ASSESSING MULTIPLE REFERENCE STATION RTK
CASE STUDY: SOUTHERN GHANA

By

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DECLARATION

I hereby declare that this submission is my own work towards the award of Master of Science and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the university, except where due acknowledgement has been made in the text.

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ABSTRACT

The use of RTK methods for surveying purposes have become an efficient way of performing survey tasks around the world. In Ghana however, the RTK surveys are restricted to a few individual private surveyors who carry out such surveys in very restricted base-to-rover distances of a maximum of 8km with a single reference station. The Survey Department of Ghana has three Continuously Observing Reference Stations (CORS) operated offline from Accra, Takoradi and Kumasi.

The research sought to compare Single Reference Station (SRS) to Multiple Reference Stations (MRS) methods of performing RTK. The comparison was in the form of tests conducted with different SRS located at different locations with base-to-rover distances of between 7-70km. These reference stations were networked to form a MRS and used to evaluate the performance of both methods. The criteria used were the time to fix ambiguity, the number of ambiguity fixed and the reliability of the coordinates computed for either method. The network of reference stations were located in Accra, Dodowa, Asamankese, Suhum, Nsawam and Winneba.

The test results showed that at distances of less than 10km, both SRS and MRS produced comparable results. However at longer base lengths exceeding this limit, the MRS produced markedly superior results. The computed Central Error Probable for the two methods in the tests revealed that the accuracies obtained by the MRS are better for the longer base-to-rover distances. The thesis ends with recommendations for the different owners of CORS in the country to work together to cover a wider area and give better accuracies across the country and also urges the Survey Department of Ghana to work with the universities and other stakeholders to come up with standards for RTK surveys to encourage its proper use.

ACKNOWLEDGEMENT

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER ONE - INTRODUCTION

1.0 BACKGROUND

Geographic Positioning System real-time kinematic (GPS-RTK) is one of the most precise positioning technologies, with which users can obtain cm-level accuracy of the position in real-time by processing carrier-phase measurements of GPS signals. Centimetre accuracies are achievable in normal atmospheric conditions over base to rover distances of up to ten kilometres. Beyond this range and under adverse atmospheric conditions the accuracies are significantly compromised due to two main sources: residual signal delay caused by the atmosphere including the ionosphere and troposphere and satellite orbit errors (Dao, 2005). In general, the resolution of GPS phase ambiguity is simpler and straightforward for short-range applications, as the differential influences on GPS observables caused by the GPS broadcast orbits and the atmosphere can be cancelled by the sufficient similarities at both the rover and base stations. For longer base lengths however, the assumption of similarities of conditions at both base and rover are no longer valid and as a result the errors must be carefully modelled.

Research has been going on for some time to overcome the problems associated with Single Reference Station (SRS) RTK and Multiple Reference Station (MRS) RTK. In the MRS method the spatially-correlated errors over the network are interpolated to rover positions (e.g. Lachapelle and Alves, 2002). Here the base-to-base network misclosures are estimated using the accurate coordinates of the reference stations and the misclosures interpolated over the network region as corrections. The corrections generated by the network are used to correct the observations made by the rover through one reference station called the primary reference station (PRS). The PRS is usually the reference station closest to the rover. The corrections sent to the rover, from the PRS, are treated in much the same way as a conventional SRS differential GPS.

1.1 COMPARISON OF MRS TO SRS

There are a number of advantages to be gained from a MRS over the traditional SRS approaches. Prominent advantages are (Dao, 2005):

I. The number of reference stations required to cover a vast area as a region or country is greatly reduced in an MRS as compared to a SRS. As shown below, for the same area, there will be the need for twenty five SRS to cover an area of size 100km by 100km with each SRS covering a radius of 10km.However only five MRS each covering an area of radius 60km will be needed to cover a similar area (i.e. 100km by 100km).

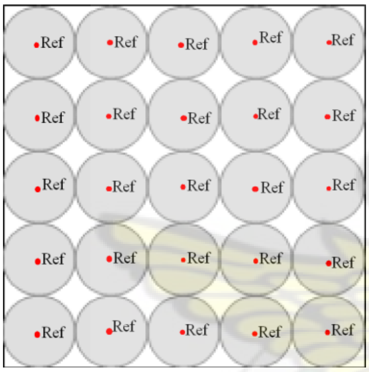


Figure 1.1 No. 25 SRS for a 100km x100km area.

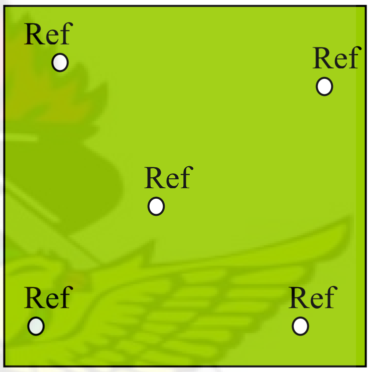


Figure 1.2 No. 5 MRS for a 100km x100km area.

II. the accuracies of the rover is generally improved over the entire region for a MRS.

III. The MRS although maybe using a few number of reference stations, offers more reliability and availability of the same geographic region (as shown by the white patches in the figures 1.1 and 1.2 above).

There are, on the other hand, some advantages of the SRS approach over the MRS approach and a few of these are as listed below (Dao, 2005):

I. The huge amounts of data collection, storage and transmission over the network among the reference stations alone are very costly.

II. Latency presents an enormous challenge for real-time applications in MRS as compared to SRS (Alves et al, 2003)

III. Additional cost is incurred by surveying additional reference stations to the high accuracies required for network referencing.

IV. Due to the high cost of implementation and maintenance, MRS can mostly only be implemented by the government or corporate bodies and not private surveyors who may need it most.

1.2 RTK IN GHANA

In Ghana, RTK surveying has been going on for some time although it has not been wide spread compared with the static survey approach which is widespread in the cadastral survey in the country. RTK surveys have mostly been carried out by private surveyors and mining companies in the country and these have carried out with the SRS approach. The Survey Department of Ghana has reference stations in the Western, Ashanti and the Greater Accra regions but unfortunately these reference stations are not networked and perform as independent SRS. Procedures and standards for the conduct of RTK, the performance standards of MRS and SRS are virtually not touched on by the Survey Department which regulates the standards of conduct of surveys in the country.

1.3 OBJECTIVES

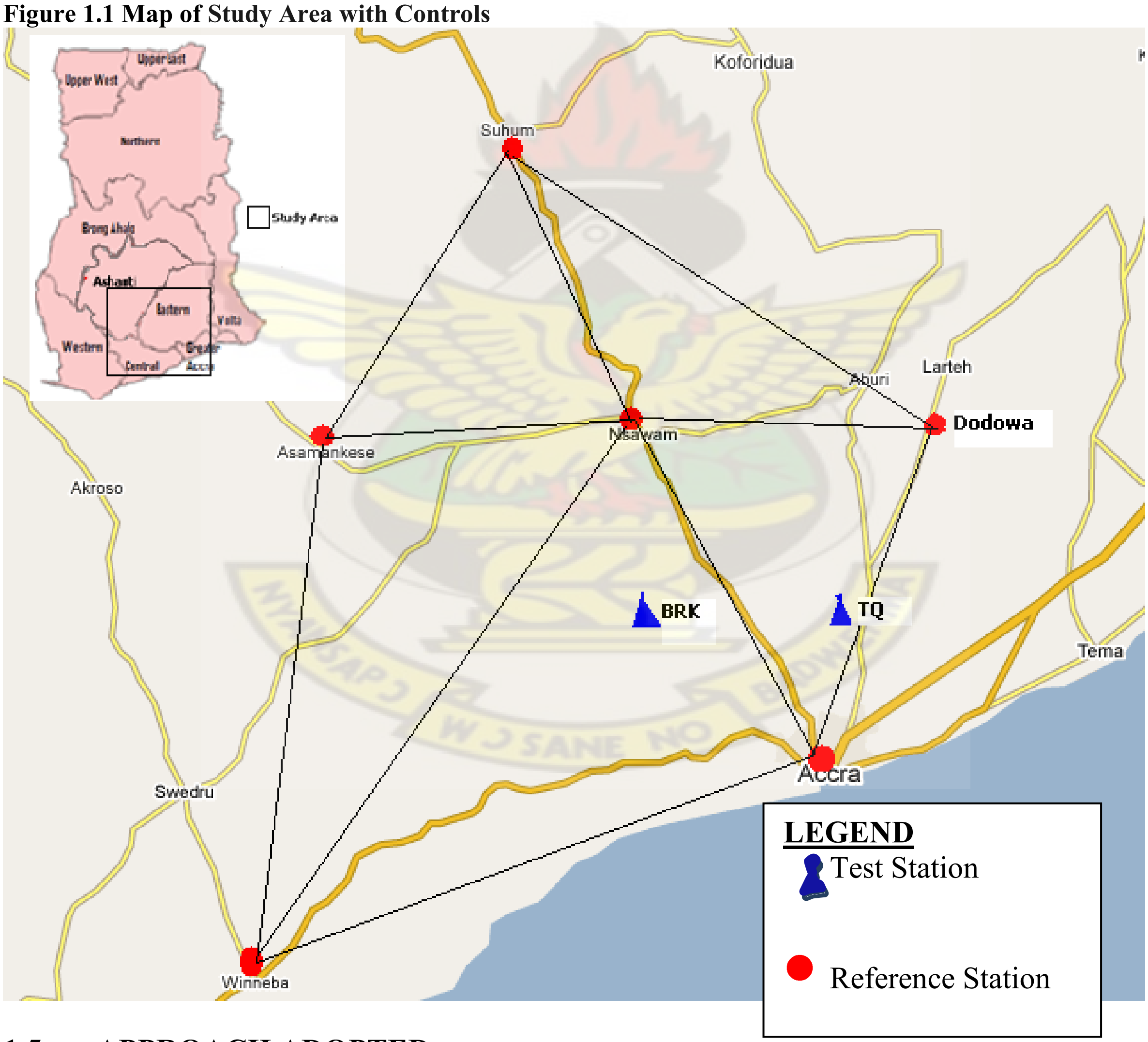
The main aim of this project is to bring to bear the speed and accuracies of the RTK surveys which can meet most of the accuracy standards of various surveys. The specific objectives of the project are threefold:

- To configure and analyze the accuracies of the RTK methods (Single Reference and Multiple Reference)
- Compare the suitability of the SRS and MRS approaches to RTK for various types of surveys
- Apply the RTK methods to a variety of survey applications

1.4 THE PROJECT AREA

The site was chosen to allow for inter-station distances of between 30km and 70km and to cut across different regions of the country. Figure 1.1 shows the sites used for the reference stations and the rover points. The controls were spread throughout the Eastern, Central and the Greater Accra Regions of Ghana. The controls covered an approximate land area of size 70km x 70km. The main controls were surveyed in a static GPS survey to compute new coordinates for suitably sited points that well fit the requirements of a GPS survey and especially be able to broadcast corrections to the rover or other MRS.

Figure 1.1 Map of Study Area with Controls



1.5 APPROACH ADOPTED

The study was done within the specified network with observations made for two different rover positions namely: BRK and TQ located respectively at Berekoso in the Eastern Region and

Shiashie in the Greater Accra Region of Ghana. These rover positions were at varying distances, of between 7km – 70km, from the various reference stations which were used in processing in a post processing mode. The results of SRS processing were then compared with those of the MRS processing and analysed.

1.6 THESIS ORGANIZATION

The thesis for this research work is presented in six chapters and these chapters are briefly described as follows:

Chapter Two gives an introduction to GPS observables and errors that are associated with these observable.

Chapter Three introduces the concept of the traditional SRS RTK and MRS RTK and the various methods. The chapter finally looks at typical algorithms for the RTK implementation.

Chapter Four deals with the methodology used to measure the performance of both approaches of RTK.

The following chapter, Chapter Five, looks at the results and analyzes the errors that are measured in the observations.

Chapter Six concludes the thesis and gives recommendations leading from the project findings.

A list of references cited in the thesis is given at the end of the thesis.

CHAPTER TWO - GPS OBSERVABLES AND ERRORS

2.0 BASIC GPS OBSERVABLES

GPS provides users with three fundamental observables, namely, the code pseudorange, carrier phase and Doppler frequency. They are available on two frequencies in P-code mode, i.e. L1 (1575.42 MHz, a wavelength of 19 cm) and L2 (1227.60 MHz, a wavelength of 24 cm), and only on L1 in C/A-code mode.

The pseudorange observable is generated by measuring the difference between the transmission time and reception time of the GPS Pseudo-Random Noise (PRN) signal.

The observation equation relating the pseudorange observable *P* in metres and unknown parameters is expressed as (Parkinson, 1996):

$$P = \rho = c(T_u - T^s) \tag{2.1}$$

where $\rho = \sqrt{(x^s - x)^2 + (y^s - y)^2 + (z^s - z)^2}$

(the true range between the GPS satellite and receiver antenna phase centre),

(x^s, y^s, z^s) is the satellite coordinate, and

(x, y, z) is the receiver antenna phase centre coordinate which is to be estimated.

Both satellite and receiver coordinates are referred to the Earth-Centered-Earth-Fixed reference frame (WGS84). T_u is the time of reception in seconds, T^s is the time of transmission in seconds, and *c* is the speed of light in metres per second.

In practice the GPS signal is corrupted by many error sources. These error sources include satellite clock error, satellite coordinate error, and atmospheric effects (including tropospheric and ionospheric components); therefore the complete equation relating the pseudorange in metres and unknown parameters is expressed as

$$P = \rho + d\rho + T + I + c\left(dT^0{}_u - dT^s{}_0\right) + \varepsilon_P \tag{2.2}$$

where $d\rho$ is the satellite orbital error in metres,

T is the tropospheric delay in metres,

I is the ionospheric delay in metres,

$dT^0{}_u$ is the receiver clock offset in seconds,

$dT^s{}_0$ is the satellite clock offset in seconds, and

ε_P is the combined effect of pseudorange multipath and receiver measurement noise in metres.

Similarly, the observation equation for the carrier phase observable, CP, in cycles is defined as

$$CP = \frac{[\rho + d\rho + T + I + c[(dT^0{}_u -] dT^s{}_0)]}{\lambda} + N + \varepsilon_{CP} \quad (2.3)$$

Where λ is the L1 or L2 carrier wavelength in meters,

N is an arbitrary number representing the unknown, but constant, initial phase ambiguity, and

ε_{CP} is the combined effect of multipath and receiver measurement noise in cycles.

The carrier phase observation equation is very similar to that of the pseudorange except that it contains an extra parameter, *N*. The ionospheric error for the carrier phase observable is the same as the pseudorange observable in units of meters but they differ in sign, as the ionosphere causes an advance to the carrier and a delay to the pseudorange (Klobuchar, 1996).

Figure 2.1 depicts a typical double difference set-up. By taking the difference between observations to the same satellite from the rover and reference GPS receiver, the satellite clock error, tropospheric error, ionospheric error, and satellite orbital error are significantly reduced. The amount of reduction depends on the spatial separation between the reference and rover GPS receivers. The derived observable is known as the single difference (SD) observable between receivers. By further differencing the SD observable between satellites (see Figure 2.1), the receiver clock errors are eliminated completely. The double difference measurement is formed by differencing two single difference measurements.

One single difference measurement is generated by subtracting two measurements from two receivers (a monitor and a remote) to one satellite and the other by differencing two measurements from the same two receivers to another satellite. Double Differencing (DD) processing is performed to reduce the errors in Equations (2.2) and (2.3).

