Palestine Polytechnic University

College of Engineering & Technology

Civil and Architectural Engineering Department

Surveying Engineering

Graduation Project

The Effects of Changing Some Parameters on GPS Accuracy

By

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Hebron-West Bank
Palestine
Jan-2007

CERTIFICATION

Palestine polytechnic university

Hebron-Palestine

The Effects OF Changing Some Parameters On GPS Accuracy

Project Team

Morad al- azzah Osama Rasheed

By the guidance of our supervisor, and the approval of members of testing committee, this project is delivered to the department of civil and architectural engineering, in the college of engineering and technology to be as partial fulfillment of the requirements of the department for the degree of B.Sc in surveying and geomatics engineering.

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Head of dep. Signature:
Name: ………………

Committee member's signature:

Name: …………………..
Name: …………………
Name: …………..

Hebron-West Bank
Palestine
Jan-2007

DEDICATION

الإهداء

إلى روح الأستاذ كمال غطاشة رحمه الله ...

إلى الذين ساروا مع الفجر ليخطوا لنا طريق الحرية ...

إلى نبع الحنان و المحبة .... أمي الحبيبة

إلى نبع البذل و العطاء .... أبي الحبيب

إلى من رووا بدمائهم الذكية تراب هذا الوطن الغالي ...

إلى أسرى الحرية داخل زنازين القمع الصهيوني ...

إلى الذين حملوا أرواحهم على اكفهم من اجل وطنهم ...

إلى حبيبتي "فلسطين" ...

إلى كل الأوفياء والمخلصين ...

إلى رفاق دربي الذين ذاقوا معي حلاوة الدنيا ومرارتها ... وأخص ذكرا رفيق عمري مصعب رشيد ...

إلى طلاب جامعة بوليتكنيك فلسطين من إخوتنا وأخواتنا ... من خالفنا منهم الرأي أو **من اتفق معنا وانطلق لآفاق التجدد و الإبداع ...**

نهديهم جمعيا هذا العمل المتواضع

"قل إن صلاتي ونسكي ومحياي ومماتي لله رب العالمين"

أسامة رشيد

DEDICATION

الإهداء

إلى أقدس أماكن الأرض.......القدس السليبة
إلى روح القائد العظيم ......**أبو عمار** ....
إلى الذين ساروا مع الفجر ليخطوا لنا طريق الحرية ...
إلى أسرى الحرية داخل زنازين القمع الصهيوني......
إلى رواد العلم المبدع، طلاب اليوم، بناة المستقبل، قادة الغد ...

إلى أنبل نساء العالم ....أمي الحبيبة
إلى روح والدي المرحوم فهمي **العزة** ...
إلى إخواني الأوفياء ....
إلى جميع أصدقائي ...
إلى من رووا بدمائهم الزكية تراب هذا الوطن الغالي ...
إلى الذين حملوا أرواحهم على اكفهم من اجل وطنهم ...
إلى حبيبتي "فلسطين"...
إلى كل الأوفياء والمخلصين...

إلى طلاب جامعة بوليتكنيك فلسطين من إخوتنا وأخواتنا ... من خالفنا منهم الرأي أو من اتفق **معنا وانطلق لآفاق التجدد و الإبداع**.

نهديهم جمعيا هذا العمل المتواضع .

"قل إن صلاتي ونسكي ومحياي ومماتي لله رب العالمين"
صدق الله العظيم

مراد العزة

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فيضي شبانة

والى كل الذين قدموا لنا العون والمساعدة

ABSTRACT

THE EFFECTS OF CHANGING SOME PARAMETERS ON GPS ACCURACY

Project team

Morad Al Azah Osamah Rasheed

Project supervisor

Eng.Faidi shabaneh

The accuracy of GPS will be affected greatly by changing some of its parameters. There are some parameters could be changed in GPS device will affect the accuracy, and we will compare the results after changing these parameters ,and the main parameters will change with GPS are:

- Time
- Method used static or RTK.
- Mask angle

The accuracy of GPS device accomplished by a lot of measured points carefully measured, compared with ancient correct measurements.The procedure is to choose some points (two control points suggested free of error , and three known coordinate points) , and comparing the standard deviations of the points that affected by changing these parameters .

Place the base on trigs (A&B), and the antenna on the controls and gain there coordinates to compare the results from GPS with fixed values , and find the percent error between the two measurements on each point , and judge about GPS accuracy by finding the standard deviation occurred by changing some parameters .(The controls are A&B buildings in our university and the points are in the university territory).

The final step is to choose the most accurate parameters and there values according to there standard deviations to be placed into GPS instrument to get high accurate measurements .

الملخص

THE EFFECTS OF CHANGING SOME PARAMETERS ON GPS ACCURACY

إعداد
مراد العزة أسامه رشيد
إشراف
الأستاذ المهندس فيضي شبانه.

إن دقة القياس باستخدام جهاز ال GPS ستتأثر بشكل كبير بتغيير بعض المعاملات في الجهاز ، وهناك بعض المعاملات التي سيتم تغييرها ، وسوف نقارن القيم التي سنحصل عليها بعد تغيير هذه المعاملات ، وهذه المعاملات هي :

- الوقت.(Time)
- طريقة القياس(static) أو (RTK).
- زاوية الانحراف عن الأفق .(Mask angle)

إن دقة جهاز نظام تحديد الموقع بالأقمار الصناعية سيتم تحديدها بقياس بعض النقاط بشكل حذر ودقيق، تقارن بقيم سابقة مأخوذة بواسطة الأعمال المساحية الدقيقة , لمقارنة الانحراف المعياري الذي سيحصل نتيجة تغيير المعاملات في الجهاز، والطريقة هي اختيار نقطتين إحداثيات ثابتة مقترحة بأنها خالية من الأخطاء ، وثلاث نقط معلومة الإحداثيات سابقا.

يتم وضع جهاز القاعدة على النقاط الثابتة المعلومة الإحداثيات والمقترحة خالية من الأخطاء ، ووضع الأنتين على النقط الثلاث داخل الحرم الجامعي (النقط الثابتة هي أ وب فوق مباني الجامعة والنقط الأخرى داخل الحرم الجامعي)، ويتم قياس إحداثيات النقط داخل الحرم الجامعي ومقارنة هذه القياسات لمعرفة الانحراف المعياري ونسبة الخطأ بين النقاط الثابتة والمقاسة بواسطة الجهاز.

في النهاية للحصول على أدق الطرق، يتم اختيار المعاملات التي أحدثت اقل انحراف معياري ونسبة خطأ ووضعها في الجهاز للحصول على أدق القياسات.

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CHAPTER ONE

INTRODUCTION

1.1 Project Background

1.2 Project Importance

1.3 Project objectives

1.4 Methodology

1.5 Study Area

1.6 Previous Studies

1.7 Problems and Limitations

1.8 Equipment Necessary to Carryout a GPS Survey

1.9 Project Outline

CHAPTER ONE

INTRODUCTION

1.1 Project Background

The aim of this project is to study the effects of changing some parameters on GPS (Global Positioning System) accuracy, certain parameters have been changed such as, the mask angle, which is important in ionospheric, tropospheric refraction, GPS time, and the method used RTK or Static.

The work conducted by using fixed control points in PPU campus (Wadi Al Hariia area) using static and real time kinematic (RTK) observation methods.

In this project we try to describe the field and office procedures of surveys, planning GPS surveys, decide about the accuracy of GPS could be obtained in field surveying, and performing GPS surveys and the future of GPS in practice of surveying .

1.2 Project Importance

Importance of using GPS and accuracy augmentation in surveying:

- There are a lot of important applications require high accuracy of GPS observations, especially in surveying and mapping, including cadastral and urban networks
- Photogrammetrical control (airborne and terrestrial) need control points in overlap area of high accuracy to determine the absolute position of the required phenomena.

- Data capture surveys for geographical information system (GIS), to get high accurate maps and precise positions.
- Engineering surveys for plain surveying or geodetic one.
- Geophysical resource surveys.
- Land navigation, to support military forces, emergency vehicles (rescue, ambulances, police, & search….etc).
- Monitoring railways, cars, taxis, valuable and dangerous cargoes, trucks …….etc.
- In sanitary and water channel to protect people and environment from fatal complaints.
- Geodetic applications, including the establishment of control networks over regional and continental extent, altitude and geoid determination.
- Geodynamic applications, for measuring the relative position of a regional network at regular intervals in order to study horizontal and vertical crusted motion.
- Transportation and communication , to support aids of navigation for land , sea and air users , time transfer operations ,land operations taking advantage of permanent GPS stations ,.
- Especially in occupied Palestine , the determination of accurate position of boundaries is very important to assign

1.3 Project Objectives

The main objective of this study is to find the effect of changing available parameters on GPS accuracy by finding the standard deviation of the observed points of the assigned area of Wadi Al-Hariia (PPU Campus), the following data and parameters should be obtained and determined:

1. Specifying available parameters could be changed in GPS instrument.
2. Specifying the boundary of study area .
3. Specifying the references and previous studies .
4. Observing the assigned points in the study area .
5. Calculation of the Root Mean Square Error and Standard Deviation of the observed points.
6. Comparing results, and finding the best value for each parameter changed, according to the RMSE and Standard deviation .

1.4 Methodology

This project deals with changing available parameters in GPS instrument , and there effects on measurements accuracy. Some parameters have been changed in GPS instrument, these parameters include: {Time, Mask angle, and Measuring method(static &RTK)} and there effect on accuracy on some control points with fixed coordinates, the work flow can be classified as:

1. Choosing the title of project.
2. Research on some references that deal with the project by connection with libraries and internet.
3. Collecting appropriate data from these sources.
4. Classification of the data that is collected from sources.
5. And side by side we are working in field to collect data by GPS instrument (Trimble 5700).
6. In the first work we will measure by the default parameters in the instrument.
7. In the other field work we will change one parameter and fix the others.
8. The measuring procedures are classified into two steps:
    a. Real time kinematics (RTK).
    b. Static.
9. All measured data stored immediately in base station and data collector.
10. After completing all measurements that meet the objectives of this project we did a computation process.
11. Finally we compared the results and the effect of each changeable parameter on accuracy.

1.5 Study Area

The study area, named Wadi Al-Hariiah (PPU Campus), is located at south Hebron city of the west bank area. Figure (1.1) and Figure(1.2) show the study area and its location, and the major land use/land cover categories in the region are: pasture, agricultural area, and stony land.

