

**DEVELOPING A DIFFERENTIAL GPS (DGPS)
SERVICE IN GHANA**

By

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ABSTRACT

The prerequisite for successful execution of projects, applications, services or products reliant on surveys or geo-information, must be a uniform and reliable coordinate reference system. Provision of control points defining these reference frames by conventional methods are expensive, tedious, limited to intervisibility between beacons and the area of survey, thus reducing the effectiveness of networks at night and in poor weather conditions. Signals from Global Navigation Satellite Systems have proven to be fast, accurate and cheaper alternative to conventional methods, but performance indices for autonomous positioning are not satisfactory and as such for high precision assignments, relative or differential positioning techniques must be employed.

However, differential positioning does place additional operational demands (two GPS receivers are required with one on known point and a data link between them when DGPS is to be implemented in real-time). A base station has been established at KNUST to provide GPS logs, reference coordinates, and to disseminate differential corrections for post-processing computations. This base will serve as the second receiver required for differential operations. Using the base station, several observation sessions were conducted and processed to compute 2D transformation parameters to integrate GPS data into the National Mapping System. The parameters computed can be used within a maximum radial error of 0.58ft around campus.

Further investigations were carried-out on observation times and the solutions obtained showed that at least three hours was found to be optimum time to be spent when coordinating newly established base stations.

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CHAPTER ONE – INTRODUCTION

The prerequisite for successful execution of projects, applications, services or products dependent on surveys or geo-referencing, must be a uniform and reliable coordinate reference system. The definition and densification of coordinate reference systems hinge on points whose 2D or 3D positions are known to a high degree of accuracy. Provision of control points by conventional methods for example traversing, triangulation and/or trilateration are expensive, tedious, limited to intervisibility between beacons and the area of survey, thus reducing the effectiveness of networks in poor weather conditions and at nights. At times, works involve traversing over long distances and trespassing on public and private property endangering the lives of surveyors.

Of the several techniques used in properly establishing accurate horizontal and vertical controls, satellite positioning technologies have been proven to be fast, accurate and cheaper alternative to conventional methods (USACE, 1996). Tracking signals from Global Navigation Satellite Systems (GNSS) will help in achieving higher accuracies and overcoming numerous limitations associated with terrestrial methods. With more satellites being deployed, modernization programs on-going to improve systems against interference, additional signals for better atmospheric modelling, and receiver costs becoming cheaper, satellite positioning techniques provide brighter future for datum definition and control networks densification. These facts coupled with accuracy, speed, adaptability and flexibility in operation make space-based technologies effective tools for the acquisition of geo-information. Depending on receiver type and integration with other auxiliary equipments, GNSS has the capability to provide absolute and/or relative 3-D position, velocity and time data. It is also a positioning system with no user charges that simply requires the use of relatively low cost hardware, and is accessible to unlimited number of users anywhere on the globe with a worldwide common grid that can easily be converted to any local grid by applying basic principles in Geodesy.

With their high accuracy, global coverage, all-weather operation and usefulness at high velocities, these global utilities offer varied applications growing in areas such as aviation, maritime and land transportation, mapping and surveying, agriculture, power and telecommunications networks, and disaster warning and emergency response, et cetera. Particularly for developing countries, GNSS applications offer cost-effective solutions to pursue economic growth without compromising preservation of the environment, thus promoting sustainable development. Although GNSS – comprising the United States Global

Positioning System (GPS), Russian Global Navigation Satellite System (GLONASS), European Galileo and Satellite-Based Augmentation System (SBAS), are different but the basic principles as in their design and operation are similar. They consists of space segments, control segments and user segments (see Interface Control Documents of System Providers, GPS Almanac, 2005; GIBS, 2005; Seeber, 2003; ESA, 2002; Hofmann-Wellenhof et al., 2001; Teunissen and Kleusberg, 1998; Leick, 1995; and Parkinson, 1994).

Considering the status of the various GNSSes, the NAVSTAR GPS is the only one operating at full capacity. While GPS is indisputably the most accurate world-wide all-weather navigation system, it still can exhibit significant errors (Seeber, 2003). In order for researchers and professionals to exploit the tremendous and ever increasing potential of the GPS, there is a need for signals received from SVs to be augmented to minimise effect of these errors. Moreover, GPS observations in Ghana must be referenced to a reliable frame such as the International Terrestrial Reference Frame (ITRF) to enable smooth integration of satellite data into the National Reference Frame. The ITRF is the worldwide adopted standard frame used as basis for all geodetic and geophysical applications. The use of GPS permanent stations for a variety of applications allows, in particular, the densification and dissemination of ITRF worldwide.

1.1 Background

GPS has two levels of positioning services; the Precise Positioning Service (PPS), which has so far remained a solitary right of the U.S agencies and allied military forces, and the Standard Positioning Service (SPS) accessed by users world-wide. System accuracy is now in the 8-20 m (95%) range (U.S-DoD, 2001), since the deactivation of Selective Availability on May 1, 2000 (Press Office, 2000). GPS offers substantial navigation and positioning capabilities, but SPS does not meet many of the user requirements for accuracy, time to alarm, availability, and coverage (NTIA, 1994).

With all these technological splendour and notwithstanding current levels of maturity in GPS hardware and algorithms, accuracy levels provided by Standard Positioning Service and receivers in autonomous operation are low and unacceptable for various positioning and navigational applications. These low accuracies are as a result of factors due to GPS system design and the environment where signal is being received. There are numerous augmentation infrastructures designed to overcome or minimise the influence of random and systematic errors in GPS positioning. These include Local Area Augmentation Systems(LAAS), Virtual

Reference Stations (VRS), Network Real-Time Kinematics (RTK), Pseudolites, Wide Area Augmentation Systems (WAAS), European Geostationary Navigation Overlay System (EGNOS), Japanese Multi-functional Transport Satellite (MTSAT), Indian GPS and Geostationary Augmented Navigation (GAGAN), integrated positioning and navigation sensors (gyro, precise clocks, Inertial Navigation System (INS), digital compass); various correction algorithms (integrity monitoring, noise filtering, atmospheric modelling, code/carrier phase smoothing, multipath detection); and in the near future, integrated satellite systems (GPS, Galileo, GLONASS, Quazi-Zenith Satellite System (QZSS), and Compass).

An augmentation system with a short implementation time, most practicable and cheaper for our part of the world is via differential corrections obtained from a continuously operating reference station. The DGPS technique is to correct biases at a location with measured biases from a geodetic grade GPS receiver at a known point/location that has been independently surveyed to a very high accuracy (§ 2.11).

In this research, a reference station has been established taking into consideration site characteristics, hardware and software components for effective logging, archiving and computation of differential corrections for disseminations. Numerous observation sessions were conducted to compute 2D transformation parameters and analyse the effects of observation time on computed solutions. Finally a website have been designed and published to distribute GPS observational logs to prospective clients.

1.2 State of DGPS in Ghana

The Survey Department of Ghana is the sole mapping agency and is responsible for planning, supervision and execution of all surveys carried out in the country. The Department also defines and provides access to a consistent national coordinate system to which all mapping, navigation, boundary demarcation, deformation measurements, and other geographic information (GI) can be referenced.

The Survey Department conducts surveys and provides accurate and reliable geographic information services through efficient utilization of appropriate technology for exploration and exploitation of natural resources. These technologies include Photogrammetry, Remote Sensing, Lithography, Geographic Information Systems and GPS. The Global Positioning Systems (GPS) technology was incorporated into its operations over a dozen years ago. GPS

usage was at first for provision of geodetic controls until tests were conducted to prove that it was viable for cadastral surveys and GI data capture (www.survey.gov.gh/ accessed on Jan, 2007).

The GPS positioning methods widely used at the public level are conventional and rapid static, with few private organizations (especially the mines) utilizing kinematic methods. In all these instances, relative mode of operation where two or more receivers are used simultaneously with one being held fixed on a known location serving as base station is employed.

The system has now been widely accepted and it is being used by almost all surveyors. But the fundamental survey principle of working from whole to part is often overlooked since there are no control points in the WGS 84/ITRF at project sites. At times surveys are carried out at the local area before they are later reintegrated into national mapping system with no proper checks. There are few mines operating base stations but data is classified for private use and also their coordinate systems have been deliberately oriented from the national one for security purposes. To gain access to these data, a lot of bureaucratic procedures are required.

Summing these up, GPS has come to stay but standards and regulations as to its usage are not strictly adhered to especially transformation of GPS processed coordinates to the National mapping system, as Fosu (2002) identified. The provision of this DGPS service will ensure the reduction in the initial capital needed for the acquisition of GPS receivers and the transformation parameters derived would assist in integrating satellite data into the national system.

1.3 Study Objectives

The project aims at setting-up a continuous operating reference station and developing a system that will support single GPS receiver operation for precise positioning and navigational assignments. This study has the following objectives:

- Establishing a reference station for GPS tracking, archiving and data processing
- Providing Dual frequency data in RINEX format for post-processing
- Providing reference coordinates for GPS observations and Densification of the ITRF at a more regional level
- Facilitating and Integrating the connection of pre-existing networks

The following approach was adopted in order to achieve the above stated objectives:

- ❖ Review of relevant documents on Satellite Surveying, GNSS, Augmentations, DGPS etc.
- ❖ Study the Architecture, Operations and Maintenance of GPS Base stations
- ❖ Review reference manuals, manuscripts, software user guide and computer codes associated with equipments and internet applications
- ❖ Set-up Base Station
- ❖ Conduct field campaigns
- ❖ Process data and compute solutions

1.4 Thesis Outline

This report is organised in six chapters. This chapter introduces the need for reference frames and the advantages of satellite positioning techniques over conventional methods in their definition and densification. The research problem, state of DGPS in Ghana and study objectives is also outlined in Chapter One.

Chapter Two provides an overview of Global Navigation Satellite Systems (GNSS), their error sources, why GPS signals are used, the need to augment these signals and the concept of DGPS techniques, dissemination of corrections and service applications.

Chapter Three takes a look at the base station, the basic considerations in its set-up, how data will be handled and the tests with adjustments carried out to coordinate the antenna position.

Chapter Four delves into all observations and data used, processing software, the data processing and solutions attained. Chapter Five continues with analysis and discussions of results and findings through statistical comparisons and graphical displays.

Chapter Six contains a summary of findings made on a chapter by chapter basis, the conclusions drawn and ends by giving some recommendations for future work.

CHAPTER TWO – GNSS, AUGMENTATIONS and DIFFERENTIAL GPS

Global Navigation Satellite Systems (GNSS) is a term used to describe all forms of satellite based navigation systems and encompasses all satellite radio-navigation systems that provide global coverage and signals that provide navigation, positioning, surveillance and timing information for ground, marine, aviation and space applications.

GNSS is composed of two operational space satellite systems, the US Global Positioning System (NAVSTAR GPS), the Russian GLONASS and the upcoming European Global Satellite Navigation System – Galileo, which will be operational from 2010 (ESA, 2002). It also includes the various regional augmentation systems; Wide Area Augmentation System (WAAS) of the Federal Aviation Administration (FAA) – USA, The European Geostationary Navigation Overlay System (EGNOS), Japanese Multi-functional Transport Satellite (MTSAT) and Indian GPS and Geostationary Augmented Navigation (GAGAN). Aside these, the Japanese Quasi-Zenith Satellite System (QZSS) and Chinese Compass satellite navigation and positioning system are additional space-based navigation systems under development.

Global satellite navigation is a revolutionary enabling utility that is affecting all facets of human activities. The scope of these improvements ranges from simple, single benefits for individual users, to enormous, multifaceted benefits for nations of the world. The scale of these improvements varies from recreational to safety-of-life applications (Rasher, 2003). Depending on receiver type and tracked signals, GNSS has the capability to provide absolute and/or relative 3-D position, velocity and time data. The use of GNSS signals for these aforementioned applications at any instance depends on:

- Line-of-sight conditions between USER spacecraft and GNSS constellation
- Receiver dependant Signal-to-Noise-Ratio (SNR) threshold for acquisition and tracking of GNSS signals
- Receiver characteristic for high dynamic environment and the related Doppler frequency shift (Enderle, 2003)

2.1 Applications of GNSS

The range of applications offered by GNSS is extremely varied and the potential spin-offs immense. GNSS signals integrated with additional information layers provide applications that stretch beyond the determination of user position and time. These applications may be classified according to the following:

- Land, Sea and Air Navigation and Tracking, including waypoints as well as precise navigation, collision avoidance, cargo monitoring, vehicle tracking, search and rescue operations, etc.
- Surveying and Mapping, on land, at sea and from the air. Includes geophysical and resource surveys, GIS data capture surveys, etc. These applications require relatively higher accuracies, for positioning in both the static and kinematic mode, and generally require specialized hardware and data processing software.
- Military Applications, the military systems are generally developed to "military specifications" and a greater emphasis is placed on system reliability.
- Recreational Uses, on land, at sea and in the air.
- Other specialised uses are time transfer, attitude determination, spacecraft operations, atmospheric studies, movement of the Earth's Crust, precision agriculture, search and rescue, environmental/crisis management, etc. *Obviously such applications require specially developed systems, often with additional demanding requirements such as real-time operation, etc* (Rizos, 1999)

The status of the various GNSS, as in GPS, GLONASS and the proposed Galileo, MTSAT and Compass and their support for space-borne applications are reviewed below.

2.2 NAVSTAR GPS

The NAVSTAR Global Positioning System (GPS) is a satellite-based radio-positioning and time transfer system designed, financed, deployed, and operated by the U.S. Department of Defense. The U.S. military began work on the GPS system in 1973 building on their experience with the Transit navigation system (Parkinson, 1996). The GPS system reached full operational capability (FOC) on July 17, 1995 (Office of the Assistant Secretary of Defense, 1995). The GPS system, like all satellite-based navigation systems, is composed of three segments: the space, control and user segments as shown below:

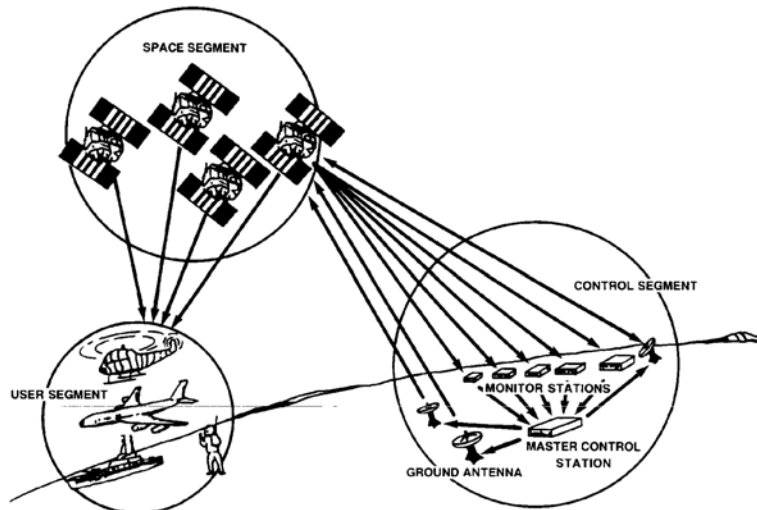


Figure 2.1: GPS Major Segments (User Equipment, 1996)

The space segment consists of a nominal constellation of around 30 functioning GPS spacecrafts inclined at 55° to the equatorial plane, and at an altitude of approximately 20,200km above the Earth with a near-circular orbital period of approximately 11hrs 58mins. The SVs are in 6 orbital planes at an angle of 60° intervals about the equator.

Currently 28 active Block II/IIA/IIR/IIR-M satellites are in operation (as at 30/08/2007) broadcasting both military and civilian signals at two frequencies – L1 (1563.42 – 1587.42MHz) and L2 (1215.6 -1239.6 MHz). A modernization program is underway to add a third safety-of-life civilian signal at 1176.45 MHz (L5), see Table 2.1. New military signals will also be added to both L1 and L2 check figure 2.2.

Table 2.1: GPS Modernisation Activities (Lachapelle and Ryan, 2001)

Activity	Implementation Date
SA Set to Zero	May 2000
GPS IIR-M Enhancements • New Civil code on L2, M-Code on L1 and L2	2003-2006
GPS IIF Enhancements • New Civil code on L2, M-Code on L1 and L2, L5	2005-2010
GPS III Enhancements • New Civil code on L2, M-Code on L1 and L2, L5 • Increased power for the M Code • Future Capabilities	2010 – To Be Determined
Operational Control Segment Enhancements	2000-2008

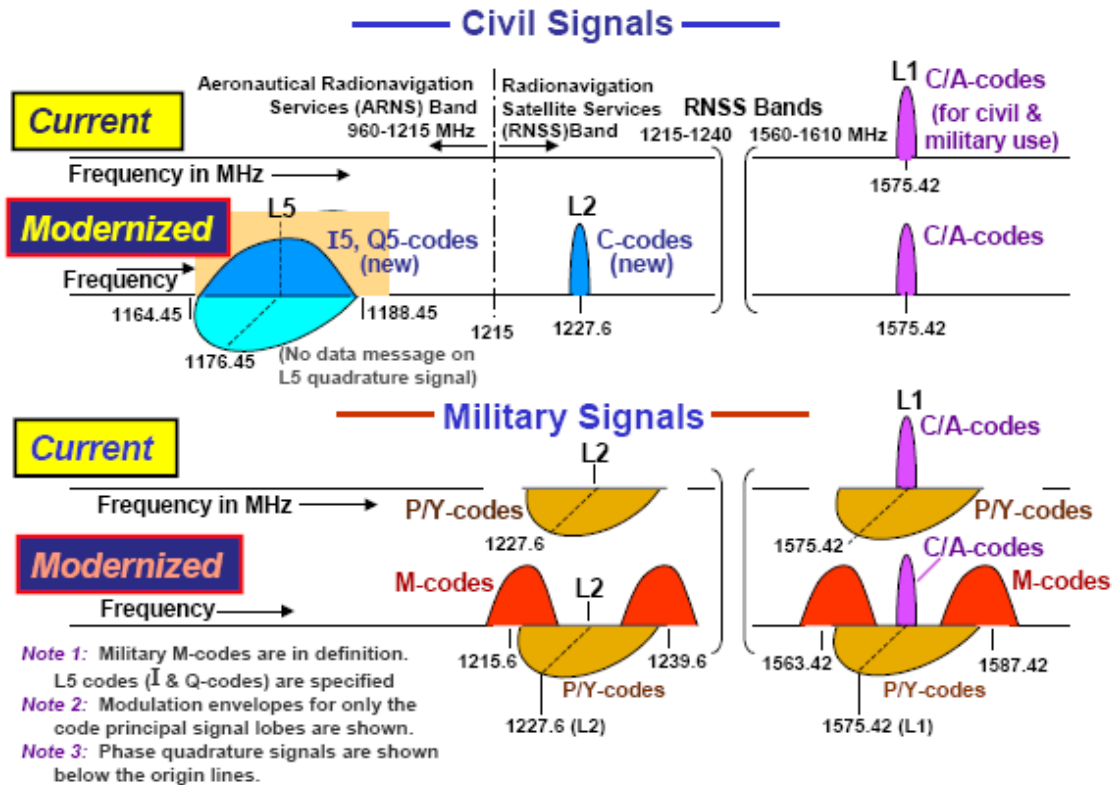


Figure 2.2: GPS Signal Evolution and Spectrum Occupancy (McDonald, 2002)

2.3 GLONASS

The Russian Global Navigation Satellite System (GLONASS) is a satellite based radio-navigation system which enables unlimited number of users to make all-weather 3D positioning, velocity measuring and timing anywhere in the world or near-Earth space, and is under the control of The Russian Space Command (GIBS, 2005).

The Russian Global Navigation Satellite System (GLONASS) is based on a constellation of active satellites which continuously transmit coded signals in two frequency bands - L1: $f_1(k) = 1602 \text{ MHz} + k * 9/16 \text{ MHz}$ and L2: $f_2(k) = 1246 \text{ MHz} + k * 7/16 \text{ MHz}$, which can be received by users anywhere on the Earth's surface to identify their position and velocity in real time based on ranging measurements. The system is a counterpart to the United States Global Positioning System (GPS) and both systems share the same principles in the data transmission and positioning methods. In 1982 the first GLONASS satellites were set into orbit, and the experimental work with GLONASS began. Over this time span, the system was tested, and different aspects were improved, including the satellites themselves (Glonass A, 1994 and Glonass B, 1993).

Fully deployed GLONASS constellation will be composed of 24 satellites in three orbital planes whose ascending nodes are 120° apart. 8 satellites are equally spaced in each plane with argument of latitude displacement 45°. The satellites operate in circular 19100-km orbits at an inclination of 64.8°, and each satellite completes the orbit in approximately 11 hours 15 minutes.

GLONASS is not fully operational yet (17 satellites are in orbit with two temporarily switched off and four undergoing decommissioning – as at 30/08/2007). Newer GLONASS-M satellites are in operation and will have higher guarantee period of service and an increase in reliability and accuracy of the system as a whole. A modernization and expansion plan is underway to put 24 satellites (for FOC) by 2011 where newer launches will include GLONASS-K satellites. These will have 10-year design life and carry a 3rd civil signal and global differential ephemeris and time corrections to enable sub-meter real-time accuracy for mobile users (<http://www.glonass-ianc.rsa.ru/>).