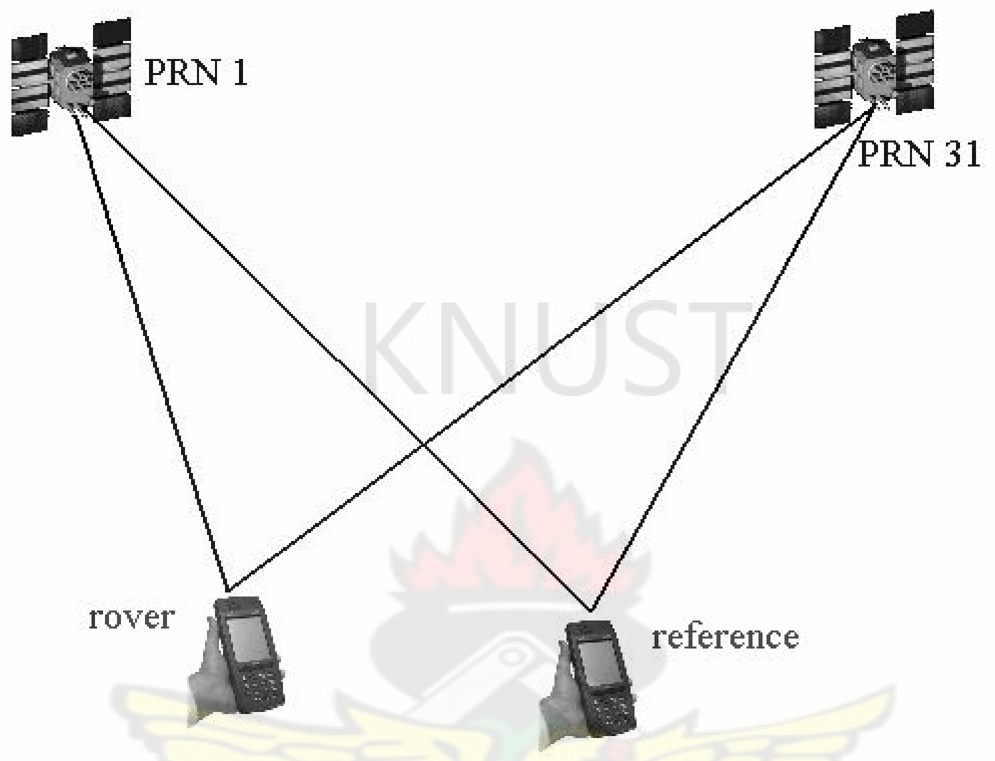


Figure 2.1 Double Differencing Concept (Source: Lui, 2003)

The DD pseudorange and carrier phase observation equations are respectively expressed as:

$$\nabla\Delta P = \nabla\Delta\rho + \nabla\Delta d\rho + \nabla\Delta T + \nabla\Delta I - \nabla\Delta dT^{s}{}_{o} + \nabla\Delta\varepsilon_{CP} \qquad (2.4)$$

$$\nabla\Delta CP = [\nabla\Delta\rho + \nabla\Delta d\rho + \nabla\Delta T - \nabla\Delta I - \nabla\Delta dT^{s}{}_{o}]/\lambda + \nabla\Delta N + \nabla\Delta\varepsilon_{CP} \qquad (2.5)$$

where $\nabla\Delta$ is the double differenced (DD) operator.

Double differenced observables have many advantages over undifferenced observables. First, the receiver clock offset is removed. Second, it is well known that the satellite clocks are highly stable (Kaplan, 1996), thus the value $\nabla\Delta dT^{s}{}_{o}$ tends to cancel as long as the observations are differenced at approximately the same time at both reference and rover stations.

The double difference observable has some disadvantage over the undifferenced observable. The most significant effect is that the noise level of the DD observable increases since it is a linear combination of the carrier phase observable.

2.1 SOURCES OF ERROR

The main sources are, residual signal delay caused by the atmosphere including the ionosphere and troposphere, satellite orbit errors and multipaths. The following sections take a more detailed look at these errors and their modelling.

2.1.1 Ionospheric Errors

The ionosphere is the ionized layer approximately 50km to 2000 km above the earth's surface. The ionization is caused by solar ultraviolet radiation and x-ray radiation coming from the corona of the sun at low and middle and particles at high altitude (Skone, 1998). Altogether, the ionosphere is electronically neutral with equal amounts of electrons and ions. It is therefore plasma. The ions are gathered around by the electron, with a certain plasma frequency, to form a sphere spinning around the magnetic field, resulting in collisions between electrons and ions (Skone 1998).

The ionosphere is composed of free electrons. These charged particles are influenced by solar activity and geomagnetic field. The spatial distribution of ions and electrons is mainly determined by two processes in the ionosphere:

1. Photo-chemical processes; they depend on the insulation of the sun, and govern the production and decomposition rate of the ionized particles.
2. Transportation processes; they cause motion of the ionized layers.

Both processes create different layers of ionized gas at different altitudes. The main layers are known as the D-, E-, F_1-, and F_2- layer (Seeber, 1993).

The D region (at altitude of 50 km -90 km) and the E region (at altitude of 90 km – 140 km) place negligible effects on GPS measurements (Klobuchar 1996). The F_1 and F_2 regions at altitude of 140 km – 210 km and 210 km – 1000 km, respectively, place the most significant impact on GPS measurements. A fifth region, the H region, at altitude of larger than 1000 km and its impact on GPS measurements can be significant under storm conditions (Klobuchar, 1996).

GPS signal that travels through the ionosphere may be attenuated depending on the signal frequency, electron collisions and the electron density along the travelling path. The first order slant ionospheric carrier phase error in units of meters, I, is (Leva *et al,* 1996)

$$I = \left[\qquad \qquad \right] \qquad \underline{C} \tag{2.6}$$

where R_e is the radius of the earth, α is satellite elevation, h_I is the height of the ionosphere above the earth's surface, f is the carrier frequency of the GPS signal, and VTEC stands for Vertical Total Electron Content in units of electrons/m^2. VTEC represents the electron density in a vertical column along the GPS signal trajectory, a quantity that varies with location and level of ionospheric activity as described above.

The main error however is due to ionosphere. Ionosphere manifests itself in Network RTK in three ways (Petrovski *et al*, 2002). It affects ambiguity resolution when overall error exceeds approximately half of wavelength. Also it interferes with correction calculation algorithm, because of fluctuations between the grid points. Lastly, high ionospheric activity causes phase scintillation in GPS signal and cycle slips as a result. The interference with ambiguity resolution creates the main problem (Petrovski *et al* 2002).

To remove Ionospheric influence, one can use linear combination of L1 and L2 which is less prone to ionosphere. Ionosphere-free linear combination L3 is noisy and has non-integer ambiguities. The following equation represents the relationship between ionospheric error on GPS L1 and L2 measurements (Petrovski *et al* 2002).

$$I_2 = \left(\quad \right) \tag{2.7}$$

2.1.2 Tropospheric Errors

The troposphere is the lowest part of the atmosphere, extending up to between nine and sixteen kilometres (9km-16km) in altitude. Neutral atmosphere can extend to several tens of kilometres. The tropospheric delay depends on conditions as temperature, humidity, and pressure. The delay varies with the height of the user. The total troposhperic delay can be separated into dry and wet component (Hopfield,1971). The dry component, which can contribute up to 90% of the delay, is comparatively easier to model because it is a function of the temperature and pressure, both of which vary slowly.

Elevation	90°	20°	15°	10°	05°
Dry Component	23.0m	6.7m	8.8m	12.9m	23.6m
Wet Component	0.2m	0.6m	0.8m	01.1m	02.2m
Total Delay	2.5m	7.3m	9.6m	14.0m	25.8m

Table 2. 1 Tropospheric Delay on Measured Ranges

The wet component is caused by a high concentration of water vapour at heights of between 0-15km above the earth's surface. It constitutes only 10% of the total tropospheric delay. The wet component is difficult to model because of the unstable nature of surface humidity. Since humidity variations are seasonal, tropospheric error has a seasonal effect on GPS measurements. The total tropospheric error at zenith $D^z_{trop} \; h_{user}$, is the sum of the dry error caused by the dry component, D^z_d, and the wet component D^z_w and can be calculated as follows (Skone, 2003):

$$D^{z}_{trop}\ h_{user} = \quad + \qquad (2.8)$$ with

the dry and wet components expressed as:

$$D^{z}_{d} = \frac{10^{-}}{5} \quad - \quad \text{for } h_{user} \le \quad = \qquad (2.9)$$

$$D^{z}_{w} = \frac{10^{-}}{5} \quad - \quad \text{for } h_{user} \le \quad = \qquad (2.10)$$

$$N_{d0} = \qquad (2.11)$$

$$N_{w0} =$$

where h_{user} is the height of the rover, h_w is the maximum height of the wet component, h_d is the maximum height of the dry components, N_{w0} represents the wet refractivity and N_{d0} stands for the dry refractivity at the earth's surface. As shown in equation (equ. 2.11), the refractivity components are a function of temperature T (T_c is temperature in degrees Celsius and T_k is temperature in degrees Kelvin), dry air pressure P_d in millibars and partial pressure of the water vapour e in millibars. The partial pressure of the water vapour is estimated as a function of relative humidity R_h and temperature T.

2.1.3 Satellite Orbital Error

Coordinates of unknown receiver positions are calculate based on the precise positions of satellites. The satellite position information is reported in an ephemeris. These positions are predicted using a set of Keplerain orbit, perturbation and satellite clock parameters (Keplan *et al,* 1996). The discrepancy is as a result of the inability to completely model the forces that act on the satellite. Differencing the observations from one satellite can reduce the error. The effect of orbital error on baseline determination is (Vanicek *et al,* 1986):

$$\frac{db}{b} = \frac{d\rho}{\rho} \qquad (2.12)$$

Where db is the error in the baseline;

b is the baseline length ;

$d\rho$ is the orbital error;

ρ is satellite-receiver range.

Relative accuracy required	Acceptable Orbital error
5 ppm	125.0 m
1 ppm	25.0 m
0.5 ppm	12.5 m
0.1 ppm	2.5 m

Table 2. 2 Relative Accuracy and Orbital Errors

The precise ephemeris is provided by various GPS agencies such as the International GPS Service (IGS), the US National Geodetic Survey (NGS) and the Geodetic Survey Division, Natural Resources Canada (GSD/NRCan). However, the precise ephemeris is available only in post-mission.

2.1.4 Multipath

Very often signal coming from satellite does not travel through the line of sight to the receiver. Such signals can find their way to the receiver after bouncing off another surface. When a signal travels to the receiver after it has bounced off another surface it is said to have undergone multipath. Multipaths are caused by signal reflective materials such as metal surfaces, trees, water and concrete surfaces. Indirect signals are responsible for inaccurate pseudo-ranges. The resulting impact on GPS carrier phase measurements is less than one quarter of the carrier wavelength (Georgiadou & Kleusberg, 1988, Ray, 2000)

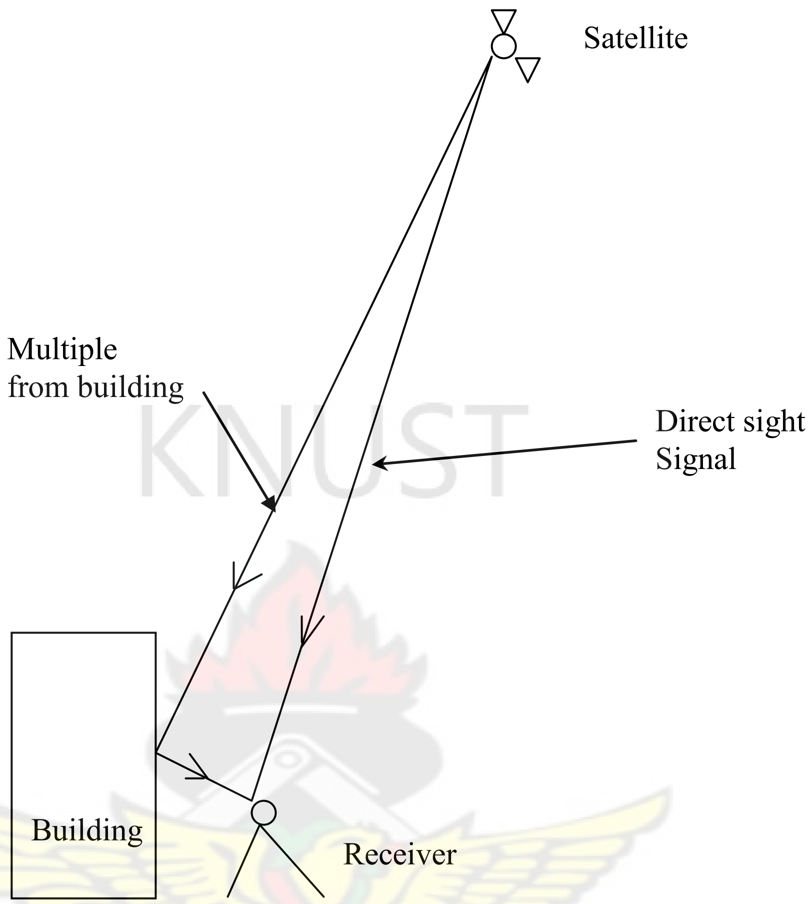


Figure 2.2 Illustration of Multipath

CHAPTER THREE - CONCEPTS AND ALGORITHMS OF RTK

3.0 CLASSICAL RTK

The basic concept behind RTK is that you have a base station receiver set on a known point that sends correction data to the rover receiver. The correction data is typically sent via UHF or spread spectrum radios that are built specifically for wireless data transfer. The corrections from the base station receiver can be sent to an unlimited number of rovers. The correction data can be sent through UHF, GSM data formats or through the internet.

Real-time positions on the rover receiver are calculated as fast as 20 times per second or as little as once per second (Resource Supply, 2006)

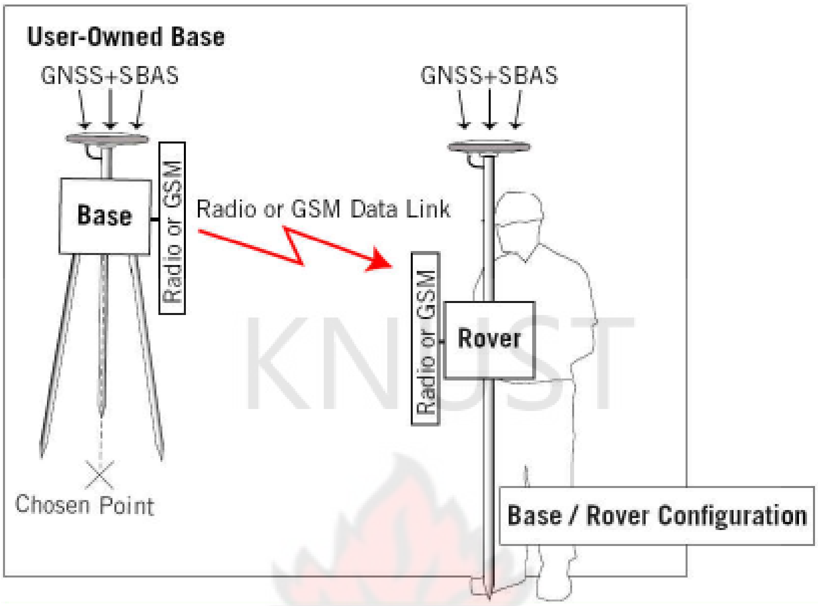


Figure 3.1 Surveyor undertaking RTK survey(Source: Resource Supply, 2006)

3.0.1 Limitations of Classical RTK Surveying

The restriction in range of classical RTK is due not only to the systematic errors but also to the range of available radio telemetry solutions. In practice this means that a temporary RTK base station must be established close to the work area. Each time such a temporary reference station is established there is an opportunity to introduce an error in the reference station co-ordinates that will be carried onto the position computed by the rover RTK receiver. Such an error can easily go undetected when using a single base station. In addition to the potential for introducing errors, productivity of the surveyor is lost each time the base station has to be set up at different reference station.

3.1 GPS NETWORK

The concept of GPS Network Reference Stations allows us to eliminate/reduce systematic errors in reference station data. This allows for an increased rover-to-base distance for RTK positioning while increasing the reliability of the system and reducing the initialization time. The GPS Network Reference Stations require continuous modem line connections between the control center and all reference stations. Data is transmitted continuously to the center. The center will calculate and transmit optimized Radio Technical Commission for Maritime Services (RTCM) correction messages and transmits it to the users.

Permanent GPS reference stations make it possible to receive RTK (Real Time Kinematics) correctional data everywhere. This means centimeter precise measurements in real time. By establishing an adequate number of GPS stations and allocating data access to the reference stations via mobile phone using Global System for Mobile phones (GSM) data modems, they can offer correction data throughout the region of interest. All the GPS reference stations in a network send "on-line" raw GPS data via permanent connections to a super-computer housed in a secure Control Center. In this way, all GPS observations can be gathered and weighted to the user's advantage. This solution gives the following advantages:

- Uniform precision of the entire network, or in other words, no additional constants due to increased distance from the individual reference stations (a well-known problem in traditional GPS RTK surveying).
- Single correction data from the entire network.
- Safety and reliability to enhance the quality of GNSS measurements.

