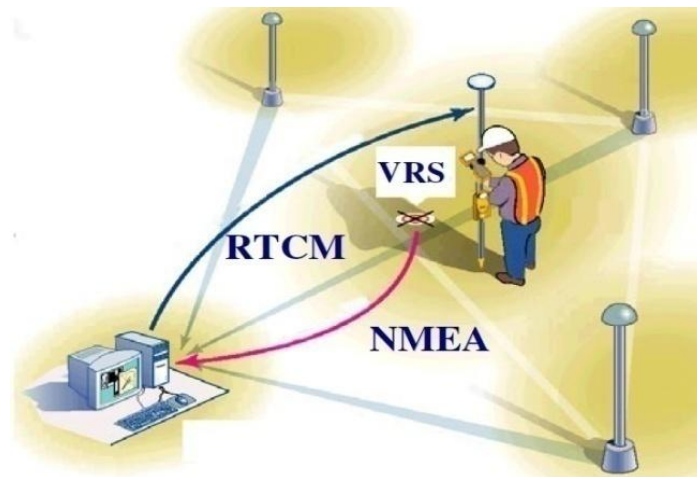


Figure 3: VRS field set-up procedure

### 4.3 VRS field-setup procedure

The rover interprets and uses the data just as if it has come from a real reference station close by and this improves the performance of RTK surveying technique based on the effect that the distance related errors (atmosphere and satellite orbits) have on the ambiguity resolution and solution precision of GPS/GNSS measurements.

This technique of creating raw reference station data for a new, invisible, unoccupied station is what gives the concept its name: "Virtual Reference Station".

With regards to the VRS measurement technique, no networks corrections are streamed to the rover if the following factors occur:

- Less than 5 common satellites are observed by both the base and rover
- The distance to the closest base station is greater than 40km
- There's less than 3 base stations in the network

The implementation of the VRS idea into a functional system solution follows the following principles (refer to Fig. 4):

- First, a number of reference stations (at least three) are needed, which are connected to the network server via some communication links.
- The GNSS rover then sends its approximate position to the control centre that is link via any technology i.e. GSM, GPRS, and 3G etc. The RTK-GNSS solution is accurate to  $\pm 1\text{m}$ , which is good enough to ensure that the atmospheric and ephemeris distortions, modelled for the entire reference station network, are applied correctly.

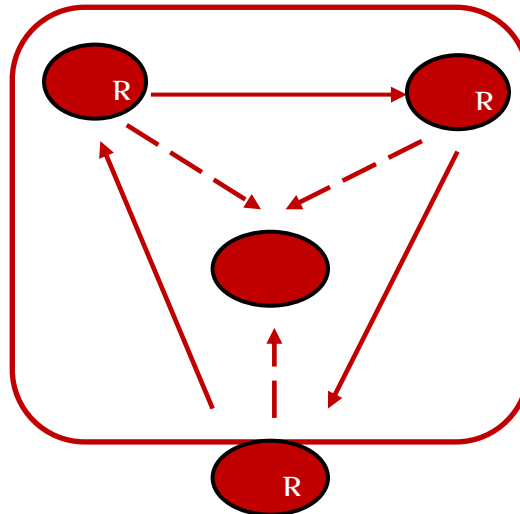


Fig. 4: VRS engine

Referring to the Fig. above, four real time VRS engines run simultaneously and corrections from three reference stations (RS1, RS2 & RS3) are interpolated onto the rover (RV) inside the network i.e.;

- RF1 – RF2
- RF2 – RF3
- RF3 – RF1
- (RF1, RV) + (RF2, RV) + (RF3, RV)

Currently the VRS technology is only available to GPS/GNSS users in three provinces i.e. RTKNetKZN (KwaZulu-Natal), RTKNetWcape (Western-Cape) and RTKNet-Gauteng (Gauteng).

Users must note that no VRS network solutions are streamed to the rover if the factors discussed earlier are not met and only single base solutions (as discussed below) are streamed to the rover.

#### 4.4 Single Base

The single base surveying technique simply refers to carrying out survey operations using one; preferably closest; TrigNet base station. The solution algorithm follows that of the Real Time Kinematic technique as previously discussed except that the observation errors and corrections for a particular station are computed at the central control station and broadcast to GPS/GNSS users.

### 5. Conclusion

In the last decade, the Real Time Kinematic (RTK) surveying technique has provided and continues to serve practitioners in the geospatial community with reliable measurement accuracies for day to day survey applications however it has; but not limited to the following limitations:

- (a) Accuracy decrease when exceeding the distance threshold (15-20)km due to limited range from single reference station and the effect that the distance related errors have on the ambiguity resolution
- (b) Potential gross error in establishing reference station
- (c) No integrity monitoring
- (d) Security concerns
- (e) Communications

As a densification to the traditional RTK surveying technique, the VRS technique resolves the network solution and increasing the number of stations gives better results because of the redundancy for ambiguity solving as opposed to RTK with one base station. Using the VRS measurement technique, the atmospheric delays and ephemeris distortions are modelled at the control centre and applied correctly by analyzing double difference observations. No physical base station is occupied hence the problem of the receiver being subjected to errors at the base station is eliminated. With RTK-DGPS, because a roving receiver cannot compute its own corrections hence whichever errors the base-station is subjected to, the roving receiver is also bound to be subjected to, including its own errors. Inside a VRS network, the VRS technique uses data from several reference stations to compute corrections that are generally more accurate than corrections from a single reference station as in the case of Single Base and RTK techniques based on the following:

#### 5.1 Single base (95% level of confidence)

Horizontal:  $\pm 1\text{cm} + 1\text{ppm}$

Vertical:  $\pm 2\text{cm} + 1\text{ppm}$

#### 5.2 RTK (95% level of confidence)

Horizontal:  $\pm 1\text{cm} + 2\text{ppm}$

Vertical:  $\pm 2\text{cm} + 2\text{ppm}$

### 5.3 VRS (95% level of confidence)

Horizontal:  $\pm 1\text{cm} + 0.1\text{ppm}$

Vertical:  $\pm 2\text{cm} + 0.1\text{ppm}$

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