2.4 GALILEO

The incoming European Global Satellite Navigation System – Galileo, will be a civil operated as opposed to the other two which are all militarily administered. The idea of Galileo came up when the European Community raised concerns about committing their navigation services to GPS. Those concerns were (1) they have no control or role in GPS operation; (2) there are no assurances that GPS civil signals will be available in times of conflict involving the US and (3) Europe would like to maintain its technological competence and participate economically in the navigation satellite field (ESA, 2002).

The Galileo project is to be released in three phases, namely project definition, development and implementation. The proposed system will consist of three components namely the space, ground and user components. The space segment of Galileo is intended to consist of a total 30 Medium Earth Orbiting (MEO) satellites configured as WALKER constellation (27/3/1) + 3 active spares, which means 27 satellites in three Medium Earth Orbit planes with 1 active spare satellite per orbit plane. The altitude is 23616 km, and the inclination is 56°. The period for one orbit revolution is 14 hours 4 minutes. The ground track will repeat each 10 days. The available power on-board a Galileo satellite will be around 1.6kW (Enderle, 2003).

Galileo will also offer a guarantee of service to users who are willing to pay for it (e.g. commercial service – CS, and Public Regulated Service PRS) in addition to a free signal

similar to that of GPS (Open Service - OS and Safety of Life service - SoL). The system will be available to the public in 2010 (EC, 2003). Currently two Galileo In-Orbit Validation Element (GIOVE – A & B) satellite have been launched carrying rubidium clocks, signal-generation units and a phase-array antenna of individual L-band elements. The GIOVE project is aimed at achieving the objectives of:

1. Securing the use of the frequencies allocated by ITU for the system;
2. Verifying on-board atomic clocks and navigational signal generators and
3. Characterizing the radiation environment of the medium-Earth orbit (MEO) for the planned constellations (ESA, 2002).

2.5 Regional GNSS – JRANS

The Japanese Regional Navigation Satellite System (JRANS) concept was conceived in September 2000 to develop a stand-alone GPS-compatible system capable of independently satisfying position, velocity and time requirements for an improved coverage in Japan and throughout the Asian region (Takahashi, 2004). The project will be owned by the Japanese government, but a cooperative government-industry arrangement is being considered in order to accommodate responsibilities for assuring GNSS services while offsetting government spending by taking advantage of commercial investments.

The proposed JRANS program is a two-phase build-up of 3 quasi-zenith satellites, with possible future expansion to a 7 quasi-zenith and geostationary orbiting satellites. Table 2.2 shows the activity schedule for the program. The JRANS concept is being designed and implemented to be:

- Fully complementary, interoperability and serve as a regional backup for GPS
- Regional coverage system capable of autonomous navigation
- Free of direct user charges
- Private sector participation and provision of commercial services

Table 2.2: Activity Schedule for JRANS

Time	Activity
June 2002	Approval to begin working on QZSS research and development.
FY 2003	Definition Phase
FY 2004	Research & Development Phase
FY 2005-2008	Engineering & Manufacturing Phase
FY 2009	1st Satellite Launch

2.6 Regional GNSS - Compass

Chinese Navigation Satellite System – COMPASS is designed to conduct all-weather PNT and communications using short messages by radiobeacons onboard its SVs. The BeiDou System covers the region between Longitude 70°~140° E and Latitude 5°~55° N. The system provides positioning service with an accuracy of about 20 to 100m and a timing service with 20-nanosecond precision (Liu et al, 2006). To improve the performance, a proposition has been laid to use one Compass satellite for an augmentation service.

Currently there are four Compass satellites in orbit and these were sent in space on Oct. 31, 2000, Dec. 21, 2000, May 25, 2003 and Feb 2, 2007 respectively. Based on its communication link, atmospheric delay and ephemeris corrections can be uploaded and broadcast to serve as an augmentation to other systems in addition to its core navigation functions. There is now a proposition to build a complete global system of 30 satellites with better positioning accuracy of 10 meters, a time of 50 ns precision and an authorized service to provide a more secure location, integrity of information and communication services.

2.7 Satellite-Based Augmentation Systems (SBAS)

They are all made up of geostationary satellites and are used to transmit real time integrity information as well as a GNSS ranging signal. The SBAS systems use the following satellites:

Table 2.3: SBAS Satellites (GPS Almanac, 2007)

SBAS	SATELLITE	ORBIT LONGITUDE	PRN NO.
EGNOS	Inmarsat-3-F2/AOR-E	15.5 ⁰ W	120
	Artemis	21.5 ⁰ E	124
	Inmarsat-3-F1/IOR-W	25 ⁰ E	126
GAGAN	Inmarsat-4-F1/IOR	64 ⁰ E	127
MSAS	MTSAT-1R	140 ⁰ E	129
	MTSAT-2	145 ⁰ E	137
	Inmarsat-3-F4/AOR-W	142 ⁰ W	122
	Inmarsat-3-F3/POR	178 ⁰ E	134
WAAS	Intelsat Galaxy XV	133 ⁰ W	135
	TeleSat Anik F1R	107.3 ⁰ W	138

Currently a total of nine geostationary satellites are used to augment GNSS. The effectiveness of the geostationary satellite's augmentation depends on the location of the user, since the elevation angle of a geostationary satellite is a function of the user's latitude and the user's longitude in relation to the satellite.

The European Geostationary Navigation Overlay Service (EGNOS) provides satellite based augmentation services in Europe. The Wide Area Augmentation System (WAAS) provides essentially the same services over the United States, as does the Multifunction Satellite Augmentation System (MSAS) for the Japan area. Another system is the Indian GPS and Geostationary Augmented Navigation (GAGAN). These Systems use a network of terrestrial monitoring stations to measure the ranging performance of navigation satellite transmissions, which are relayed to central processing facilities. Here, measurements are gathered, checked for integrity, and corrections generated. They are uploaded to these geostationary satellites then relay the data to users over a GPS-like ranging signal. These augmentation systems provide improve navigation accuracy and transmit Integrity messages to users should satellite signals deviate from predefined operational norms. By our location (thus Ghana being close to the equator) all footprints of the SBAS/WAAS pass here.

2.8 GNSS Error Sources

Global Navigation Satellite Systems have been playing increasing roles in surveying, geodesy, navigation and other position/location sensitive disciplines. However, these space-borne systems' accuracy, availability and reliability are subjected to numerous biases or errors. Aside these biases GNSS's are subjected to various limitations and these include:

- Interoperability
- Signal attenuation or jamming
- Geometric heights as compared to physical heights
- Satellites Geometric (Rizos, 1999)

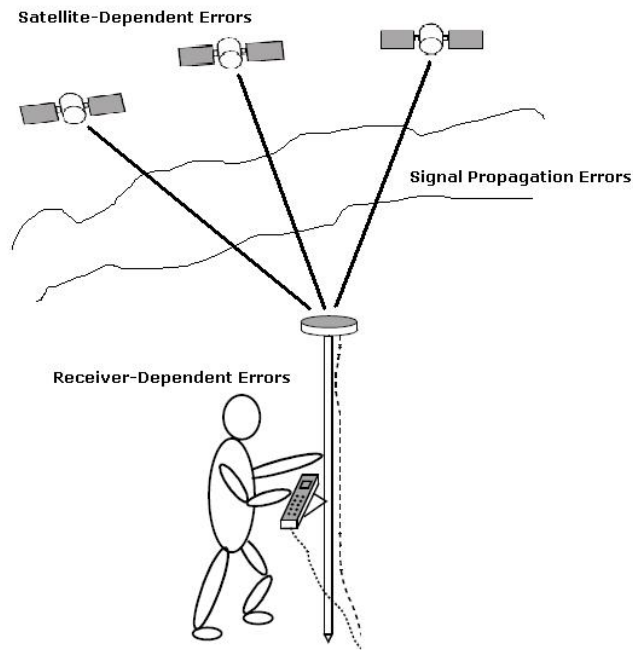


Figure 2.3: GPS Error Sources

In general, the biases/errors can be considered to belong to one of these four classes:

2.8.1 Satellite-Dependent Errors

The ephemeris information used to calculate the satellite positions is generated from the tracking data collected by monitor stations of the Control Segment. The data is processed and the satellite navigation message information is uploaded to every satellite, and made available to users at the time of observation. The *satellite orbit bias* is therefore the discrepancy between the "true" position (and velocity) of a satellite and its broadcast ephemeris. The magnitude of this discrepancy can vary from a few metres to several tens of metres. Again, on-board GNSS spacecrafts are high quality caesium or rubidium atomic clocks for time-keeping and signal synchronization, there are unavoidable clock errors which change with time due to instability.

2.8.2 Receiver-Dependent Errors

Receivers are equipped with relatively inexpensive quartz crystal oscillators. Times defined by individual receiver clocks have arbitrary origins that have to be tied to a well established time scale. The offset between the receiver clock time and GNSS system time is the *receiver clock error* that contaminates all satellite-receiver ranges made at that instant by that receiver.

2.8.3 Signal Propagation Errors

These errors are ionospheric delay and tropospheric delay. The troposphere extends from the surface of the earth to about 50 km. Signals traveling through this medium will experience a

tropospheric refraction delay. This delay is a function of elevation and the altitude of the receiver, and is dependent on the atmospheric pressure, temperature, and water vapour pressure. The bias ranges from approximately 2m for signals at the zenith to about 20m for signals at an elevation angle of 10 degrees (Brunner & Welsch, 1993). The ionosphere is the band of the atmosphere from around 50 to 1000 km above the surface of the earth. In this region, free electrons are released as a result of the gas molecules being excited by solar radiation. When GNSS signals which are electromagnetic propagate through this medium dispersion occurs, changing the velocity of the propagated signal. The *ionospheric propagation delay* of the code signals will cause the measured range to be longer than the true range. On the other hand, the delay to the carrier phase signals is negative, and hence will cause the measured phase-range to be shorter than the true range (Wells et al., 1987).

2.8.4 Multipath

The phenomenon whereby a signal is reflected or diffracted from various objects and arrives at the receiver via multiple paths (Braasch and Van Graas, 1991). An example of this effect is shown in Figure 2.3. As a result, it is highly dependent upon the conditions surrounding the receiver antenna and the type of antenna that is used. Due to the reflective property, the environment surrounding the antenna of a GPS receiver significantly affects the signal propagation by introducing noise into the measured pseudoranges and carrier phase observable (Ogonda, 2003).

The effect of Multipath on satellite signals are in two folds:

1. the direct and the reflected signal sum up together to cause the received signal to increase in amplitude and
2. multipath signals travel longer distance than direct ones causing the two C/A code correlations to displace in time resulting in distortion in the correlation peak and subsequently errors in range measurements.

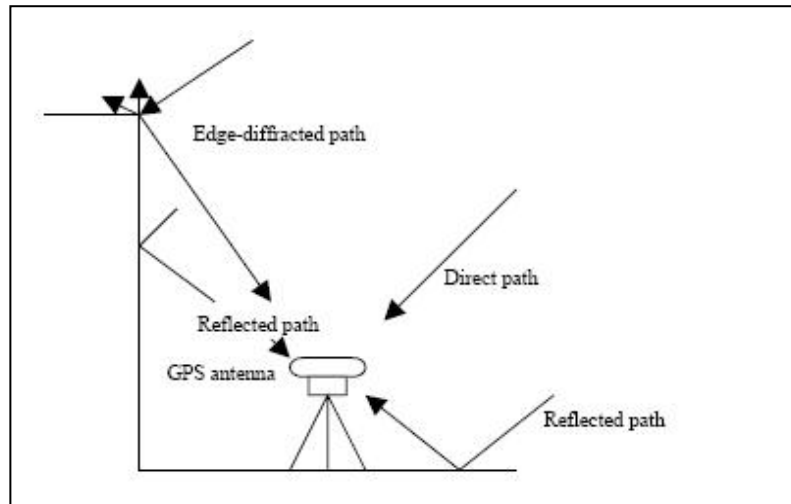


Figure 2.4: Multipath (Ogaja, 2000)

The range error resulting from residual satellite clock bias, satellite orbit bias, receiver clock error, ionospheric delay and tropospheric refraction delay can vary from a few metres to as much as 15m in single-point positioning. To overcome, reduce or correct for these errors/biases, various strategies and positioning methods must be employed. In the case of satellite clock bias, using precise ephemeris as generated by the International GPS Services is an option. For receiver clock error, the clock bias should be treated as an additional parameter in the pseudo-range navigation model. The ionospheric delay on a signal is a function of the single frequency, hence dual-frequency receiver are used to mitigate this effect. Moreover, coefficients of correction formulas are transmitted within the satellite navigation message to reduce the effect. Tropospheric effect can be accounted for by avoiding low elevation satellites and treating the residual bias as a parameter in the final position solution (Olynik, 2002 and Rizos, 1999)

On the issue of Multipath and its dependency on the antenna's environment, it cannot be eliminated by data differencing techniques and as such these measures must be adhered to:

- Sites free of reflective surfaces must be selected for antenna sites/monuments
- Use of multipath resistance quality antennas
- Use of receivers with capabilities of internally digitally filtering multipath disturbances
- Avoid low elevation satellite signals which are highly susceptible to multipath.

2.9 GPS Signals

Recalling status of the four systems, Galileo and Compass is yet to broadcast; GLONASS is not operating to full capacity (i.e. 12 satellites in operation as against nominal constellation 24

satellites). That leaves GPS which is fully operational with 30 satellites in orbit, 6 more than when the system was declared FOC in 1995. Moreover, intentional degradation has been relaxed due to Federal Policy Directive and also planned modernization programs are on-going smoothly. It is also a positioning system with no user charges that simply requires the use of relatively low cost hardware, it has precise timing system, transmits continuous real-time information that is accessible to unlimited number of users anywhere on the globe and a worldwide common grid that can easily be converted to any local grid.

2.9.1 GPS Positioning Services

GPS has two levels of positioning services; the Precise Positioning Service (PPS), which has so far remained a reserve to the U.S. government and is available only to authorized users based on internal U.S. defense requirements or international defense commitments. PPS receivers can achieve 0.2metres per second 3-D velocity accuracy depending on receiver design.

The other service - Standard Positioning Service (SPS) is a less accurate positioning and timing service which is available to all GPS users. Accuracy levels of SPS have improved from an initial of 100m in the horizontal and 156m in the vertically at 95% confidence level to 5m horizontally and 9m vertically at 2sigma after the removal of selective availability (SA).

2.9.2 GPS Observable and Positioning Modes

The two carrier signals that are transmitted give rise to three main GPS measurements namely the code, carrier phase, and Doppler measurements. Denys (2002) as shown in Table 2.4, states that five GPS observables, namely, the two carrier phase observables and the three pseudorange observables, C/A, P1 and P2, can be measured on the L1 and L2 carrier signals respectively. These observables determine the type of positioning methods available and the nominal precisions associated with these methods.

Table 2.4: GPS Observables

Carrier Signal /Observable	Measurement	Frequency Type	Wavelength
L1	Carrier Phase	1575.42 MHz	≈0.190m
	Pseudorange		≈293.0m
	Pseudorange		≈29.3m
L2	Carrier Phase	1227.60 MHz	≈0.244m
	Pseudorange		≈29.3m

2.9.2.1 Single Point Positioning (SPP)

When GPS observations made at only one particular station are used to independently derive the position coordinates of the point with respect to the reference frame WGS-84, the positioning technique is referred to as single point positioning. Quoted accuracy levels are similar to values for SPS. With the availability of precise GPS orbits and satellite clock corrections, centimeter level accuracies can be obtained (Zumberge et al., 1997, Ghoddousi-Fard and Dare, 2005). This technique uses the carrier phase measurements from both frequencies (L1 and L2), with the post mission IGS data. SPP is the most widely used positioning method in military and commercial real-time navigation and location based applications.

2.9.2.2 Relative or Differential Positioning

This requires at least two receivers set up at more than one station (with at least one location known) to collect satellite data simultaneously in order to determine coordinate differences. This method positions the receivers relative to each other and provides improved accuracies. The main disadvantage of relative positioning is that the accuracy of the determined position is dependent on the distance between the two stations, with the residual error increasing with the distance and the quality of the reference station. Relative positioning is further classified, depending on the status of the rover receiver and the period of observation as static, fast-static, kinematic or real-time kinematic (Ogonda, 2003).

From the GNSS review, it can be shown that Positioning Services available freely have performance limitations when used in autonomous mode for survey and positioning applications. Moreover, these systems offer flexibility for integration with other systems to reduce the influence of random and systematic errors and enhance the capabilities of satellite surveying.

2.10 Augmentation

The Precise Positioning Service (PPS) provides full system accuracy primarily to U.S. and allied military users, whereas the Standard Positioning Service (SPS) provides civilian and all other users throughout the world with a less accurate positioning capabilities. With all these technological splendour and notwithstanding current levels of maturity in GPS hardware and algorithms, accuracy levels provided by Standard Positioning Service and receivers in autonomous operation are low and unacceptable for various positioning and navigational

applications. These low accuracies are as a result of factors due to GPS system design and the environment where signal is being received.

With applications such as densification of controls, datum definition and others requiring higher levels of precision and accuracy, some form of correction or augmentation must be applied so as to reduce the influence of random and systematic errors on the autonomous positioning solution (Fraser et al., 2005). Research works by Qui (1993) and Olynik (2002) have shown that most errors are cumulative and spatially correlated.

In order to improve the performance of positioning service provided by SPS, various systems have been developed and others proposed to augment the performance of GPS to meet the requirements of specific users (NTIA, 1994). These systems provide additional data that are used to compensate for errors (as in satellite orbits, receiver/satellite clocks and atmospheric path delays) and enhance the capabilities of GPS. Brief descriptions of these developed stand alone augmentations or integration with other systems are given below:

2.10.1 Augmented GPS Systems

The augmentations identified include:

- 1.Low Frequency (LF)/Medium Frequency (MF) Radio beacon System — broadcasts local augmentation data from beacons in the marine radio navigation spectrum between 283.5 and 325 kHz. This system is used to cover coastal waters, inland waterways, and harbour approaches.
- 2.Wide Area Augmentation System (WAAS) - broadcasts augmentation data and a supplementary ranging signal from Geosynchronous Earth Orbit (GEO) satellites on L1 for aviation
- 3.Continuously Operating Reference Station (CORS) System — monitors GPS signals at precisely surveyed reference sites and stores the data for real-time or post-processing support of local geodetic surveying, mapping, geographic information systems (GIS), and other applications.
- 4.Inertial Navigation System (INS) — provides altitude, position, and velocity information that can be integrated with the GPS navigation solution.
- 5.Pseudolite System — broadcasts supplementary navigation signals from ground-based transmitters that imitate a GPS satellite (NTIA, 1994).

The description of a system whose technical equipments, potential for meeting user requirements and with short implementation time that will be favorable for this study is the CORS approach.

2.11 Differential GPS Concept and Technique

The idea behind all differential positioning is to correct biases on one location with measured biases at a known position. DGPS is based on the principle that receivers in the same vicinity will simultaneously experience common errors on a particular satellite ranging signal. Within the process of differential positioning, corrections are estimated by the comparison between measured pseudo-ranges and geometric ranges which are calculated from known coordinates.

Various DGPS techniques are employed depending on the accuracy desired, where the data processing is to be performed, and whether real-time results are required. If real-time results are required then a data link is mandatory between the base and rovers. For applications without a real-time requirement, the data is collected, archived and processed later. The accuracy requirements usually dictate which measurements are used and what algorithms are employed. Differential positioning techniques also require software at the reference site to track all SVs in view and form individual correction observables for each SV.

DGPS systems can be designed to serve a limited area from a single reference station, or can use a network of reference stations with special algorithms to extend the validity of the DGPS Technique over a wide area (i.e. Virtual Reference Station concept). DGPS may be implemented in real-time or post-processed mode. The range corrections method is preferred for real-time implementations because only the set of corrections for all visible satellites are to be transmitted. On the other hand, if implemented in the post-processed mode, all the raw observations made by the rover receiver would have to be written to file as well as the differential corrections computed at the base receiver.

2.11.1 Mathematical Models of Differential Corrections

In general, the rover (mobile) receivers use measurements from the reference receiver to remove the spatially correlated errors. In order to accomplish this, the DGPS positioning equations are formulated so that the common errors cancel. At an epoch, t , the geometric range from a satellite, s , to a receiver, r , is given by

$$\vec{R}_r^s(t) = \vec{X}^s - \vec{X}_r \quad - (2.1)$$

But equation 2.1, being the true range is seldom obtained since measurements are not done in absolute time frame and signals are propagated through an atmosphere full of charged particles which affects readings. In summary measurements are plagued with errors i.e. measurements cannot be made to perfection. Hence whatever is measured is the pseudorange, P, which is longer than the true range and the mathematical models as given by Wells et al., (1987) are the equations (2.2) and (2.3) below:

$$\rho(t) = \bar{R}_r^s(t) + c(\Delta t^s - \Delta t_r) + d_{ion} + d_{trop} + \varepsilon + d_{orb} \quad - (2.2)$$

where, d_{orb} is orbital error, d_{ion} is ionospheric error, d_{trop} is tropospheric error, c is speed of light, Δt^s and Δt^r are satellite and receiver clock errors and ε is receiver noise. Similarly, carrier phases are given by:

$$\Phi(t) = \bar{R}_r^s(t) + c(\Delta t^s - \Delta t_r) + \lambda N - d_{ion} + d_{trop} + \varepsilon + d_{orb} \quad - (2.3)$$

where λ is wavelength and N is integer ambiguity.

Taking note of the basic observables, differencing is done to account for correlated errors and it is carried out first between receivers, then to satellites and finally between successive epochs.