The Control Center of super computer takes care of the following numerous tasks:

- Import of raw data and quality assurance routines
- Storing of RINEX data

- Correction of antenna phase center wandering
- Modelling and estimation of systematic errors
- Calculation of correction data in RTCM format for the users
- Transmission of data to users in the field

There exist many Networking approaches where GPS signals corrections can be sent to mobile rover in the field for Real Time Positioning.

3.1.1 Virtual Reference Station

An RTK rover located near the center of several reference stations would be affected by systematic errors if using any one of these reference stations. If, however, measurements from all these reference stations are combined, a model of the geometric and atmospheric errors over the area can be determined and a VRS can be created adjacent to the rover's location, dramatically reducing the systematic errors. Figure 3.2 shows how the VRS is implemented.

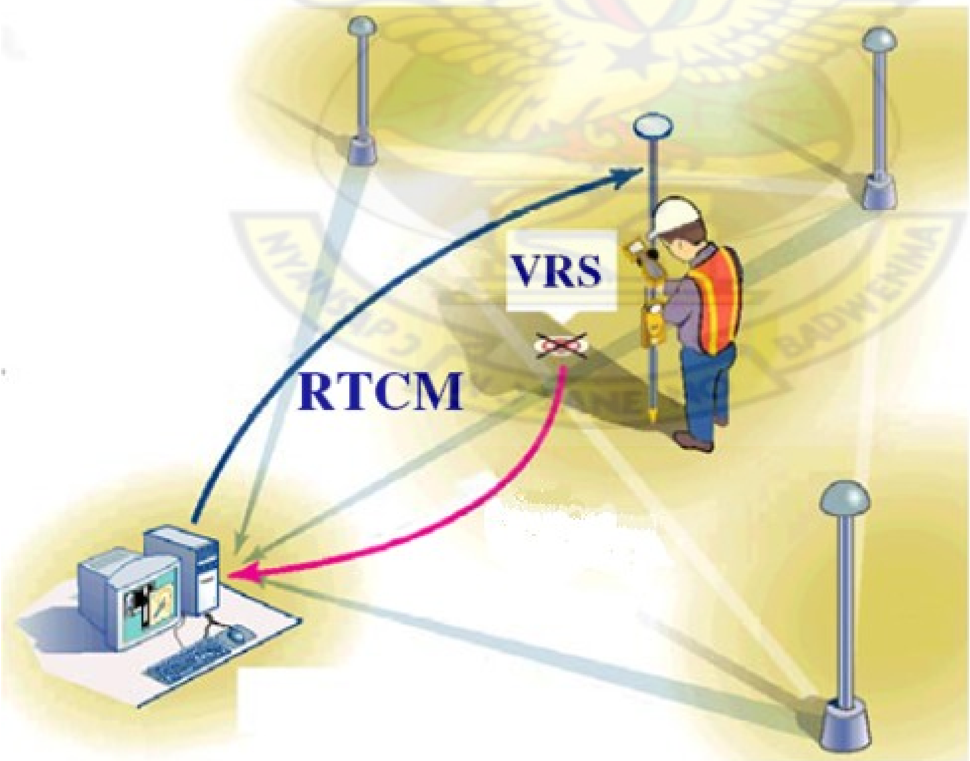


Figure 3.2 Implementation of the VRS (Source: Trimble, 2005)

Virtual Reference Station (VRS) Technique

The basic requirement of the virtual reference station (VRS) concept is the need of a duplex communication link between the reference station network and the rover. The rover has to transmit its approximate coordinates to the network, which then interpolates a reference data stream VRS for the given position. The data relates to the observation space (Wübbena *et al*., 1996):

$$\breve{X}_{VRS} = \breve{X}_j$$

$$VRS_{ij}^k = CPR_{ij}^k + f(FKP_i^k, \Delta\varphi_{ij}, \Delta\lambda_{ij}, \Delta h_{ij}) + \Delta T_{model,ij} \quad (1)$$

Equation (4.20) contains a tropospheric term, which describes the difference between the tropospheric delay models used in the network processing on the original reference station and the virtual reference station. Due to the RTCM definitions, the reference station may not correct for tropospheric errors. This is in general a reasonable restriction, because it avoids the problem of using inconsistent models for reference station and rover, while the rover is responsible to compute corrections for both sides. This, however, requires the knowledge of the reference station coordinates at the rover. Since the only coordinates the rover knows about are originating from the RTCM data stream, the rover does only know the coordinates of the VRS. Hence, the rover cannot compute the tropospheric correction for the real, but only for the VRS. In consequence, the network has to apply the tropospheric correction between real and virtual reference station. And here there is again the problem of possible inconsistency, if it is done with a different model than the rover applies.

In the VRS concept, the coordinates (in RTCM message type 3) are changed to VRS location, hiding the true reference station completely from the rover. One disadvantage of the VRS concept is that, for a kinematic rover, continuously updated approximate coordinates have to be used for the VRS *computation* (moving reference station). Today, most rover systems cannot handle a kinematic reference station. A system reset is performed, if the VRS coordinates are changing, which will result in frequent initialization of ambiguities. In practice, the VRS position therefore does not change. However, this implies that distance dependent errors will be present in the rover's solution once it starts to move away from the virtual reference.

Typically, some irregular physical effects occur, which can hardly be determined by a reference station network with given station distances. In this context, the reference station network can be considered as a limited number of monitoring stations or sensors with a certain and restricted spatial capability. The errors may arise from local troposphere or turbulent ionospheric conditions. Even if these higher order errors cannot be determined by the reference station network, it is obvious that their magnitude is a function of distance from the next true reference station.

Thus, if the rover knows the reference station position(s), it can take into account these higher order errors and improve its own RTK models, e.g. by stochastic ionospheric modeling. If the rover knows only the VRS position, it has no chance to do such kind of improvement. It should be mentioned that there are different types of VRS depending on the type of networking model. A VRS derived from the observation space (OSP-VRS) shows different behavior than a VRS derived from a state space model (SSP-VRS) (Marzooqi *et al*., 2006). This results from the fact, that a SSP-VRS is much less affected by current individual reference station errors than the OSP-VRS (Wübbena *et al*., 2001).

Since the state vector is the result of a continuously running filter, the influence of station dependent errors reduces, the more the redundancy (number of stations and satellites) available in the network. A similar filtering in the observation space can only be done with arbitrary models and is therefore less effective. Especially the non- depressive part of the signal is much smoother if derived from state information than from the observation state.

3.1.2 Area Corrections Parameters (FKP) Technique

One way of representing the additional corrections for the distance dependent errors is a polynomial parameterization to describe the influence for any rover position in a certain area. Depending on the temporal and spatial variation the orders of the representation must be defined. The RTCM standard currently limits the correction data to be formulated in the observation space, which means that modified GPS observable must be used. The area correction parameters (commonly called FKP), are the most flexible and suitable way to represent the state. FKP can be assumed for this discussion as a representation of the full state space information. FKP are more or less simplified to reduce the required bandwidth for transmission or the complexity to apply it at the rover. The state has to be transferred to the observation space, because most rover systems are currently not capable to handle any state space information. The FKP allow the prediction of the distance dependent error term for the approximately known rover position:

$$\boldsymbol{\Delta}\delta D_{ij}^{k} = f\left(FKP_i^{k}, \boldsymbol{\Delta}\varphi_{ij}, \boldsymbol{\Delta h}_{ij}\right)$$

$$\Delta\delta\hat{D}_{ij}^{k} = f\left(FKP_i^{k}, \Delta\varphi_{ij}, \Delta h_{ij}\right) \qquad (2)$$

This can be done independently from the network processing, as only the rover coordinates and satellite information are required. It is a major advantage, that FKP can be distributed by broadcast media, which is requested by most service providers. The FKP do not contain absolute tropospheric information, but gradients of the troposphere. The tropospheric effect for a reference station can therefore be figured out and applied correctly to the data by the rover. The dimensions of networks and the coverage of distribution media often make a linear FKP representation sufficient (Marzooqi *et al.,* 2006). The coverage of a linear FKP model is then centered to a real reference station, and the FKP describe the horizontal gradients for the geometric and ionospheric signal components in the observation space (Figure 3.3).

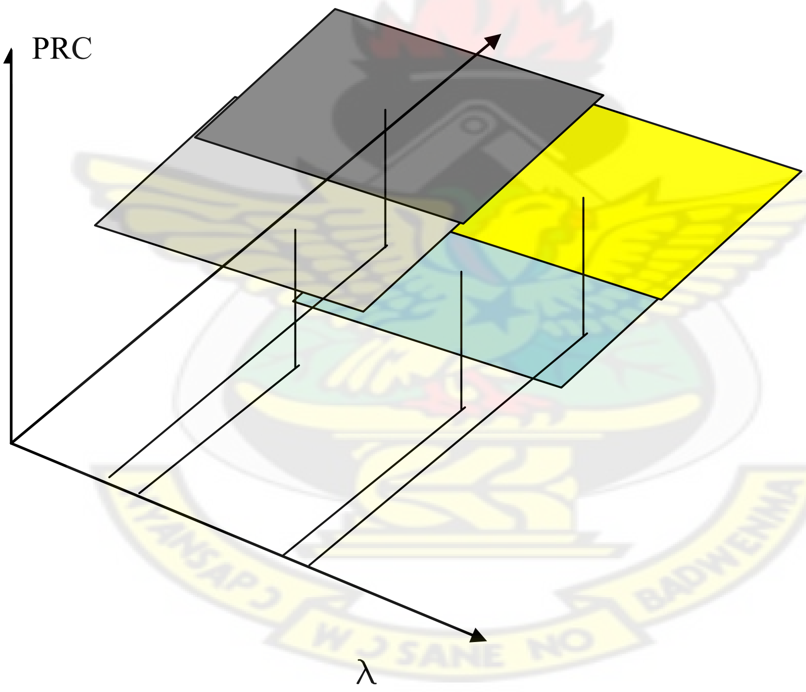


Figure 3.3 : Linear FKP planes for four reference stations

3.2 ALGORITHMS

After the double-differenced ambiguities associated with the reference station receivers have been fixed to their correct values, the double-differenced GPS/Glonass residuals can be generated. The spatially correlated errors to be interpolated could be the pseudo-range and carrier phase residuals for the L1 and/or L2 frequencies, or other linear combinations. One core issue for multi-reference receiver techniques is how to interpolate the distance-dependent biases generated from the reference station network for the user's location. Over the past few years, in order to interpolate (or model) the distance-dependent residual biases, several interpolation methods have been proposed.

They include the Linear Combination Model (Han & Rizos, 1996; Han, 1997), the Distance-Based Linear Interpolation Method (Gao et al., 1997; 1998), the Linear Interpolation Method (Wanniger, 1995; Wübbena et al., 1996), the Low-Order Surface Model (Wübbena et al., 1996; Fotopoulos & Cannon, 2000), and the Least Squares Collocation Method (Raquet, 1997; Marel, 1998).

The Linear Combination Model is formed from the single-differenced functional equation for baselines from the user receiver to two or more reference stations (Han & Rizos, 1996; Han, 1997). The advantage of this model is the elimination of the orbit bias. The residual ionospheric delay and the tropospheric delay can also be reduced to the same degree that the epoch-by-epoch and satellite-by-satellite ionosphere and the troposphere models are able to. Multipath and measurement noises can be reduced if the user receiver is located within the network of reference stations.

A distance-based linear interpolation algorithm for ionospheric correction estimation has been suggested by Gao et al. (1997). In order to improve interpolation accuracy, two modifications were made by Gao & Li (1998). The first modification is to replace the ground distance with a distance defined on a single-layer ionospheric shell at an altitude of 350km. The second modification is to extend the model to take into account the spatial correction with respect to the elevation angle of the ionospheric delay paths on the ionospheric shell. Although this method was originally proposed by Gao et al. (1997) to interpolate residual ionospheric biases, it can also, to a certain degree, mitigate other distance-dependent biases such as tropospheric bias and orbit errors.

The Linear Interpolation Method (LIM) was first proposed by Wanninger (1995) for a regional differential ionospheric model derived from dual-frequency phase data from at least three GPS monitor stations surrounding a user station. Unambiguous double-differenced ionospheric biases can be obtained on a satellite-by-satellite and epoch-by-epoch basis after ambiguities in the reference station network have been fixed to their correct integer values. Ionospheric corrections for any station in the area can be interpolated by using the known coordinates of the reference stations and approximate coordinates of the station(s) of interest. Wübbena et al. (1996) extended this method to model the distance-dependent biases such as the residual ionospheric and tropospheric biases, and the orbit errors. Similar methods have been proposed by Wanninger, 1999), Schaer (1999), Chen et al. (2000), Vollath et al. (2000). The advantage of this method for real-time implementation is that the implementation is easier because only two coefficients for each satellite pair are required for transmission to the user. The distance-dependent biases exhibit a high degree of spatial correlation across a reference station network.

Low-order surfaces can be used to 'fit' the distance-dependent biases (Wübbena et al., 1996; Fotopoulos, 2000). The fitted surfaces are known as trend or regression surfaces, and they model the major trend of the distance-dependent biases. The coefficients of the low-order surfaces can be estimated via a least squares adjustment using data from the reference station network. The variables of the fitting function could be two (i.e. the horizontal coordinates), or three (horizontal coordinates and height). The fitting orders could be one, two or higher. For this method, the required number of reference stations depends on the fitting variable and the fitting order. In general, the minimum number of reference stations is four if the plane-fitting function is used.

Least Squares Collocation has been used for many years to interpolate gravity at any given location using only measurements at some discrete locations. It was proposed for interpolating the distance-dependent biases in a network by Raquet (1997). This method explicitly attempts to minimise the differenced phase-code biases between any reference station receiver and the user receiver. Note that the accuracy of the Least Squares Collocation Method is dependent upon the accuracy of the covariance matrix (Raquet, 1998). In practice it is very difficult to calculate precise covariance matrices.

The theoretical and numerical comparison of the various interpolation algorithms has been made by Dai et al. (2003b).

CHAPTER FOUR - METHODOLOGY

4.0 THE NETWORK OF BASE STATIONS

A network of base stations was designed and implemented in a survey carried out in September 2008. The network was designed to cover three of the ten regions in the country namely; the Eastern, Greater Accra and the Central Regions.

4.1 INSTRUMENTATION

The instruments used in this project were all of the integrated type of receivers (i.e the L1/L2 and GNSS receiver, antennae, memory and power component all in one unit). The instruments were: a Sokkia GSR 2700 RSX which was permanently fixed and operated for the offices of Geo-Tech Systems Ltd., two GSR 2700 ISX, two GSR 2700 IS and two Radian IS which were used variously at temporary reference stations and rover stations. Table 4.1 shows a list of the instruments with their corresponding serial numbers.

MODEL	Owner	Type	Serial Number
Sokkia GSR 2700 ISX	Geotech	GNSS	NCD07220052
Sokkia GSR 2700 ISX	Geotech	GNSS	NCD07220049
Sokkia GSR 2700 IS	Geotech	Dual Frequency	NZH06190022
Sokkia GSR 2700 IS	Geotech	Dual Frequency	NZG1100H040
Sokkia Radian IS	Geotech	Dual Frequency	NPV01220009

Figure 4.1 GSR 2700IS

4.2 RECONNAISSANCE

A thorough reconnaissance was done to select stations that will be suitable for the establishment of a network of base stations. Desk study of the map of Ghana was carried out and townships were selected to form triangles with good strength and without acute angles. After a careful study these towns were chosen, Winneba, Asamankese, Suhum, Dodowa, Nsawam and Accra were chosen to host base stations to form the network.

For the actual GPS survey to establish the coordinates of these selected sites, two Continuously Observing Reference Station (CORS), one at the Kumasi office of the Building and Road Research Institute (BRRI) and another at the Geotech Systems Limited offices in Accra, the Geotech Base, were identified and used.

Figure 3.1 shows the distribution of the stations on a section of the map of Ghana. Together, the network covers an area of size of 80km x 80km.