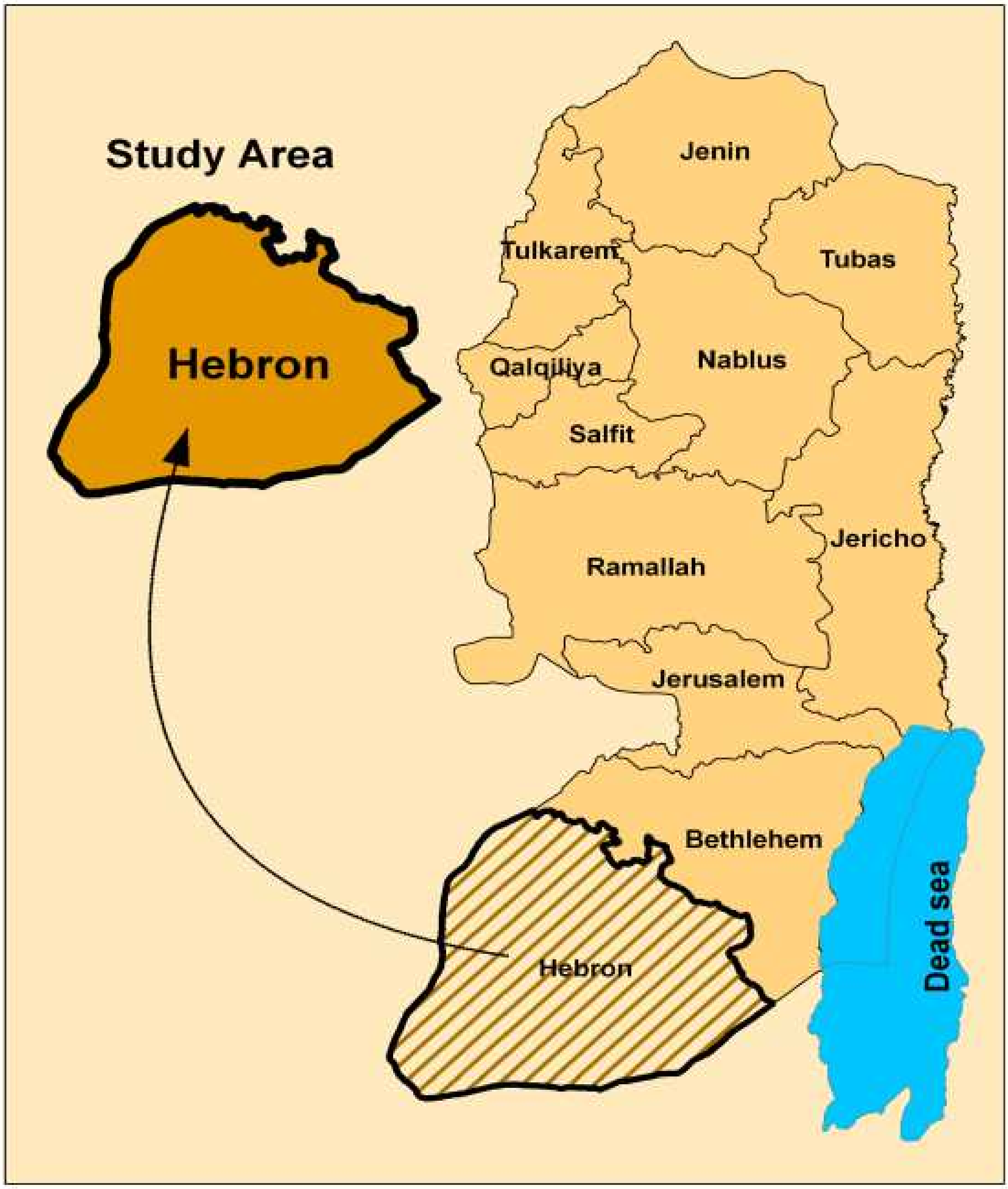


Figure (1.1): Hebron City

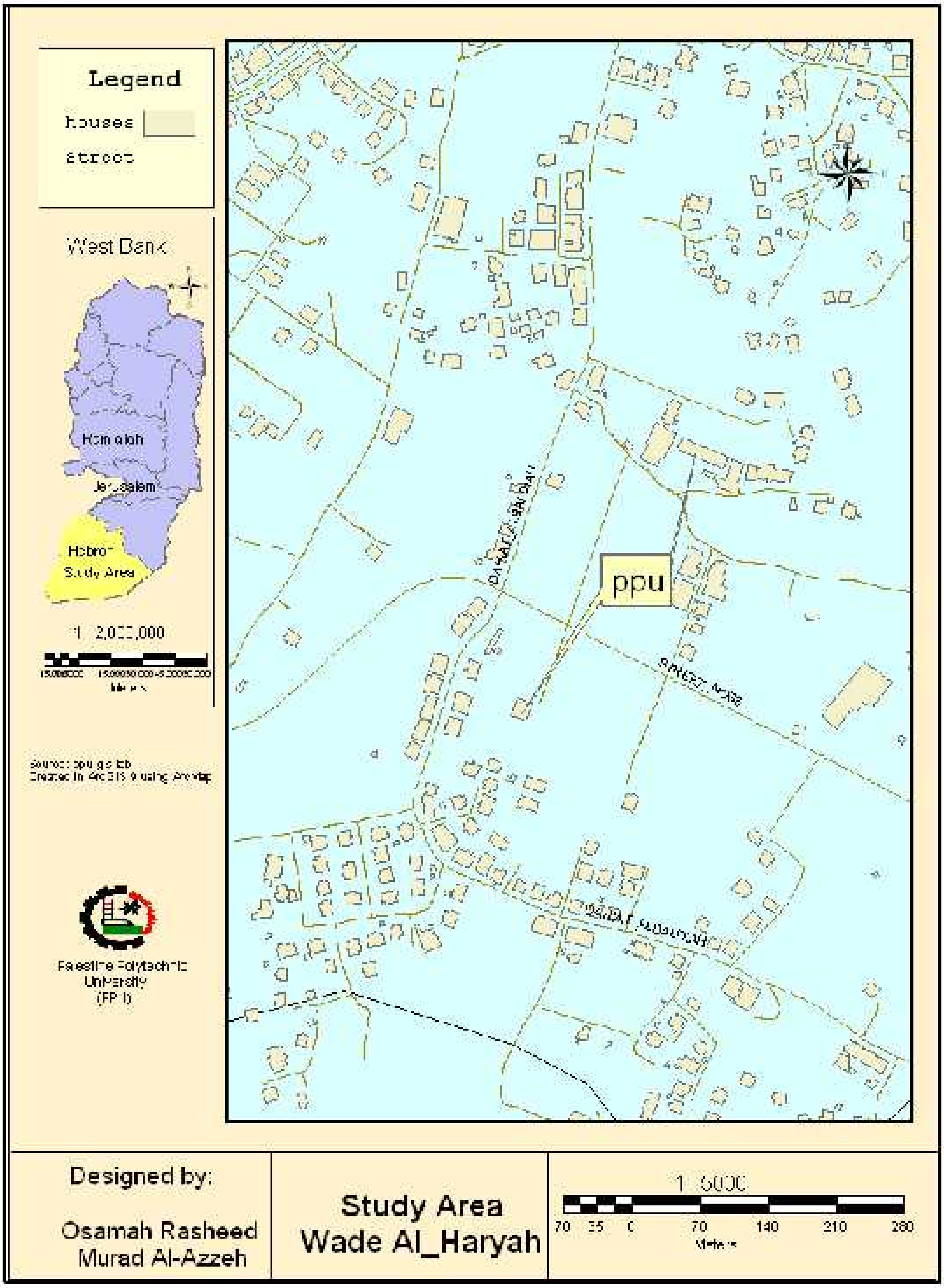


Figure (1.3): Study Area

1.6 Previous Studies

In our country, the GPS studies are limited some investigators have studies the GPS of different targets in the West Bank and especially in Palestine polytechnic university in order to develop additional usable of the GPS constellation .

- In the study of Mufeed, S. et al (2005), Comparison between Surveying techniques Static and RTK using GPS in the Hebron area of PPU Campus .

- In the study of Ammar, J. et al (2006), Geodetic network using GPS techniques in Hebron area, between the three university buildings .

1.7 Problems and Limitations

There is only one problem present in this project due to the Lack of references, the references that covers this project are highly limited .

1.8 Equipment Necessary to Carryout a GPS Survey

✓ **Equipment for instrument station**

The following list may be taken as a guide:

- GPS receiver, antenna and associated cabling.
- External batteries (including spares), Battery charger.
- Antenna tripod, tribrachs or adaptors for mounting antenna on pillars.
- Field books, access details, observation schedule instructions, etc.
- Useful ancillary equipment: camera, communications equipment.

✓ **Equipment at base station or field office**

The following equipments may be taken as a guide:

- List of station coordinates topographic maps, observation schedules, and recovery\ access diagrams.
- Portable computer with suite of software for the down loading, checking, pre-processing, and perhaps baseline processing of GPS data collected by individual field parties if available.
- Data storage as flash memory for the archiving and storage of tracking data.
- Computer modem for transmitting to head office.
- Cables and ancillary equipment for downloading data from GPS receivers.
- Communication equipment as wireless radios, or mobiles to ensure contact between field parties and head office.
- Spare equipments like receiver , batteries , cables , and other field equipments like total station (EDM) , 30 m tape ,…..etc .
- Conveyance and transportation.

1.9 Project Outline

The study report has been prepared in accordance with the objectives and scope of work. The report consists of seven chapters.

The first chapter entitled "**Introduction**" outlines the problem, project objectives, literature review, study area, and structure of the report.

The second chapter entitled "**Introduction to GPS and GPS Errors**" explains GPS constellation, GPS signals, the accuracy of GPS, GPS error budget, GPS positioning modes, the effect of terrain on GPS solutions, and differential GPS.

The third chapter entitled" **GPS Parameters and There Effect on Accuracy** " deals with mask angle, Geometric dilution of precision, GPS time, and Effect of Antenna performance on the GPS signal accuracy.

The fourth chapter entitled" **Software and 5700 GPS Receiver**" deals with Trimle geomatics office v1.6 software, 5700 GPS receiver, and setup receiver and start RTK survey and Static.

The fifth chapter entitled" **Field Measurements and Data Description**" deals with Positioning Trimble's main antenna, Network establishment, Net work measurement, Real time kinematic observations, Static observations, Analysis of fixed baseline measurements, Analysis of repeat baseline measurements, and Least squares adjustment of GPS networks **.**

The sixth chapter entitled" **Calculatins**" deals with Positioning of Trimble's main antenna, and Calculation Diagrams.

The overall **Conclusions** and **Recommendations** are given in chapter seven.

CHAPTER TWO

INTRODUCTION TO GPS AND GPS ERROR

2.1 GPS Theoretical background

2.2 What's the signal

2.3 How accurate is GPS

2.4 GPS error budget

2.5 GPS positioning modes

2.6 The effect of terrain on GPS solutions

2.7 Differential GPS

CHAPTER TWO

INTRODUCTION TO GPS AND GPS ERROR

2.1 GPS Theoretical Background

2.1.1 GPS Definition

GPS is a satellite-based radio navigation system, initially developed in the early 1960s and operated by the U.S. Department of Defense (DOD) since then. However, subsequent to a 1966 Presidential Decision Directive which was later passed into law, the "ownership" from DOD was transferred to an Interagency GPS Executive Board (IGEB), co-chaired by senior officials of the Departments of Transportation and Defense to provide management oversight and to assure that GPS meets both civil and military user requirements. The optimum system was viewed as having the following attributes: global coverage, continuous (all weather) operation, ability to serve highly dynamic platforms and high accuracy.

GPS consists of three segments - the satellite constellation, ground control network, and user equipment. The satellite constellation comprises satellites in low earth orbit that provide the ranging signals and navigation data messages to the user equipment. The ground control network tracks and maintains the satellite constellation by monitoring satellite health and signal integrity and maintaining the satellite orbital configuration. Furthermore, the ground control network also updates the satellite clock corrections and ephemeris as well as numerous other parameters essential to determining user position, velocity and time (PVT). The user equipment receives signals from the satellite constellation and computes user PVT.

2.1.2 Components of GPS

2.1.2.1 Space Segment

The baseline satellite constellation consists of 24 satellites positioned in six earth-centered orbital planes with four operation satellites and a spare satellite slot in each orbital plane. The system can support a constellation of up to thirty satellites in orbit. The orbital period of a GPS satellite is one-half of a sidereal day or 11 hours 58 minutes. The orbits are nearly circular and equally spaced about the equator at a 60-degree separation with an inclination of 55 degrees relative to the equator. The orbital radius (i.e. distance from the center of mass of the earth to the satellite) is approximately 26,600 km.

With the baseline satellite constellation, users with a clear view of the sky have a minimum of four satellites in view. It’s more likely that a user would see six to eight satellites. The satellites broadcast ranging signals and navigation data allowing users to measure their pseudo ranges in order to estimate their position, velocity and time, in a passive, listen-only mode. Note Figure (2.1).