Consider these observables between two receivers, i and j , and satellite, s :

$$\rho_i^s(t) = \bar{R}_i^s(t) + c(\Delta t^s - \Delta t_i) + d_{ion} + d_{trop} + \varepsilon_i + d_{orb} \quad - (2.4)$$

and

$$\rho_j^s(t) = \bar{R}_j^s(t) + c(\Delta t^s - \Delta t_j) + d_{ion} + d_{trop} + \varepsilon_j + d_{orb} \quad - (2.5)$$

Differencing equations, 2.4 and 2.5 results in a single difference between receivers:

$$\nabla \rho_{ij}^s(t) = \rho_i^s(t) - \rho_j^s(t) = \bar{R}_{ij}^s(t) - c\Delta t_{ij} + \varepsilon_{ij}^s \quad - (2.6)$$

When a second satellite, q , is added a single difference can be formed for the second satellite below:

$$\nabla \rho_{ij}^q(t) = \rho_i^q(t) - \rho_j^q(t) = \bar{R}_{ij}^q(t) - c\Delta t_{ij} + \varepsilon_{ij}^q \quad - (2.7)$$

The single difference equations (2.6 and 2.7) can be differenced thus creating a double difference involving two receivers (i & j) and two satellite (s & q):

$$\Delta \nabla \rho_{ij}^{sq}(t) = \bar{R}_{ij}^{sq}(t) + \varepsilon_{ij}^{sq} \quad - (2.8)$$

From equation 2.8 all correlated error have been accounted for leaving receiver noises to be solved for by comparing computed coordinates with known base station positional data. Additional double difference equations can be written for other combinations of satellites in view and successive epochs, and these multiple double difference can be difference (i.e. Triple Difference) to remove integer ambiguities for carrier phases and measurement noises. Differential pseudorange corrections are computed at the base stations for onward transmissions.

Considering a measured pseudorange to be in error by a specific amount for any epoch, t , equation 2.2. At the base station, geometric ranges are computed and compared with the measured pseudorange with the difference in the two values yielding the necessary corrections, $PRC^j(t)$ (Fraser et al., 2005). The computed error at the base site, PRC , for satellite j , at reference epoch, t_0 is

$$PRC^j(t_0) = \rho(t_0) - R_r^j(t_0) \quad -(2.9)$$

At the rover, the corrected pseudorange $R_{corr}^j(t_{corr})$ is

$$R_{corr}^j(t_{corr}) = R_{rover}^j(t) + PRC^j(t) \quad -(2.10)$$

2.11.2 Differential Corrections Dissemination

Once corrections have been generated, the issue of relaying them to roving receiver(s) needs to be dealt with. Since the sources of errors are continuously changing, it is necessary to match the error correction data from the base station very closely in time to the rover data. One way of doing this is to record the data at the base station and at the rover. The data sets can be processed together at a later time. This is called post processing and is ideal for surveying applications and gives higher accuracies. The other way is to transmit the data from the base station to the rover. The error calculation is made at the rover site in real time. This process is called real-time DGPS and a data link is required.

Post Processing: is when differential correction takes place after field data collection. The GPS data collected in the field is saved, and the differential correction is added at a later date. Under this scheme, all the raw observations made by the rover receiver would have to be written to file as well as the differential corrections computed at the base receiver. Corrections are then applied by tagging the rover data to that of the base station's data on a PC with the requisite processing software. Issues that must be taken care of are: ensuring that both records have common time frame and cycle-rates have to be specified. In cases where the base station will serve a community, observational data and computed corrections must be written to files in time-block increments on the host facility. A possible installation of an electronic bulletin board service to stream data for roving users to download for remote processing must be also considered.

An important consideration for post-processed GPS schemes is data file formats. There are two file format options available for data to be post-processed. The first is the receiver-specific (proprietary) data formats, only useful if the same make of receivers are used as bases and

rovers; and the universally recognised standard format for GPS data known as the RINEX (Receiver INdependent EXchange) format. Base stations generally should make data available to users in the two formats via optical disk technology, the web site, or by email based on their request.

Real Time Processing: the correction is directly effected during the survey to afford users the desired improved accuracy at the time the equipment is being used. Alternatively, real-time processing is when signals are received from a differential provider, and used by the receiver at the same time as signals from the GPS satellite are received to calculate a much more precise position instantaneously. For real-time processing, special formats are employed. There are two predominant formats currently being employed namely NMEA-0183 and RTCM-104. NMEA-0183 (www.nmea.org) is a data format commonly employed for off shore communications between ship-borne navigation electronics. GPS receivers are capable of generating this format but do not accept it, instead radio receivers are used to decode these messages for GPS receivers. The second format, RTCM-SC104 is a protocol agreed on by the Radio Technical Commission for Maritime Services (www.rtc.org) to standardize terrestrial DGPS operation. RTCM data formats are not instrument-specific, hence Brand "X" rover receiver can apply the corrections even though they were generated by a Brand "Y" base receiver.

A summary of comments made on the two implementation types is given in Table 2.5. Ironically advantages of post-process are the disadvantages of real-time and vice-versa

Table 2.5: Comparison of Post-process against Real-time

	Post-process	Real-Time
Advantages	<ul style="list-style-type: none"> ○ No additional instrumentation (such as communications equipment) is required. ○ Quality assurance measures can be applied. ○ Control over position results. ○ Datum issues can be easily dealt with 	<ul style="list-style-type: none"> ○ No data archiving required and no post-processing is necessary. ○ Where "open service" broadcast is available, all receivers can operate independently. ○ Can take advantage of communication link to transmit other (non-positional) data to and from the base facility.
Disadvantages	<ul style="list-style-type: none"> ○ The operation requires coordination of data capture at both rover and base receivers. ○ Requires a software and trained operator to handle post-processing operations. 	<ul style="list-style-type: none"> ○ The requirements of a communication channel calls for additional receivers or auxiliary units. ○ Real-time tracking has capacity and coverage limitations and sources can be expensive ○ Quality assurance within real-time system is more difficult than in the case of data post-processing. ○ Inconsistencies in reference frames once

In order to disseminate correction information in real-time, there must be a data link between the base and remote stations. The greatest consideration for the DGPS data link is the rate of update of the range corrections and coverage. If the data rate or message latency is too great then temporal decorrelation occurs, and the benefit of the DGPS corrections is diminished. The link can be established through HF/VHF/UHF Radio Systems, Cellular (or mobile) phone network and Electronic Bulletin Board Services.

2.11.3 Telemetry

The communication link must provide a fast and reliable method for the transfer of differential corrections and should not cause any significant transmission time delays. It is also required that such a link should be available without much restriction in order to cover a wide range of users. There are several ways of transferring differential corrections for real-time applications using either direct "wired" serial, Ethernet LAN/WAN or modem connection, or wirelessly via RF or a cellular connection. The link can be established using Radio Data services utilizing subcarrier frequencies of existing FM or TV stations, TCP/IP protocols over Local/Wide Area Networks or Cellular networks (GSM or GPRS). All transmission modes have advantages as well as disadvantages but must in general be able to support real-time applications as in low data latencies, good mobile performance, inexpensive user equipment, and greater coverage. The pros and cons of the various communication links as identified by Pala et al, (2005), Hu et al, (2002) and Petrovski et al. (2001) are highlighted below.

2.11.3.1 The Internet

Among the many advantages are:

- several users can connect with any LAN/WAN or wireless system and through any Internet provider to that address and download in real time the differential corrections.
- It is possible to create a low-cost infrastructure
- No requirements for license registration/application
- There is a possibility of establishing bi-directional communication between server and a user, in which case the demands from the user will be transferred to the reference station
- users can select subsets of correction information that are of particular importance to them and will serve their purposes better

These are the identified shortfalls:

- high network latency times and sudden disconnections from the server during the survey and
- data rates can be influenced by network overload conditions.

2.11.3.2 GSM/GPRS – Wireless Cellular Technology

The advantages of this system are:

- allows bi-directional communication between a user and the data control center;
- there is no need to apply for radio frequencies, and
- reduced installation cost

These are the limitations:

- limited number of parallel users imposed on the mobile phone control center;
- Disruptions can occur when moving from cell to cell
- It is expensive because the user needs to be logged on constantly while accepting corrections

2.11.3.3 Radio Data Systems

Data communication is performed by encoding the digital signal on an analog waveform which is capable of being passed via radio modulation. This signal, called the base band modulation, is designed to provide a signal waveform that can be transmitted and received by the radio hardware.

The advantages are:

- uses existing radio service infrastructure
- allows for the use of very small low-cost radio receivers to receive and decode the RTCM message.

The disadvantages are:

- licensed registration/applications must be sought for;
- frequencies and power greatly regulate the use of RDS transmissions, thus rendering most application being device dependent
- the DGPS range is limited to that of the radio signal reception range
- radio signals in VHF and UHF frequency bands are largely limited to line-of-sight.
- one-way communication system and as such base stations are required to send all available data, which could result in data-link overloading, or define a subset that will be useful only to a particular group of user.

As it is possible to transfer data based on budgetary constraints, time frame and type of service to be provided, in all cases a custom receiver (or software) is used to assemble the data in a form that is acceptable to the GPS receiver, which by terrestrial applications standard RTCM-104 is preferred. Data conforming to this standard is then sent via the data link settled on to roving receivers. It is also desired that the links are available without much restriction in order to cover a wide range of users.

Considering the advantages and disadvantages of the three data transmission modes, streaming differential corrections over the internet has the greatest advantages with minimal limitations. With the available facilities for this project, real-time data transmission will be put on hold and greater consideration will be put on post-processing.

Greater emphasis is being placed on Post-processing because:

- Greater accuracies and reliability can be achieved with this method for surveys than with real-time DGPS which is ideal for navigation and GIS data capture
- Quality Assurance and Quality Control of post-processed results can be guaranteed
- The immediacy of real-time correction is not needed for datum definitions and control densifications which forms greater part of GPS surveys in Ghana

For the purposes of this assignment, a web site has been designed and published (see Appendix A1 and www.knust.edu.gh/ceng/dgps.php) to inform would-be users of data availability. Due to volume of space on the school's server, a day's data will be made available online and older data archived on compact discs.

Concluding Remarks: GNSSes are satellite-based radio navigation system available continuously on a world-wide scale and independent of meteorological conditions providing precise three-dimensional position, navigation, and time information to suitably equipped users. From the review, Galileo and Compass is yet to broadcast; GLONASS is not operating to full capacity and that leaves GPS which is fully operational with 30 satellites in orbit, 6 more than when the system was declared FOC in 1995. The positioning services available freely from GPS have performance limitations when used in autonomous mode for survey and positioning applications. To improve upon the performance some form of corrections or augmentations must be applied so as to reduce the influence of random and systematic errors on the autonomous positioning solution. An augmented system whose technical equipments, potential for meeting user requirements and with short implementation time that will be favorable and adopted for this study is the CORS approach based on the Differential positioning concept.

CHAPTER THREE - THE KNUST REFERENCE STATION

Accuracies attainable through unassisted Standard Positioning Service (SPS) and autonomous operation of GPS are sufficient for most applications such as navigation, GIS and recreation, but a whole range of studies and experiences has shown that sub-metric accuracies can be attained through performance of GPS surveys using enhanced satellite systems, improved equipment and streamlined field procedures (Ogonda, 2003).

In order to achieve positional accuracies to the sub-metric levels or better, relative positioning technique is employed. Relative positioning processes may be performed either in real-time or in a post-processed mode for the computations of unknown coordinates. Continuously Operating Reference Station (CORS) plays a fundamental and essential role in the establishment, definition, and use of a DGPS Service. Base Stations depending on their configurations, aside supplying GPS observational data needed for relative positioning, can contribute to a variety of efforts such as the generation of precise satellite ephemerides and clock correction data, meteorological studies, crustal motion and earth rotation studies.

The Department of Geomatic Engineering through the assistance of Bayerische Kommission fur die Internationale Erdmessung of the Bavarian Academy of Sciences established a base station on December 1995. The GPS receiver was a Turbo Rogue SNR-800 and was installed on top of the Architectural Studio block. The establishment of the station was aimed at:

- ❖ Serving as a GPS reference station for Ghana
- ❖ Establishing a National Geodetic Reference Frame using GPS techniques
- ❖ Investigation of the Geodynamic phenomenon at Keta (Ehrnsperger and Fosu, 1996)

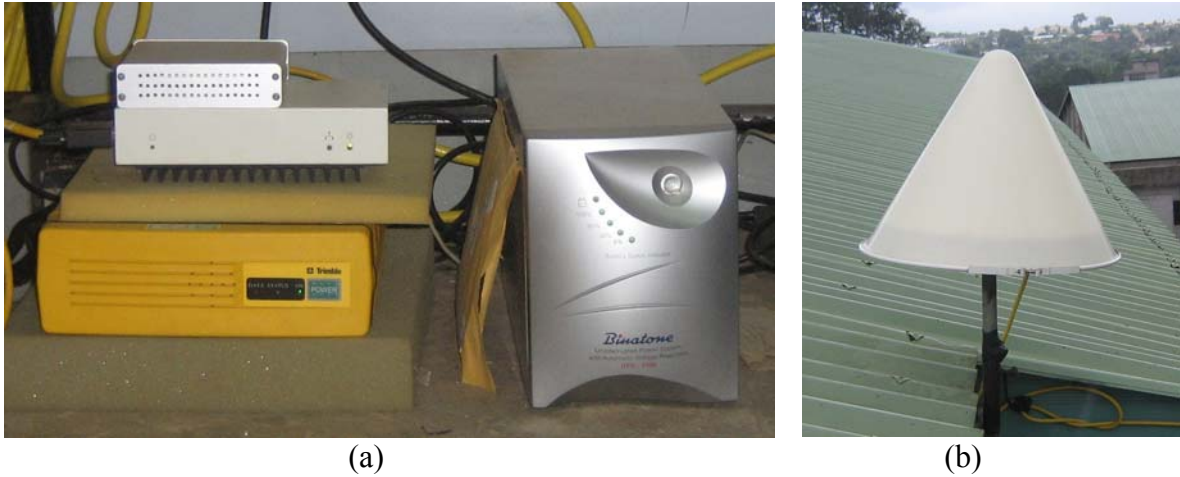
Transmission of data started from the month of March 1996. In its initial test phase, data were offloaded from the receiver and copied on diskettes and sent by post to Germany. Later on email attachments were used in sending logged files through the University Library. The station run smoothly for over nine months until the wooden tripod got broken and was re-fixed precisely on 23rd September, 1996. This new setup worked flawlessly without any severe outage until data transmission stopped due to problems with internet connectivity around the middle of 1998. The station was revived around December 1998 but got broken down again. This has necessitated the establishment of a new station to continue with the development of satellite positioning applications.

3.1 Base Station Instrumentation

Data collection, storage and transmission dictate the equipments to be used at the base station. The hardware components of the reference station are the GPS receiver, the antenna, an on-site computer, and peripheral equipment such as an uninterruptible power supply and a mechanism for connecting the facility to the outside world, such as modem and telephone line or network connection.

The receiver is the core of the base station's configuration. Its functions includes selection of satellites, acquiring signals, achieving time synchronization, performing measurements and computing navigation solutions. In order to support a wide realm of activities, the receiver must be a high quality geodetic unit capable of tracking and recording all components of the GPS signal. Ideally, a base station receiver should be able to collect P-code and C/A-code pseudo-ranges as well as L1 and L2 carrier phases (Stone, 1996). Other receiver characteristics that should be considered include data collection and latency rate, channel number, real-time output capability, interfaced with other brands and ease of remote operation. The KNUST Base Station's receiver shown in figure 3.1(a) is a 9-channel L1C/A code, L1/L2 full cycle carrier with 2 RS-232 ports and baud rates up to 38400bps Trimble 4400 receiver. The receiver's part number is 29887-11 and the serial number is 3652A18127 with a firmware of 7400MSI, Nav 2.38 and Sig 2.38. More specification can be found in its technical manual. The Antenna shown in figure 3.1 (b) is a Trimble L1/L2 Compact with a Ground Plane and Radome to protect the antenna from the effects of environmental exposure (i.e. wind, rain, sand, UV, etc). The antenna's part number is 220220-00 and the serial number is 0220079730.

In addition to the GPS receiver, an on-site computer thus a 299MHz, 128MB of RAM and an 8GB Bravo-200 PC running on Windows XP operating system have been installed with a primary function of controlling, monitoring and recording observational data. An Uninterruptible Power Supply (UPS) equipment which will provide power for smooth operation in case of power outages have been provided.



(a) Figure 3.1: Base Station Equipment (b)

3.2 Site Location

Great care was taken in selecting a site for the base station equipments, since coordinates of the antenna's phase center is used in computing corrections. In taking care of good site characteristics for GPS observation these factors were adhered to:

- A clear view of the sky
- Away from traffic and passers-by and possibility to leave the system unattended
- There is ready access to an AC power source
- There is convenient access to the college's local area network
- Site should be reached with a minimum of bureaucratic and logistical procedures
- Security of equipment

After all these issues were considered, Room A410 in the New Engineering Block is being used to house the base equipments and the antenna is mounted on top of the same building.

3.3 Reference Station Software

The Trimble Reference Station software version 1.02 ©Trimble Navigation Limited, 1999, is used to log data onto the Bravo-200 PC. The software has been installed with the single-user option, hence logged data is written to the system's hard disk for onward transmission and sharing.

3.4 Data Handling

The base station without any hindrances have been configured to collect and record GPS observation data all the time at an elevation mask of 0 degree (0°). The Trimble 4400 GPS receiver collecting data at a 5-second collection rate for a 24-hour period generates about 11

megabytes of data in an uncompressed format and 3.6MB in a zipped compressed format per day. This data is quite huge when allowed to be resident on one central unit.

Ultimately, it is the data itself that is of great importance to users or clients of the base station facilities, so data handling as in archiving and sharing have been considered carefully in maintaining and running the station. Issues including data format, distribution, and archival, as well as quality control, have all been addressed. Receiver manufacturers have designed their products to output observational logs in a proprietary format unless otherwise changed on a PC with resident reference station software. This proprietary format works very well for users combining data from receivers that are all of the same type and who are utilizing the processing software provided or recommended by the manufacturer. However, in order to facilitate the processing of data from different receiver manufacturers, the base station is configured to utilize the receiver independent exchange (RINEX) format for data distribution. RINEX is simply a well-defined universal format for GPS observation data that is independent of the brand of GPS receiver used to collect the data (Gurtner, 2001).

The data distribution and sharing mechanism being utilized by most CORS programs is an electronic bulletin board system where requests are granted online. Access to this service is through the world-wide web for clients outside the host's organization or LAN for internal subscribers. Figure 3.2 shows how GPS data sets will be sent to clients.

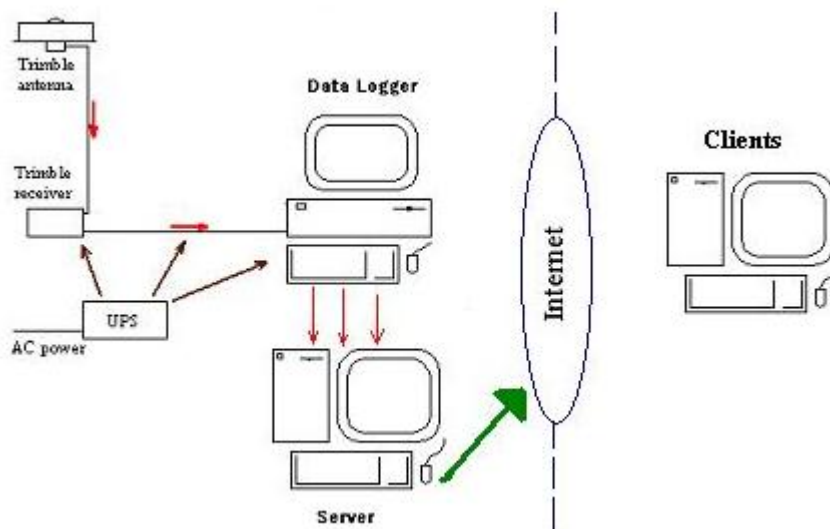


Figure 3.2: Data Flow from Base Station

Data will be made available through web file uploads; email attachments or clients will have to send their data to have them processed. After some time, the old data will be taken off-line and

burned unto compact disks. These off-line data can be accessed by users but a special request must be made to the system operator. Base station data can be accessed on this web site:

<http://www.knust.edu.gh/ceng/dgps.php> (see Appendix A1 for the web pages)

In order to ensure that high quality data are being distributed, periodic pre-processing routines will be run to analyze observation data in order to identify problems such as antenna multi-path situations, severe receiver noise or cycle-slip occurrences to alert users. Additionally, repeated inter-station baseline sessions will be conducted to monitor antenna positional stability in order to identify problems or changes with the antenna installation.

3.5 Coordinates of the Antenna Position

All computations and the resultant differential corrections are derived from the comparisons of measured pseudoranges and geometric ranges calculated from known coordinates (§ 2.11 DGPS Concept). Because of this, the coordinates of the antenna position must be precisely known in the reference system similar to that of the measured data. Coordinates of base stations are derived by either of the following:

- Averaging positional logs over a longer period of time
- Computing precise single point positions
- Least Squares Adjustment of GPS Network of baseline measurements when coordinates of one station is precisely known.