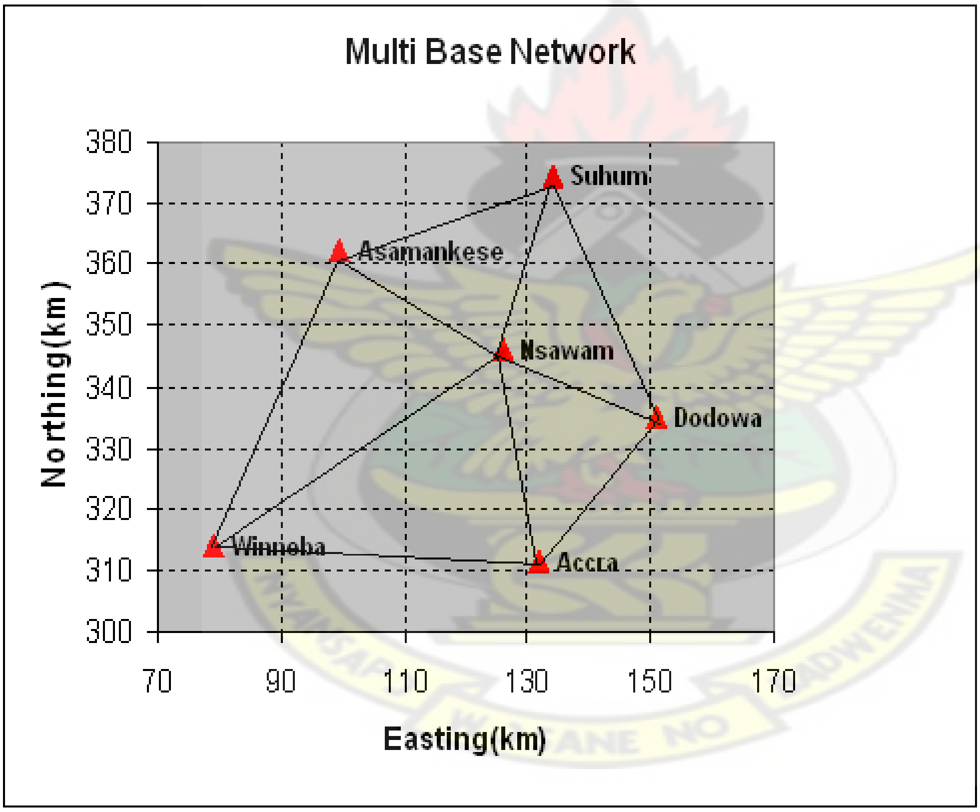


Figure 4.2 Distribution of Network Stations

4.3 ESTABLISHING THE NETWORK

All the network points were established in the static survey which was carried out in September 2008 and the values of these points were computed using the Spectrum Survey rev 3.6 software of Sokkia Inc. The equipment at each station was a Sokkia dual frequency receiver. The master base station was equipped with the Sokkia Reference Station software which allowed logging of data and filing such data in batches of four hours. The coordinates obtained after the computations are as shown in Table 3.1.

In choosing the locations of the reference stations, preference was given to locations that allow for a clear sky view, a good geometry for the triangles formed, and accessibility to electricity and other utility such as internet access.

Each reference station point was selected to be in an area that permits a clear sky for the observation of the satellites. The point in Accra, Geotech, is located on the roof of a story building which should have been the case for all the points, had it not been difficult to convince building owners to allow for the use of the roofs of their buildings.

The reference station Geotech is linked directly to the internet through the address www.80.87.88.59. Once again in the ideal operation of the CORS MRS network, all the stations would be linked to the internet or some other mains to directly broadcast corrections.

All the data from the various reference stations were downloaded and processed with the Spectrum Survey software and adjusted constraining at least two of the already established points.

Town	Easting(m)	Northing(m)	Elevation(m)
Accra	99413.77	362207.6	18.331
Asamankese	131655.053	311393.557	146.271
Dodowa	134200.697	374317.435	82.331
Nsawam	125873.185	346173.325	52.000
Suhum	150961.801	334906.520	175.999
Winneba	78972.774	313876.421	23.842

Table 4.2 Computed Coordinates of Network

4.4 TESTING METHODOLOGY

All the data for both SRS and MRS are collected in the kinematic mode and processed in the post-mission mode. A further two points were surveyed using static survey methods. Their coordinates were computed to be in accuracies of 0.01m in the horizontal and 0.02m in the vertical. The points were selected to allow for the SRS and MRS tests to be conducted on both close range RTK and medium to long range RTK.

The data collection was done using Sokkia dual frequency receivers namely the Radian IS and the GSR 2700 IS. The data was collected for packets of five epochs over the periods of observation. Each epoch was set to a second. For each test point, the observation was done over a period of six hours. The SDR software was used on a data logger to carry out the kinematic survey.

After the survey, the raw data obtained is processed and the coordinates are compared to the coordinates obtained from the static survey for the same points. The data processing for the SRS method uses only one reference station that is most suitable in respect of the particular range being evaluated (whether short or medium range). In the processing of data for the MRS method, the data is processed by fixing the positions of the various stations in the network so they can together 'correct' the test point. The Distance-Based Interpolation Method was used with the Spectrum Survey software to obtain the results for the MRS RTK.

The data for the SRS is processed with different base stations at varying distances for the rover station. The rover station is set on a tripod, instead of the traditional pole, to remove any errors that may be due to unsteady handling and wind effects. A minimum of thirty thousand (30,000) epochs were collected for each point of observation.

The first point TQ, located near the Tetteh Quarshie over pass, was chosen to be about seven kilometres (7 km) from the closest network reference station and another point BR, located near the Brekoso village, near Aburi in the Easter Region of Ghana, was chosen to over twenty kilometres (20 km) from the closest network reference station. These points did not necessarily have very ideal conditions as the network stations since they were chosen to replicate typical conditions in which surveys would be carried out in Ghana. The points are shown in Figure 3.2

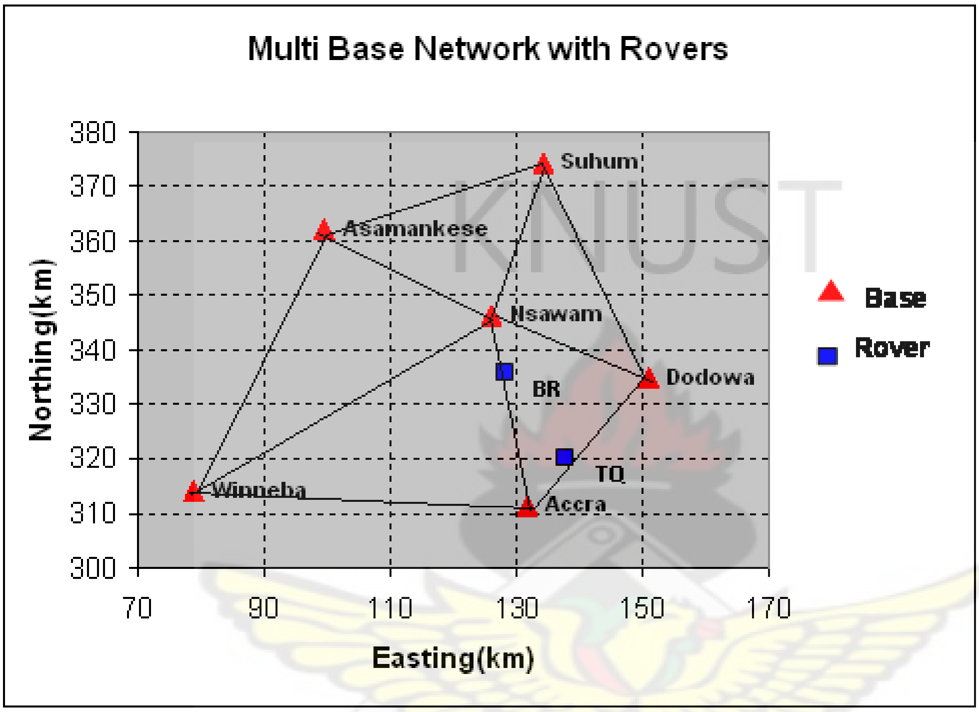


Figure 4.3 Base Network with Rovers

4.5 EVALUATION MEASURES

In evaluating the quality of the observations, three measures are used namely:

1. possibility of ambiguity resolution,
2. the amount of time required for the resolution and
3. the reliability of the results of the fixed solutions (Kjørsvik, 2002).

These measures are applied to the SRS from at least two base stations and then to the MRS. Both results are compared to that of the static survey which is taken as the standard.

CHAPTER FIVE - RESULTS AND ANALYSIS

5.0 DATA PROCESSING

On the 13th September 2008, each of the reference stations was observed with the exception of the station at Nsawam which did not have favourable conditions to facilitate its observation on that day. The TQ2 station had been observed previously by a static survey and coordinates established as shown in Table 3.3.

The Sokkia Spectrum Survey software Version 3.6 was used for the processing of the vectors and trajectories for the project. This version of the software is capable of processing both GPS / GLONASS data. The processing of the trajectories allows for epoch-by-epoch processing of satellite data with processing intervals of one second.

After processing the data, the results were exported to Microsoft Excel and SPSS for further statistical analysis.

The results from the processing of the trajectories were exported in the following format: <time tag><solution type><number of satellites> <latitude> <longitude> <elevation><std.dev.-latitude> <std.dev.-longitude> <std.dev.-elevation><GDOP> . The format therefore made it easy to assess the specific time for the first fixed solution which was found along with analyzing the quality of the results.

5.1 TEST FOR TQ

The network configuration used for the test on rover position TQ, are described and the evaluation measures applied to the results form the observation.

5.1.1 Network Configuration

The configuration used for the test with the rover station TQ, located at the Tetteh Quarshie interchange in Accra is shown in Figure 5.1. The closest base station in this case was the Accra station also called the Geotech station which was around seven kilometres (7km) from the rover station and the furthest was the Asamankese base station which was about sixty kilometres (60km) from the rover station TQ. The longest inter-base distance for the configuration was about seventy five kilometres (75 km) which was the Winneba-Suhum stations and the shortest was about thirty kilometres (30 km) – between the Suhum-Asamankese stations. Figure 4.1 shows the configuration for the test on the rover station at TQ.

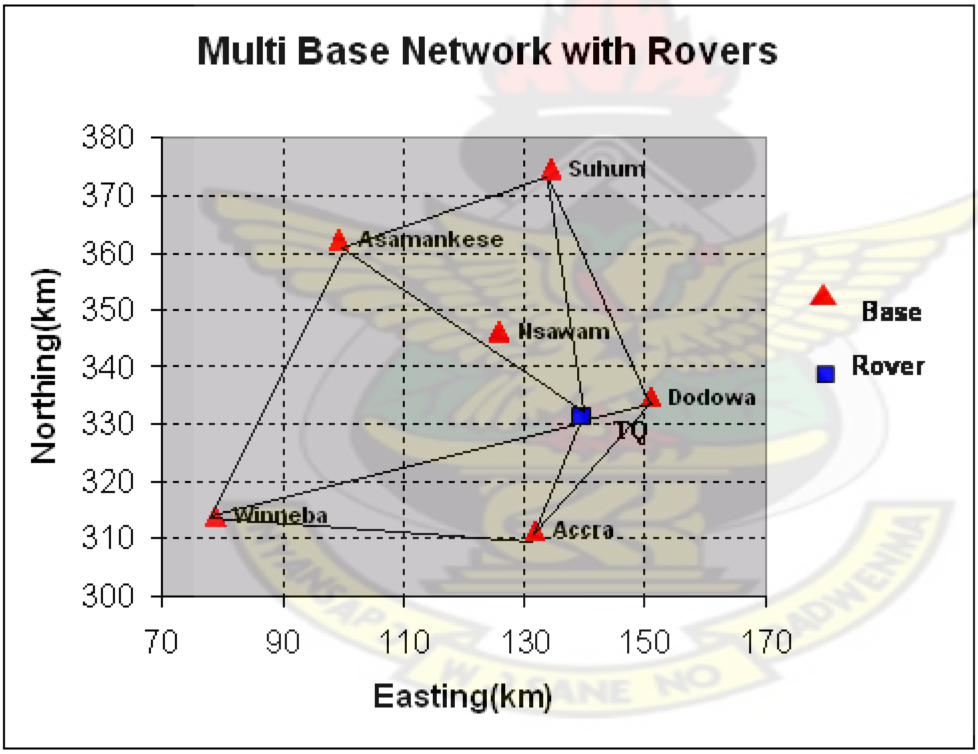


Figure 5.1 Network Configuration for Test Station TQ

5.1.2 Ambiguity Resolution

In using the ambiguity resolution to evaluate the performance of a station, the important criteria are the time to first fix (TTFF), the type of solution and the number of fixes. Tables 5.1 – 5.2 show these qualities for a number of selected stations used in the test.

Number of Trajectories Observed	3535
Number of Correct Fixes	3117
Percentage of Correct fixes	88.18%
Time To Fix First (sec)	649

Table 5.1 Ambiguity Fixing for TQ with Geotech

Number of Trajectories Observed	3535
Number of Correct Fixes	3185
Percentage of Correct fixes	90.10%
Time To Fix First (sec)	66

Table 5.2 Ambiguity Fixing for TQ with MRS

As seen from Tables 5.1 and 5.2, there are significant gains in the time required to resolve the ambiguities for the first, TTFF, and also there are a slightly greater number of observations which are correctly fixed. A correct fix was set in the software not to exceed the horizontal error of 10 centimetres and a vertical error of 20 centimetres. These results could however be due to the type of instruments used and the site selection and may vary for other instruments or site selection.

5.1.3 Coordinate Reliability

The data set collected for the TQ point is computed firstly with a single reference station and later the MRS computation is done for the same data set using the reference stations closest to the rover station. The results of these processes are shown in the following tables and error distribution diagrams.

Figures 5.2, 5.3 and 5.4 show the scatter plots of the TQ data set processed as a SRS at a distances of about 7 km and 29.5 km from the rover station with stations Geotech and Dodowa respectively, and lastly with MRS.