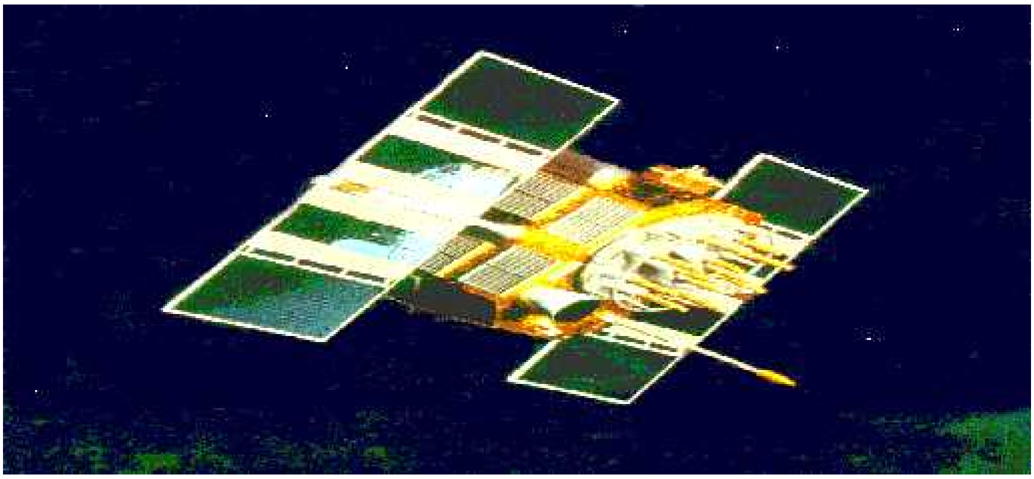


Figure (2.1): Space Segment

2.1.2.2 Control Segment

At the heart of the Ground Control Network is the Master Control Station (MCS) located at the Schreiber (formerly named Falcon) Air Force Base near Colorado Springs, Colorado. The MCS operates the system and provides command and control functions for the satellite constellation.

The satellites in orbit are continuously tracked from six USAF monitor stations spread around the globe in longitude: Ascension Island, Diego Garcia, Kwajalein, Hawaii , Cape Canaveral and Colorado Springs . The monitor stations form the data collection component of the control network. A monitor station continuously makes pseudo range measurements to each satellite in view. There are two cesium clocks referenced to GPS system time in each monitor station. Pseudo range measurements made to each satellite in view by the monitor station receiver are used to update the master control station’s precise estimate of each satellite’s position in orbit. Figure (2.2)

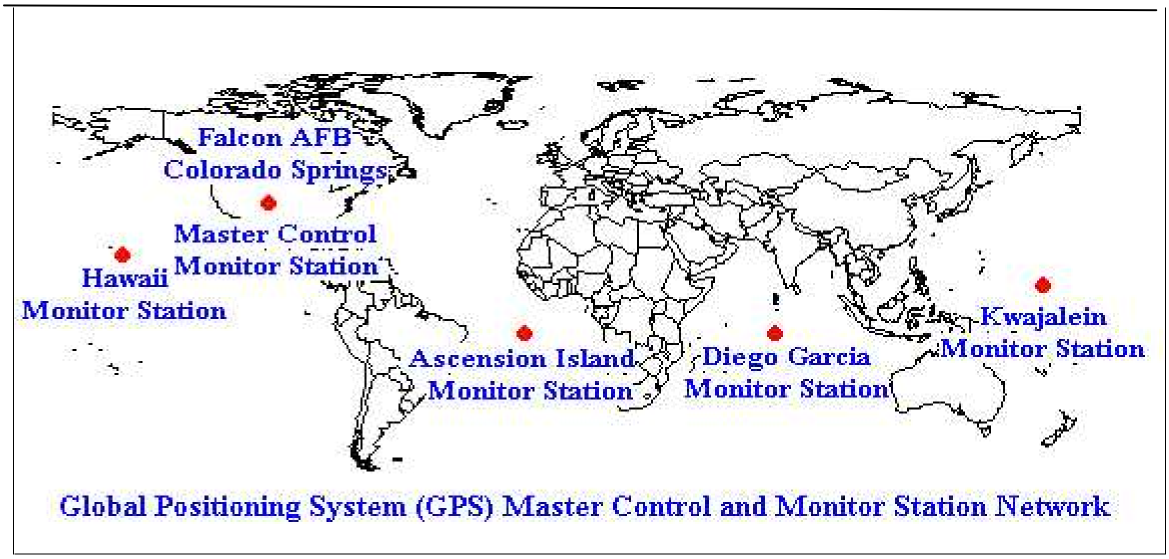


Figure (2.2):Control Segment

2.1.2.3 User Segment

The user equipment often referred to as “GPS receivers”, captures and processes L-band signals from the satellites in view for the computation of user position, velocity and time. Figure (2.3)

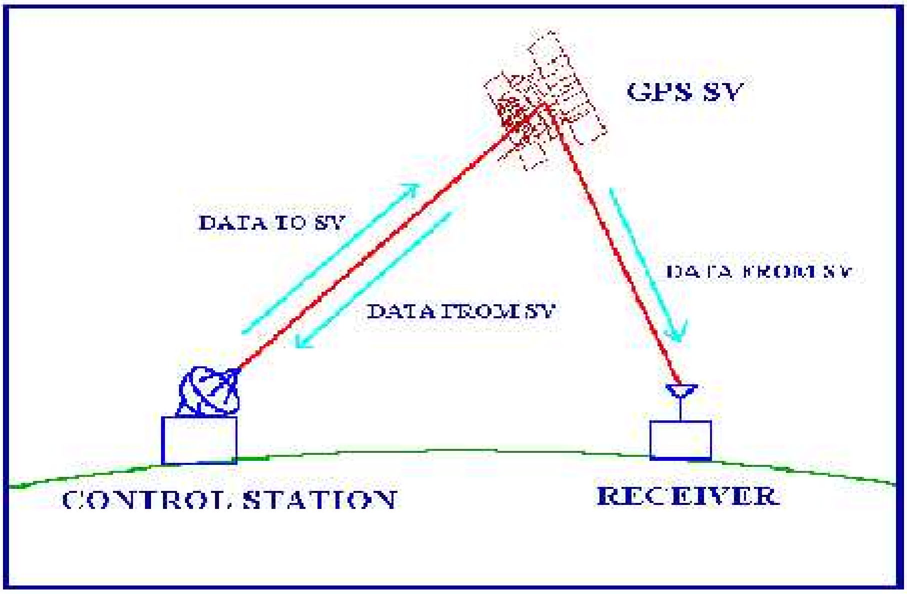


Figure (2.3):User segment

2.1.3 How GPS Works

GPS satellites circle the earth twice a day in a very precise orbit and transmit signal information to earth. GPS receivers take this information and use triangulation to calculate the user's exact location. Essentially, the GPS receiver compares the time a signal was transmitted by a satellite with the time it was received.

The time difference tells the GPS receiver how far away the satellite is. Now, with distance measurements from a few more satellites, the receiver can determine the user's position and display it on the unit's electronic map. Figure (2.4)

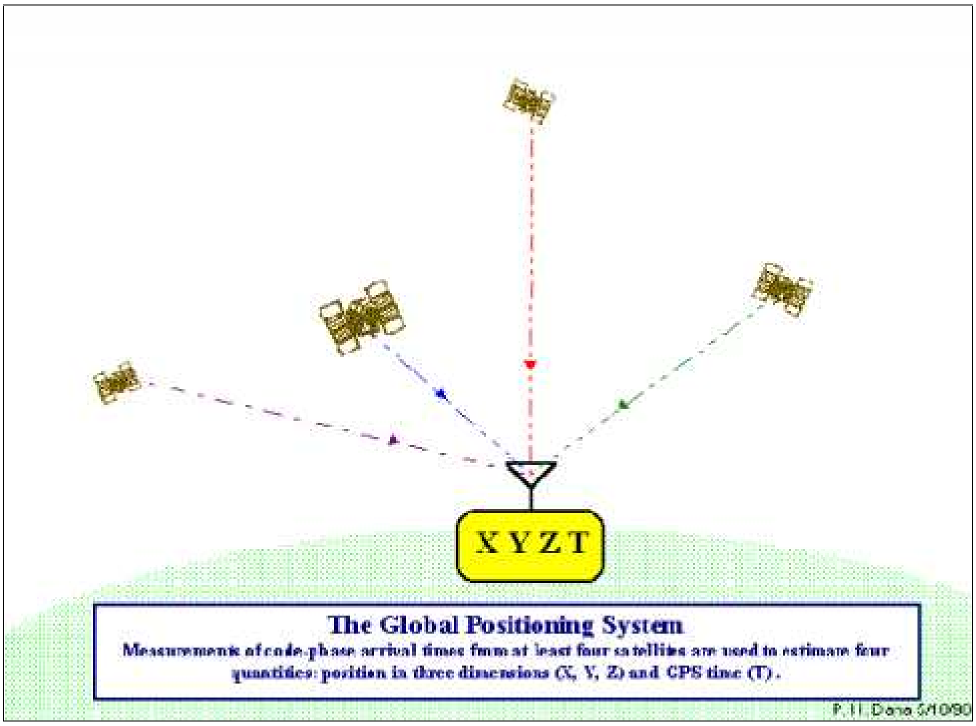


Figure (2.4): How GPS works

A GPS receiver must be locked on to the signal of at least three satellites to calculate a 2D position (latitude and longitude) and track movement. With four or more satellites in view, the receiver can determine the user's 3D position (latitude, longitude and altitude). Once the user's position has been determined, the GPS unit can calculate other information, such as speed, bearing, track, trip distance, distance to destination, sunrise and sunset time and more.

2.2 What's the Signal?

GPS satellites transmit two low power radio signals, designated L1 and L2. Civilian GPS uses the L1 frequency of 1575.42 MHz in the UHF band. The signals travel by line of sight, meaning they will pass through clouds, glass and plastic but will not go through most solid objects such as buildings and mountains.

A GPS signal contains three different bits of information - a pseudorandom code, ephemeris data and almanac data. The pseudorandom code is simply an I.D. code that identifies which satellite is transmitting information. You can view this number on your Garmin GPS unit's satellite page, as it identifies which satellites it's receiving.

Ephemeris data tells the GPS receiver where each GPS satellite should be at any time throughout the day. Each satellite transmits ephemeris data showing the orbital information for that satellite and for every other satellite in the system.

Almanac data, which is constantly transmitted by each satellite, contains important information about the status of the satellite (healthy or unhealthy), current date and time. This part of the signal is essential for determining a position. Figure (2.5)

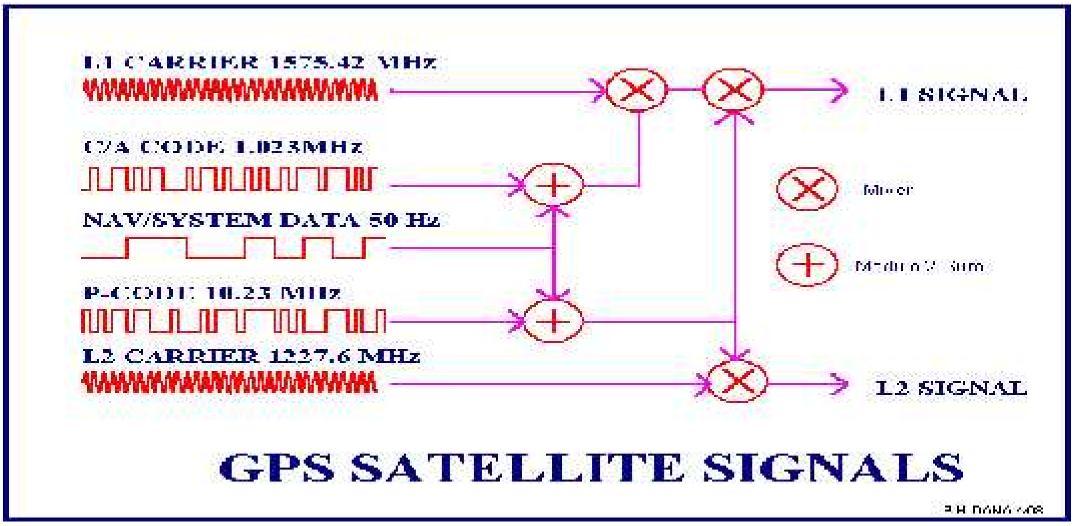


Figure 2.5: GPS signals

2.3 How Accurate is GPS?

Today's GPS receivers are extremely accurate, thanks to their parallel multi-channel design. 12 parallel channel receivers are quick to lock onto satellites when first turned on and they maintain strong locks, even in dense foliage or urban settings with tall buildings. Certain atmospheric factors and other sources of error can affect the accuracy of GPS receivers. GPS receivers are accurate to within 15 meters on average.