Data sent to the Canadian Precise Positioning Service for processing as Precise single point gave results in the ITRF 2000 and 2005 frame, but this reference frame differ slightly from WGS 84 and can only be considered equal at the 10cm level. The Precise Positioning Service used was Canada Spatial Reference System's online positioning service (www.geod.nrcan.gc.ca). Another positioning service, the AUSPOS Online GPS Processing Service, also gave results in ITRF 2000 but this service computes longer baselines from a network of reference stations around the unknown base station. The service can be found from the home page of Geoscience Australia (www.ga.gov.au). This option was not considered but used as a check to give an idea of the final adjusted coordinates. Again the option of averaging positional logs over long periods was ignored, since there were several outages and as such the base set-up could not operate smoothly for a considerable longer period of time.

Finally, the third option was considered since the coordinates of the pillar UST/SS 68 on top of the Architectural Studio Block is known precisely in the WGS 84 reference frame (Ehrnsperger and Fosu, 1996).

3.5.1 Measurement and Data Processing

Ten static GPS observation sessions were carried-out for the network shown in figure 3.3 with a perimeter of 475.45m. Table 3.1 gives a summary of sessions conducted and the details of receivers used are represented in Table 3.2.

Table 3.1: Sessions Conducted for Antenna Position

	Date	Julian Day	Observation time		Total Time
			From	To	
Session 1	21/04/2006	111	08:14:45.00	12:18:55.00	244 min
Session 2	24/10/2006	297	09:08:15.00	12:09:00.00	180 min.
Session 3	25/10/2006	298	09:29:50.00	11:49:30.00	139 min.
Session 4	26/10/2006	299	08:15:20.00	11:10:20.00	175 min.
Session 5	27/10/2006	300	08:14:40.00	12:29:50.00	255 min.
Session 6	30/10/2006	303	08:07:30.00	11:18:50.00	191 min.
Session 7	31/10/2006	304	08:20:10.00	11:24:40.00	184 min.
Session 8	01/11/2006	305	08:24:10.00	11:40:40.00	196 min.
Session 9	02/11/2006	306	08:41:00.00	13:11:30.00	270 min.
Session 10	03/11/2006	307	08:17:30.00	10:52:30.00	155 min.

The locations for the points occupied were at the Architectural Studio Block (point A), the N Block (point N) and the New Engineering Block (point B). The three stations formed a triangular network, that is geometrically stable and provides enough checks to allow for adjustments to be carried out on points constituting the network. The receivers were set to log raw static observational data at a rate of 10 seconds to file for post-processing.

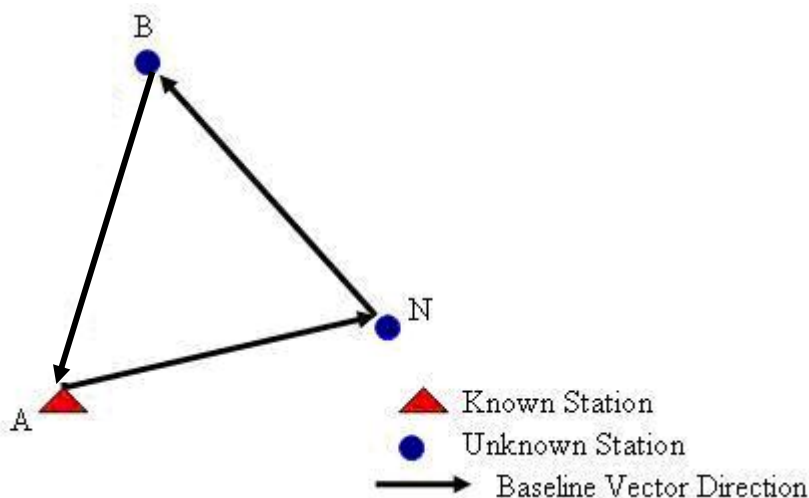


Figure 3.3: GPS Observation Network

These receivers logging GPS data simultaneous yielded three baselines for each observation session. A total of over 33 hours of data were written to file and available for processing. The logged data were post processed using Sokkia's Spectrum Survey, version 3.50 [licensed], copyright 2005, Point Incorporated (<http://www.point.com>). The coordinates of the reference station, point A, were taken from Ehrnsperger and Fosu (1996) and later confirmed by Dr. Christoff Voelksen (personal communication) from BEK, Munchen – Germany after several days of data were sent for processing. The coordinates are given below:

$$\begin{array}{ll} X = 6333145.04000\text{m} \pm 0.04 & \text{Lat} = 6^{\circ} 40' 27.6389'' \pm 0.001'' \\ Y = -172977.01000\text{m} \pm 0.04 & \text{Lon} = -1^{\circ} 33' 52.5044'' \pm 0.001'' \\ Z = 736412.30011\text{m} \pm 0.04 & \text{Hgt}_{\text{ellp}} = 311.48\text{m} \pm 0.04 \end{array}$$

Table 3.2: Receivers Used for the Network Survey

Unit	Receiver Type	Serial No.	Antenna Type	Antenna Height(cm)	Data Logger
Rover (B)	Trimble 4400	3647A17580	Compact L1/L2 w/Ground Plane + Radome	6.25	Bravo 200 Mini PC
Base (A)	Sokkia GSR2600	NUA05180001	SK 702	14.2	Compact Flash Card
Rover (N)	Sokkia GSR2600	NUA05190015	SK 702	14.2	Compact Flash Card

Precise ephemeris and clock models (<http://igsceb.jpl.nasa.gov/>) were used and an elevation cut-off of 10degrees (10°) was set for post-processing criterion. The processing results gave coordinate differences (inter-station vectors) calculated and referenced in terms of a 3D, earth-centered coordinate system utilizing X, Y, and Z values based on the WGS 84 geocentric ellipsoid model. Table 3.3 gives the baseline vectors ($\Delta X, \Delta Y, \Delta Z$), distances between stations and the covariance matrices ($d_{xx} d_{yy} d_{zz} d_{xy} d_{xz} d_{yz}$) for the ten-day observation session.

3.5.2 Least-Squares Adjustment of the GPS Network (ABNA)

There is an established fact that no measurements can be made to perfection and as such all raw data contain errors. To account for these errors, and to increase the precisions of positions determined, GPS observations for this project were made according to strict specifications defined in the USACE engineering manual (1996). The fact that errors are present in the observations makes it necessary to analyze the measurements for acceptance or rejection. Also, because redundant observations have been made, the principle of least squares can be incorporated in the adjustment procedure so that the consistencies of all measured values are guaranteed.

But before the actual least squares solution was applied in adjusting baseline vector components in the network, a pre-adjustment is done. The pre-adjustment stages help in analyzing data for internal consistency and elimination of possible blunders. For this project two pre-adjustment analysis procedures were considered and they were (1) measures of central tendency and (2) loop closures.

3.5.2.1 Measures of Central Tendency

The mean and standard deviation of each baseline components have been computed and the results shown in Table 3.4. Analysis based on data outside the range of three sigma (3σ) was conducted and the indication was that three out of ninety baseline components fell outside this range. The values were $\Delta X = -17.189$ and $\Delta Z = -41.452$ all belonging to the A – N baseline and $\Delta Y = -27.242$ for N - B baseline. These occurred on Julian day 111 and with this; results from the session conducted on this day will be treated as an outlier.

3.5.2.2 Loop Closures

The network shown in figure 3.3 is a closed loop formed by points ABNA. For such a loop the algebraic sum of the ΔX as well as ΔY and ΔZ should equal zero. These quantities are no different from latitude and departure closure conditions found in traverses with large closure values triggering alarms.

The resultant loop closures are determined by finding the square root of the sum of the squares of the closures in X, Y, & Z components for ABNA loop. These closures are denoted as cx , cy and cz , and are computed by adding the baseline components algebraically. The closure in X, Y & Z for the loop ABNA are

$$\left| \begin{array}{l} cx = \Delta X_{AN} + \Delta X_{NB} + \Delta X_{BA} \\ cy = \Delta Y_{AN} + \Delta Y_{NB} + \Delta Y_{BA} \\ cz = \Delta Z_{AN} + \Delta Z_{NB} + \Delta Z_{BA} \end{array} \right| \quad (eqn 3.1)$$

Solutions from the equations above are used in computing for the resultant closure for the loop. The resultant closure is given by the equation shown below:

$$\text{resultant closure} = \sqrt{cx^2 + cy^2 + cz^2} \quad (eqn 3.2)$$

All the computed values for resultant closures shown in Table 3.4 are less than 1cm, and this value clearly indicates a strong level of consistency in data collected. The results obtained from the two pre-adjustment analyses indicate a great measure of consistency and no possible blunder in observation sessions conducted on Julian days 297 – 300 and 303 – 307. These indications justify full-scale least squares adjustments to be run on the nine observation sessions.

Table 3.5: Resultant Loop Closure – Units (m)

10/24/2006					10/25/2006				
Baseline	ΔX	ΔY	ΔZ	Distance	Baseline	ΔX	ΔY	ΔZ	Distance
A – B	2.994	-128.258	-180.694	110.536	A - N	-17.179	-101.039	-41.442	110.55
B – N	-20.174	27.233	139.255	221.606	N - B	20.172	-27.227	-139.254	221.61
A – N	-17.18	-101.025	-41.436	143.32	A - B	2.985	-128.262	-180.696	143.317
Vector Sum	0	0	-0.003	475.462	Vector Sum	0.008	0.004	0	475.477
Resultant Closure = 0.003					Resultant Closure = 0.008944				
10/26/2006					10/27/2006				
Baseline	ΔX	ΔY	ΔZ	Distance	Baseline	ΔX	ΔY	ΔZ	Distance
A – N	-17.169	-101.028	-41.447	110.541	A - N	-17.175	-101.031	-41.44	110.542
A – B	2.99	-128.255	-180.699	221.608	N - B	20.163	-27.23	-139.25	221.604
N – B	20.156	-27.231	-139.247	143.31	A - B	2.993	-128.261	-180.689	143.313
Vector Sum	-0.003	-0.004	-0.005	475.459	Vector Sum	-0.005	0	0.001	475.459
Resultant Closure = 0.00707107					Resultant Closure = 0.005099				
10/30/2006					10/31/2006				
Baseline	ΔX	ΔY	ΔZ	Distance	Baseline	ΔX	ΔY	ΔZ	Distance
A – N	-17.174	-101.034	-41.442	110.545	A - N	-17.175	-101.022	-41.438	110.533
A – B	2.989	-128.264	-180.687	221.604	N - B	20.171	-27.23	-139.252	221.595
N – B	20.172	-27.229	-139.247	143.311	A - B	2.992	-128.254	-180.683	143.316
Vector Sum	0.009	0.001	-0.002	475.46	Vector Sum	-0.004	-0.002	0.007	475.444
Resultant Closure = 0.009274					Resultant Closure = 0.008307				
11/1/2006					11/2/2006				
Baseline	ΔX	ΔY	ΔZ	Distance	Baseline	ΔX	ΔY	ΔZ	Distance
A – N	-17.177	-101.034	-41.44	110.545	A - N	-17.174	-101.031	-41.438	110.541
A – B	2.992	-128.268	-180.691	221.61	N - B	20.177	-27.232	-139.245	221.603
N – B	20.171	-27.229	-139.257	143.32	A - B	2.998	-128.263	-180.686	143.311
Vector Sum	0.002	0.005	-0.006	475.475	Vector Sum	-0.005	0	-0.003	475.455
Resultant Closure = 0.008062					Resultant Closure = 0.005831				
11/3/2006									
Baseline	ΔX	ΔY	ΔZ	Distance					
A – N	-17.168	-101.029	-41.44	110.539					
A – B	2.998	-128.261	-180.688	221.603					
N – B	20.165	-27.236	-139.248	143.313					
Vector Sum	-0.001	-0.004	0	475.455					
Resultant Closure = 0.004123									

3.5.2.3 Full-scale Adjustment

Before the application of least squares is considered, observation equations are written that relate station coordinates to the observed coordinate differences and their residual errors. For the network shown in Figure 3.3, observation equation for each measured baseline component is given below:

(1) for baseline AB

$$X_B = X_A + \Delta X_{AB} + v_{xAB}$$

$$Y_B = Y_A + \Delta Y_{AB} + v_{yAB}$$

$$Z_B = Z_A + \Delta Z_{AB} + v_{zAB}$$

(2) for baseline AN

$$X_N = X_A + \Delta X_{NB} + v_{xAN} \quad (\text{eqn 3.3})$$

$$Y_N = Y_A + \Delta Y_{NB} + v_{yAN}$$

$$Z_N = Z_A + \Delta Z_{NB} + v_{zAN}$$

(3) for baseline NB

$$X_B = X'_N + \Delta X_{NB} + v_{xNB}$$

$$Y_B = Y'_N + \Delta Y_{NB} + v_{yNB}$$

$$Z_B = Z'_N + \Delta Z_{NB} + v_{zNB}$$

Observation equations of the form above would be written for all subsequent baselines measured on the remaining sessions. For Figure 3.3 there were a total of 3 measured baselines, so the number of observation equations that can be developed is 9. Also, the station B and N have three unknown coordinates each. For a total of 9 observation sessions, there are $81 - 6 = 75$ redundant observations in the network. The matrix form of the 81 observation equations can be expressed as:

$$AX = L + V \quad (\text{eqn 3.4})$$

Arranging the observation equations for the network and substituting the values from Table 3.2 the A, X, L and V matrices are shown on the next page. The least squares solution of unknowns, X, would be:

$$X = (A^TWA)^{-1} (A^TWL) \quad (\text{eqn 3.5})$$

In GPS relative positioning, the three measured baseline components are correlated. Therefore, a 3 x 3 covariance matrix derived for each baseline as a product of the least-squares adjustment of the carrier-phase measurements is used to weight the observations in the network adjustment in accordance with the equation below (Wolf and Ghilani, 2001):

weight matrix = inv(covariance matrix)

$$\text{Reference Standard Deviation}(S_o) = \sqrt{\frac{V^T WV}{m-n}} \quad (\text{eqn 3.6})$$

where $m = \text{number of equations}$ & $n = \text{number of unknowns}$

$$(A^TWA)^{-1} = N^{-1} = Q_{ii} \quad (\text{eqn 3.7})$$

where Q_{ii} = is the variance-covariance matrix

$$\text{Standard Deviation of Adjusted Quantities } (S_i) = S_o \sqrt{Q_{ii}} \quad (\text{eqn 3.8})$$

$$A = \begin{bmatrix}
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 \\
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 \\
\dots & & & & \\
\dots & & & & \\
\dots & & & & \\
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 & 0 \\
0 & 0 & 1 & 0 & 0 \\
0 & 0 & 0 & 1 & 0 \\
0 & 0 & 0 & 0 & 1 \\
0 & 0 & 0 & 0 & 1
\end{bmatrix}
\quad
L = \begin{bmatrix}
6333148.03460 \\
-173105.26801 \\
736231.60618 \\
6333127.86060 \\
-173078.03501 \\
736370.86118 \\
6333127.86060 \\
-173078.03501 \\
736370.86418 \\
6333148.02560 \\
-173105.27201 \\
736231.60418 \\
6333148.03360 \\
-173105.27601 \\
736231.60418 \\
6333127.86160 \\
-173078.04901 \\
736370.85818 \\
\dots \\
\dots \\
\dots \\
6333148.03860 \\
-173105.27101 \\
736231.61218 \\
6333148.03760 \\
-173105.27501 \\
736231.61218 \\
6333127.87260 \\
-173078.03901 \\
736370.86018
\end{bmatrix}
\quad
X = \begin{bmatrix}
X_B \\
Y_B \\
Z_B \\
X_N \\
Y_N \\
Z_N
\end{bmatrix}
\quad
V = \begin{bmatrix}
-0.00059317704290 \\
-0.00330555776600 \\
0.00339135585818 \\
0.00552452262491 \\
-0.00482316169655 \\
-0.00179713137913 \\
0.00552452262491 \\
-0.00482316169655 \\
-0.00479713140521 \\
0.00840682256967 \\
0.00069444222027 \\
0.00539135583676 \\
0.00040682312101 \\
0.00469444223563 \\
0.00539135583676 \\
0.00452452246100 \\
0.00917683829903 \\
0.00120286864694 \\
\dots \\
\dots \\
\dots \\
-0.00459317676723 \\
-0.00030555776902 \\
-0.00260864419397 \\
-0.00359317753464 \\
0.00369444224634 \\
-0.00260864419397 \\
-0.00647547747940 \\
-0.00082316168118 \\
-0.00079713133164
\end{bmatrix}$$

Matrix Parameters

Reference Standard Deviation computed from equation 3.6 = 0.64687473604545

Diagonal elements of variance-covariance matrix of computed quantities from equation 3.7 are:

- 7.56904530002696E-06
- 2.74009377023586E-06
- 2.36035542077179E-06
- 8.57025678314418E-06
- 2.93633722828361E-06
- 2.93433532298314E-06

The final computed coordinates of the base station's antenna position and pillar at the N-Block denoted by stations B and N in the network with its corresponding standard errors are shown in Table 3.6.

Table 3.6: Final Computed Coordinates

Reference Frame	Station B (Base Station)	Station N (N-Block Pillar)
WGS 84 (Geocentric)	X = 6,333,148.03401 (0.00178)	X = 6,333,127.86612 (0.00189)
	Y = -173,105.27132 (0.00107)	Y = -173,078.03983 (0.00111)
	Z = 736,231.60957 (0.00099)	Z = 736,370.85938 (0.00111)
WGS 84 (Geodetic)	Latitude = 6°40'21.77262" N (0.00099)	Latitude = 6°40'26.35376" N (0.00111)
	Longitude = 1°33'56.47607" W (0.00107)	Longitude = 1°33'55.60776" W (0.00111)
	Ellipsoidal height = 296.924 m (0.00178)	Ellipsoidal height = 292.343 m (0.00189)
UTM	E = 658,545.2882 m (0.00107)	E = 658,571.5455 m (0.00111)
	N = 737,799.4760 m (0.00099)	N = 737,940.2696 m (0.00111)

Concluding Remarks: In order to achieve positional accuracies to the sub-metric levels or better, relative positioning technique is employed. Within the process of relative or differential positioning, corrections are estimated by the comparison between measured pseudo-ranges and geometric ranges which are calculated from known coordinates. The known coordinates of the antenna position are provided to the system from the established base station. The results shown in Table 3.6 has been used to fix the coordinates of the base station for the computation of differential corrections for all sessions tied to the reference station.

CHAPTER 4 - GPS DATA OBSERVATIONS, PROCESSING AND RESULTS

As already mentioned in Chapter 1, the main objectives of this project were to establish Continuous Operating Reference Station for logging and archiving GPS Datasets and to develop a system that will support Single receiver operations.

To achieve these goals, the base station has been installed with a Trimble compact geodetic L1/L2 antenna with ground plane and a radome connected to a Trimble 4400 receiver and a PC running the Trimble Reference Station software. The antenna location is high enough in relation to the surrounding environment and has a good view of the sky and free from intruders.

4.1 Data Observations

The Base Station was configured and started tracking and logging GPS datasets on February 20th 2006 (i.e. 051 GPS day and 1363 GPS week). This set-up served the purpose of a reference receiver and kept tracking and logging continuously with no serious outages until April 21, 2006. Prior to this day, a series of static precise point processing were done and the results showed that, there has been a slight movement in the antenna mount. This revelation called for a new antenna monument that will be more stable and withstand harsh climatic conditions. Again, all data from this earlier set-up have been discarded and shelved. The monument was re-adjusted and shortened, this new set-up have been tracking and logging GPS datasets continuously from 09 hours UTC on April 21st (i.e. 111 GPS day and 1371 GPS week) and it is still working to date. The GPS observation sessions involving rover stations were carried out using suitable field procedures given in FGCC (1998) and USACE (1996) which take into account the accuracy requirements, satellite availability and logistical considerations during observation. A brief description of pillars visited and existing data used are given below.

4.1.1 Antenna Height Measurements

Of the various field operations performed during GPS surveys, the determination of the exact spatial relationship between antenna phase centers L1 and L2 and a designated physical point or reference mark is paramount. Proper time, care and concentration should always be devoted to achieve this important task.

The height of the reference mark for the base station was 6.5cm. The antenna heights for the Sokkia GSR2600 and Radian IS were 14.2cm and 21.7cm respectively (using reference

manuals). The true antenna height for the stations were found by adding the height of the tribrach (which in all cases was 7.7cm) to the values given above.

4.1.2 Study Area - KNUST Campus

A total of 16 points were chosen on the University Campus and these include boundary pillars and internal traverse pillars to densify controls and for setting-out construction projects. These points were specifically observed to work out a two-dimensional four transformation parameters for KNUST Campus and its surrounding suburbs. At least 20 minutes was spent on each pillar. The maximum distance between the chosen points and the Base station was 7km and the minimum was about 100m. The Table 4.1 below summarizes pillars visited and sessions conducted:

Table 4.1: Pillars on KNUST Campus

Sessions	Date	Julian Day	Pillars Observed
01	07/04/2006	097	GCGA/29/49/155 & GCGA/29/49/156
02	21/04/2006	111	UST/TP1 & UST/TP6
03	08/08/2006	220	KU6, GCGA/29/49/90 & GCGA/29/49/92
04	11/09/2006	254	GCGA/29/49/16 & GCGA/29/49/79
05	05/10/2006	278	ENG1, ENG4, GE-1-78-114, GE-1-78-134 & GE1-02-1

4.1.3 Study Area - Pillars beyond KNUST Campus

Different observation sessions were conducted on control point within the Kumasi metropolis. Table 4.2 shows pillars observed.