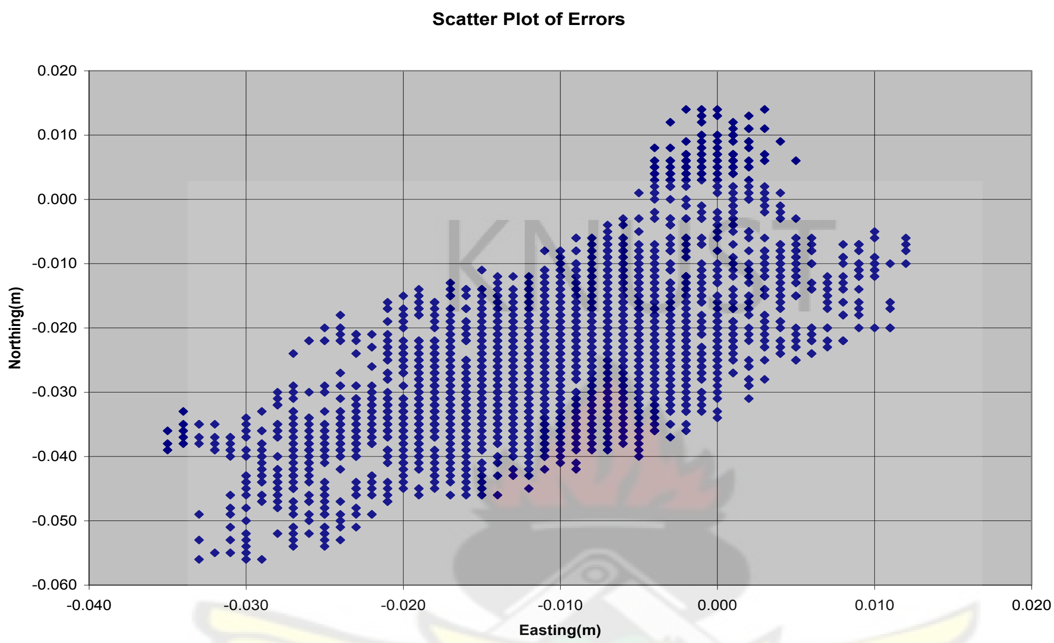


Figure 5.2 Scatter Plots of Errors of TQ Rover Data with Geotech Station (7.0 km)

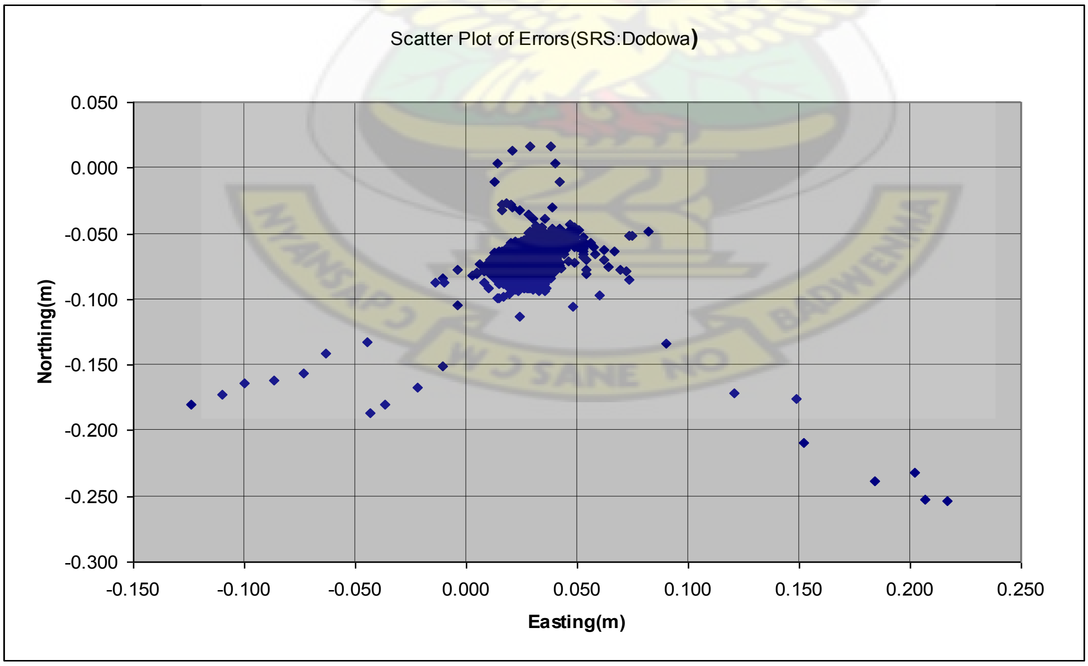


Figure 5.3 Scatter Plots of Errors of TQ Rover Data with Dodowa Station (29.5 km)

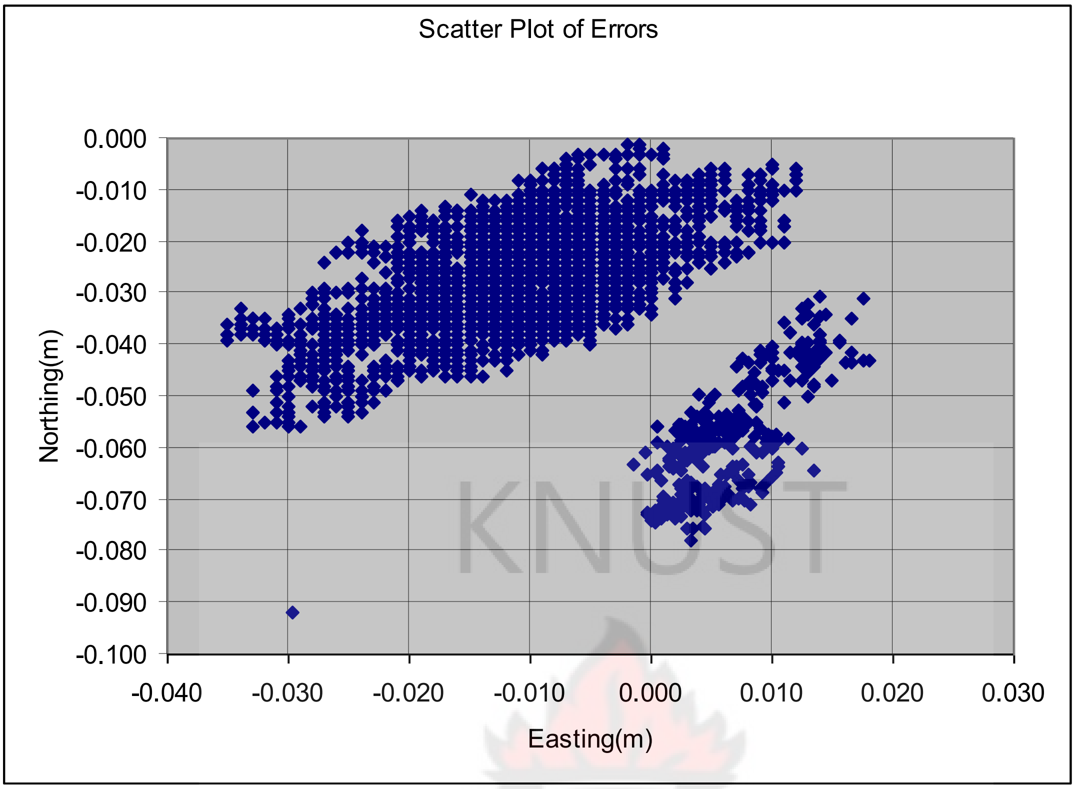


Figure 5.4 Scatter Plots of Errors of TQ Rover Data with MRS

The scatter plots show a close relationship between the MRS and the SRS with the Geotech reference station which is seven kilometer from the rover station. At a distance of less than ten kilometres the errors of the SRS are expected to be at sub centimetre and compared to the MRS results, there are only a slight improvement in relative to the Geotech SRS. There are however a significant improvement in the results if compared to the Dodowa reference stations' SRS results.

The following Tables, 5.3-5.5, show the statistics of the accuracies of the results from the respective reference stations and the method used.

	N	Minimum	Maximum	Mean	Std. Deviation
dE	1654	-0.0350	0.0120	-0.0100	0.0085
dN	1654	-0.0560	0.0140	-0.0244	0.0085
dH	1654	-0.2040	0.0320	-0.0716	0.0341
Valid N (listwise)	1654				

Table 5.3 Statistics of the Geotech SRS results (7 km)

	N	Minimum	Maximum	Mean	Std. Deviation
dE	1654	-0.0350	0.0060	-0.0139	0.0073
dN	1654	-0.0560	-0.0090	-0.0295	0.0091
dH	1654	-0.1260	0.0040	-0.0831	0.0205
Valid N (listwise)	1654				

Table 5.4 Statistics of the MRS results

	N	Minimum	Maximum	Mean	Std. Deviation
dE	1654	-0.0350	0.0060	-0.0290	0.0120
dN	1654	-0.0560	-0.0090	-0.0711	0.0132
dH	1654	-0.1260	0.0040	-0.0214	0.0314
Valid N (listwise)	1654				

Table 5.5 Statistics of the Dodowa SRS results (29.5 km)

As seen in the tables, there are marked improvements in the standard deviations and means of the MRS method over the SRS with Dodowa as the reference station. There is only a slight improvement when compared to that of the much short base length with Geotech as the reference station.

Figures 5.5-5.7 show the distribution of the combined Easting and Northing errors for the various reference station and methods of processing. As expected, there are close similarities between the MRS and the 7 km baseline from the rover station to the Geotech reference station. The distribution of the horizontal errors in the case of the Dodowa reference station, however, is much worse than any of the other two and these graphs are consistent with the other analysis done so far.

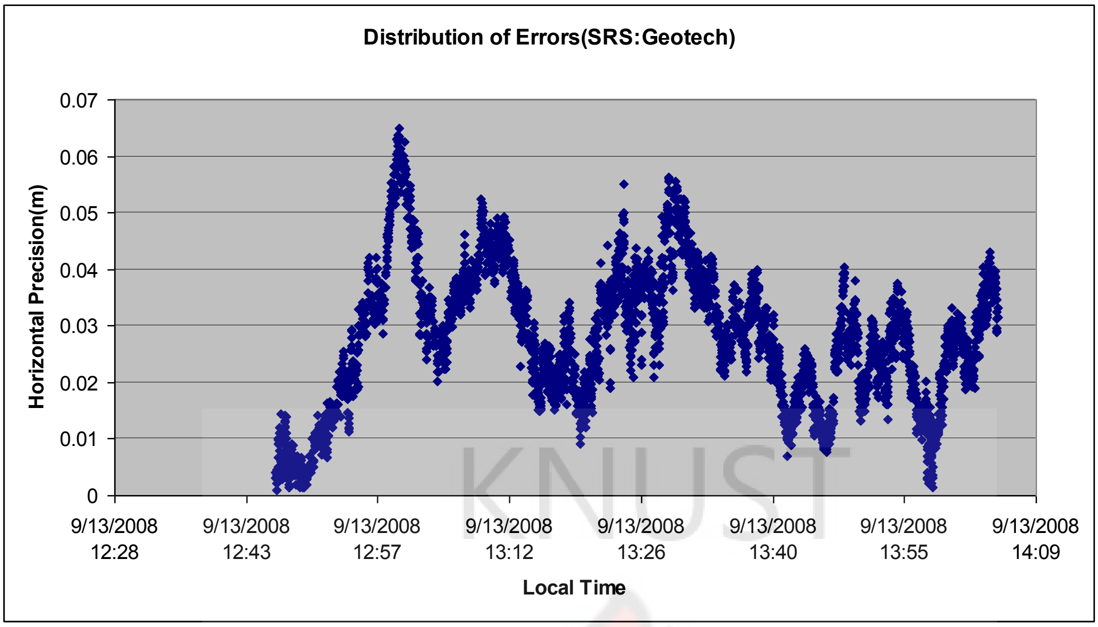


Figure 5.5 Distribution of over the period of observation (SRS: Geotech)

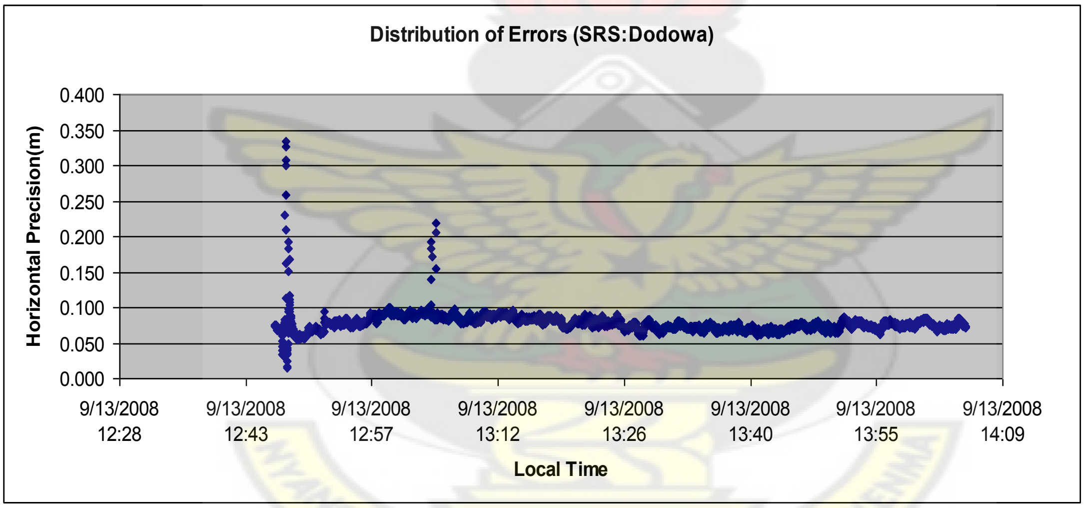


Figure 5.6 Distribution of over the period of observation (SRS: Dodowa)

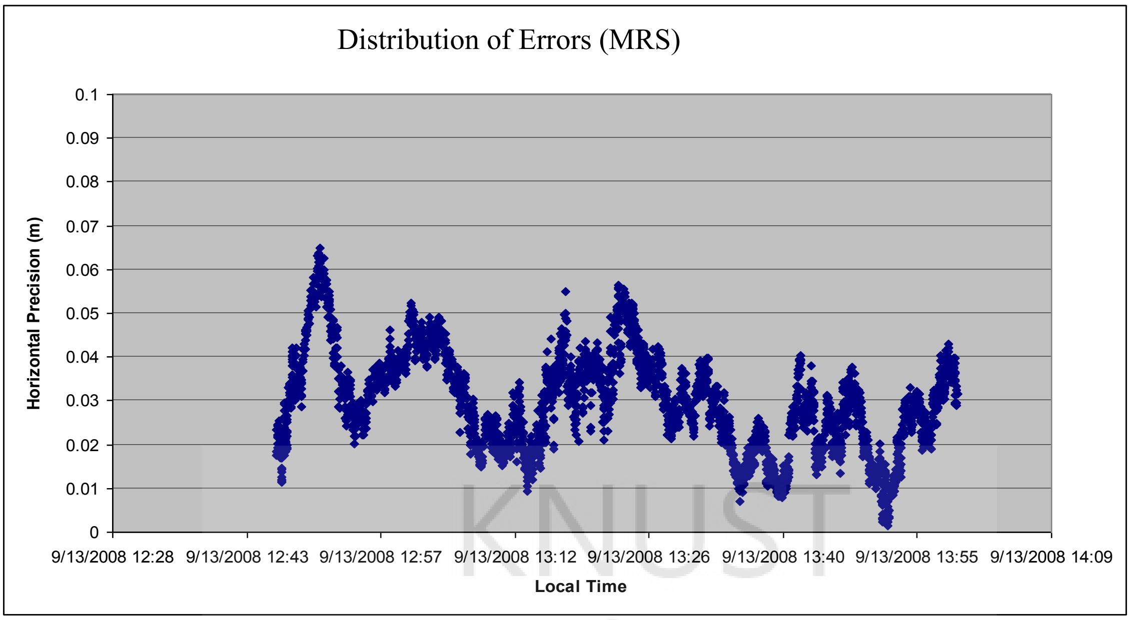


Figure 5.7 Distribution of over the period of observation (MRS)

As shown in Figures 5.8-5.10, the bar charts with normal curves for the various stations reveal a similar trend as discussed above. The cumulative distribution diagrams also have inserts of the magnitude of the errors that are to be representative of 95% and 99% of the errors associated with the point computation for respective station.

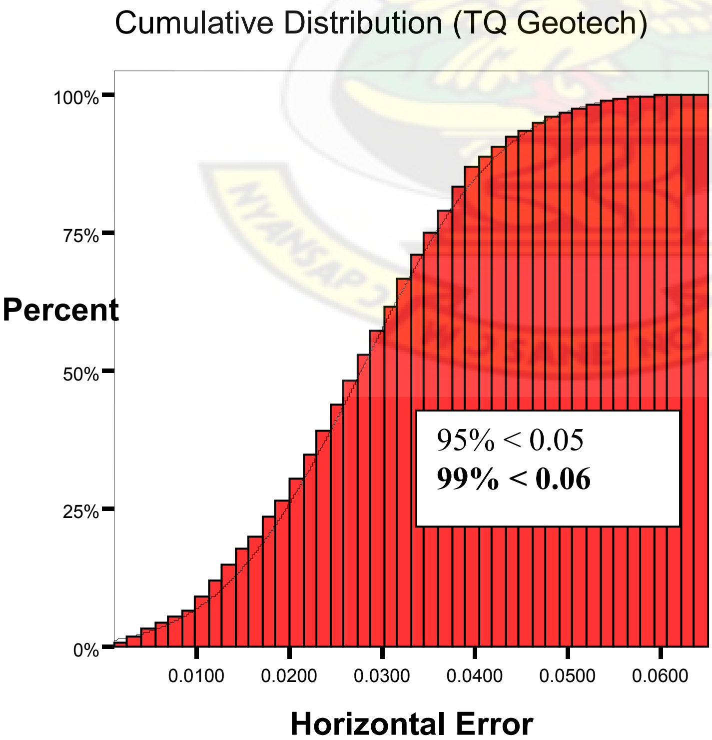


Figure 5.8 Cumulative Distribution of Horizontal Error

Figure 5.9 shows the distribution of horizontal error and indicates the mean and standard deviations of the points to be 0.0276 and 0.012 respectively (insert). The normal curve is superimposed on the distribution of frequencies.