Newer GPS receivers with WAAS (Wide Area Augmentation System) capability can improve accuracy to less than three meters on average. No additional equipment or fees are required to take advantage of WAAS. Users can also get better accuracy with Differential GPS (DGPS), which corrects GPS signals to within an average of three to five meters. The U.S. Coast Guard operates the most common DGPS correction service. This system consists of a network of towers that receive GPS signals and transmit a corrected signal by beacon transmitters. In order to get the corrected signal, users must have a differential beacon receiver and beacon antenna in addition to their GPS. Figure (2.6)

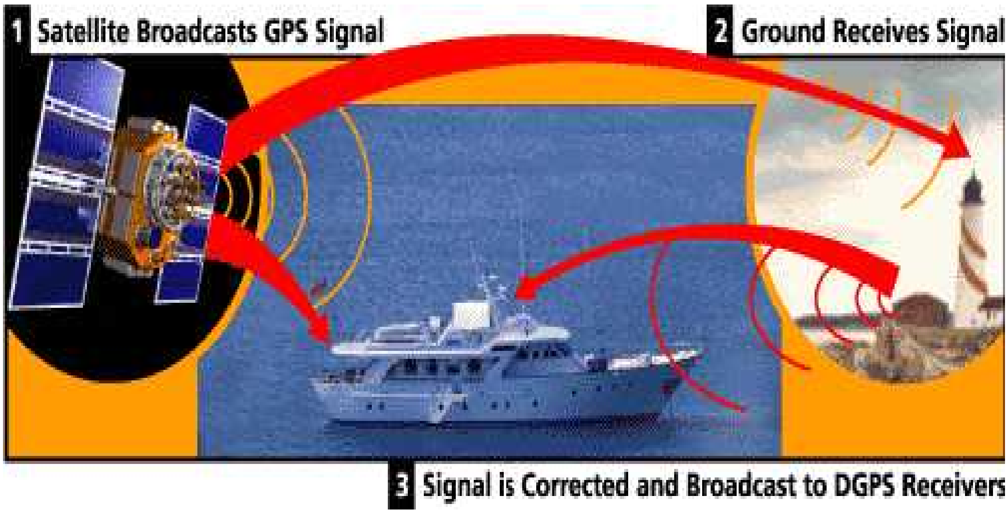


Figure (2.6): GPS Accuracy

2.4 GPS Error Budget

Factors that can degrade the GPS signal and thus affect accuracy include the following:

2.4.1 Ionosphere and troposphere delays — the satellite signal slows as it passes through the atmosphere. The GPS system uses a built-in model that calculates an average amount of delay to partially correct for this type of error.

2.4.2 Signal multi path — this occurs when the GPS signal is reflected off objects such as tall buildings or large rock surfaces before it reaches the receiver. This increases the travel time of the signal, thereby causing errors.

2.4.3 Receiver clock errors — a receiver's built-in clock is not as accurate as the atomic clocks onboard the GPS satellites. Therefore, it may have very slight timing errors.

2.4.4 Orbital errors — also known as ephemeris errors, these are inaccuracies of the satellite's reported location.

2.4.5 Number of satellites visible — the more satellites a GPS receiver can "see," the better the accuracy .Buildings, terrain, electronic interference, or sometimes even dense foliage can block signal reception, causing position errors or possibly no position reading at all. GPS units typically will not work indoors, underwater or underground.

2.4.6 Satellite geometry/shading — this refers to the relative position of the satellites at any given time. Ideal satellite geometry exists when the satellites are located at wide angles relative to each other. Poor geometry results when the satellites are located in a line or in a tight grouping.

2.4.7 Intentional degradation of the satellite signal — Selective Availability (SA) is an intentional degradation of the signal once imposed by the U.S. Department of Defense. SA was intended to prevent military adversaries from using the highly accurate GPS signals. The government turned off SA in May 2000, which significantly improved the accuracy of civilian GPS receivers.

SA was a technique implemented by the DOD to intentionally degrade a user's navigation solution. The single largest source of error for SPS users was SA. The net result of SA was about a five-fold increase in positioning error. DOD achieved signal degradation by altering (also known as dithering) the satellite clock. Another means ephemeris parameters.

The DOD-authorized users were able to undo SA. However, due to the fact that SA is spatially correlated, civil users were able to eliminate SA through the implementation of Differential GPS (DGPS), albeit an additional expense on the part of the users.

2.5 GPS Positioning Modes

Static positioning: coordination of stationary points, either in absolute or relative mode. This is generally synonymous with the SURVEYING mode of positioning, based on the analysis of carrier phase observations.

Kinematic positioning: coordination of moving points, either in absolute or relative mode. This is generally the NAVIGATION mode of positioning, based on pseudo-range observations.

RTK positioning: Real Time Kinematic GPS has been adopted across a broad range of engineering survey activities. From its incept as a tool to densify site control RTK has moved quickly to become the preferred system for engineering stake-out and measure and is now making rapid in-roads in the new and innovative application on construction and earthmoving equipment.

2.5.1 Static Surveying

Static used for long lines, geodetic network, tectonic plate studies etc, offers high accuracy over long distances but is comparatively slow.

This was the first method to be developed for GPS surveying .it can be used for long baselines (usually 20 km an over) in this method tow or more GPS receivers at two or more stations simultaneously receive signals from a minimum of four satellites. one receivers is placed on point whose coordinate are known accurately in UTM or local.

The other receivers is placed on the end of the other end of the baselines and is known as the rover, data is then recorded at both stations simultaneously it is important that data is being recorded at the same rate epoch at each station.

The data collection rate may be typically set to 15 , 30 or 60 seconds ,occupation time depends on the type of GPS receivers, the separation distances between receivers, the ionosphere activity ,number of satellites and the geometry .

As a rule of thumb, the observation time is a minimum of 1hour for 20 km line with 5 satellites longer line required observation time .good coordination is required between the survey crews in order to maximize the potential of having three receivers.

2.5.2 Kinematics Surveying

Used for detail survey and measuring many point in quick succession. very efficient way measuring many point are close together. However if there are obstructions to the sky such as bridges , trees ,tall building etc ,and less than 4 satellite are tracked , the equipment must be reinitialized which can take 5-10 minutes.

The kinematic technique is typically used for detail surveying recording the technique involves a moving rover position can be calculate relative to the reference (base).

The kinematic surveying is that receivers must maintain a lock to minimum of four satellite the reference and rover are switched on and remain absolutely stationary for (5-20) minutes collecting data ,the actual time depends on the baseline from the reference and the number of satellite observed after this period the rover may then move freely.

A major point to watch during kinematic surveys is to avoid moving too close to objects that could block the satellite signal from the rover receiver.

If any time less than four satellite are tracked by the rover receiver ,you must stop, move into a position where four or more satellite are tracked and perform an initialization again before continuing .

2.5.3 (RTK) Real-Time Kinematic GPS

Uses a radio data link to transmit satellite data from the reference to the rover this enables coordinates to be calculated and displayed in real time, as the survey is being carried out used for similar application as kinematic .a very effective way for measuring detail as results are presented as work is carried out .this technique is however reliant upon a radio link, which is subject to interference from other sources and also line of sight blockage.

The reference station has a radio link attached an rebroadcasts the data it receives from the satellite. The rover also has a radio link and receives the signal broadcast from the reference. The rover also receives satellite data directly from the satellite Via its own GPS Antenna .These two sets of data can be processed together at the Rover to resolve the ambiguity and therefore obtain a very accurate position relative to the Reference receiver.

Once the Reference Receiver has been set up and is broadcasting data through the radio link, the Rover Receiver can be activated. When it is tracking satellites and receiving data from the Reference, it can begin the initialization process.

Once the initialization is complete, the ambiguities are resolved and the Rover can record point and coordinate data. At this time, baseline accuracies will be in the1-5 cm range. It is important to maintain contact with the Reference Receiver; otherwise the Rover may lose the ambiguity. This results in a far less accurate position being calculated. Additionally, problems may be encountered when surveying close to obstructions such as tall buildings, trees etc. as the satellite signal may be blocked.

RTK is quickly becoming the most common method of carrying out high precision high accuracy GPS surveys in small areas and can be used for similar applications, as a conventional total station.

2.6 The Effect of Terrain on GPS Solutions

A common issue of concern among GPS users is how to correctly model the effects of local terrain on GPS predictions. If a user is standing in a crater, surrounded by walls of the same height on all sides, raising your receiver mask angle to match that of the terrain is appropriate. If, however, you're sitting in the GPS Support Center, with Pike's Peak to the west and flat plains to the north, east, and south, raising your mask angle might not be the best solution.

For those users who think terrain may be having an impact on their GPS solutions, there is a relatively simple two-step process that can help to rule out local terrain as a source of interference. The first step is to determine your GPS receiver's mask angle. Each receiver has a mask angle built into it, often referred to as the 'receiver mask'. The purpose of the mask angle is to screen out all satellites below a certain angle above the horizon. The mask angle is usually set to 0, 5, or 10 degrees above the horizon. Any satellites below this mask will be ignored by the receiver. Figure (2.6) contains a visual example of a receiver mask angle. If the user's receiver has a 10 degree mask angle, the receiver will ignore the satellite if it passes below the red line.

Likewise, if the receiver is set to a 5 degree mask, the receiver will ignore the satellite if it passes below the yellow line. Users should consult their receiver's manual or contact the receiver manufacturer to obtain this information.

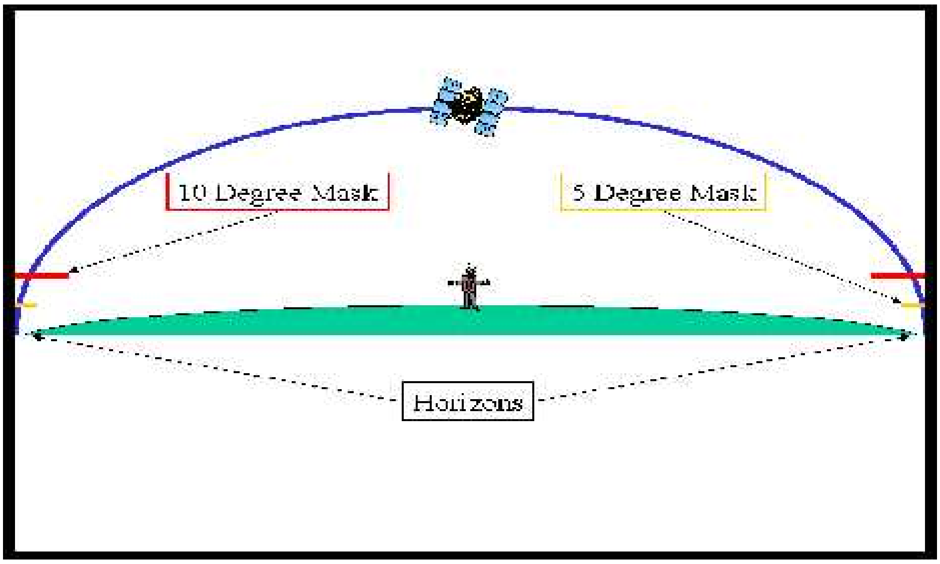


Figure (2.7): The effect of terrain on GPS solutions

The second step is to determine how many degrees the local terrain is actually masking. Figure (2.7) shows the relationship between relative terrain height, distance from the terrain, and resulting mask angle. The different colored lines each represent a different height of terrain with respect to the user. The horizontal white line represents a 5 degree mask angle (the standard military mask angle per the Navstar User's Overview). By referencing the terrain height relative to the user's current position and the terrain's distance from the user, the mask angle caused by the terrain can be determined. Using the GPS Support Center as an example, Pikes Peak is slightly over 14,000 ft high. The support center is slightly over 6,000 ft high, giving a relative terrain height of 8,000 ft (the Blue line). The Support Center is a little over 20 miles from the base of Pike's Peak. Using the chart, we can determine that Pike's Peak causes less than a 5 degree terrain mask from our position.