Table 4.2: Pillars Outside KNUST Campus

Sessions	Date	Julian Day	Pillars Observed
01	07/04/2006	097	SGA/1/72/4B, SGA/1/72/4C & CTS11
02	13/04/2007	103	SGA1/80/5 & TH-26H-07

In all instances the static positioning mode was used and an approximate time of 20 minutes was spent on each pillar with some running into several hours. Figure 4.1 gives a pictorial view of the areas where observations sessions were conducted.

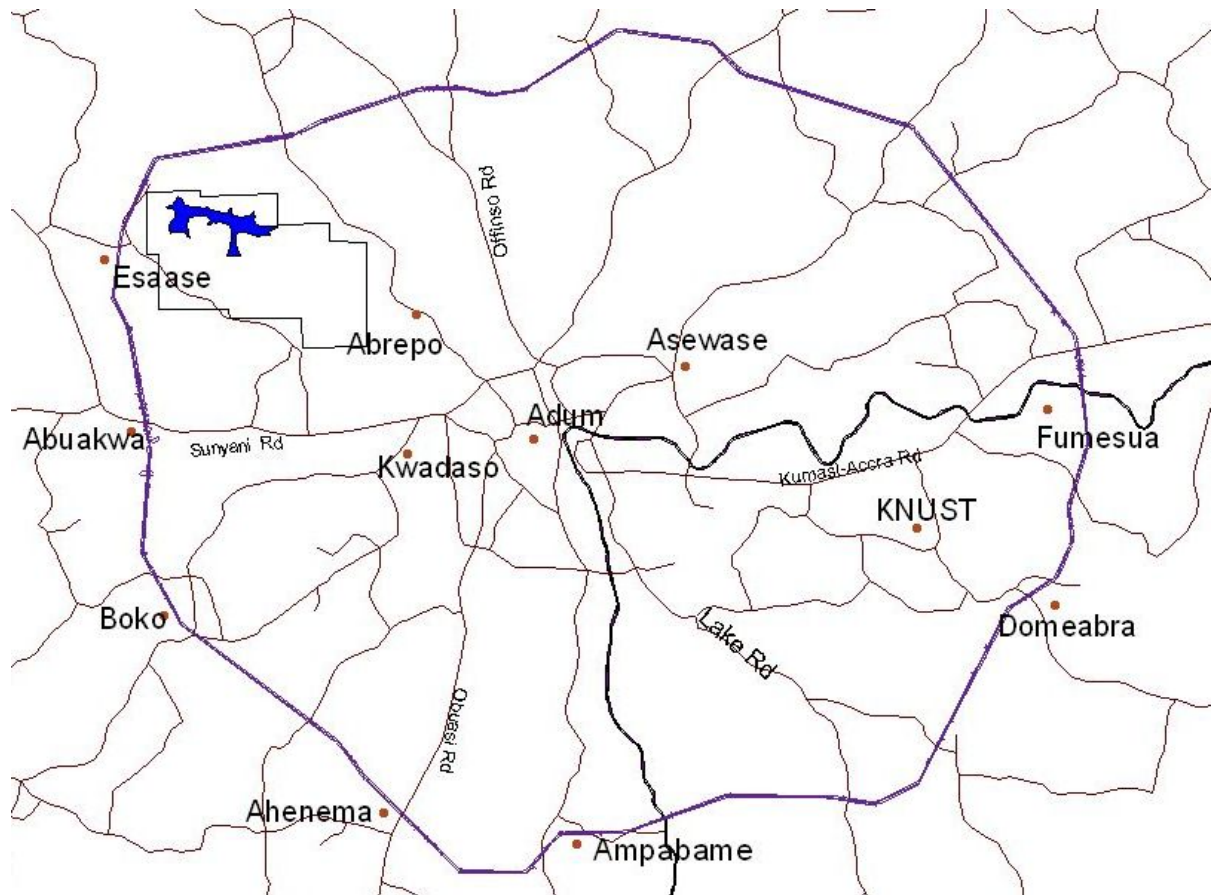


Figure 4.1: Map of Proposed Ring Road and Areas where Pillars are located

4.2. Processing Software

GPS processing software should enable pre-survey planning, data logging and downloading, data editing and processing, quality control and representation modules (e.g. output, graphics etc.) There are basically three types of GPS data processing software;

- Commercial-off-the-shelf (COTS) software developed by GPS receiver manufacturers and they normally come with the receivers as one package
- specialist software intended for specific applications and data integrations example being GIS data capture, airborne and marine operations, altitude determination, etc.
- packages and suites mainly designed by research institutes, governments or universities for specific research purposes and incorporates all real-world issues (Ogonda, 2003).

4.2.1 Trimble Reference Station (TRS)

Trimble Reference Station (TRSTM) base station software is a product of Trimble Inc. It is a powerful client-server application and can be configured to serve a single reference station as well as multiple receivers. The software allows data to be logged directly onto the system's hard disk or LAN/WAN and allows full World Wide Web and file transfer protocol (FTP)

functionalities. There is a remote access feature that can be used when higher data security and minimal human operations are required (www.trimble.com).

4.2.2 Sokkia Spectrum Survey

The Spectrum Survey software is an example of the COTS software developed by POINT, Inc. of Olathe, Kansas - U.S.A. It is a powerful, advanced survey and adjustment package for GPS and supports most raw data formats therefore accommodating mixed-brand receiver surveys. Importations of control/raw observation data into spectrum's projects are fast, convenient and accurate. Baselines are formed based on common time tags as a result of simultaneous observations for base and rover stations. The software processes L1/L2 data and reports the processed project results/output in text format (www.point.com).

4.2.3 Trimble Geomatics Office (TGO)

TGO is also part of the COTS software family developed by Trimble Navigation Ltd., Dayton, Ohio – U.S.A. It is a whole package for almost all survey tasks and uses the Weighted Ambiguity Vector Estimator (WAVE) to compute GPS vectors from field observations made using static, FastStatic, or kinematic data collection procedures. It comes with features similar to Spectrum Survey (§ 4.2.2), but output its results in an HTML format (www.trimble.com).

4.2.4 Leica GNSS QC

Leica GNSS QC is part of the COTS developed by Leica Geosystems AG, Heerbrugg, Switzerland. It's a quality monitoring software to compliment reference station software. It is a stand-alone software that can perform automatic quality checking, detailed site evaluation, receiver performance testing, multipath assessment and reporting of the logged RINEX data. It also performs RINEX data management (i.e. concatenation & decimation). Results from this application can be viewed in any text editor and information on the Leica family can be found on www.leica-geosystems.com.

4.2.5 UNAVCO TEQC

Translate Edit and Quality Check (Teqc) developed by the University NAVSTAR COnsortium is a freeware. As the name implies, TEQC quality check functionality includes complete statistics, clock offset detection, time windowing capability, decimation and concatenation of rinex files. Further information on TEQC including tutorials, software downloads and frequently asked questions can be accessed on www.unavco.org.

For this assignment the Trimble Reference Station (TRS) and Sokkia Spectrum Survey which are all COTS were used since no processing software was specifically written. Some scripts have been written in MatLAB to handle the projections and transformations of coordinates to the local system (Appendix E).

4.3 Data Processing

The GPS observations were carried out following field procedures clearly defined in FGCC, (1998) and USACE, (1996), that take into account the accuracy requirements, satellite availability and logistical considerations during observations. A prerequisite for data processing is that reference data must be accurate, precise and known in local and global reference frames, it must be held fixed through out the session and an elevation cut-off of not greater 20° should be used. The World Geodetic System 84 (DMA, 1987) reference frame was used for this project and quotations for GPS satellite orbital coordinates (ephemerides) are referred to this frame.

Office reduction procedures were conducted to generate GPS baseline solutions through an iterative process, thus observed values are compared to computed values, and an improved set of positions obtained using least-squares minimization procedures and equations modeling potential error sources. A generalized flow of the processes used in reducing GPS baselines is outlined below with its corresponding flowchart shown in figure 4.2:

1. Create New Project
2. Download/Import Raw GPS Data from Receivers/Electronic Bulletin Boards
3. Download Precise Ephemeris Data if Required
4. Make Changes and Edits to Raw GPS Data (Pre-process)
5. Set the processing style & baseline flow sequence
6. Process Baseline(s)
7. Review, Inspect, and Evaluate Adequacy of Baseline Reduction Results
8. Make Changes and Rejects
9. Reprocess Baselines and Re-evaluate Results
10. Review Loop Closures and Adjust Baseline Network

Greater emphasis must be laid on stage 4 on the generalized flow (i.e. Pre-processing). Pre-processing consists of converting proprietary receiver formats to Rinex, concatenation (and decimation if possible) of rinex files, quality checking and smoothing. Rinex smoothing and editing involves determination and elimination of cycle slips, editing gaps in information, checking station names and antenna heights. In addition, the elevation mask angle setting is also considered during this stage.

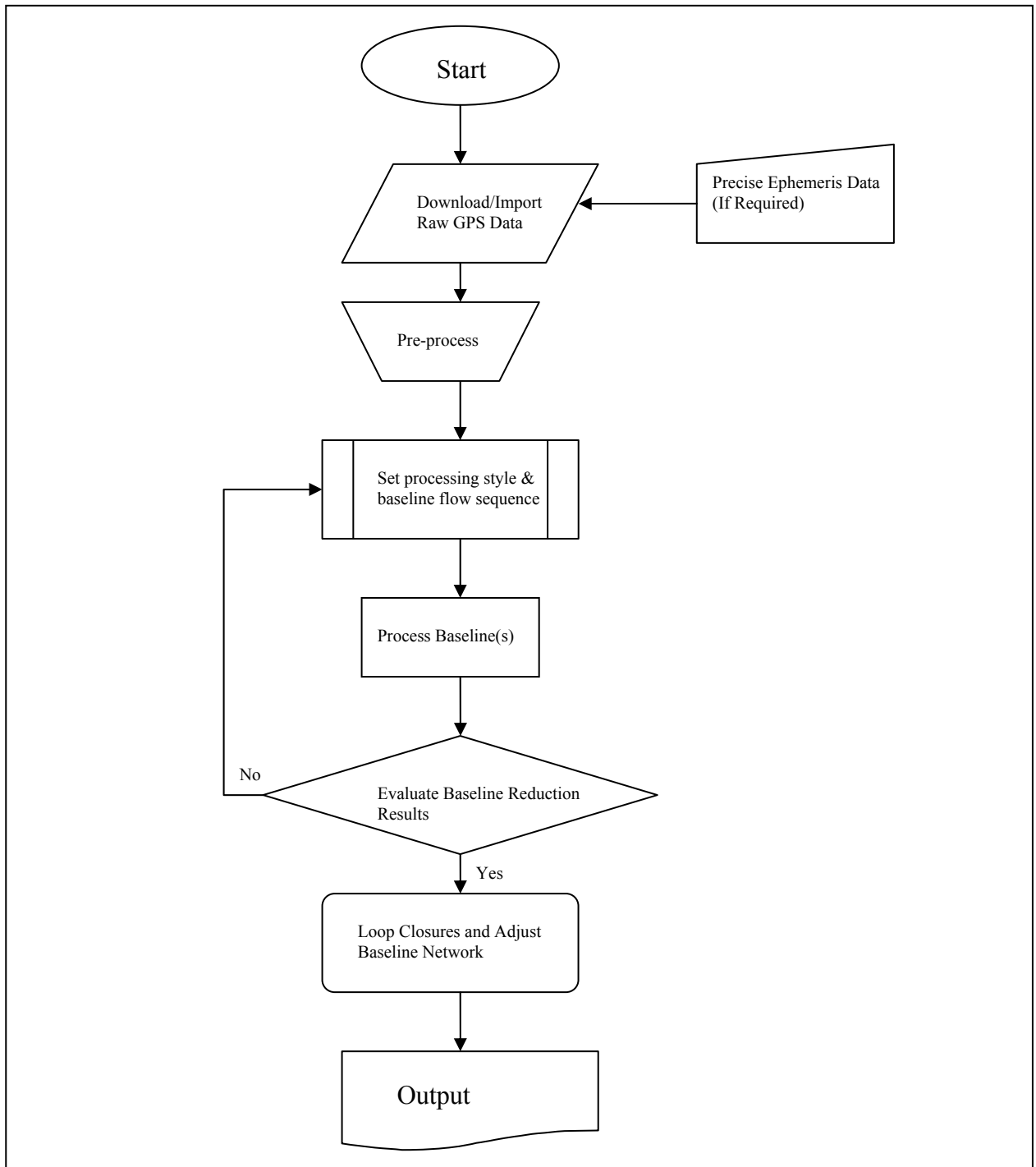


Figure 4.2: Data Processing Routine

Any satellite that was healthy and available above the 10° elevation mask was used in post processing GPS observational logs. Most final solutions were determined using double-difference carrier phase measurements, and the ionosphere-free linear combination of the L1 and L2 model (Spectrum™ and TGO™) with most ambiguities fixed and very few float solutions.

4.4 Results

The GPS code pseudorange and carrier phase data were processed in double differenced mode with ionospheric free and narrow-lane solution types. The position fixes obtained from the GPS processed reports were in the Earth-Centered Earth Fixed coordinates WGS84 reference frame and some later projected onto the Universal Transverse Mercator (UTM) mapping system. The Eastings, Northings and Heights baseline results as well as X,Y,Z in WGS84 have been tabulated below for purposes of analysis.

The antenna heights were taken to zero (i.e. measured to the bottom of the antenna mount) meaning all the positions computed are referred to the antenna phase centers. The antenna heights supplied to the software were those given by system manufacturers and embossed on the antennas.

Transformation Parameters: The objective of carrying-out this task is to come out with two-dimensional (2D) four parameter transformation values for KNUST campus. The dual frequency data logged at the various stations were then processed using the following processing criterion:

- Sokkia Spectrum Survey software was used
- An Elevation Mask of 10 degrees
- L5 narrowlane/L3 fixed Iono-free processing style
- Precise Ephemeris and SP3 Clock Model
- Processing Interval of 10 seconds
- Hopfield Tropospheric model

Table 4.3: UTM Results for Pillars on KNUST Campus

Pillar ID	Distance from Base (m)	Easting (m)	Northing (m)	Height (m)	$\sigma_{\Delta E}$	$\sigma_{\Delta N}$	$\sigma_{\Delta H}$
ENG-4	63.985	658502.093	737846.680	288.091	0.005	0.005	0.015
ENG-1	142.298	658612.098	737925.115	290.635	0.004	0.005	0.010
TP6	160.367	658602.546	737949.267	291.685	0.004	0.003	0.006
TP1	239.842	658582.179	738036.464	290.660	0.006	0.005	0.008
KU6	257.529	658429.925	738029.720	284.533	0.006	0.006	0.010
GCGA29-49-79	449.803	658773.501	737411.866	278.860	0.006	0.005	0.008
GE1-78-114	518.445	658097.968	738061.563	273.271	0.006	0.007	0.024
GE1-78-113	768.724	657823.941	738065.172	289.355	0.005	0.004	0.008
SEA3/99/14	944.024	657770.825	738339.280	289.189	0.138	0.080	0.336
GE3/04/4	988.221	657572.990	737622.792	287.909	0.004	0.005	0.011
LSGE4/03/12	1337.531	657710.077	738844.182	300.321	1.685	2.162	1.373
LSGE4/03/1	1491.850	657589.297	738944.770	304.098	0.004	0.004	0.008
GE7/99/17	1674.663	657324.638	738945.997	302.589	0.009	0.006	0.061
GE-ED4-96-3	2028.585	656548.980	737439.043	287.525	0.161	0.099	0.353
GCGA29-49-16	2106.745	658801.809	739890.545	282.635	0.006	0.005	0.018
GCSA29-49-155	6908.154	665367.934	738883.035	286.055	0.006	0.005	0.011
GCSA29-49-156	7182.027	665652.962	738830.245	278.548	0.004	0.003	0.006

Observation Times: The objective of carrying-out this task is to investigate the effects of different observation times on rover position fixes. And also to determine the optimum time that one needs to stay at a point in a given session for an accurate position. The dual frequency data logged at the various stations were then processed using the following post-processing criterion:

- Trimble Geomatics Office software was used
- Elevation Mask of 13 Degrees
- L1/L3 fixed Iono-free processing style
- Broadcast Ephemeris and Broadcast Clock Model
- Varying Observation Times (session length)
- Rinex data format
- Hopfield Tropospheric model

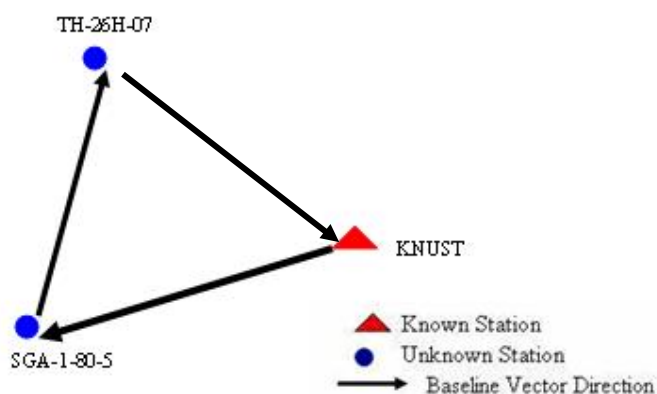


Figure 4.3: GPS Observation Network

Table 4.4: XYZ Results for Processed Baselines

BASELINE		X	Y	Z	$\sigma \Delta X$	$\sigma \Delta Y$	$\sigma \Delta Z$
FROM	TO						
KNUST-Base	SGA-1-80-5	6332762.07452	-179457.58405	738097.93526	0.00354	0.00062	0.00061
KNUST-Base	TH-26H-07	6332361.69812	-178017.83143	741884.74075	0.00450	0.00067	0.00072
SGA-1-80-5	TH-26H-07	6332361.68952	-178017.83102	741884.72959	0.00205	0.00036	0.00035
TH-26H-07	SGA-1-80-5	6332762.08310	-179457.58440	738097.94656	0.00205	0.00036	0.00035

Loop Closures: The network shown in figure 4.3 is a closed loop formed by points KTSK. Recalling section § 3.5.2.2, the algebraic sum of the ΔX as well as ΔY and ΔZ should be zero for such a loop but the answer is not always zero in a real situation.

The resultant loop closures are determined by finding the square root of the sum of the squares of the closures in X, Y, & Z components for KTSK loop. These closures are denoted as c_x , c_y and c_z , and are computed by adding the baseline components algebraically. The closure in X, Y & Z for the loop KTSK are:

$$\begin{cases} cx = \Delta X_{KS} + \Delta X_{ST} + \Delta X_{TK} \\ cy = \Delta Y_{KS} + \Delta Y_{ST} + \Delta Y_{TK} \\ cz = \Delta X_{KS} + \Delta Z_{ST} + \Delta Z_{TK} \end{cases} \quad (eqn 4.1)$$

Solutions from the equations above are used in computing for the resultant closure for the loop. The resultant closure is given by the equation shown below:

$$\text{resultant loop closure} = \sqrt{(cx^2 + cy^2 + cz^2)} \quad (eqn 4.2)$$

The computed value for resultant loop closures is shown below. These indications justify full-scale least squares adjustments to be run on the session conducted.

Table 4.5: Resultant Loop Closure

Baseline	ΔX	ΔY	ΔZ	Distance
K -- S	-385.95941	-6352.31260	1866.32576	6632.044
K -- T	-786.33581	-4912.55998	5653.13125	7530.569
S -- T	-400.38500	1439.75303	3786.79433	4070.996
	0.00860	0.00041	0.01116	Total = 18233.609
Resultant Closure = 0.014095				

The observation equations for the network shown in figure 4.3 for each measured baseline component are given below:

(1) for baseline KS

$$\begin{aligned} X_S &= X_K + \Delta X_{KS} + v_{xKS} \\ Y_S &= Y_K + \Delta Y_{KS} + v_{yKS} \\ Z_S &= Z_K + \Delta Z_{KS} + v_{zKS} \end{aligned}$$

(2) for baseline KT

$$\begin{aligned} X_T &= X_K + \Delta X_{KT} + v_{xKT} \\ Y_T &= Y_K + \Delta Y_{KT} + v_{yKT} \\ Z_T &= Z_K + \Delta Z_{KT} + v_{zKT} \end{aligned} \quad (eqn 4.3)$$

(3) for baseline ST

$$\begin{aligned} X_T &= X'_S + \Delta X_{ST} + v_{xST} \\ Y_T &= Y'_S + \Delta Y_{ST} + v_{yST} \\ Z_T &= Z'_S + \Delta Z_{ST} + v_{zST} \end{aligned}$$

(4) for baseline TS

$$\begin{aligned} X_S &= X'_T + \Delta X_{TS} + v_{xTS} \\ Y_S &= Y'_T + \Delta Y_{TS} + v_{yTS} \\ Z_S &= Z'_T + \Delta Z_{TS} + v_{zTS} \end{aligned}$$

For Figure 4.3 there were a total of 4 measured baselines, so the number of observation equations that can be developed is 12. Also, station T and S have three unknown coordinates each. For the one day observation session, there are $12 - 6 = 6$ redundant observations in the network. The matrix form of the 12 observation equations can be expressed as:

$$AX = L + V \quad (\text{eqn 4.4})$$

Arranging the observation equations for the network and substituting the values from Tables 4.4 & 4.5 the A, X, L and V matrices are given below. The least squares solution of unknowns, X, would be:

$$X = (A^TWA)^{-1} (A^TWL) \quad (\text{eqn 4.5})$$

weight matrix = inv(covariance matrix)

$$\text{Reference Standard Deviation}(S_o) = \sqrt{\frac{V^T WV}{m-n}} \quad (\text{eqn 4.6})$$

where $m = \text{number of equations}$ & $n = \text{number of unknowns}$

$$(A^TWA)^{-1} = N^{-1} = Q_{ii} \quad (\text{eqn 4.7})$$

where Q_{ii} is the variance-covariance matrix

$$\text{Standard Deviation of Adjusted Quantities}(S_i) = S_o \sqrt{Q_{ii}} \quad (\text{eqn 4.8})$$

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad L = \begin{bmatrix} 6332762.07452 \\ -179457.58405 \\ 738097.93526 \\ 6332762.08310 \\ -179457.58440 \\ 738097.94656 \\ 6332361.69812 \\ -178017.83143 \\ 741884.74075 \\ 6332361.68952 \\ -178017.83102 \\ 741884.72959 \end{bmatrix} \quad X = \begin{bmatrix} X_s \\ Y_s \\ Z_s \\ X_T \\ Y_T \\ Z_T \end{bmatrix} \quad V = \begin{bmatrix} 0.006834982 \\ -0.000412946 \\ 0.0085359274 \\ -0.001745018 \\ -0.000062946 \\ -0.002764073 \\ -0.007881839 \\ 0.0006754631 \\ -0.008758884 \\ 0.0007181615 \\ 0.0002654631 \\ 0.0024011164 \end{bmatrix}$$

Matrix Parameters

Reference Standard Deviation computed from equation 3.6 = 11.023764.