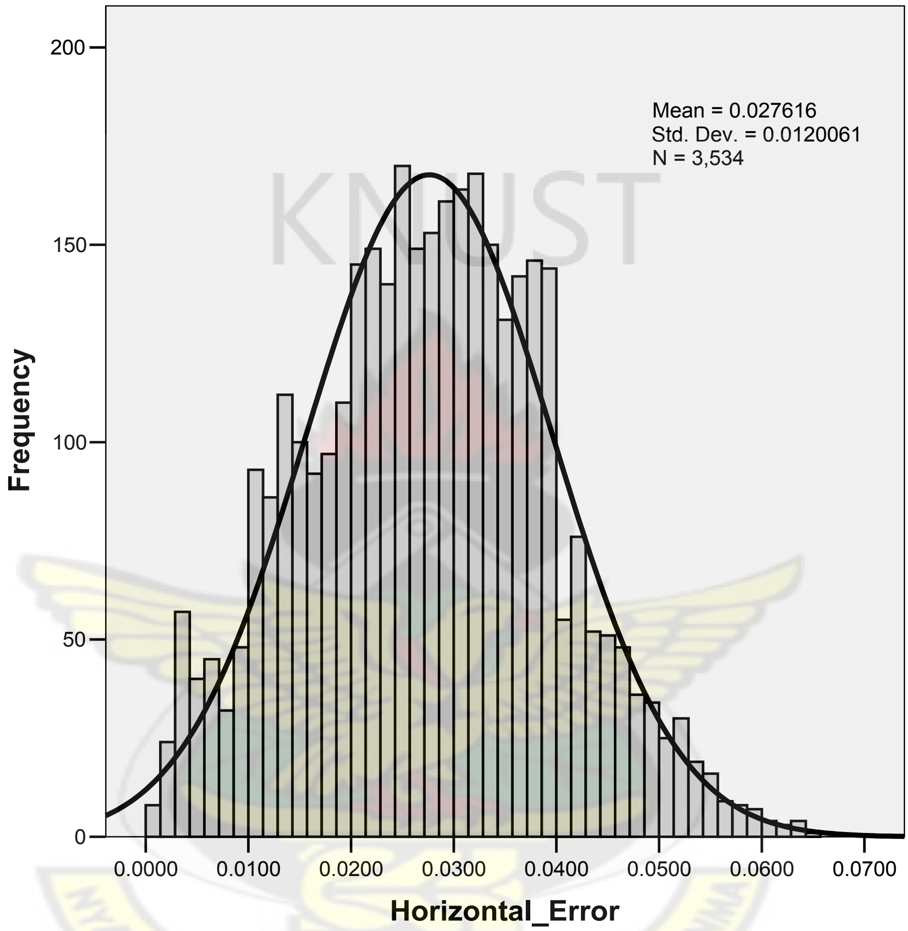


Figure 5.9 Histogram Horizontal Errors (SRS: Geotech)

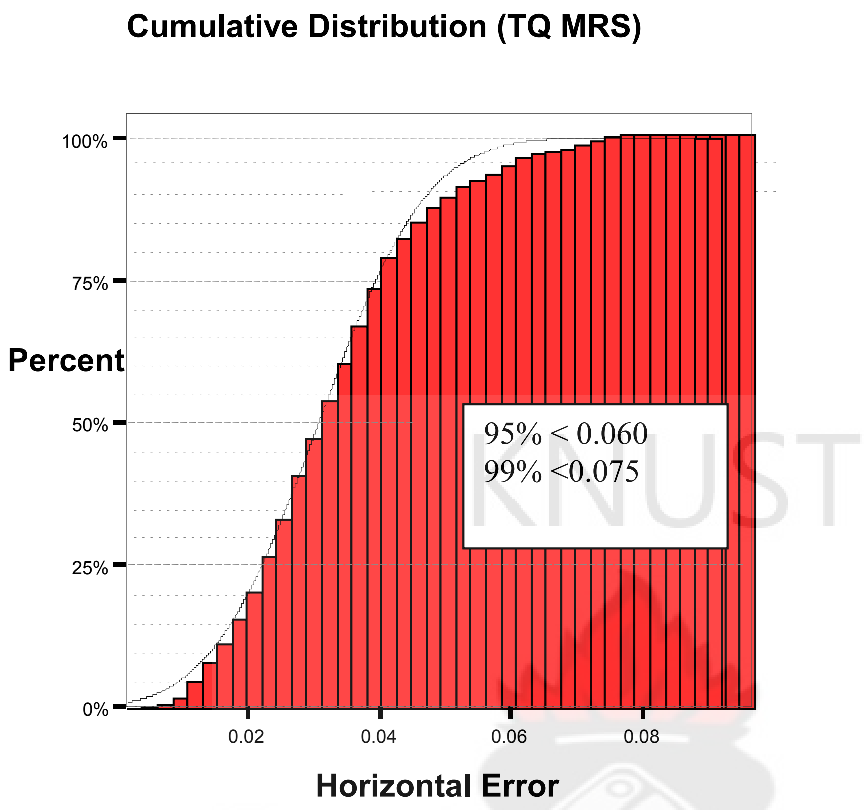


Figure 5.10 Cumulative Distribution of Horizontal Error (TQ: MRS)

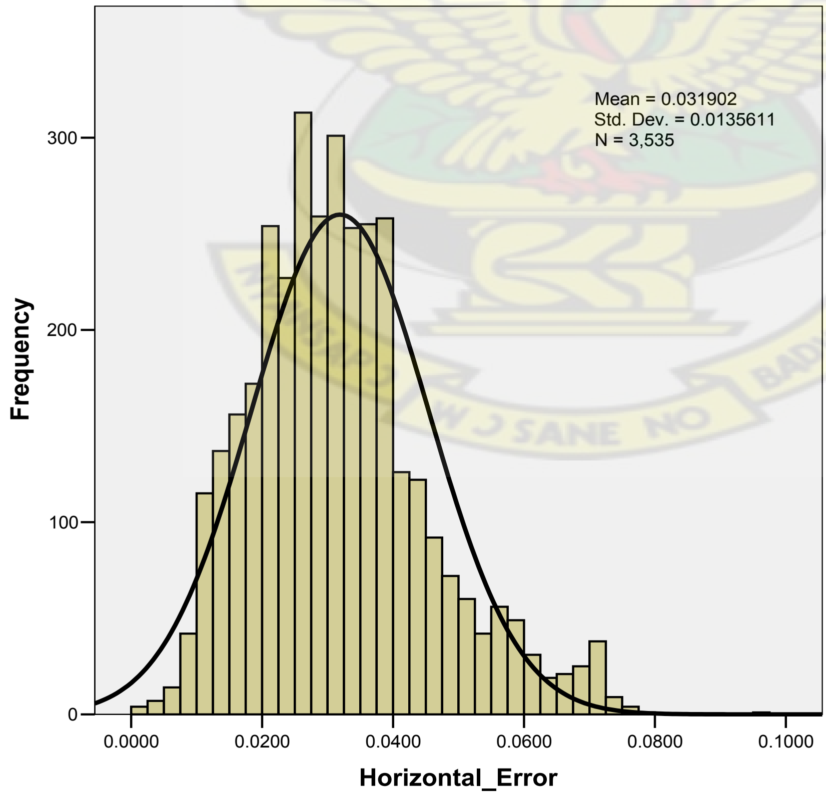


Figure 5.11 Histogram of Horizontal Errors (TQ: MRS)

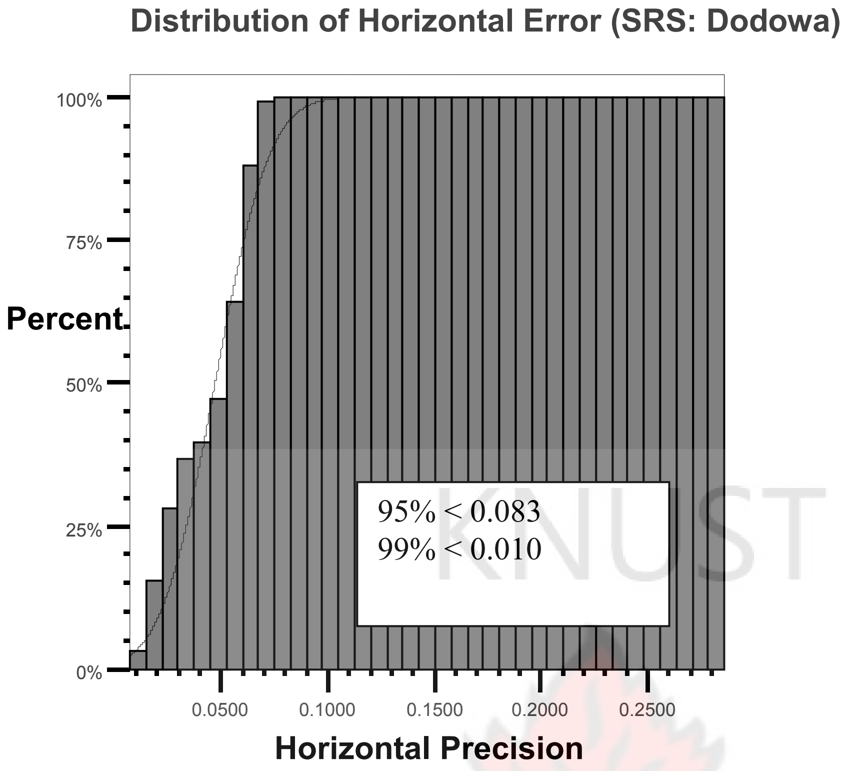


Figure 5.12 Cumulative Distribution of Horizontal Error

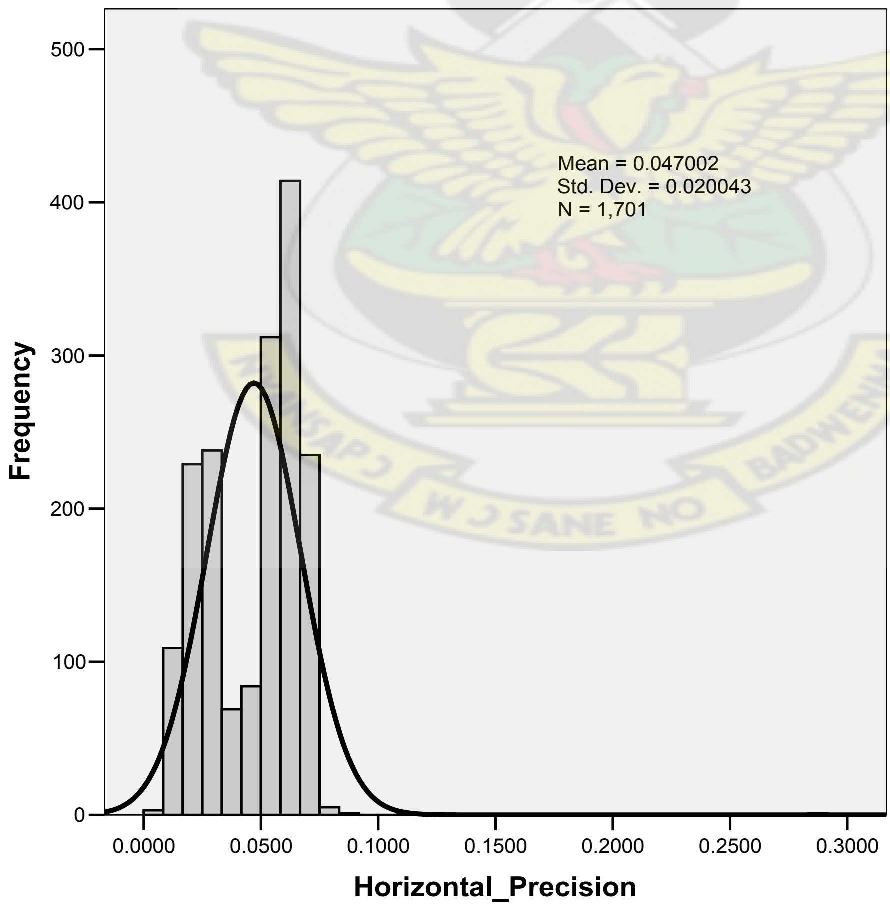


Figure 5.13 Histogram Horizontal Errors (SRS: Dodowa)

5.2 TEST FOR BEREKUSU

The network configuration used for the test on rover position BRK, are described and the evaluation measures applied to the results form the observation.

5.2.1 Network Configuration

The configuration used for the test with the rover station BRK near Berekoso in the Eastern Region of Ghana is as shown in Figure 5.14. The configuration of the reference stations is much the same as that for the testing of the TQ rover station as discussed in the section 5.1.1. The closest base station in this case was the Accra station also called the Geotech station which was about twenty and half kilometres (20.5 km) from the rover station and the furthest was the Winneba base station which was about sixty one kilometres (61 km) from the rover station. The longest inter-base distance for the configuration was about seventy five kilometres (75km) which was the Winneba-Suhum stations and the shortest was about thirty kilometres (30km) – between the Suhum-Asamankese stations. Figure 5.14 shows the configuration for the test on the rover station at BRK.

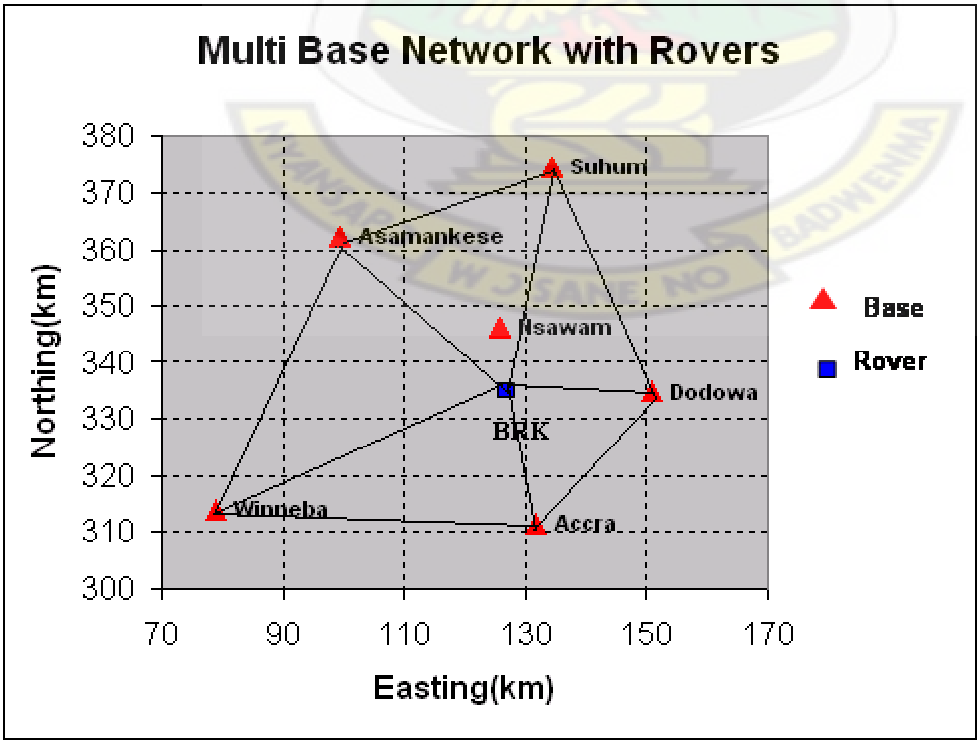


Figure 5.14 Network Configuration for Test Station BRK

5.2.2 Ambiguity Resolution

The ambiguity resolution to evaluate the performance of the BRK station was a little different from that of the TQ station because the reference stations receiver engines were not reset at the beginning of the test. For this reason, the TTFF could not be measured for the rover station. Tables 5.6 – 5.7 show the other standard qualities for a number of selected stations used in the test.

Number of Trajectories Observed	1698
Number of Correct Fixes	1698
Percentage of Correct fixes	100%

Table 5.6 Ambiguity Fixing for TQ with Geotech

Number of Trajectories Observed	1698
Number of Correct Fixes	1698
Percentage of Correct fixes	90.10%
First Time To Fix (sec)	66

Table 5.7 Ambiguity Fixing for BRK with MRS

As seen from Tables 5.6 and 5.7, there are significant gains in the time required to resolve the ambiguities for the first, TTFF, and also there are a slightly greater number of observations which are correctly fixed. A correct fix was set in the software not to exceed the horizontal error of 10 centimetres and a vertical error of 20 centimetres.