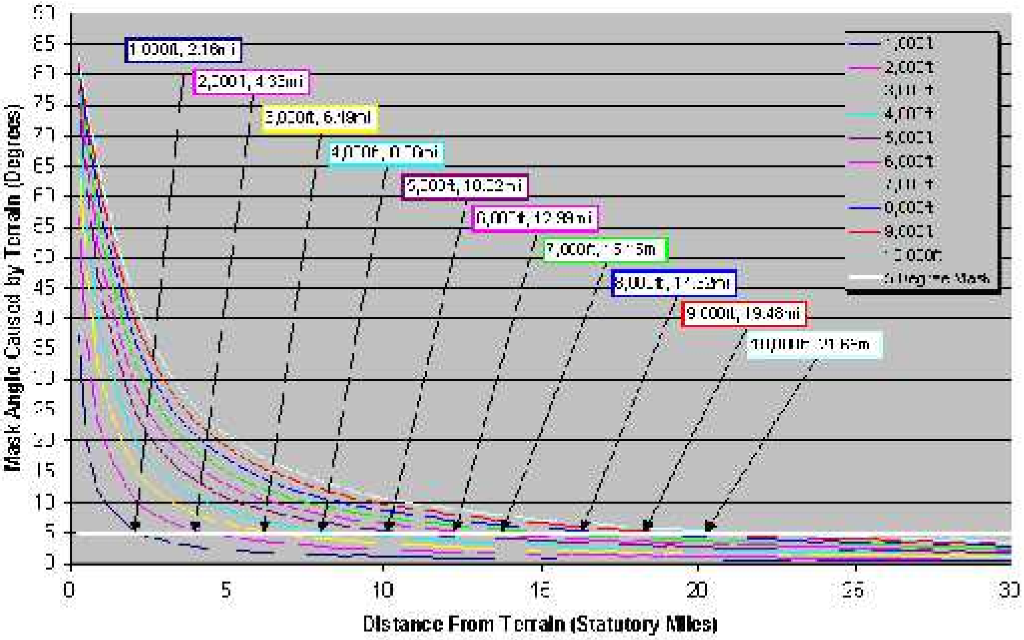


Figure (2.7): Terrain mask angle (Terrain heights are relative to observer)

If the terrain mask angle is less than the receiver's mask angle, the terrain can be completely ignored for the purposes of predicting GPS accuracy. If, however, the terrain mask angle is greater than the receiver's mask angle, users' options for determining terrain's effects are somewhat limited.

One option is to obtain the raw data from your receiver and post-process it to see which satellites were tracked. This isn't of much use to someone trying to predict future GPS performance. Another option is to integrate terrain and elevation data into your prediction tool. The National Imagery and Mapping Agency (NIMA) has already compressed this data for approximately 70% of the worlds landmass into a single resource, Digital Terrain Elevation Data (DTED). DOD and civilian users can obtain DTED through NIMA. With DTED integrated into a prediction tool, the effects of having an 8,000 ft peak due west of your position can be factored in without resorting to raising your mask angle in all 360 degrees. Users interested in having DTED data integrated into their GPS prediction software should contact their software provider or configuration manager.

2.7 Differential GPS

DGPS achieves enhanced accuracy since the reference and user receivers both. Experience common errors that can be removed by the user. Position errors less than 10 meters are typically realized.

In the basic form of DGPS, the position of a reference receiver at a monitoring or reference station is surveyed in, that is, its position is known accurately. The user receiver should be no more than about 300 miles away from the reference receiver which makes pseudo range measurements, just as any user receiver would. However, because the reference receiver knows its position accurately, it can determine “biases” in its pseudo range measurements. For each satellite in view of the reference receiver, these biases are computed by differencing the pseudo range measurement and the satellite-to-reference receiver geometric range. These biases incurred in the pseudo range measurement process include errors arising from ionospheric delay, troposphere delay, and satellite clock offset from GPS time**.** For real-time applications, the reference station transmits these biases, called differential corrections, to all users in the coverage area of the reference station. Users incorporate these corrections to improve the accuracy of their position solution.

For the basic local area DGPS (LADGPS) the position solutions of users further away from the reference station are less accurate than those closer to the monitoring station because pseudo range measurement errors tend to be spatially correlated.

This loss of accuracy due to spatial de correlation can be improved with more sophisticated techniques that fall under the heading of wide area DGPS (WADGPS) such as WAAS.

CHAPTER THREE

GPS PARAMETERS AND THERE EFFECTS ON ACCURACY

3.1 Mask Angle

3.2 Geometric Dilution of Precision

3.3 GPS Time

3.4 Effect of Antenna Performance on the GPS Signal Accuracy

CHAPTER THREE

GPS PARAMETERS AND THERE EFFECTS ON ACCURACY

There are a set of basic performance parameters that are useful for making comparisons between different accuracies. This set of parameters together, can be used to determine what type of accuracy one should choose for a particular application. The parameters of interest are:

- Mask angle
- Dilution of precision
- Time in GPS
- Method RTK and Static

3.1 Mask Angle

The satellite mask angle, which is specified in units of degrees, defines the elevation angle above which satellites are considered to be visible. There are several reasons for including such a parameter, as itemized in the list below:

a. Satellites that are very close to the horizon generally have significantly lower signal to noise ratios and therefore have observations that are of lower quality (are noisier) than other satellites with higher signal to noise ratio’s.

b. Low elevation satellites are subject to tropospheric delay terms that are larger in magnitude than satellite’s that are at higher elevations. Although the GPS receiver applies a nominal model for correction of atmospheric delay, the model is somewhat crude.

For reference, the model used in the MG5000 GPS Receiver is the Chao model as used within the GS700 GPS simulator. This model computes the tropospheric error using following formula:

$$T_{chao} = Z \exp(-h/H) / (\sin(e) * c) \qquad (3.1)$$

Where Z is the static zenith delay error at sea level (in meters, value of 2.208 m), h is the user altitude above sea level, although the GPS receiver uses altitude above the spheroid (in meters), H is the tropospheric scale-altitude (in meters), e is the satellite elevation angle (in radians) and *c* is the speed of light.
The output is saturated at a maximum value of 500 ns.

c. Lower elevation satellites may be subject to more multipath than higher elevation satellites.

d. When differential GPS corrections are being used, it is important to ensure that the GPS receiver is not using satellites for which differential corrections are not being received. This means that if the DGPS station is using a mask angle of seven degrees, then the mobile receiver should use a mask angle of greater than seven degrees.

e. For receivers where a limited number of hardware channels are available (or for large GPS satellite constellations) it may be necessary to artificially reduce the number of visible satellites by using a non-zero mask angle.

Typically a default value of five degrees has been chosen, although this will be different given different applications. The only danger with this parameter is in setting it too high as this may reduce the number of visible satellite to less than three, thereby causing the GPS receiver to begin sky searching. Note that during a sky search operation artificial concepts like mask angles have no effect whatsoever, since sky search is basically performed when no GPS receiver parameters such as position are defined and satellite elevation angles cannot be determined.

3.2 Geometric Dilution of Precision (GDOP)

GDOP is a dimensionless multiplicative factor that is an instantaneous measure of the error in the positioning solution, contributed by the geometric relationships of the GPS satellites, as seen by the receiver. As an example, if two lines of position are necessary to establish a user position, the least amount of error is present when the lines cross at right angles. The greatest error is present as the lines approach parallel. (See Figure 3.1) Similarly, for GPS, the greatest amount of error is present when the lines-of-sight between the user and two or more satellites approach parallel, or when all four satellites approach the same plane.

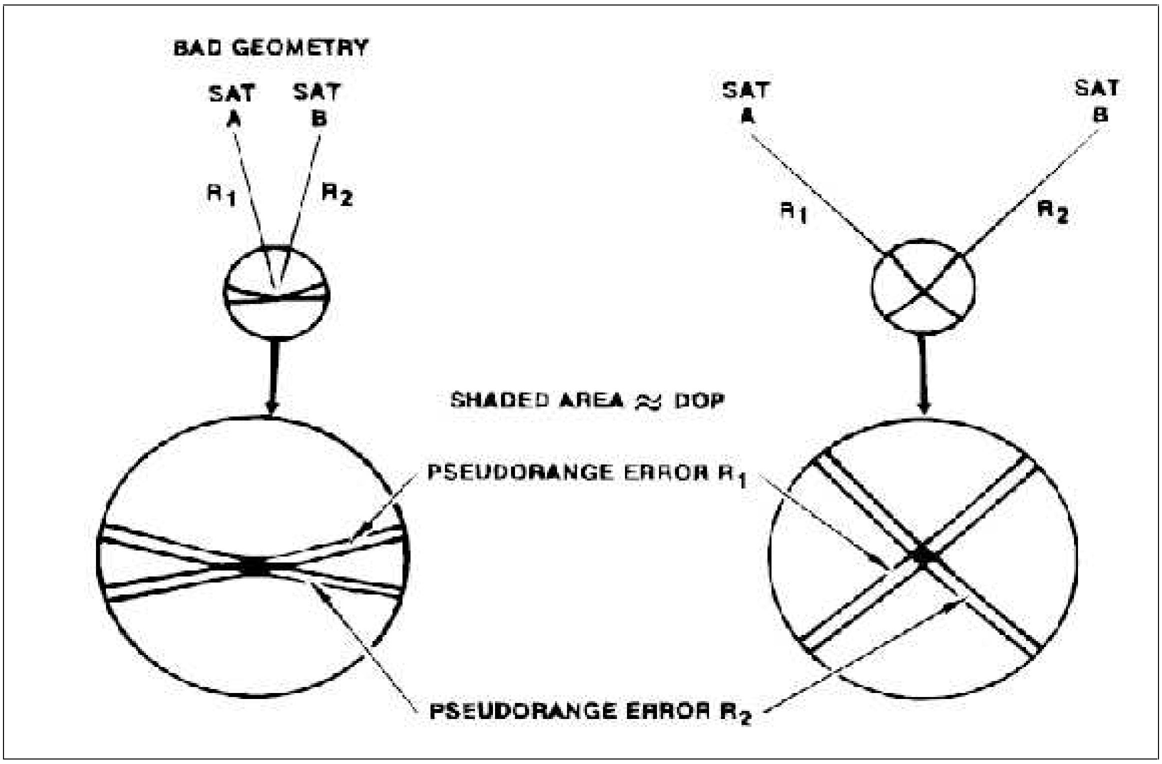


Figure (3-1): Dilution of Precision

Technical Characteristics of the Navstar GPS" contains the mathematical definition and derivation of GDOP. In short, if the one-sigma pseudo range measurement errors for all satellites are assumed to be unity, GDOP is defined to be the square root of the sum of the variances of the position and time error estimates.