The variance-covariance matrix of computed quantities from equation 3.7 is:

$$(\text{values} * 10^{-5}) \begin{bmatrix} 0.3144776 & -0.00738120 & 0.03533054 & 0 & 0 & 0 \\ -0.00738120 & 0.00963688 & -0.0001265 & 0 & 0 & 0 \\ 0.03533054 & -0.00012659 & 0.00920524 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.34819782 & -0.00876686 & 0.03951796 \\ 0 & 0 & 0 & -0.00876686 & 0.00992026 & -0.00039404 \\ 0 & 0 & 0 & 0.03951796 & -0.00039404 & 0.00985444 \end{bmatrix}$$

Executing this script (below) in Matlab gave the eigenvalues and eigenvectors that are used in computing the semi-axes of the standard error ellipses of the two stations. The orientation of the standard error ellipse is derived from this equation:

$$\theta = \frac{1}{2} \operatorname{atan} \left(\frac{-2\sigma_{xy}}{\sigma_x^2 - \sigma_y^2} \right)$$

The semi-axes of the error ellipse are:

$$S_{major} = \sqrt{\operatorname{RefVar} * \sigma_u}$$

$$S_{minor} = \sqrt{\operatorname{RefVar} * \sigma_v}$$

```

%
% Matlab function to compute error ellipses for points
% computed given covariance matrix
%
% Input:
%   position covariance matrix
%   Reference variance
% Output:
%   EMAX   = semi-major axis of error ellipse
%   EMIN   = semi-minor axis of error ellipse
%   AZMAX  = orientation of major axis
%
load cov_var.dat
Refvar = 11.023763981;
stn1 = cov_var(1:2,1:2);
stn2 = cov_var(4:5,4:5);
%% Eigen Vectors and Eigen Values
[eigenvecs1,eigenvals1] = eig(stn1); % for 1st station (ie SGA-1-80-5)
[eigenvecs2,eigenvals2] = eig(stn2); % for 2nd station (ie TH-26H-07)
%%Orientation
angle1 = (180/pi) * 0.5 * atan((-2 * stn1(1,2))/(stn1(1,1) - stn1(2,2)));
angle2 = (180/pi) * 0.5 * atan((-2 * stn2(1,2))/(stn2(1,1) - stn2(2,2)));
%% semi-axes
EMIN1 = sqrt(Refvar * eigenvals1(1,1))
EMAX1 = sqrt(Refvar * eigenvals1(2,2))
EMIN2 = sqrt(Refvar * eigenvals2(1,1))
EMAX2 = sqrt(Refvar * eigenvals2(2,2))

```

Table 4.6: Ellipsoidal Parameters

	Station S (SGA-1-80-5)	Station T (TH-26H-07)
Semi-major axis	1.86244352625848	1.95983508076313
Semi-minor axis	0.3229019074617	0.32688782090965
Orientation	1° 23' 10.45''	1° 29' 0.82''

The final computed coordinates of the unknown stations' antenna position with their standard errors in the network (figure 4.3) are shown in Table 4.7 below.

Table 4.7: Final Computed Coordinates

Reference Frame	Station S (SGA-1-80-5)	Station T (TH-26H-07)
WGS 84 (Geocentric)	X = 6332762.081355 (0.01955)	X = 6332361.690238 (0.02057)
	Y = -179457.584463 (0.00342)	Y = -178017.830755 (0.00347)
	Z = 738097.943796 (0.00334)	Z = 741884.731991 (0.00346)
WGS 84 (Geodetic)	Latitude = 6°41'22.90342" N (0.00334)	Latitude = 6°43'27.00056" N (0.00346)
	Longitude = 1°37'23.56080" W (0.00342)	Longitude = 1°36'37.07015" W (0.00347)
	Ellipsoidal height = 306.43093 m (0.0196)	Ellipsoidal height = 310.85737 m (0.0206)
UTM	E = 652,180.3056 m (0.00342)	E = 653,597.2069 m (0.00347)
	N = 739,659.0161 m (0.00334)	N = 743,474.7805 m (0.00346)

The results of the data processing after the whole session lengths were split into smaller segments are tabulated in Tables 4.8 and 4.9 below respectively.

Table 4.8: XYZ Results for Processed Baselines for Station SGA-1-80-5

Session Length	X	Y	Z	$\sigma\Delta X$	$\sigma\Delta Y$	$\sigma\Delta Z$	Radial Error
10min	6332762.02591	-179457.56805	738097.93695	0.008754	0.002976	0.002584	0.00960
15min	6332762.11203	-179457.57572	738097.94490	0.007698	0.002647	0.002249	0.00845
20min	6332762.03318	-179457.57441	738097.93504	0.005885	0.002118	0.001706	0.00648
25min	6332761.94606	-179457.57194	738097.92450	0.004809	0.001794	0.001386	0.00532
30min	6332762.11342	-179457.57637	738097.94414	0.004402	0.001665	0.001261	0.00487
1.0 hour	6332762.02977	-179457.57738	738097.92846	0.003254	0.001353	0.000914	0.00364
1.5 hours	6332762.11352	-179457.58713	738097.93800	0.002594	0.001124	0.000773	0.00293
2.0 hours	6332762.06444	-179457.58205	738097.93316	0.006395	0.001043	0.001075	0.00657
2.5 hours	6332762.07633	-179457.58577	738097.93642	0.005775	0.000973	0.001018	0.00594
3.0 hours	6332762.07690	-179457.58425	738097.93679	0.005123	0.000875	0.000941	0.00528
3.5 hours	6332762.08157	-179457.58315	738097.93795	0.004925	0.000801	0.000884	0.00507
4.0 hours	6332762.07712	-179457.58272	738097.93619	0.004671	0.000718	0.000799	0.00479
4.5 hours	6332762.07023	-179457.58252	738097.93508	0.004500	0.000681	0.000758	0.00461
5.0 hours	6332762.06172	-179457.58351	738097.93346	0.004253	0.000677	0.000727	0.00437
5.5 hours	6332762.06232	-179457.58353	738097.93384	0.003843	0.000652	0.000671	0.00396
6.0 hours	6332762.06334	-179457.58325	738097.93458	0.003692	0.000635	0.000634	0.00380
6.5 hours	6332762.07119	-179457.58378	738097.93488	0.003593	0.000630	0.000619	0.00370

Table 4.9: XYZ Results for Processed Baselines for Station TH-26H-07

Session Length	X	Y	Z	$\sigma\Delta X$	$\sigma\Delta Y$	$\sigma\Delta Z$	Radial Error
10min	6332361.635735	-178017.844373	741884.730190	0.013176	0.005163	0.006455	0.01555
15min	6332361.634520	-178017.840652	741884.733437	0.011212	0.004134	0.005683	0.01323
20min	6332361.642349	-178017.831655	741884.747941	0.009765	0.003693	0.004337	0.01131
25min	6332361.613745	-178017.818561	741884.752569	0.007122	0.002648	0.002725	0.00807
30min	6332361.609502	-178017.818442	741884.751759	0.005951	0.002212	0.002167	0.00671
1.0 hour	6332361.636392	-178017.824114	741884.743192	0.004279	0.001712	0.001422	0.00482
1.5 hours	6332361.635710	-178017.825323	741884.736310	0.003497	0.001439	0.001101	0.00394
2.0 hours	6332361.626674	-178017.829371	741884.730310	0.008924	0.001334	0.001606	0.00916
2.5 hours	6332361.641701	-178017.830408	741884.730847	0.007763	0.001222	0.001380	0.00798
3.0 hours	6332361.681756	-178017.836142	741884.737133	0.007519	0.001230	0.001355	0.00774
3.5 hours	6332361.673196	-178017.847270	741884.740182	0.008027	0.003800	0.001584	0.00902
4.0 hours	6332361.685336	-178017.829484	741884.741245	0.008144	0.003700	0.001481	0.00907
4.5 hours	6332361.686642	-178017.826755	741884.739534	0.007475	0.003557	0.001321	0.00838
5.0 hours	6332361.674437	-178017.821496	741884.737769	0.006884	0.003339	0.001204	0.00775
5.5 hours	6332361.672008	-178017.833103	741884.735355	0.003843	0.000652	0.000671	0.00396
6.0 hours	6332361.674996	-178017.832265	741884.736014	0.003692	0.000635	0.000634	0.00380
6.5 hours	6332361.677116	-178017.832632	741884.736575	0.003593	0.000630	0.000619	0.00370

CHAPTER 5 – ANALYSES

5.1 Base Station's Status

A quality check analysis was carried out to check the status and stability of the base station. Five days data were picked randomly from the months of September, 2006 to March, 2007. None of the data used had a session length of less than 24 hours. The resulting SVs availability, PDOP values and observation times after a pre-processing have been run using Unavco's TEQC are tabulated below (see Appendix D1 for the detailed quality check report).

Table 5.1: PDOP Values for KNUST Base Station Data

Month	GPS Week & Day	Time of First Obs:	Time of Last Obs:	Session Length (Hrs)	PDOP			Average No. SVs
					Min	Max	Ave	
Sept, 06	1390, 6	02/09/2006, 00:00:00	03/09/2006, 06:13:55	30.23	2.6	9	3.7	8.1
	1391, 4	07/09/2006, 00:00:00	08/09/2006, 08:02:55	30.05	2.6	9.4	3.7	8.1
	1393, 1	18/09/2006, 18:04:45	19/09/2006, 23:59:55	29.92	2.6	6.7	3.5	8.7
	1393, 5	22/09/2006, 00:00:00	23/09/2006, 07:59:25	31.99	2.7	10.0	3.7	8.3
	1393, 6	23-09-2006, 18:05:55	24-09-2006 23:59:55	29.90	2.6	8.4	3.5	8.6
Oct, 06	1396, 1	09/10/2006, 00:00:00	09/10/2006, 23:59:55	24.00	2.7	8.4	3.7	8.3
	1397, 2	17/10/2006, 00:00:00	17/10/2006, 23:59:55	24.00	2.7	9.8	3.8	8.3
	1398, 0	22/10/2006, 00:00:00	22/10/2006, 23:59:55	24.00	2.7	9.9	3.6	8.6
	1398, 2	24/10/2006, 00:00:00	24/10/2006, 23:59:55	24.00	2.7	10.0	3.6	8.5
	1398, 5	27/10/2006, 00:00:00	27/10/2006, 23:59:55	24.00	2.7	9.9	3.7	8.3
Nov, 06	1399, 3	01/11/2006, 00:00:00	01/11/2006, 23:59:55	24.00	2.6	9.4	3.6	8.6
	1399, 4	02/11/2006, 00:00:00	02/11/2006, 23:59:55	24.00	2.6	9.2	3.6	8.6
	1399, 5	03/11/2006, 00:00:00	03/11/2006, 23:59:55	24.00	2.6	9.1	3.6	8.6
	1399, 6	04/11/2006, 00:00:00	05/11/2006, 00:29:55	24.50	2.6	6.4	3.6	8.5
	1401, 3	15/11/2006, 00:00:00	15/11/2006, 23:59:55	24.00	2.6	8.3	3.6	8.7
Dec, 06	1404, 0	03/12/2006, 00:00:00	03/12/2006, 23:59:55	24.00	2.6	8.6	3.5	8.7
	1404, 1	04/12/2006, 00:00:00	04/12/2006, 23:59:55	24.00	2.6	8.6	3.5	8.7
	1404, 3	06/12/2006, 00:00:00	06/12/2006, 23:59:55	24.00	2.6	8.5	3.5	8.7
	1405, 0	10/12/2006, 00:00:00	10/12/2006, 23:59:55	24.00	2.6	9.0	3.6	8.3
	1405, 1	11/12/2006, 00:00:00	11/12/2006, 23:59:55	24.00	2.6	8.3	3.5	8.7
Jan, 07	1408, 1	01/01/2007, 00:00:00	01/01/2007, 23:59:55	24.00	2.6	7	3.7	8.5
	1408, 2	02/01/2007, 00:00:00	02/01/2007, 23:59:55	24.00	2.6	9.1	3.7	8.5
	1408, 3	03/01/2007, 00:00:00	03/01/2007, 23:59:55	24.00	2.6	7.6	3.7	8.5
	1408, 4	04/01/2007, 00:00:00	04/01/2007, 23:59:55	24.00	2.6	7.7	3.7	8.5
	1409, 0	07/01/2007, 00:00:00	07/01/2007, 23:59:55	24.00	2.6	7.7	3.7	8.5
Feb, 06	1414, 4	15-02-2007 00:00:00	15-02-2007 23:59:55	24.00	2.6	10.1	3.5	8.8
	1414, 6	17-02-2007 00:06:15	18-02-2007 00:29:55	24.39	2.6	8.0	3.5	8.8
	1415, 1	19-02-2007 00:00:00	19-02-2007 23:59:55	24.00	2.6	9.9	3.5	8.8
	1415, 5	23-02-2007 00:00:00	23-02-2007 23:59:55	24.00	2.6	9.5	3.5	8.8
	1416, 3	28-02-2007 00:00:00	28-02-2007 23:59:55	24.00	2.6	10.1	3.5	8.8
Mar, 06	1416, 6	3-03-2007 00:00:00	3-03-2007 23:59:55	24.00	2.6	9.9	3.5	8.7
	1417, 2	6-03-2007 00:00:00	6-03-2007 23:59:55	24.00	2.6	8.0	3.5	8.7
	1417, 6	10-03-2007 00:00:00	11-03-2007 00:29:55	24.50	2.6	10.3	3.5	8.6
	1418, 4	15-03-2007 00:00:00	15-03-2007 23:55:35	23.93	2.6	10.7	3.5	8.8
	1420, 0	25-03-2007 00:00:00	25-03-2007 23:59:55	24.00	2.6	7.9	3.5	8.8

Figure 5.1 presents the plot of minimum, maximum and average PDOP values for the data selected. The highest and lowest values were recorded to be 10.7 and 2.6 respectively. Even

though the maximum values fluctuate, those for the averages and minimums stood fairly constant. These values indicate a level of stability for the base set-up.

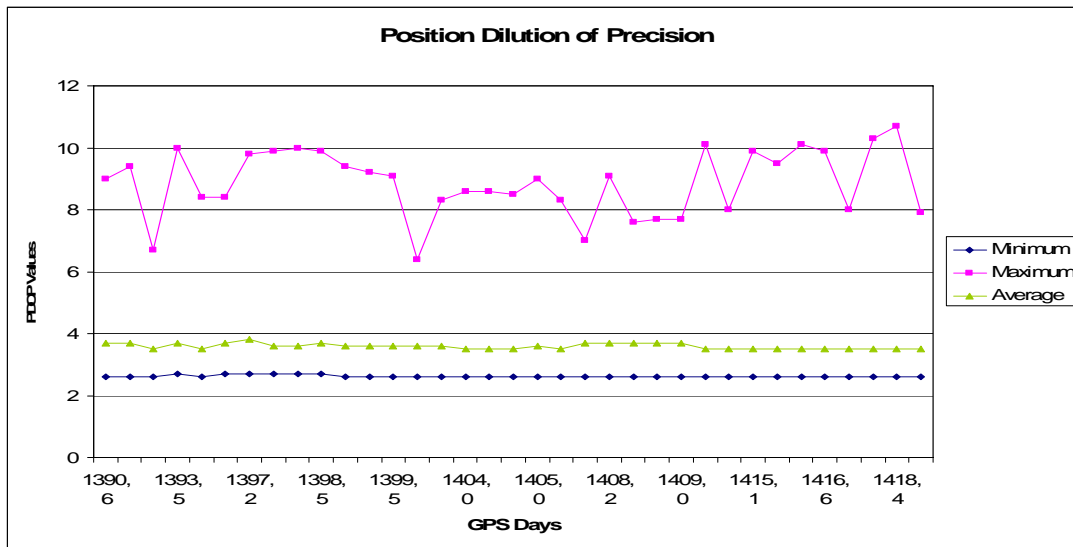


Figure 5.1: PDOP Values for Selected Base Station Data

Barring any satellite outages, GPS signals and footprints are repeated each day (as specified in ICD-GPS-200C). A series of processing were done on base files to check particular satellites that are tracked and all reports showed similar results for the number of SVs and their Pseudorandom Code Number (PRN). One of such tables is reproduced in Table 5.2.

Table 5.2: Satellites Tracked in Kumasi

Time		Satellites Above the Horizon (PRN)	Total # of SVs
From	To		
00:00	01:00	1, 7, 11, 14, 16, 19, 20, 23, 25	9
01:00	02:00	1, 11, 13, 19, 20, 23, 25	7
02:00	03:00	1, 11, 13, 17, 20, 23, 25, 27, 28	9
03:00	04:00	11, 13, 17, 19, 20, 23, 27, 28	8
04:00	05:00	4, 8, 11, 13, 17, 20, 23, 24, 27	9
05:00	06:00	4, 8, 13, 17, 20, 23, 24, 27, 28	9
06:00	07:00	2, 4, 8, 13, 17, 20, 24, 27, 28	9
07:00	08:00	2, 4, 8, 10, 17, 24, 27, 28	8
08:00	09:00	2, 4, 8, 9, 10, 17, 24, 27, 28	9
09:00	10:00	2, 4, 8, 9, 10, 17, 24, 27, 28	9
10:00	11:00	2, 4, 5, 9, 10, 17, 26, 28	8
11:00	12:00	2, 5, 9, 10, 17, 26, 30	7
12:00	13:00	2, 5, 9, 10, 17, 18, 26, 30	8
13:00	14:00	2, 5, 6, 9, 18, 26, 30	7
14:00	15:00	2, 5, 6, 9, 14, 18, 22, 26, 30	9
15:00	16:00	5, 6, 9, 14, 18, 21, 22, 26, 30	9
16:00	17:00	1, 5, 6, 7, 9, 14, 18, 21, 30	9
17:00	18:00	1, 5, 6, 7, 14, 18, 21, 25, 30	9
18:00	19:00	1, 6, 7, 14, 18, 21, 22, 25, 30	9
19:00	20:00	1, 7, 14, 18, 21, 22, 25, 30	8
20:00	21:00	1, 7, 14, 16, 18, 21, 22, 25, 30	9
21:00	22:00	1, 7, 11, 14, 16, 18, 22, 25	8
22:00	23:00	1, 7, 11, 14, 16, 19, 22, 25	8
23:00	00:00	1, 7, 11, 14, 16, 19, 20, 22, 23	9

A plot of the number of satellites tracked against hours in a day is shown in figure 5.2.

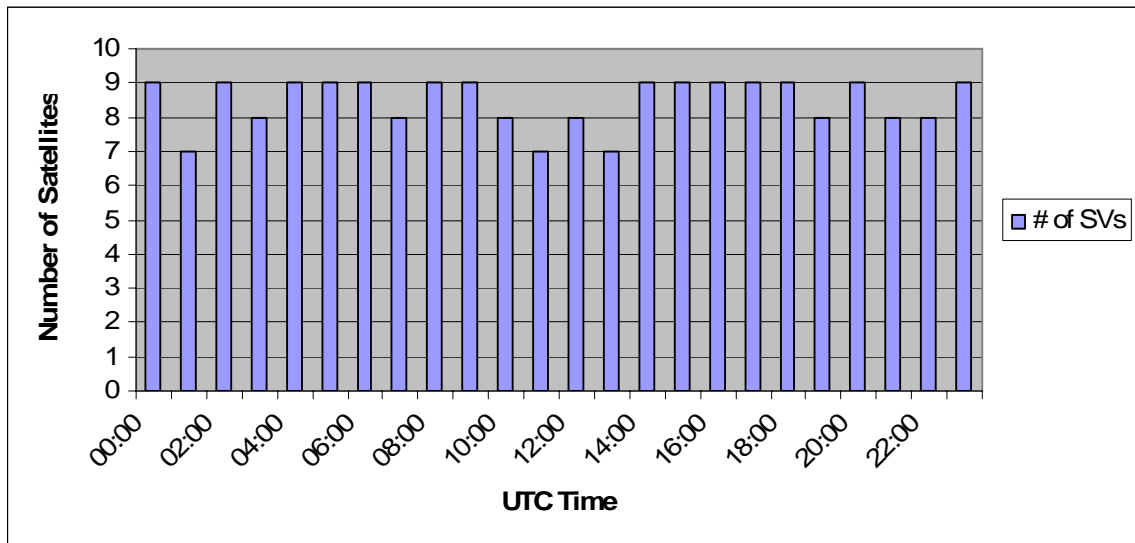


Figure 5.2: Number of SVs Tracked in a Day

From the figure and recalling § 3.1 confirms the maximum number of satellites tracked by the receiver and this leads us to findings on the appropriate times to work in a day. These times are found to be between the hours 06:00 and 11:00 GMT and 14:00 to 18:00 GMT. A note of caution must be sounded as the number of SVs reduces when elevation mask increases.