5.2.3 Coordinate Reliability

The data set collected for the BRK point is computed firstly with a single reference station and later the MRS computation is done for the same data set using the reference stations closest to the rover station. The results of these processes are shown in the following tables and error distribution diagrams.

Figures 5.15, 5.16 and 5.17 show the scatter plots of the BRK data set processed as a SRS with at a distances of about 20.5 km and 20.6 km from the rover station with stations Geotech and Dodowa respectively, and lastly with MRS.

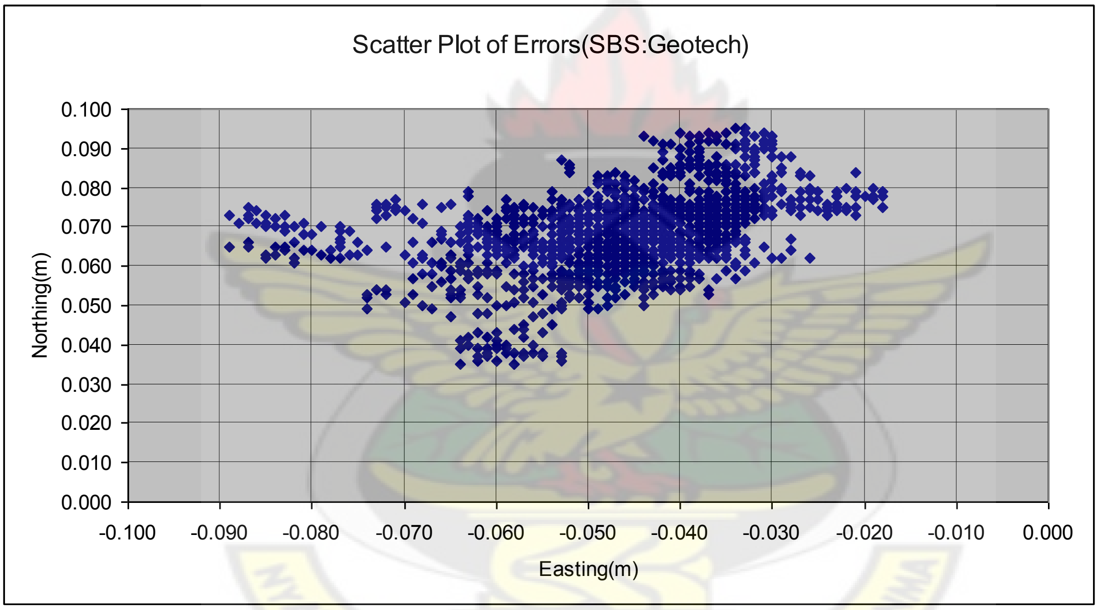


Figure 5.15 Scatter Plots of Errors of BRK Rover Data with Geotech Station (20.5km)

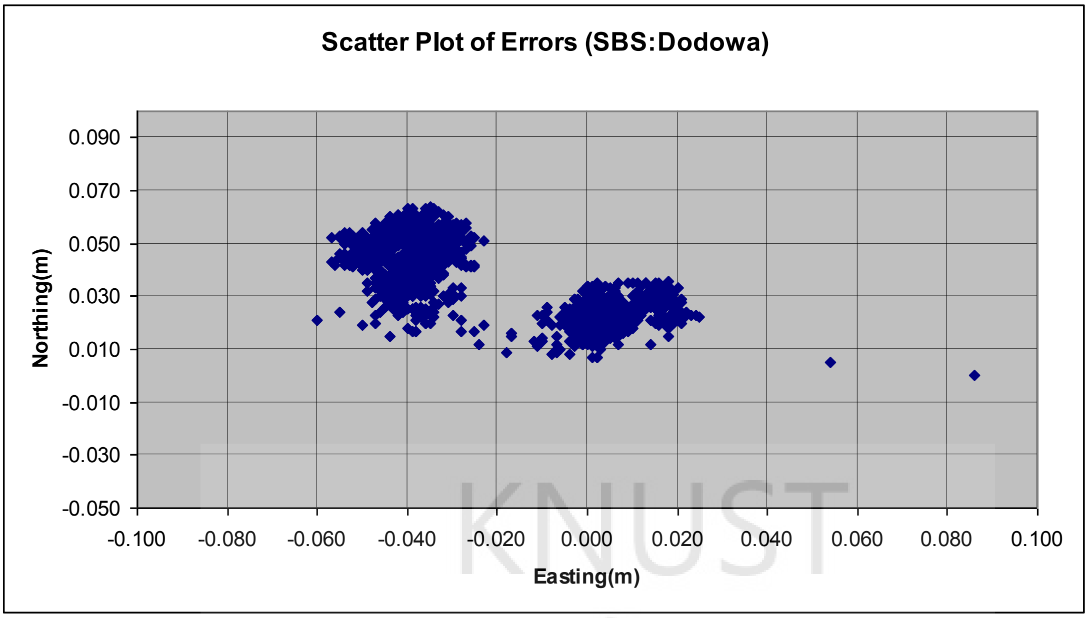


Figure 5.16 Scatter Plots of Errors of BRK Rover Data with Dodowa Station (20.6 km)

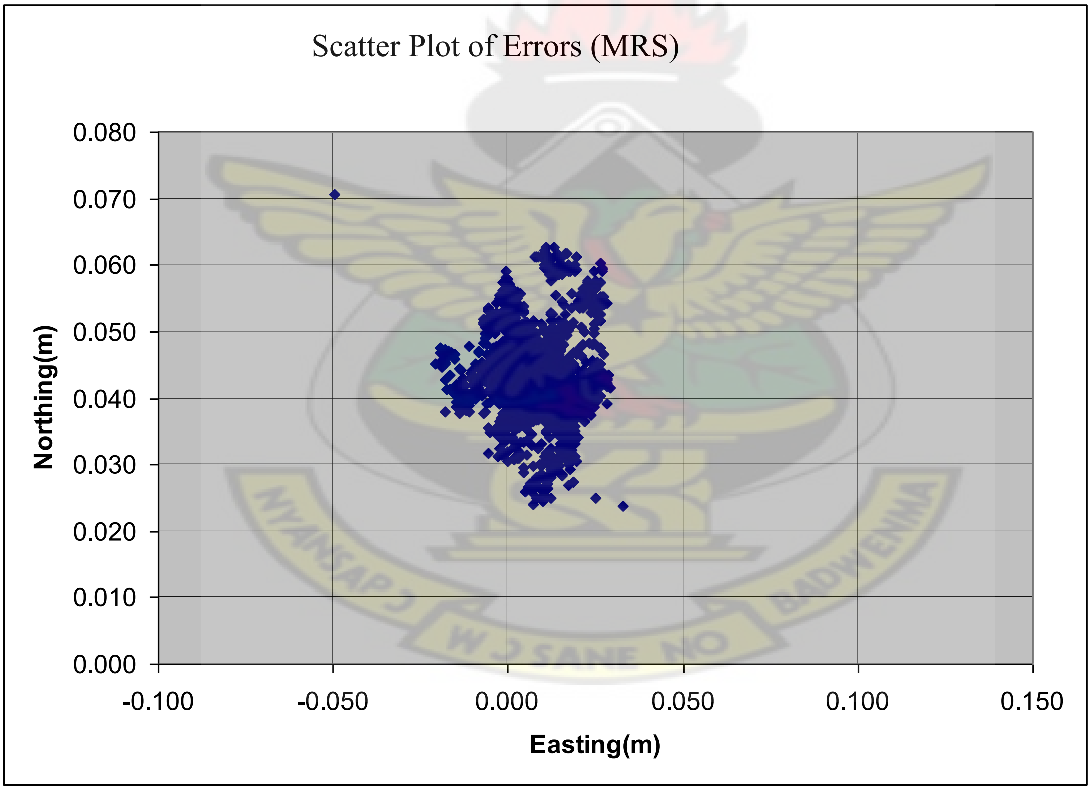


Figure 5.17 Scatter Plots of Errors of BRK Rover Data with MRS

The scatter plots shown above indicate a close relationship between the errors obtained from the points from the Dodowa and Geotech reference stations. The scatter plot of errors for the MRS shows improvements when compared to the plot of errors for the closest reference stations.

The following Tables 5.8-5.10 show the statistics of the accuracies of the results from the respective reference stations and the method used.

Descriptive Statistics (BRK:Dodowa)

	N	Minimum	Maximum	Mean	Std. Deviation
dE	1701	.0099	0.35200	-0.02246	0.0251
dN	1701	.0105	0.16000	0.036514	0.0157
dH	1701	.0273	0. 60700	-0.1051	0.0745
Valid N (listwise)	1701				

Table 5.8 Statistics of Errors for Dodowa (20.6 km)

Descriptive Statistics (BRK:Geotech)

	N	Minimum	Maximum	Mean	Std. Deviation
dE	1698	-.0890	-.0180	-.046352	.0120691
dN	1698	.0350	.0950	.068554	.0104273
dH	1698	-.0310	.1080	.032857	.0220847
Valid N (listwise)	1698				

Table 5.9 Statistics of Errors for Geotech (20.5 km)

Descriptive Statistics(BRK:MRS)

	N	Minimum	Maximum	Mean	Std. Deviation
dE	1698	-.0495	.0983	.007322	.0099862
dN	1698	-.0335	.0707	.043514	.0068973
dH	1698	-.1610	.1172	-.023278	.0276789
Valid N (listwise)	1698				

Table 5.10 Statistics of Errors for MRS

The descriptive statistics of the errors associated with the points processed with the various single reference stations as compared with that of the MRS also shows significant gains in accuracy of the easting, northing and height although the gain in easting is much pronounced. Figures 5.18 - 5.20 show the distribution of the combined Easting and Northing errors for the various single-reference-station and methods of processing. The distribution of the horizontal errors in the case of the Dodowa reference station however is much worse than any of the other two and these graphs are consistent with the other analysis done so far.

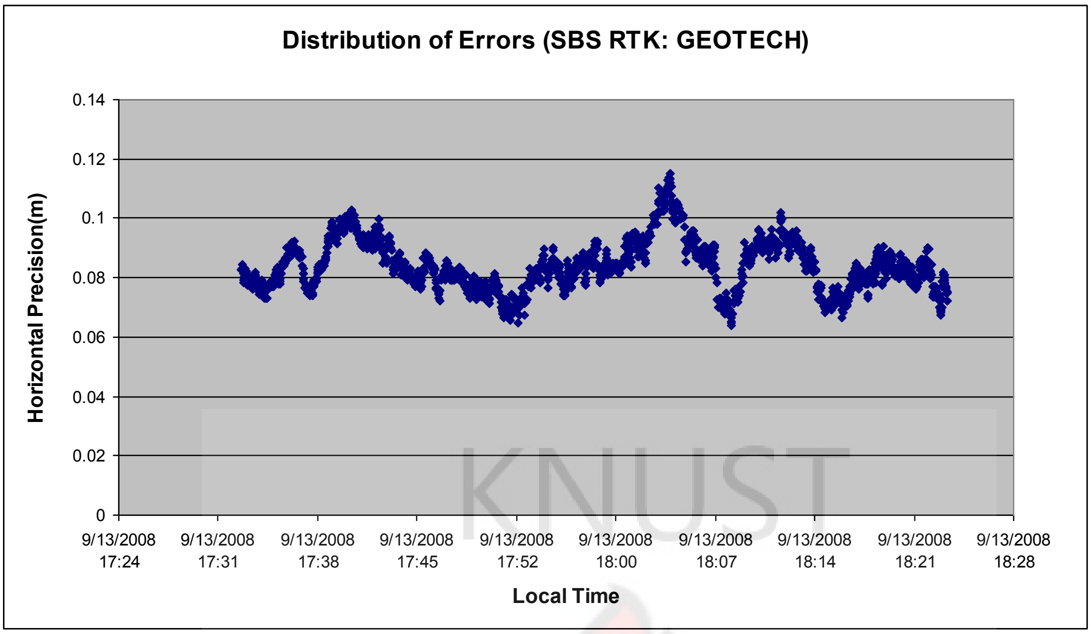


Figure 5.18 Distribution of over the period of observation (SRS: Geotech)

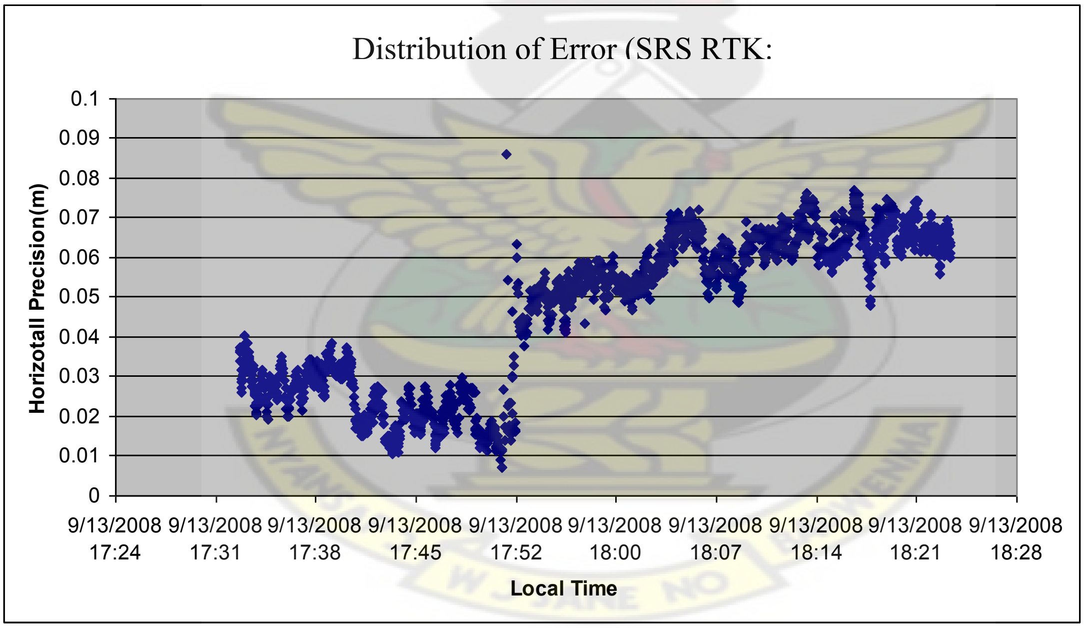


Figure 5.19 Distribution of over the period of observation (SRS: Dodowa)

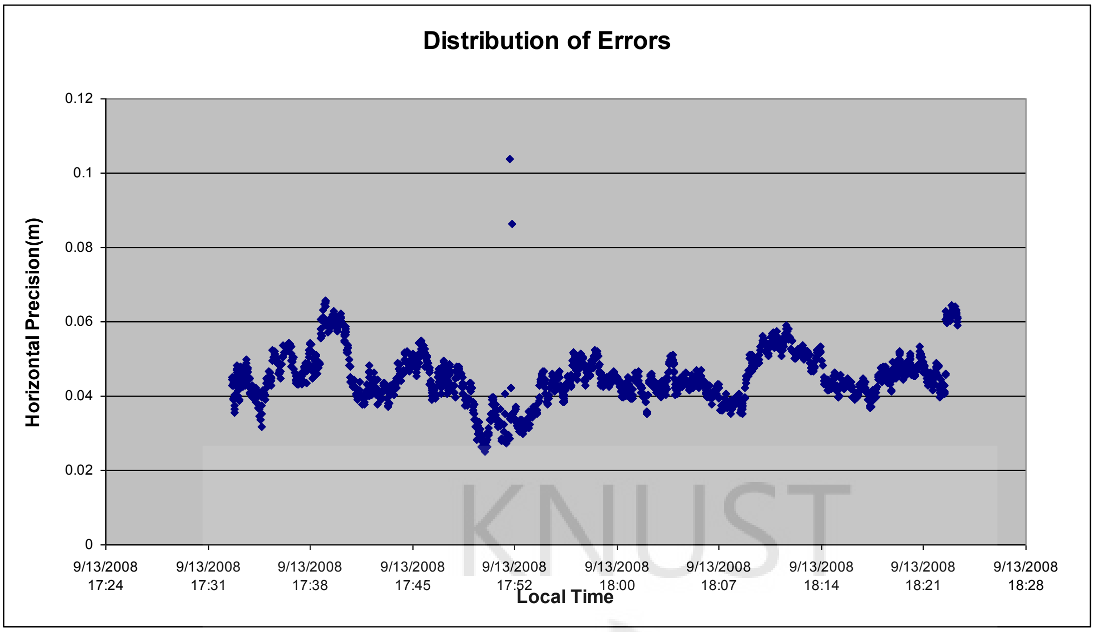


Figure 5.20 Distribution of over the period of observation (MRS)

Figures 5.21 - 5.20 show the distribution of the combined Easting and Northing errors for the various single-reference-station methods of processing and that of the MRS method. The cumulative distribution diagrams show much improvement in the horizontal errors for the MRS method over the SRS methods. The distribution of the horizontal errors in the case of the Dodowa reference station however is much worse than any of the other two and these graphs are consistent with the other analysis done so far in relating the base length distances between the base and the rover. The magnitude of errors for 95% and 99% of the points are shown along with the cumulative distribution diagrams.