$\mathrm{GDOP} = (S_x^2 + S_y^2 + S_z^2 + C^2St^2)^{1/2}$ ………………………..……………………… (3.2)

(Where "c" is the speed of light and "t" is the user clock bias)

GDOP is therefore considered to relate the standard deviation of the satellite range errors (UERE) to the standard deviation of the position solution errors. GDOP is normally considered to be unitless; the units (meters) being carried by the range error and position solution errors. Expressed as a mathematical formula:

$S_{\text{user}} \text{ x GDOP} = S_{\text{position solution error}}$……………………………………………..……….. (3.3)

Other dilution of precision factors can be defined which a subset of GDOP and have a more specific physical are meaning with respect to the x, y, and z axes in a local coordinate system. They include position dilution of precision (PDOP), horizontal dilution of precision (HDOP), vertical dilution of precision (VDOP) and time dilution of precision (TDOP). Mathematically they are defined as follows:

$\mathrm{PDOP} = (Sx^2 + Sy^2 + Sz^2)^{1/2}$ ………………………………………………………… (3.4)

$\mathrm{HDOP} = (Sx^2 + Sy^2)^{1/2}$ ……………………………………..………………... (3.5)

$\mathrm{VDOP} = (Sz^2)^{1/2}$ ……………………………………………………………………... (3.6)

$\mathrm{TDOP} = (St^2)^{1/2}$ ……………………………………………………………………… (3.7)

HDOP can be further resolved into its X and Y components. If the X axis is oriented in an East-West direction, an "East" DOP (EDOP) and "North" DOP (NDOP) can be defined as follows:

EDOP = $(Sx^2)^{1/2}$ …………………………………………………………………….. (3.8)
NDOP = $(Sy^2)^{1/2}$ ………………..……………………………………...…………… (3.9)

Similarly, if the Y axis is oriented along the track of a moving vehicle, a "cross-track"

DOP (XDOP) and an "along-track" DOP (ADOP) can be defined:

XDOP = $(Sx^2)^{1/2}$ ………………………..……………………………………………. (3.10)
ADOP = $(Sy^2)^{1/2}$ …………………………………………………………………... (3.11)

The various elements of GDOP can also be calculated for an over-determined position solution, that is, where the available satellite or aiding measurements exceed the required minimum of four, and an "all-in-view" solution is calculated. The mathematical formulations are similar, and generally result in a lower value of GDOP (hence better solution accuracy) for each additional measurement that is added to the calculation.

GDOP can also be "weighted" with a vector of UERE values in the matrix calculations for real-time or short-term error estimates where the satellite (or aiding) UERE values are not equal. As mentioned previously, this is generally the case for instantaneous values of UERE, and especially true for SPS where large differences in instantaneous UERE can be caused by Selective Availability. This is also true for aiding situations where the equivalent "UERE" of the aid is usually different than the typical satellite UERE. This "weighted" Navigation Error (UNE) and is sometimes termed "KDOP". KGDOP has the same definition as GDOP except that the statistical satellite range errors are not required to be equal. Similarly there are analogous subset definitions of KPDOP, KHDOP, etc.

Which DOP value may be most relevant to a particular application is dependent on the mission and associated accuracy requirements of that mission. (K)HDOP may be most important for land and open ocean navigation where horizontal position location and rendezvous are primary mission requirements.

It should be emphasized that it may be perfectly valid to translate user accuracy requirements between different dimensions and probability levels assuming a spherical error distribution and Gaussian error characteristics, if that is appropriate for the particular mission or application. The fact that GPS accuracy performance is nonspherical and non-Gaussian does not impose a similar condition on user requirements.

3.3 GPS Time

3.3.1 Introduction

Accurate time is transmitted around the world using satellite navigation technology, with the Global Positioning System (GPS) as the foremost example. This works by a worldwide MEO satellite navigational system formed by 24 satellites orbiting the earth and their corresponding receivers on the earth. The satellites orbit the earth at approximately 12,000 miles above the surface and make two complete orbits every 24 hours. The GPS satellites continuously transmit digital radio signals that contain data on the satellites location and the exact time to the earth -bound receivers. The satellites are equipped with atomic clocks that are precise to within a billionth of a second.

Based on this information the receivers know how long it takes for the signal to reach the receiver on earth. As each signal travels at the speed of light, the longer it takes the receiver to get the signal, the farther away the satellite is. By knowing how far away a satellite is, the receiver knows that it is located somewhere on the surface of an imaginary sphere centered at the satellite. By using three satellites, GPS can calculate the longitude and latitude of the receiver based on where the three spheres intersect. By using four satellites, GPS can also determine altitude.

The accuracy of time signals from GPS is limited to ±340 nanoseconds (where 1 nanosecond = 0.000 000 001 seconds) by a deliberate distortion of the satellite signal (for military security) called Selective Availability.

UTC is designed to be a compromise between the time defined by atomic clocks, and the time based on the earth's rotation about its axis. While the seconds of UTC are counted by atomic clocks, allowance is made to keep UTC within 0.9 seconds of Earth's rotation- time by inserting leap seconds (to take account of the speeding up or slowing down of the Earth) at the end of each quarter. Twenty two leap seconds have been added between January 1st 1972 and January 1st 1999 either at the end of June or December. Without the addition of leap seconds, the sun would be seen overhead at midnight (rather than noon) after approximately 50 000 years.

3.3.2 Receiver Time Accuracy

A dedicated PTTI port should normally be used for precise time output from a GPS receiver. Significant time delays and uncertainties from microseconds to milliseconds can be introduced if time output is accomplished via a digital data interface. For a PPS P-code GPS receiver, tracking 4 satellites, an absolute time accuracy of better than 200 nanoseconds (95%) relative to UTC is possible in a stationary or low-dynamic situation at an un surveyed location. Equivalent SPS C/A code accuracy is 340 nanoseconds (95%). Higher dynamics will increase time error. Errors in the PTTI output result from errors in the GPS receiver as well as the Control and Space segments. The system time transfer error budget is shown in Table (3.1).

Processing errors in the GPS receiver and unaccounted time delays to propagate the timing pulses to the PTTI port can add other (60-100) nanoseconds (95%), depending on receiver design. Therefore, a total (RSS) time error of (209-224) nanoseconds (95%) can be expected.

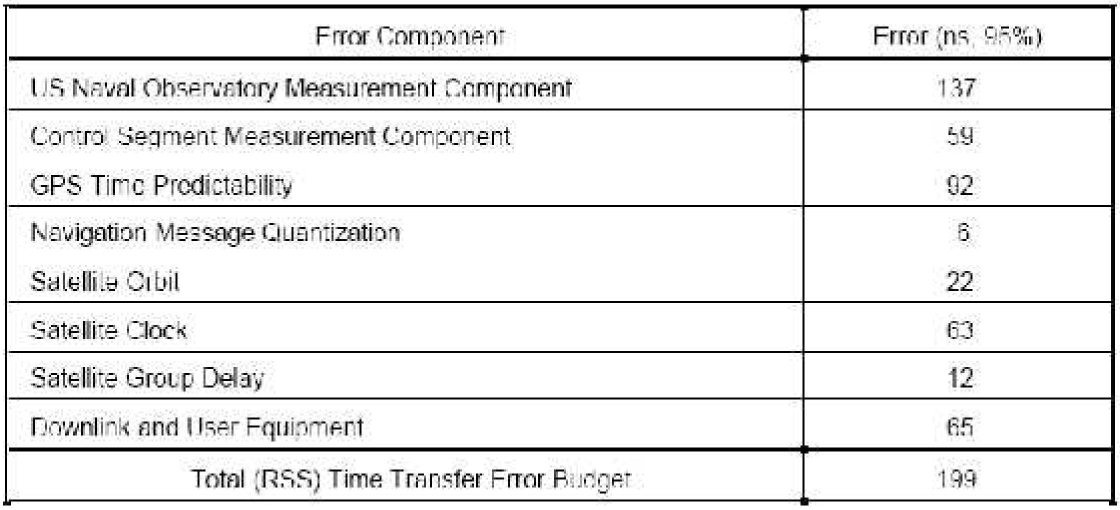
Typical 95% time accuracies expected for precise time dissemination for different categories of GPS receivers are shown in Tables (3.2) and (3.3), assuming an RSS of 88 ns for the Control and Space Segment errors, and 78 ns for the PTTI error.

3.3.2.1 TIME-TO-FIRST-FIX

Time-To-First-Fix (TTFF) is a measure of the elapsed time required for a receiver to acquire the satellite signals and navigation data, and calculate the first position solution. TTFF begins when initialization of the receiver is complete. And the receiver is commanded to begin the positioning function. Some source material (U.S. DOD in particular) may refer to $TTFF_1$ and $TTFF_2$. $TTFF_1$ is based on C/A-code acquisition with hand over to P-code tracking. $TTFF_2$ is based on direct P-code acquisition.

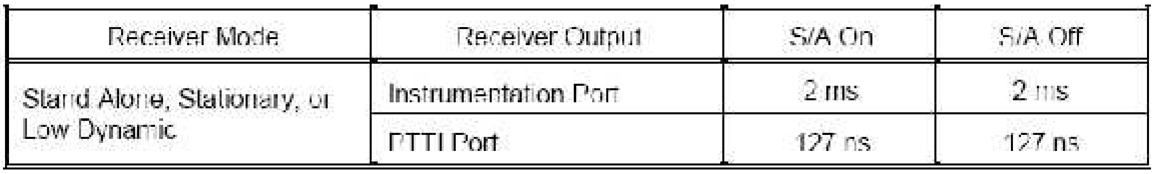
REAC (reaction time) is the term typically used to include both the initialization process and TTFF. Since initialization may necessitate operator action, REAC specifications or require ments may require assumptions of operator response times. TTFF is a function of the initial receiver state as well as receiver design. The following paragraphs describe the satellite acquisition and initial positioning processes in more detail.

Table (3.1): Time Error Budget



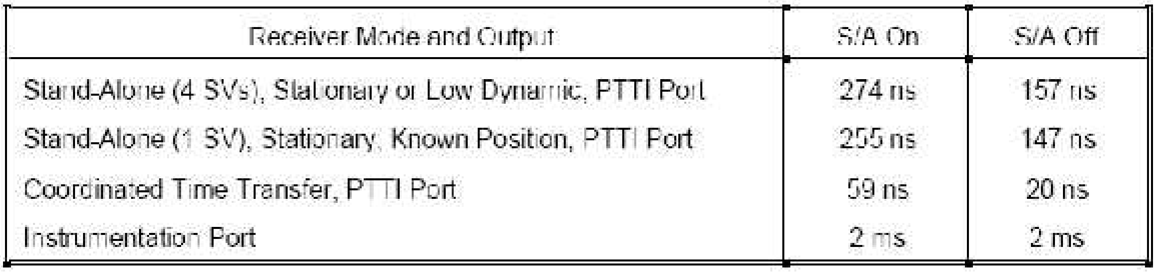
Error Component	Error (ns, 95%)
US Naval Observatory Measurement Component	137
Control Segment Measurement Component	59
GPS Time Predictability	92
Navigation Message Quantization	6
Satellite Orbit	22
Satellite Clock	63
Satellite Group Delay	12
Downlink and User Equipment	65
Total (RSS) Time Transfer Error Budget	199

Table (3.2): Precise Time Output Accuracy (95%) for a Typical PPS P-code Receive



Receiver Mode	Receiver Output	S/A On	S/A Off
Stand Alone, Stationary, or Low Dynamic	Instrumentation Port	2 ms	2 ms
	PTTI Port	127 ns	127 ns

Table(3.3):Precise Time Output Accuracy(95%) for a Typical SPS C/A-code Receiver



Receiver Mode and Output	S/A On	S/A Off
Stand-Alone (4 SVs), Stationary or Low Dynamic, PTTI Port	274 ns	157 ns
Stand-Alone (1 SV), Stationary, Known Position, PTTI Port	255 ns	147 ns
Coordinated Time Transfer, PTTI Port	59 ns	20 ns
Instrumentation Port	2 ms	2 ms

3.3.2.2 Warm Start, Cold Start, and Hot Start

Three different variations of TTFF are commonly defined and any one or all three can be specified or required for a particular receiver. A warm or normal start is based on the assumption that the receiver has an estimate of current time and position as well as a recent copy of the satellite almanac data. Typically, time should be known within 20 seconds of GPS time, position should be known within 100 kilometers, velocity within 25 meters per second, and the satellite almanac should have been collected within the past few weeks. TTFF1 for warm starts is typically in the 2 to 5.5 minute range.