5.2 Transformation Parameters for KNUST Campus

Four transformation parameters have been determined to easily transform UTM-derived coordinates from GPS surveys carried-out on KNUST campus and its environs to the National Coordinate System. The relative positioning mode where coordinate differences between two receivers simultaneously measuring satellite code ranges and/or carrier phases from GPS SVs was employed for data acquisition (ref: Table 4.3). The UTM coordinates were then subsequently transformed to fit the national coordinate system using 2D similarity transformation. The Similarity Transformation Model used in arriving at the parameters is shown below (EPSG, 2005):

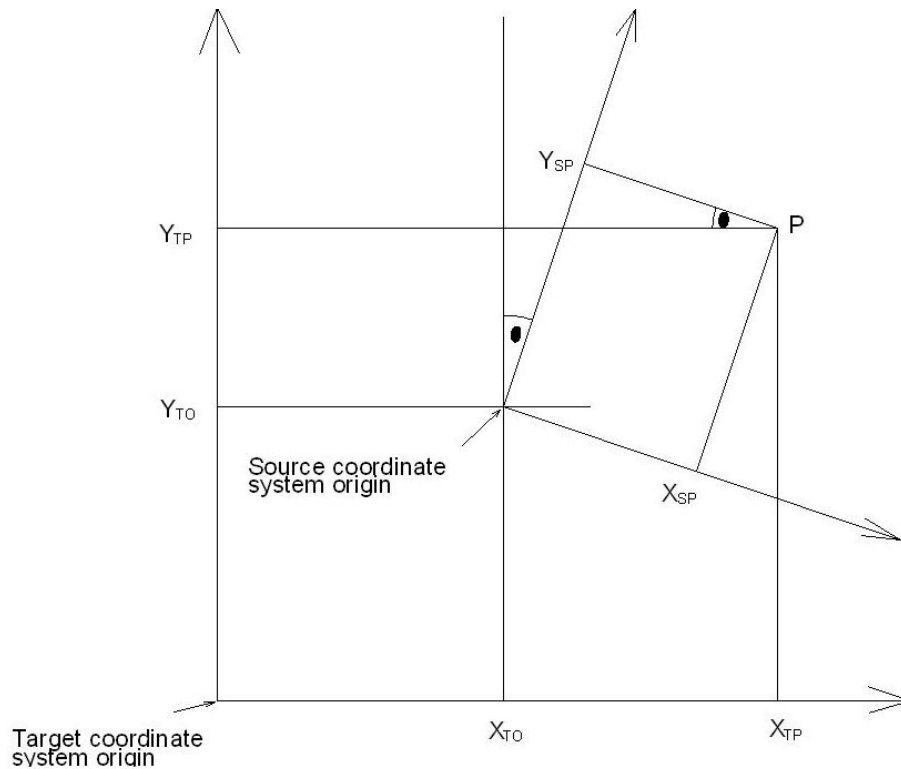


Figure 5.3: 2D Similarity Transformation Model

The 2D similarity transformation with two translational parameters, one rotation and a scale parameter as given by Hofmann-Wellenhof et al., 2000 is shown below:

$$\begin{bmatrix} E_T \\ N_T \end{bmatrix} = \begin{bmatrix} E_{TO} \\ N_{TO} \end{bmatrix} + M \begin{bmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{bmatrix} \begin{bmatrix} E_S \\ N_S \end{bmatrix} \quad \text{eqn 5.1}$$

The choice of Similarity Transformation was settled on based on these criteria:

- Coordinate systems have orthogonal axes and
- Same scale along both axes (EPSG, 2005).

Considering equation 5.1 above, at least two points are needed with coordinates in both reference frames to compute the four transformation parameters. Of all the stations' data that were logged and used for computations, four boundary controls and two internal controls around the central teaching area gave satisfactory results. Table 5.3 shows controls used that yielded parameters with the least deviations when compared with original coordinates.

Table 5.3: Control Points Used

Pillar ID	UTM (m)				National Grid Coordinates (ft)	
	Easting	σE	Northing	σN	Easting	Northing
GCGA/29/49/156	665652.962	0.004	738830.245	0.003	718066.14	730024.84
GCGA/29/49/155	665367.934	0.006	738883.035	0.005	717131.82	730201.51
GCGA/29/49/16	658801.809	0.006	739890.545	0.005	695605.28	733592.91
GCGA/29/49/79	658773.501	0.006	737411.866	0.005	695479.68	725462.41
UST/TP1	658582.179	0.006	738036.464	0.005	694860.14	727515.35
UST/TP6	658602.546	0.004	737949.267	0.003	694925.84	727228.00

The final transformation parameters were generated using Adjust® Software (Wolf and Ghilani, 2001). The output report is shown below:

Transformed Control Points				
POINT	EASTING	NORTHING	Ve	Vn
GCGA29-49-16	695,605.280	733,592.910	-0.003	-0.694
GCGA29-49-79	695,479.680	725,462.410	0.062	-0.403
GCGA29-49-155	717,131.820	730,201.510	0.072	-0.119
GCAA29-49-156	718,066.140	730,024.840	0.072	0.158
UST/TP1	694,860.140	727,515.350	-0.123	1.047
UST/TP6	694,925.840	727,228.000	-0.081	0.011

Transformation Parameters and estimated errors

a = 3.28044 ± 0.00006
 b = -0.01323 ± 0.00006
 Te = -1475348.132
 Ty = -1684856.555

Rotation = 359° 46' 07.9"

Scale = 3.28047

Adjustment's Reference Variance = 0.2268

A test was run to check the computed transformation parameters on control pillars whose coordinates were known to be accurate and have not been altered (ref. Geomatic Eng. Survey Unit files). Tables 5.4 & 5.5 summarize the results obtained.

Table 5.5: Differences of Computed from Original Coordinates

Pillar ID	Index	Δ East (ft)	Δ North (ft)
GE1-78-134	1	-0.2120	-1.2260
TP1	2	-0.1230	1.0470
TP6	3	-0.0810	0.0110
KU6	4	-0.1690	-0.3880
GE1-02-1	5	-0.6380	-1.0570
ENG-4	6	-0.3970	0.3130
ENG-1	7	0.2320	-0.0200
GE1-78-114	8	0.0000	-0.5680
GCGA-29-49-16	9	-0.0030	-0.6940
GCGA-29-49-79	10	0.0620	-0.4030
GCGA29-49-155	11	0.0720	-0.1190
GCGA29-49-156	12	0.0720	0.1580
GCGA29-49-90	13	-0.5520	-0.1870
GCGA29-49-92	14	-0.7230	1.1160
CTS 11	15	0.0910	0.0470
SGA1-72-4B	16	-1.0380	-1.2540
SGA1-72-4C	17	-0.9200	-1.1680
SGA-1-80-5	18	0.9950	-0.5630

From the results in Table 5.5 and Figure 5.4, the maximum deviations on test conducted on eighteen (18) controls are [1.0380ft] and [1.2540ft] for Eastings and Northings respectively, and minimum deviations of [0.0ft] and [0.0110ft]. Taking absolute values of the differences in columns 3 and 4 of Table 5.5, a mean deviation of 0.3544 and 0.5744, and standard errors of ± 0.3611 and ± 0.4582 for Eastings and Northings were deduced. Hence these parameters can be used within a radial error margin of 0.583ft.

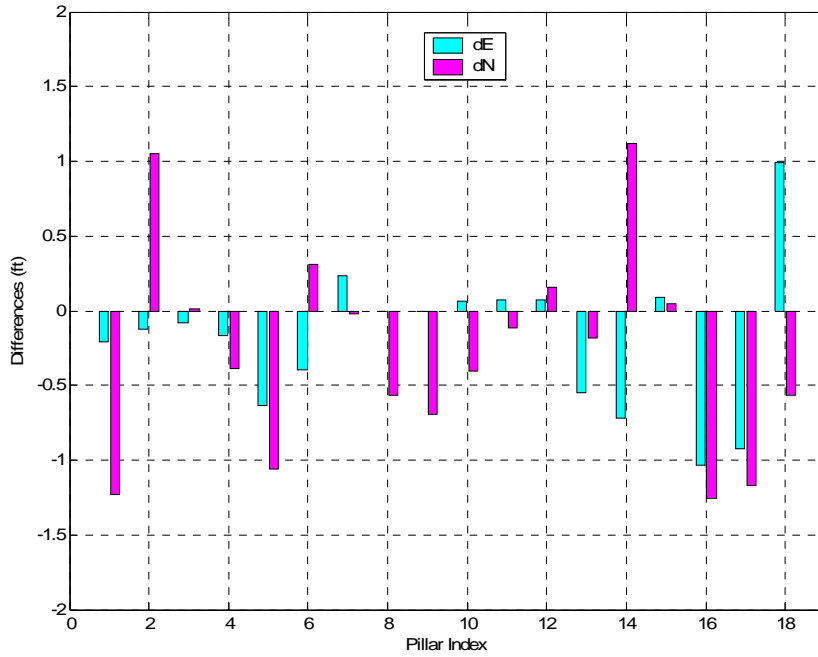


Figure 5.4: Plot Showing the Differences

5.3 Observation Times

Error ellipses plot from the parameters in Table 4.6 is shown below in figure 5.5. This figure clearly shows that the errors are greater in the northing direction and follows similar trend.

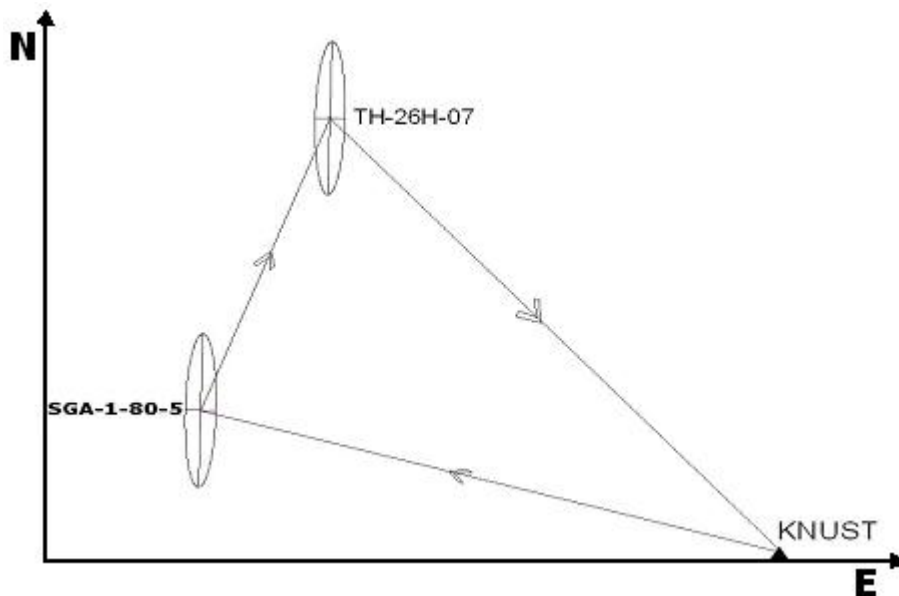


Figure 5.5: Error Ellipses

The final coordinates resulting from adjustments carried-out in § 4.4 and Table 4.7 to be precise were held fixed and compared with batch processing. Tables 5.6 and 5.7 show the variations.

Table 5.6: Comparison against Adjusted Coordinates – SGA-1-80-5

Session Length	dX	dY	dZ
10min	0.055445	-0.016413	0.006846
15min	-0.030675	-0.008743	-0.001104
20min	0.048175	-0.010053	0.008756
25min	0.135295	-0.012523	0.019296
30min	-0.032065	-0.008093	-0.000344
1.0 hour	0.051585	-0.007083	0.015336
1.5 hours	-0.032165	0.002667	0.005796
2.0 hours	0.016915	-0.002413	0.010636
2.5 hours	0.005025	0.001307	0.007376
3.0 hours	0.004455	-0.000213	0.007006
3.5 hours	-0.000215	-0.001313	0.005846
4.0 hours	0.004235	-0.001743	0.007606
4.5 hours	0.011125	-0.001943	0.008716
5.0 hours	0.019635	-0.000953	0.010336
5.5 hours	0.019035	-0.000933	0.009956
6.0 hours	0.018015	-0.001213	0.009216
6.5 hours	0.010165	-0.000683	0.008916

Table 5.7: Comparison against Adjusted Coordinates – TH-26H-07

Session Length	dX	dY	dZ
10min	0.06238	0.01299	0.01071
15min	0.06359	0.00927	0.00746
20min	0.05576	0.00027	-0.00704
25min	0.08437	-0.01282	-0.01167
30min	0.08861	-0.01294	-0.01086
1.0 hour	0.06172	-0.00727	-0.00229
1.5 hours	0.06240	-0.00606	0.00459
2.0 hours	0.07144	-0.00201	0.01059
2.5 hours	0.05641	-0.00097	0.01005
3.0 hours	0.01635	0.00476	0.00377
3.5 hours	0.02491	0.01589	0.00072
4.0 hours	0.01277	-0.00190	-0.00035
4.5 hours	0.01147	-0.00463	0.00137
5.0 hours	0.02367	-0.00988	0.00313
5.5 hours	0.02610	0.00172	0.00554
6.0 hours	0.02311	0.00089	0.00489
6.5 hours	0.02099	0.00125	0.00432

A plot of the differences resulting from the comparisons against session length is shown in figures 5.6 and 5.7.

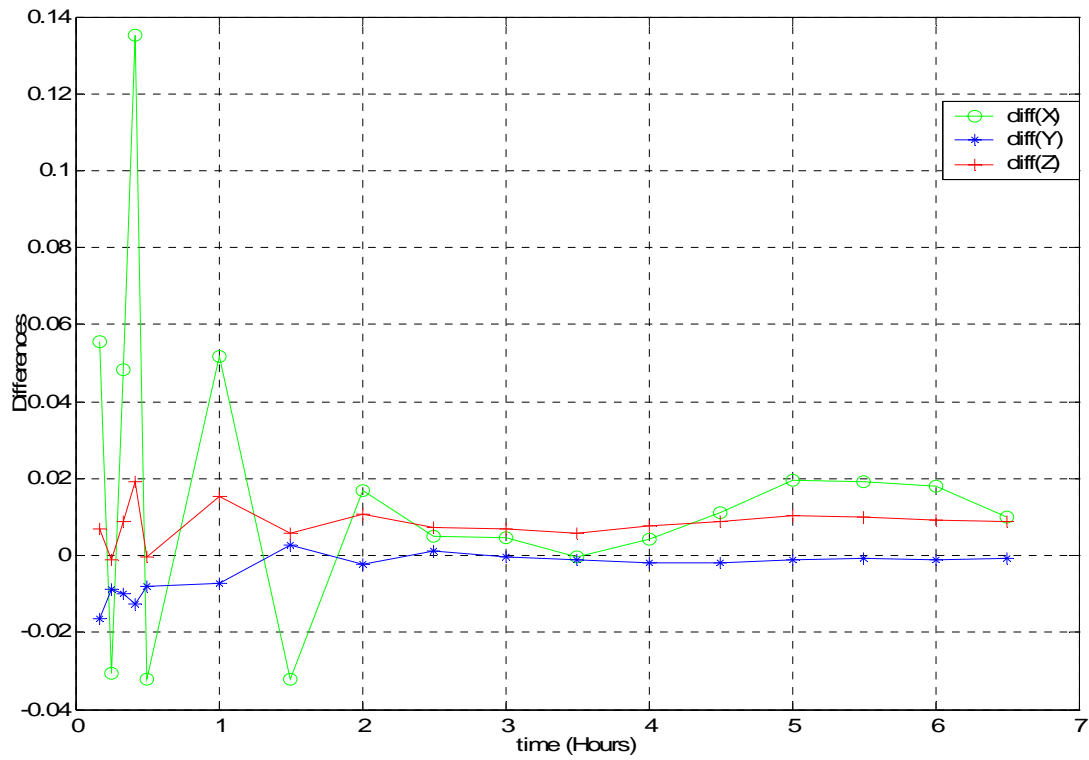


Figure 5.6: Plot of Differences against Session Length for SGA-1-80-5

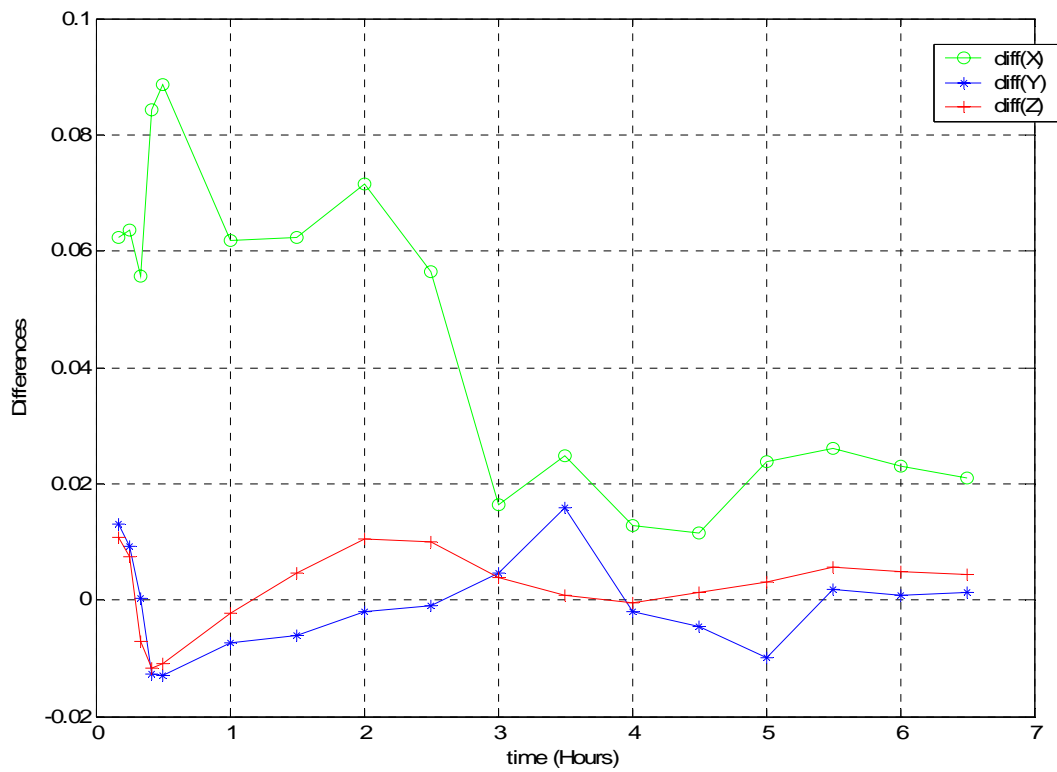


Figure 5.7: Plot of Differences against Session Length for TH-26H-07

Considering figures 5.6 and 5.7 solutions with the minimum deviations are arrived at the hours of 3 or more. Hence for newly established points that need to be coordinated in the WGS 84 reference frame an observation time of at least three hours must be spent on the station.

Concluding Remarks: Quality check analyses have been carried out to check the status and stability of the base station. PDOP values shown in Table 5.1 and Figure 5.1 clearly confirm that the station is stable and working flawlessly. Further inquiry on appropriate times to work in a day using the number of satellites tracked during particular times revealed that between the hours 06:00 to 11:00 GMT and 14:00 to 18:00 GMT are the best times to observe. Additionally, four parameters have been derived to integrate satellite data into the National mapping frame using the 2D transformation model.

CHAPTER 6 – CONCLUSIONS AND RECOMMENDATIONS

In this assignment, a base station has been set-up for logging GPS datasets onto a PC serving as the data logger. The logged data are converted to rinex format and then published on the station's website with 24 hour latency. The published data will be taken offline after a day for successive logs to be made available online. Request for data not published or offline will be granted through email attachments.

Series of observation sessions were carried out for the analysis. Nine consecutive days' data were then used to compute the coordinates of the base antenna position from a triangular network involving the point on the Architectural Studio and the N1 pillar. Using the established base, GPS baseline surveys were conducted on KNUST Campus and a 2D four transformation parameters have been determined. An additional network survey was conducted and the adjusted coordinates compared with 30-minute time segments to find the appropriate occupation times needed for new points to serve as bases on site.

Summing these up and considering the findings on analyses performed, all stated objectives were attained and the following conclusions have been drawn.