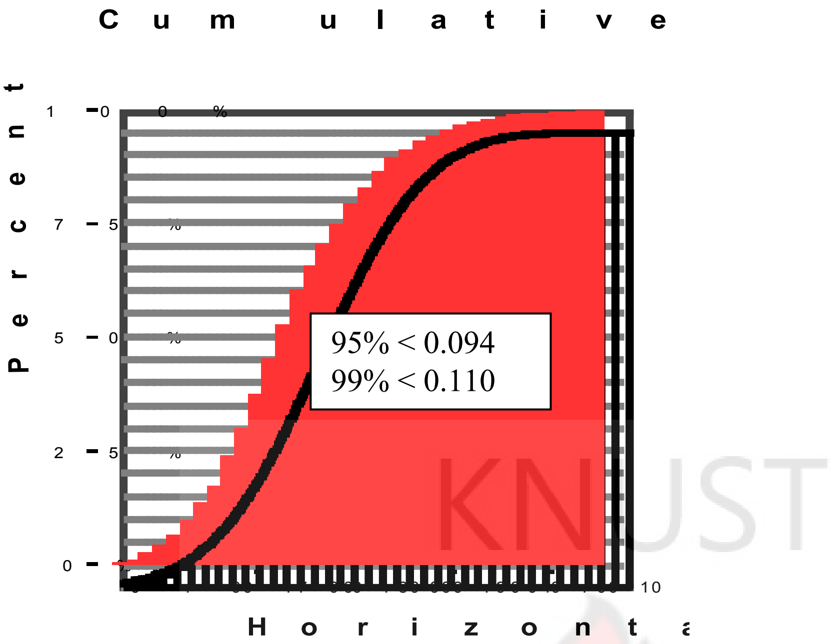


Figure 5.21 Cumulative Distribution of Horizontal Error (Geotech)

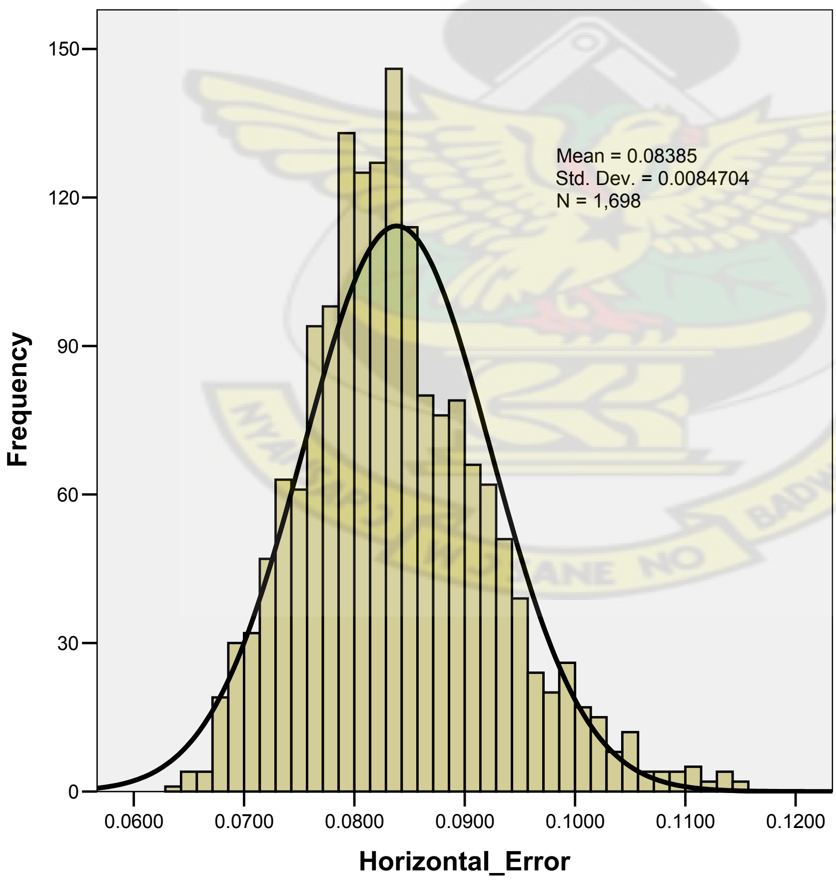


Figure 5.22 Histogram Distribution of Horizontal Error (Geotech)

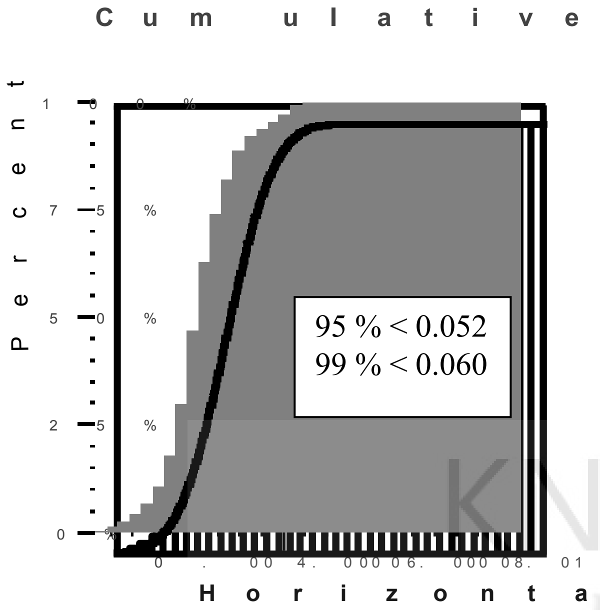


Figure 5.23 Cumulative Distribution of Horizontal Error (MRS)

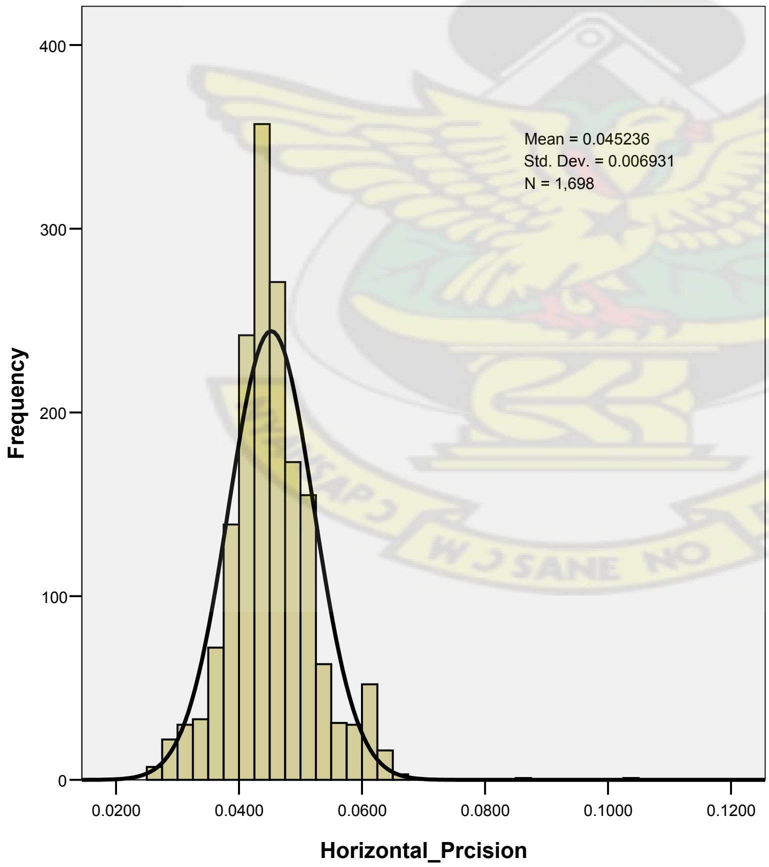


Figure 5.24 Histogram Distribution of Horizontal Error (MRS)

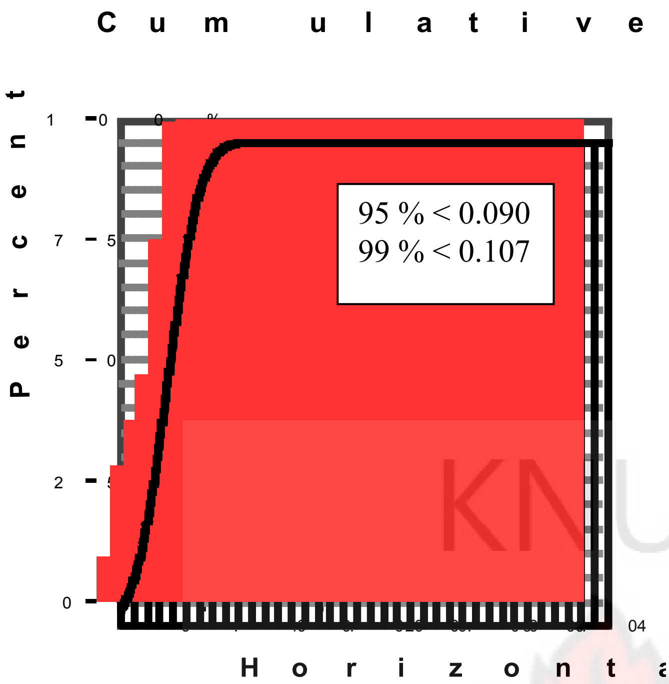


Figure 5.25 Cumulative Distribution of Horizontal Error (Dodowa)

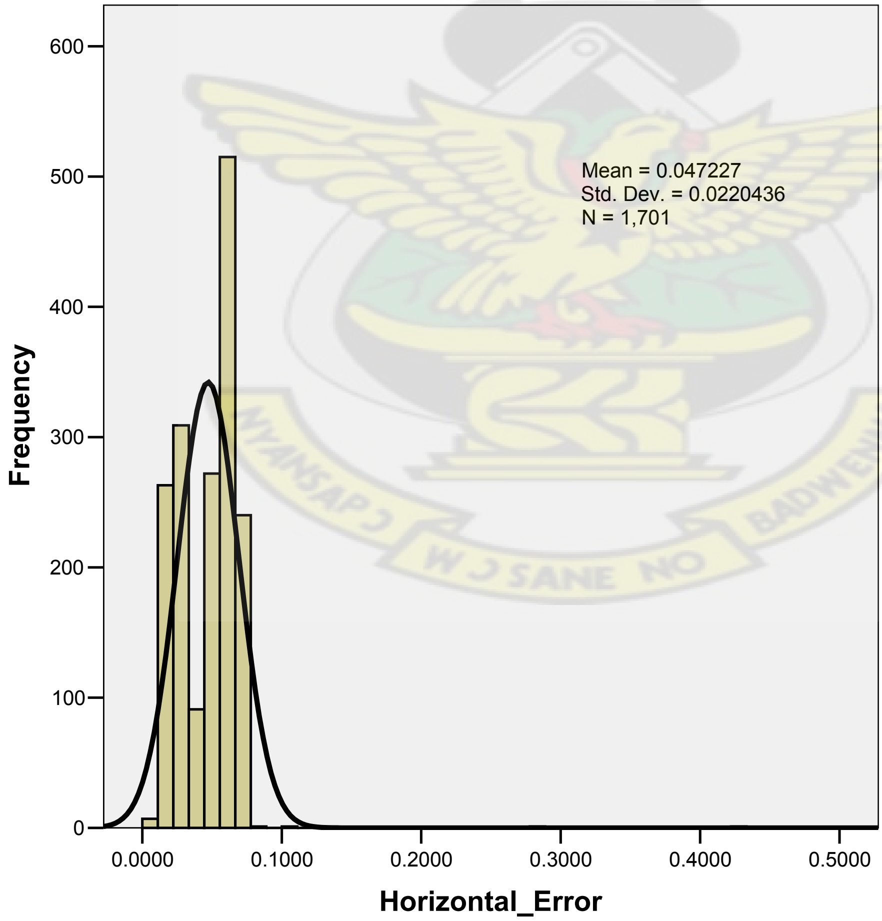


Figure 5.26 Histogram Distribution of Horizontal Error (Dodowa)

5.3 DISCUSSION

From the results obtained after the processing of the observation, the following accuracies were computed based on the following formulae (Seeber, 1993)

$$CEP = 0.59(\sigma_x + \sigma_y)$$

$$DRMS = \sqrt{\sigma_x^2 + \sigma_y^2}$$

$$CEP_{95} = CEP * 2.08$$

where CEP is the Circular Error Probable. It defines the radius of a circle, centred at the true position containing 50% of the estimated positions.

CEP_{95} is the Circular Error Probable. It defines the radius of a circle, centred at the true position containing 95% of the estimated positions.

DRMS is the Distance Root Mean Square

σ_x is the standard deviation in the easting

σ_y is the standard deviation in the northing

The following tables Table 5.11 and Table 5.12 summarizes the above mentioned accuracy measures for the two rover test locations.

	CEP	CEP_{95}	DRMS
Geotech	0.01003	0.0258774	0.017839
Dodowa	0.014868	0.03835944	0.017839
MRS	0.009676	0.02496408	0.011666

Table 5.11 Error Computation for TQ

	CEP	CEP_{95}	DRMS
Geotech	0.01327	0.03424402	0.0159497
Dodowa	0.02407	0.06210576	0.0296057
MRS	0.00996	0.025700064	0.012137

Table 5.12 Error Computation for BRK

CHAPTER SIX - CONCLUSION AND RECOMMENDATIONS

6.0 CONCLUSION

The tests have shown that under normal atmospheric conditions, the network RTK give much higher accuracies than that from any other single reference station system with base-to-rover distances of more than ten kilometres. In the case of the TQ test, there were only slight improvements in the quality of the coordinates obtained, the TTFF and the number of ambiguities solved. The computed CEPs for the TQ rover position were 0.01003 and 0.009676 for the closest SRS (Geotech) and MRS respectively. In the case of the BRK test, there were significant improvements observed for the quality of the coordinates obtained. The MRS results proved to be much better than any other SRS from the closest SRS which was over twenty kilometres (20km) from the rover station. The computed CEPs were 0.01327 and 0.009967 for Geotech SRS and MRS respectively. These results hold to the network configuration and the MRS results holds for other locations in the configuration.

The fact that the experiments were done in normal field conditions shows that these RTK methods can be used in various field conditions. The accuracies obtained also show that the SRS can be used in applications as cadastral, engineering, hydrography and many other surveys. For the distances of less than ten kilometres (10km), the SRS method will be good enough to satisfy the accuracies required for such works. However, for projects that have no reference stations in the region of ten kilometres radius, the MRS will prove to be a very useful tool for achieving high accuracies.

6.1 RECOMMENDATIONS

In Ghana, the Survey Department which is in charge of all manner of surveys currently operates three reference stations located in Accra, Takoradi and Kumasi. There are other privately owned reference stations mostly used by the mining companies in the Ashanti and Western Regions of

Ghana. These are however not properly configured to for a MRS to transmit corrections to potential users. As the results from this project have shown, there are enormous benefits to be obtained by way of time and accuracy. It goes without saying that the use of a single receiver by surveyors in a MRS instead of buying a base and rover receivers will bring huge savings as such receivers cost in the region of $25,000 per unit.

There are no standards as regards field procedures for RTK and its accuracy requirements for various applications and since there are plans of publishing a new Technical Instruction for Survey, I recommend that these standards be included.

On further research I recommend that studies be conducted in the different atmospheric conditions to measure the behaviour of the two systems in these differing conditions.

Another research could also be conducted to compare the performance of the various algorithms that are currently in use in both SRS and MRS.

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