A cold start occurs whenever there is a problem with these key data elements. This is typical of a receiver as delivered from a manufacturer, supply depot, or repair depot. Date and time will not be maintained if the receiver "keeps alive" battery has been removed or drained. If the receiver clock and memory remains active, the last known position might be at a factory or depot thousands of kilometers from the present position, and the almanac may be several months old. Under such conditions, the receiver may have to systematically "search the sky" until it can find a satellite and retrieve time and a current almanac. A cold start can add at least 12.5 minutes to TTFF1 over that based on a warm start.

A hot start occurs when a receiver is provided with a standby feature to maintain oscillator temperature, time, position, and individual satellite ephemerides (as well as the almanac). When the receiver is commanded out of the standby mode, the time required to achieve the next full position fix is usually Termed Time to Subsequent Fix (TTSF) rather than TTFF. Typically, TTSF is on the order of 10 seconds for standby periods of a few hours.

3.3.2.3 Receiver Warm-Up

When a GPS receiver is initially turned on, time must be allowed for the receiver crystal oscillator to warm up and stabilize at its normal operating temperature. In a GPS receiver it typically takes up to 6 minutes to complete this process. If the receiver is provided with a mode that keeps the oscillator warm, this contribution to TTFF can be avoided.

3.3.2.4 Almanac Collection

The first time a receiver is operated, it must perform an iterative search for the first satellite signal unless it can be loaded with a recent satellite constellation almanac, the approximate time and the approximate receiver location. The almanac gives the approximate orbit for each satellite and is valid for long time periods (up to 180 days). The almanac is used to predict satellite visibility and estimate the pseudo range to a satellite, thereby narrowing the search window for a ranging code. Once the first satellite signal is acquired, a current almanac can be obtained from the NAV msg. It takes up to 12 1/2 minutes to collect a complete almanac after initial acquisition. An almanac can be obtained from any GPS satellite. Most modern receivers can update the almanac periodically and store the most recent almanac and receiver position in protected memory. A clock can also be kept operating when the receiver is off or in standby mode, so as to minimize initial acquisition time for the next start-up.

3.3.2.5 Initial Uncertainties

The initial uncertainties associated with a GPS receiver's initial position, velocity, acceleration, and time inputs must be specified when satellite acquisition times are being tested. Acquisition and reacquisition times will vary depending on the accuracy of the receiver initialization. Some military TTFF requirements that include jamming and other sensitive parameters in the start-up scenario may be classified.

3.3.2.6 Ephemeredes Collection

Ephemeris data forms part of the 50 Hz NAV message transmitted from the GPS satellites. Unlike almanac data which can be obtained for the whole constellation from a single satellite, ephemeris must be collected from each satellite being tracked on acquisition and at least once every hour. Ephemeris information is normally valid for 4 hours from the time of transmission, and a receiver can normally store up to 8 sets of ephemeris data in its memory. Acquisition and reacquisition times for a receiver will vary, depending on whether valid ephemeris data is already available to the receiver. When testing acquisition time it is necessary to specify whether a valid set of ephemeris is resident or not within the receiver. Depending on the NAV msg collection scheme employed in a particular receiver, it can take between 30 seconds and 3 minutes to collect the ephemeris information.

3.3.2.7 Enhanced Acquisition Techniques

A number of enhanced acquisition techniques have been developed for modern receivers. TTFF performance can be significantly improved by the use of multi-tap correlations and multi-channel search algorithms. Multi-tap correlations are essentially multiple correlations in the same package which greatly enlarge each search window for code correlation. Similarly, using all available receiver channels in the search for the first satellite can reduce TTFF by maximizing the effective search window of the receiver.

3.3.2.8 Direct P(Y)-Code Acquisition

Direct P(Y)-code acquisition can be effectively achieved using enhanced acquisition techniques to enlarge the search window and/or by us ing atomic clock aiding to reduce the initial time uncertainty. Similarly, aiding from an inertial reference system can be used to reduce the initial velocity and position uncertainty.

Downloading initialization data from another receiver can be used for direct P(Y)-code acquisition as well.

3.3.2.9 TTFF Requirements

Figure (3.2) is a decision chart for determining TTFF requirements for the various initial conditions described above, as well as the TTFF1 and TTFF2 acquisition strategies and different receiver designs.

3.3.2.10 Satellite Reacquisition

Satellite reacquisition assumes a temporary loss of a satellite signal due to masking or similar loss of satellite visibility. A satellite reacquisition time of 10 seconds or less is typically achievable. As described in paragraph 3.5.3, the accuracy of the receiver position estimate is a primary factor in determining satellite reacquisition time. Vehicle dynamics and elapsed time from loss of the signal are therefore important in determining the accuracy of the receiver position estimate, as is the presence of GPS aids such as an INS. Laboratory testing is recommended since these factors are difficult to control and predict in the field.

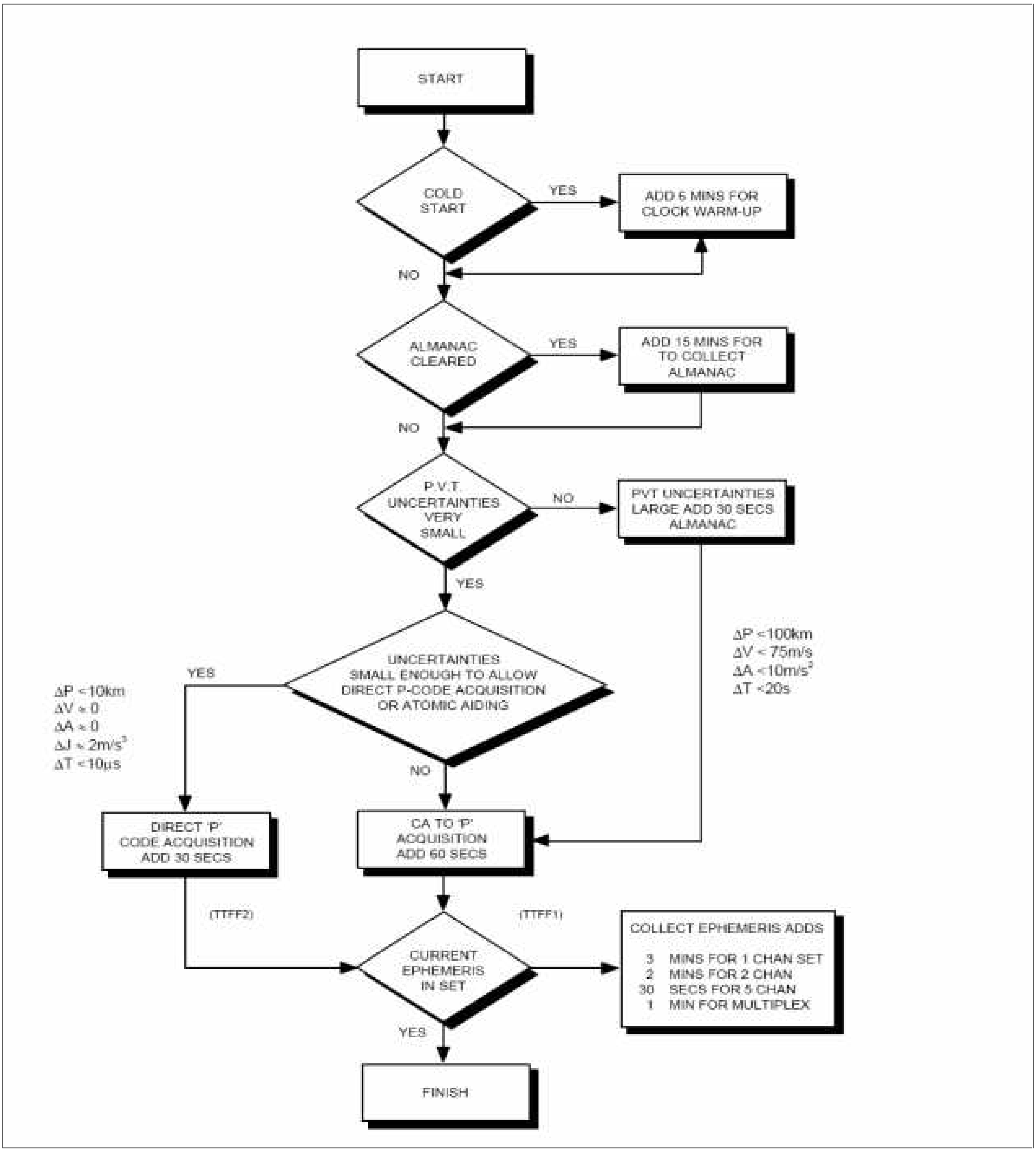


Figure (3.2): Time-To-First-Fix (TTFF)

3.4 Effect of Antenna Performance on the GPS Signal Accuracy

3.4.1 Introductions

The effect of antenna performance on the carrier phase measurement accuracy is described. The antenna performance characteristics in the presence of multipath are analyzed in terms of an antenna Axial Ratio and an antenna Noise Figure. In this analysis, the multipath is assumed to originate from a single point located on a perfectly conducting ground.

The analysis focuses on the carrier phase sensitivity with respect to various parameters such as antenna Axial Ratio, Noise Figure, ground reflection coefficient, etc.

3.4.2 The Antenna Effects

The antenna is an important part of the GPS receiver system. The GPS antenna receives and translates the GPS signal from an electromagnetic wave into a RF signal that contains the amplitude and phase information of the GPS signal. An antenna's characteristics and performance will set the boundaries of how well the GPS receiver system will perform. Show Figure (3.3).

There is ongoing development of various correction techniques (DGPS, Pseudolites, etc.) to meet an increasing demand for accuracy, integrity, availability and continuity of satellite based positioning. Multipath and receiver system thermal noise still remains as the main obstacles to achieve the above mentioned goals.

Some methods are more effective against the thermal noise but less effective against multipath and vice-versa.

CHAPTER THREE GPS PARAMETERS AND THERE EFFECTS ON ACCURACY

The antenna is a natural receptor of multipath generated copies of the GPS signal; therefore the antenna’s ability to reject these multipath signals is described in terms of Axial Ratio patterns.

An active GPS antenna (with built in Low Noise Amplifier – LNA) sets the overall Noise Figure of the receiver system, hence the contribution of its Noise Figure on the GPS signal accuracy is also described.

Group delay versus frequency is of most interest in microwave components, while in the case of an antenna it is useful to consider the variation of group delay versus elevation and azimuth angles. Thus, in GPS applications, maximum accuracy requires that the receiving antenna have a uniform group delay response for all angles of incidence in most of the upper hemisphere, otherwise signals from satellites at different elevation/azimuth angles will experience timing errors.

The amplitude and phase of the received RF carrier signal are used as quality measures of the GPS signal accuracy.

All modern GPS receivers use carrier phase measurements to achieve sub-centimeter accuracies, which isn’t the case with amplitude of the signal.

Traditionally, the amplitude of the signal had found little use in GPS signal processing.

This analysis is performed to determine the limits of GPS signal accuracy and their sensitivity to the following type parameters:

- Axial Ratio of the GPS antenna.
- Distance difference between the reflected and direct line-of-sight (LOS) received GPS signal.
- Reflection coefficient of the ground plane from which the specular multipath is originated.

- Overall Noise Figure of the antenna Group Delay variations versus elevation/azimuth angle.

A theoretical study of the antenna performance on the GPS signal carrier has been performed in the presence of multipath. Three important aspects of the antenna performance have been analyzed with respect to GPS signal accuracy: the Axial Ratio, Noise Figure and group delay.

Important relationships between carrier phase/amplitude accuracy of the GPS signal and antenna performance parameters have been investigated: these can be summarized by the following assertions:

- Poor Axial Ratio of the antenna pattern will cause significant phase/amplitude errors in a high multipath environment, exceeding by far the thermal noise contribution to the phase/amplitude errors of the GPS signals.
- Amplitude error is much more sensitive to multipath than the carrier phase error. This effect can be minimized with an antenna with low Axial Ratio characteristics; however, on the other hand, the amplitude variation can be used to detect the presence of multipath generated Signals.