6.1 Conclusions

GNSS is a technology that provides accurate, inexpensive and consistent positioning, but the signals are beset with errors. Various Augmentation Systems have been developed to account for the effects of these random and systematic errors. The CORS is an augmentation system whose technical equipments, potential for meeting user requirements and with the shortest implementation time was adopted for this research. CORS works on the differential positioning concept which is the basis of all high precision satellite positioning applications. The DGPS technique requires the placement of an extra GPS receiver at a known point/location that has been independently surveyed to a very high accuracy. The established base station will serve as the reference receiver and most importantly the second receiver required for relative positioning applications.

On the issue of transformation, a two-dimensional similarity transformation which is efficient for relating GPS networks to terrestrial networks has been computed. The derived 2D-four transformation parameters will facilitate and integrate the connection of pre-existing networks.

Computer programs have been written to automatically transform UTM coordinates from GPS processed results to the National Grid System. The parameters computed can be used within a maximum radial error of 0.58ft. or 0.177m around campus.

The computer scripts written are being used to process data from projects carried-out by students and surveyors on and outside campus and in all instances the base data and reference coordinates are used. The base station data will be available to aid in supporting local densification of geodetic networks to meet requirements for surveying, mapping, charting, GIS and emergency response applications. Further investigations into observation times revealed that to coordinate newly established base stations, a session length of at least 3 hours must be conducted.

The provision of this DGPS service will ensure the reduction in the initial capital needed for the acquisition of GPS receivers and assist in integrating satellite data in National System.

6.2 Recommendation

From this study, the following recommendations regarding the use and further investigations of Differential GPS Service can be made:

1. New computer codes and scripts must be developed to handle automatic uploads of base data as most steps used for the study were handled manually.
2. Accessories and other computer gadgets need to be acquired to assist in further studies concerning real-time differential correction transmission and location-based services.
3. For integrity purposes the solutions obtained for the coordinates of the antenna position should be checked, at least once or twice, using a network with longer baselines.

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APPENDICES

Appendix A1: Base Station's Web Site

The screenshot shows a Windows Internet Explorer browser window displaying the website for the College of Engineering at KNUST. The browser's address bar shows the URL: `H:\Thesis Update\College of Engineering Differential GPS Service @ KNUST.htm`. The page title is "College of Engineering ::Differential GPS Service @ KNUST - Windows Internet Explorer provided by Yahoo!".

The website header features a banner with several images and the text "COLLEGE OF ENGINEERING" and "Kwame Nkrumah University of Science & Technology". The date "Sunday, 1 June 2008" is displayed on the right. Navigation links include "KNUST | Home | Staff Login | Student Login (Intranet) | Contact Us".

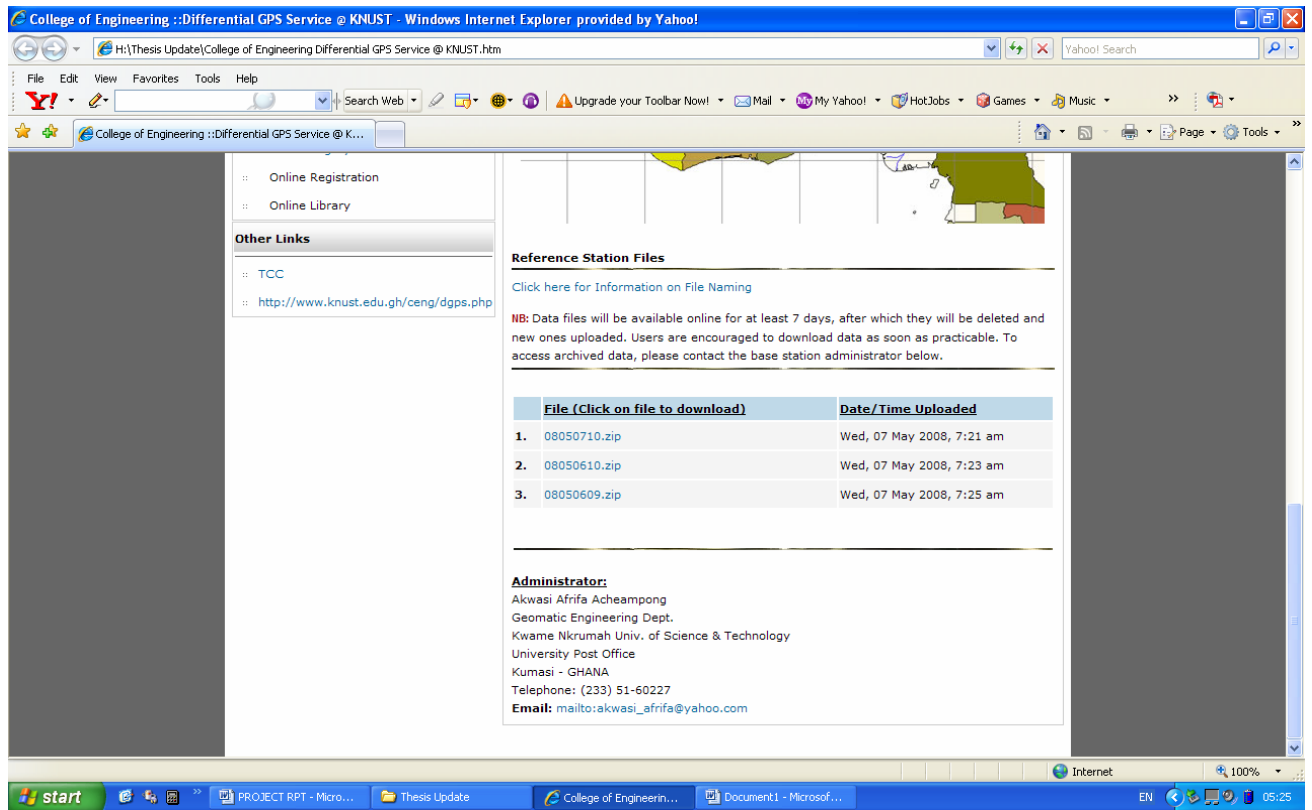
The main content area is divided into two columns. The left column contains a "General Information" menu with links to Home, About Us, Provost Office, Faculty and Departments, News, Events, Research, Collaborations, and Contact Us. Below this is a "Staff Corner" with links for Staff Search and Abstracts.

The right column is titled "Differential GPS Service @ KNUST (Geomatic Engineering Department)" and includes a link for "About Us for DGPS Station". It contains a "Station Details" section with the following information:

Station ID	KNUST
Latitude:	6° 40' 21.77262" N
Longitude:	1° 33' 56.47607" W
Height above Ellipsoid:	296.924m
Datum:	WGS 84
Elevation Mask:	0°
Logging Interval:	5 seconds

Below the station details is a "Base Station Location" section, which includes a map showing the station's location on a geographical map.

The Windows taskbar at the bottom shows the Start button, several open applications (PROJECT RPT - Micro..., Thesis Update, College of Engineerin...), and the system tray with the date and time (05:24).



Appendix A2: Web Links and Educational Resources

Base Stations' Resources	http://www.ngs.noaa.gov/CORS
International GPS Service (IGS)	http://igs.cb.jpl.nasa.gov/
ITRF	http://schubert.ign.fr/CIAG/WITRF/ITRF-GPS.html
Magazines and Journal	www.gpsworld.com www.insidegnss.com
Online GPS Processing Service	http://www.ga.gov.au/bin/gps.pl http://www.geod.nrcan.gc.ca/online_data_e.php http://www.ngs.noaa.gov/OPUS
Pre-processing Tools	http://www.unavco.org www.leica-geosystems.com/corporate/en/ndef/

Appendix B: List of Acronyms

2D	Two dimension
3D	Three dimension
CORS	Continuously Operating Reference Station
DGPS	Differential GPS
ECEF	Earth-Centered Earth Fixed
EGNOS	European Geostationary Navigation Overlay Service
FOC	Full Operational Capability
GAGAN	GPS and Geostationary Augmented Navigation
GIOVE	Galileo In-Orbit Validation Element
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global Standard for Mobile
ITRF	International Terrestrial Reference Frame
ITU	International Telecommunication Union
JRANS	Japanese Regional Navigation Satellite System
KNUST	Kwame Nkrumah University of Science and Technology
LAN	Local Area Network
MEO	Medium Earth Orbiting
MSAS	Multifunction Satellite Augmentation System
NAVSTAR	NAVigation System with Time And Ranging
NMEA	National Marine Electronics Association
PDOP	Position Dilution of Precision
PNT	Positioning Navigation and Time
PPS	Precise Positioning Service
QZSS	Quasi-Zenith Satellite Systems
RINEX	Receiver INdependent EXchange
RTCM	Radio Technical Commission for Maritime Services
TEQC	Translate Edit and Quality Check
TGO	Trimble Geomatics Office
TRS	Trimble Reference Station
SBAS	Satellite-Based Augmentation Systems
SPS	Standard Positioning Service
SPP	Single Point Positioning
SV	Space Vehicles
UNAVCO	University NAVSTAR Consortium
USACE	United States Army Corps of Engineers
UTM	Universal Transverse Mercator
WAN	Wide Area Network
WAAS	Wide Area Augmentation System
WGS 84	World Geodetic Service 84

Appendix C: GPS Data Collection Record

Contacts (Who)

Project Leader: _____ Region: _____
Date: _____ Phone: _____
Division/Section/Unit: _____

Field Crew Members

Name/phone (1): _____
Name/phone (2): _____
Name/phone (3): _____
Names of additional members: _____

Primary computer operator: _____
Location of computer files: _____

Survey Description (Where & Why)

Location Surveyed: _____
Purpose of Survey: _____

Equipment

Mode of Operation (Circle one): Autonomous Differential Kinetmatic FastStatic
Static

Method of Operation (Circle one): Standalone Post Processing Real Time

Base Station used (Circle one)? Yes No
If Yes Base Station Info: _____

Tripod/range poles used (Circle one)? Yes No
If YES, list make and height of pole used next to each receiver. _____

Make & Model of GPS Receivers/Antennas. Indicate if a receiver was used as a base station.

Receiver/Antenna (1): _____
Receiver/Antenna (2): _____
Receiver/Antenna (3): _____

List additional receiver/antenna configurations on the back of form

GPS Settings

Epoch (Sec): _____ Mask Elevation (degrees): _____ Measuring Units _____
Horizontal Datum (e.g., WGS 84): _____
Horizontal Projection (e.g., UTM): _____
Vertical Datum (e.g., WGS 84): _____

Appendix D1: GPS Quality Check Report

Leica GNSS QC v1.2 (Free Version) Quality Report

Program Run: 29/01/07 11:31:35

File Details:

Observation File: KNUSTJAN23.07o
Navigation File: KNUSTJAN23.07n

Quality Testing: Pass

Station Details:

Marker Name/Number: KNUST Base
Observer/Agency: Akwasi Afrifa GEOMATIC
Receiver #/Type/Vers: 00017580 TRIMBLE 7400MSI Nav 2.38 Sig 2.38
Antenna #/Type: 0000 TR GEOD L1/L2 GPDOME
Antenna Offsets (HEN): 0.000 0.000 0.000
Approx Position (XYZ): 6333150.500 -173105.010 736231.810
Approx Position (plh): 6° 40' 21.76980 -1° 33' 56.46536 299.389m
Diff. Est-Header: -5.1 dX -4.647 dY -0.699 dZ
Diff. Est-Header: 6.9 m (8762 estimates)

Session Summary:

Time of first obs: 23-01-2007 11:49:50 GPS
Time of last obs: 23-01-2007 23:59:55 GPS
Session length: 12.17 hours
GPS week: 1411, day 2

Num SVs with obs: 24
Num SVs with nav: 26

SVs with obs: G1 G2 G3 G4 G8 G9 G10 G11 G13 G14 G16 G17 G18 G19
G20 G22 G23 G24 G25 G26 G27 G28 G29 G31

SVs without obs: G5 G6 G7 G12 G15 G21 G30

SVs with nav: G1 G2 G3 G4 G8 G9 G10 G11 G13 G14 G16 G17 G18 G19
G20 G21 G22 G23 G24 G25 G26 G27 G28 G29 G30 G31

SVs without nav: G5 G6 G7 G12 G15

Total SV orbits: 1291

Obs interval: 5.00 seconds

Quality Indicators:

Num epochs w/ data: 8762
Num epochs w/o data: 0

Num obs > 0°: 77494
Num possible obs > 0°: 92781
Num obs w/ invalid nav: 0
Num obs w/o nav: 0
Num obs to unhealthy SV: 0
Num obs w/ WLF change: 0

```

Num obs > 10°:          74033          (97.8 % complete)
Num possible obs > 10°: 75734
Num complete obs > 10°: 72231          (95.4 % complete)

Data Gaps:              0.00 seconds

PDOP min, max, av:     2.8          5.3          3.4
GDOP min, max, av:     3.3          6.4          4.0

Average # SV:          8.4
Epochs w/ < 5 SV > 10°: 0          (100.0 % complete)

Points MP Moving Av.:  25
MP1 RMS:                0.428 m
MP2 RMS:                1.040 m

IOD Slips > 10°:       2
Cycle Slips > 10°:     47(0.065% of complete obs, 1537 obs/cycle slip)
Outliers > 10°:       2974

Clock Slips > 10°:     7

Max RX clock offset:   0.500127 ms (at 23/01/07 13:34:25)
Num of RX clock resets: 14
Total clock drift:     +14.000000 ms
Rate of clock drift:   +1.312 ms/hr
Av time between resets: 45.726 minute(s)

Quality Testing:

CycleSlips:            Pass (Value 47 slips, Threshold 122 slips)
Multipath:              Pass (Value 0.43m MP1 / 1.04m MP2, Threshold 1.5 m)
DataCompleteness:      Pass (Value 95.4 %, Threshold 95.0 %)
EpochsWithData:       Pass (Value 100.0 %, Threshold 99.0 %)
NavData:                Pass
Format:                 Pass
RX Clock:               Pass
Other:                  Pass

```

Appendix D2: GPS Processing Report

Spectrum® Survey 3.50
VECTOR: ARCHITO-N1

VECTOR SUMMARY
VECTOR OCCUPATION NO.: 01

Coordinate System: UTM [Universal Transverse...] Datum: WGS84
Geoid Model: <None> Units: Meters
Processing Date: 2006/11/06 19:17:38 (UTC)

Ephemeris: Precise Clock Model: SP3 Elevation Mask: 10deg

BASE STATION (ARCHITO) [C:\Sokkia\BASE9\Data\00153041.pdc]

Antenna Height: 0.142 [Meas.: 0.000] Antenna Model: SK702 (meters)
Met. Measurements Used: Default

WGS84 (meters)		WGS84 (meters)	
X:	6333145.041	Lat:	N 6 40 27.63906
Y:	-172977.010	Lon:	W 1 33 52.30449
Z:	736412.300	Hgt:	311.471

UTM (meters)		Convergence:	
E:	658672.877		0 10 00.74709
N:	737980.045	Grid Scale Factor:	0.99991162
		Elevation Factor:	0.99995101

REMOTE STATION (N1) [C:\Sokkia\BASE9\Data\00013041.pdc]

Point Occupation: 01
Antenna Height: 0.142 [Meas.: 0.000] Antenna Model: SK702 (meters)

WGS84 (meters)		WGS84 (meters)	
X:	6333127.866 +/- 0.009	Lat:	N 6 40 26.35385 +/- 0.005
Y:	-173078.032 +/- 0.005	Lon:	W 1 33 55.60752 +/- 0.005
Z:	736370.862 +/- 0.005	Hgt:	292.343 +/- 0.009

UTM (meters)		Convergence:	
E:	658571.553 +/- 0.005		0 10 00.33098
N:	737940.272 +/- 0.005	Grid Scale Factor:	0.99991122
		Elevation Factor:	0.99995402

VECTOR RESULTS

Solution Type: L5 fixed narrowlane Processing Interval: 10.00 seconds
Time Span: 2006/10/31 08:30:30.00 to 2006/10/31 11:12:20.00 [161 min.]
Observations: 7673 Observations Used: 7289 [95.00%] Ratio: 4.8

WGS84 Vector (meters)		WGS84 (meters)	
dx:	-17.175 +/- 0.0088	Slope:	110.533 +/- 0.011
dy:	-101.022 +/- 0.0050	FwdAz:	248 44 08.23795
dz:	-41.438 +/- 0.0052	BwdAz:	68 44 07.85407
		FwdVA:	99 57 56.45562
RMS	0.005 (m)	BwdVA:	80 02 07.06778
		dHgt:	-19.128

UTM (meters)	
Grid Distance:	108.851
Grid Azimuth:	248 34 07.50698
Vector Comb. Factor:	0.99986394

COVARIANCE MATRIX

	dx	dy	dz
dx	7.749339e-05		
dy	-4.334442e-07	2.540232e-05	
dz	3.944634e-06	-7.457040e-07	2.663903e-05

Appendix E: MatLab Scripts

```
% Least Squares Adjustments of Antenna Position
% Reference Standard Deviation

format long
load ref_var.dat;

[n,p] = size(ref_var);
%A matrix
A = (ref_var(:,1:6));
%L matrix
L = (ref_var(:,7));
% cov-mat
cov_mat = (ref_var(:,8:88));
% weight matrix
weight_mat = inv(cov_mat);
% final coords
X = inv((A' * weight_mat) * A) * ((A' * weight_mat) * L);
[m,p] = size(X);
wklwrite('antenna_position', X);
%%% Variances
V = (A * X) - L;
%% Reference standard deviation
refstd = sqrt(((V' * weight_mat) * V)/(n - m));
%% covariance matrix of computed quantities
comp_covar = inv((A' * weight_mat) * A);
dcomp_covar = diag(comp_covar);
all_calc = [comp_covar dcomp_covar];
wklwrite('calc_covar', all_calc);

-----

%
% Ghana TM
% Projection: Transverse Mercator
% War Office Ellipsoid
% Units = feet conv 0.30479973444444 && 3.28084275343182
% True origin: Latitude [4 40 0] & Longitude [1 0 0]W
%%%%%%%%%Departmental Table
%% Computed Results are in feet
format long
% Longitude of origin
lon_cen = 1;
lon_cr = lon_cen * pi / 180; % Longitude in rads
% Latitude of origin
lat_cen = 4.666666666666667;
lat_cr = lat_cen * pi / 180; % Longitude in rads
% false Easting
FE = 900000.0;
FN = 00.0;
Sf = 0.99975; %Scale factor at Origin
a = 20926201.00;
b = 20855505.00;
f = 1/296;
format long
ee = (2*f - f^2); % first eccentricity
ec = (ee / (1 - ee)); % second eccentricity

% Accept Values
```

```

fileN = input('Enter Filename (enclose in single quotation
marks):.....');
Ao = wklread(fileN);
[r,c] = size(Ao);
No = Ao(:,1); % Station IDs
lat_dec = Ao(:,2) + Ao(:,3)/60 + Ao(:,4)/3600; %Latitude
lon_dec = Ao(:,5) + Ao(:,6)/60 + Ao(:,7)/3600; %longitude

% convert to radians
lat_r = lat_dec * pi / 180;
lon_r = lon_dec * pi / 180;
lat_sin = sin(lat_r);
lon_sin = sin(lon_r);
lat_cos = cos(lat_r);
lat_tan = tan(lat_r);
% Prime Vertical Radius of Curvature @ 90deg to p-----
v = a ./ sqrt(1 - (ee * (lat_sin .*lat_sin)));
%Meridonal Radius of Curvature-----
p1 = (1 - ee * (lat_sin .* lat_sin));
p = (a * (1 - ee)) ./ (sqrt(p1.*p1.*p1));
phii = v ./ p;
% sin 1 sec
sin_1s = 4.8481368111e-006;
%%%%%% Coefficients
M = v * sin_1s;
K = 1/4 * v * (sin_1s*sin_1s);
T = (v ./ (3*p)) .* ((sin_1s*sin_1s) * (lat_cos.*lat_cos));
O = (1/24)* v .* ((sin_1s)^4 * (lat_cos.*lat_cos)).* lat_sin .* (5 -
(lat_tan .* lat_tan));
N = (1/6)* v .* ((sin_1s)^3 * (lat_cos.*lat_cos.*lat_cos)).* ((v ./ p) -
(lat_tan .* lat_tan));
w = (lon_cen - lon_dec)*3600; %%% Diff in Longitude reduced to seconds

%% Distance along Central meridian Xo
M1 = (1 - ee/4 - 3*ee^2/64 - 5*ee^3/256) * lat_r;
M2 = (3 * ee/8 + 3*ee^2/32 + 45*ee^3/1024) * (sin(lat_r * 2));
M3 = (15*ee^2/256 + 45*ee^3/1024) * (sin(lat_r * 4)) - (35*ee^3/3072)*
(sin(lat_r * 6));
M_lat = a * (M1 - M2 + M3);

M1o = (1 - ee/4 - 3*ee^2/64 - 5*ee^3/256) * lat_cr ;
M2o = (3 * ee/8 + 3*ee^2/32 + 45*ee^3/1024) * (sin(lat_cr * 2));
M3o = (15*ee^2/256 + 45*ee^3/1024) * (sin(lat_cr * 4)) - (35*ee^3/3072)*
(sin(lat_cr * 6));
Mo = a * (M1o - M2o + M3o);

Xo = Sf* (M_lat - Mo);

%Plane Coords
Easting = FE + M.*(w.*lat_cos) + N .* (w .* w .* w);

Northing = Xo + K .* ((w .* w) .* sin(2 * lat_r)) + O .* (w .* w .* w .*
w);

Plane_crd = [No Easting Northing];

wklwrite('GhanaTMf', Plane_crd);
disp('Results have been write to GhanaTM.wk1 file.....')

```