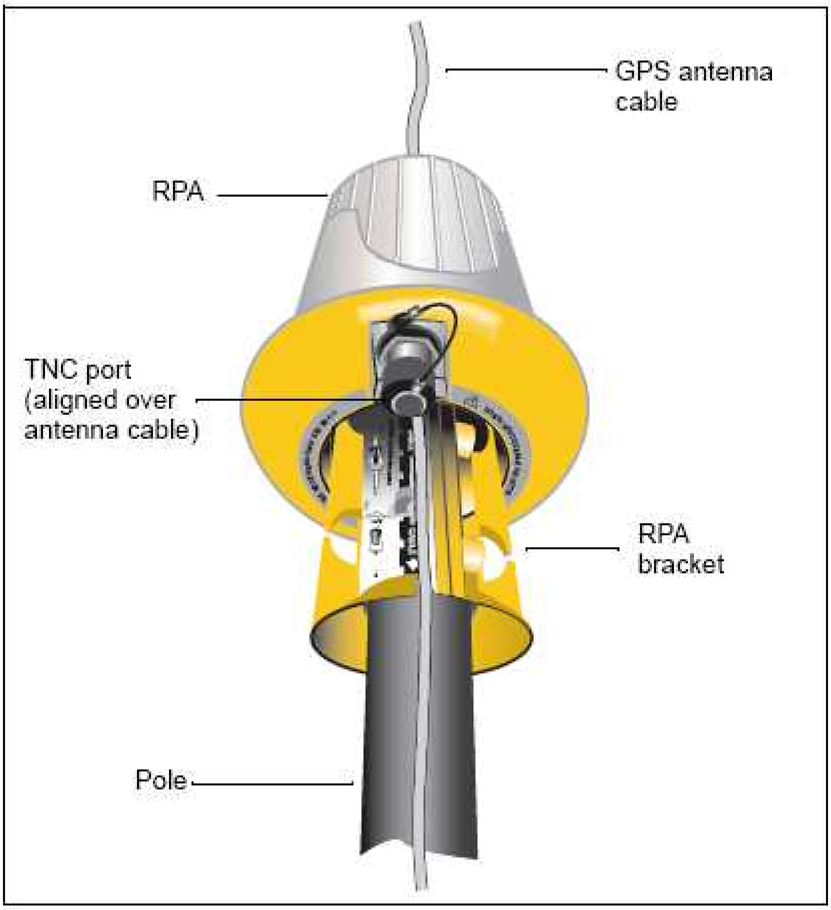


Figure (3.3): GPS Antenna

CHAPTER FOUR

SOFTWARE AND 5700 RECEIVER

4.1 Trimble Geomatics Office v1.6 Software

4.2 5700 GPS Receiver

4.3 Setup Receiver and Start RTK Survey and Static

CHAPTER FOUR

SOFTWARE AND 5700 RECEIVER

4.1 Trimble Geomatics Office v1.6 Software

The Trimble geomatics office software is a key component in the Trimble toolbox of integrated surveying solutions. Never has the collection, processing, and management of survey data been so easy. surveyors and engineers who work with data received from GPS, digital levels , laser instruments , road design packages or GIS databases , appreciate its ease of use and common interface for all operations .

Trimble geomatics office software provides a seamless link from design to field completion, with powerful processing capabilities to generate the final data in whatever from is desired.

4.1.1 Complete Survey Data Processing

The Trimble geomatics office software takes land survey office software one step further by integrating common tasks into a single , unified package tasks such as :

- Processing of GPS, conventional, and digital level survey data.
- Quality assurance and quality control of data (QA/QC).
- Road design data import and export.
- Survey data import and export.
- Digital terrain modeling and contouring.
- Datum transformation and projections.

- Creating ground coordinates systems and definitions, based on hundreds of published coordinate systems allover the world.
- GIS data capture and data export.
- Selecting points and observations.
- Features coding.
- Projects reporting.
- Survey project management.
- GPS base line processing.
- Survey network adjustment for GPS and conventional data.

With numerous innovative and unique features, the Trimble geomatics office software is exceptionally easy to use, intuitive and flexible. Visualization tools such as back ground maps and the survey plan views help you see the data in the context of the whole project .and powerful spatial data management capabilities bring anew level of productivity and efficiency to the surveying and civil engineering office.

4.1.2 Intuitive Visual Interface

In addition to the standard and familiar widows interface , the Trimble geomatics office software features a project bar and tool bar , both set out to follow your workflow and design to make the software easy to learn and use . Full Microsoft intellimouse support laterally puts real time zoom and pan functions at your finger tips.

The survey view and plan view allow you to switch seamlessly between a view of the survey displayed as observations and a view displayed as features on alpine.

The survey view shows you survey information, such as RTK base stations, conventional setups and control points.

After processing feature codes , the plan view shows topographic information , such as trees , fence lines , and roads . This complementary representation of data enables office operators to visualize what happened in the field, even if they did not collect the field data.

The survey view is used to view raw data, analyze survey observations, process GPS baselines, and perform least-squares network adjustment. GPS observations are shown as vectors and optical observations are show as observations from the instrument point. Different observation types, such as post processed GPS, real time GPS, conventional, laser, etc; are color coded for instant recognition. View filters allow observation types to be displayed or hidden in order to concentrate on a specific set of observations.

In the plan view, the survey is displayed as a plot with features, point styles, lines and text annotations just as it would be in the final plan. You can use this view to process feature codes, edit the features and line-work in the survey, and access the powerful road link and DTM link software.

4.1.3 Main Parts of Geomatics Office

1. Tool bar puts common actions just a mouse click away.
2. Intuitive project bar makes Trimble geomatics office exceptionally easy to learn and use.
3. Click on an observation in the distinct color allow different observation types to be easily distinguished, such as post processed GPS, real-time GPS, conventional optical and digital level observations.
4. Zoom navigator window always shows the entire project area, with an outline of the current view area for quick and easy navigation around the project.
5. Familiar, standard windows interface.
6. Plan view displays the survey plotted as features.
7. Survey view displays the individual observations in the survey.
8. Click on an observation in the survey view or on a feature in the plan view, and the properties box displays the detailed information for that observation or feature.

4.1.4 Integrated Surveying

Trimble geomatics office brings all yours survey data together .integrated surveying is the sky to fast and efficient surveying. The ability to seamlessly integrate a wide range of different survey data types is at very heart to the Trimble geomatics office software.

The software offers the freedom to use any survey instrument required for the job a survey-grade GPS receiver.

Design to handle each type of survey data that the surveyor and engineer are ever likely to use, the software has unrivalled data integration capabilities and can read in data such as:

- (RTK) real-time kinematic GPS data.
- Raw GPS data.
- Road design data in more than 20 different native formats used worldwide, include: AutoDesk civil design.
- Custom ASCII data.

The software supports a two way flow of digital data , allowing data to be loaded into the TSCE or TSCl controllers running trimble survey controller software for use in the field , such as :

- Points of all kinds, including control points, data points and design points.
- Datum and projection parameters.
- Digital terrain models (Grid or TIN).
- Geoid models.
- Combined datum grid files.
- Road design files complete with full alignment geometry.
- Feature and attribute libraries.
- GIS data dictionary files.

Data can also be exported by anyone of over 30 data formats for third-party survey, design, CAD and GIS software including AutoCAD, Arc View, MapInfo, Micro station and many more.

4.1.5 GPS Baseline Processing And Network Adjustment

The WAVE baseline processing and network adjustment modules in the Trimble geomatics office software is designed to be simplicity itself for those just who need the right answers fast while advanced controls can be accessed for those who need more control over the processing of there data .

Intelligent default parameter values ensure that users who only want to press bottom and see the right answers fast, just can do that.

For the advanced user, advanced controls can be accessed using styles, allowing the user to take control of baseline processing parameters or network adjustment parameters.

Extensive QC tools provide fast and accurate assessment of data quality, while visual cues, such as red flags, instantly alert the user to out of tolerance data. Data can also be browsed and queried visually using the graphical timeline display.

The fast and powerful least-square network adjustment module is also accessed from the survey view. Vectors can be include or excluded from that can be included or excluded from the adjustment with the click of the mouse. And observations can be queried or disabled graphically using simple point –and click techniques. Combining GPS and conventional data in a network adjustment is simple; you can get results you need with identical workflows, no matter what data you have in the project.

After adjustment, each station's horizontal and vertical error ellipses are displayed in the survey view for quick and easy inspection of network quality. Fixing control points for the network adjustment is also quick and easy, enabling you to achieve the high quality results you need fast.

4.1.6 Quick and Simple CAD Work in the Plan View

Tidying up the survey for delivery to the client is quick and simple using the Trimble geomatics office software. Maximum use has been made of toolbars, graphics and the mouse commands to make the software exceptionally intuitive and easy to learn.

Powerful feature code processing quickly transforms raw survey observations into a final plan. The software allows the user to define and customize feature codes, point and line styles, and other CAD elements.

4.1.7 Processing Road Design Data is Fast and Easy

Using the innovative road link software, engineers and surveyors alike can now take just about any road design out into the field and perform stakeout with ease.

The Trimble geomatics office software is designed to read in almost any type of road design data that you need to work with. Importing road design data is so easy it gives you full control of how the road design is imported. You can even import cross-section data to use as templates. Design files in the following native formats among other can be imported directly into the Trimble geomatics office software: AutoDesk civil design.

Design data can be graphically displayed, edited, and then loaded into the Trimble survey controller software as a job file for stakeout on site.

The file allows the horizontal and vertical alignments and templates not just a list of points to be taken into the field. This enables any station and offset to be specified for stakeout, providing the field screw with the flexibility required in the construction environment.

When stakeout is complete, the job file with as staked positions can be transferred back to the Trimble geomatics office software for a quality control check. The staked points are shown on a plane of the site and cut sheets can be prepared in a wide variety of cut sheet report formats to meet your needs.

4.1.8 Creating Contour Surface Models and Volume Calculations

If you already have a contour model in the popular 3-D faces AutoCAD format, you can import it to DTM link, as well as export any surface created in DTM link in the 3D faces format.

Sending digital terrain models to the Trimble survey controller software for stakeout is simple, and you have the choice of using a grid DTM or triangulated irregular network (TIN).

4.1.9 Outstanding Quality Assurance and Quality Control Capabilities

Quality control of survey data is more important today than it has ever been. With outstanding QA/QC capabilities you can sure that your surveys are always produced to the high standards your clients expect.

Every module of the Trimble geomatics office software is loaded with features to help you maintain the highest standards of quality and quickly spot problem data.

The Trimble window provides a graphical display of observed data over time. Customizable displays allow the advanced user to analyze different combinations of correlated variables for quality control or troubleshooting purposes. Time line can be used to display dependent baselines, providing both the flexibility to determine independent baselines and full control of what is passed to a network adjustment just another way to help you process the data you need.

To check the quality of your post processed network, simply use the loop closures report. You have the choice of letting the Trimble geomatics office software perform the report either on the entire network or on a selection you define by using any of the extensive selection tools available.

For first time users and for those who just need their results fast the Trimble geomatics office software makes the maximum use of intelligent default values and graphical tools, such as the ability to graphically disable and edit observations for quick and painless completion of high quality surveys.

4.1.10 Minimum Hardware Requirements

The minimum requirements for the computer running the Trimble geomatics office software are:

- Pentium-based computer, 150 MHz or faster with 32-MB RAM and a 1-GB hard drive.
- SVGA color 800x600.
- Keyboard with mouse or trackball
- CD-ROM drive.
- The Trimble geomatics office software operates under Microsoft windows 95/98/Me/2000/xp.

4.2 5700 GPS Receiver

The 5700 GPS receiver, which is designed for GPS surveying applications. The 5700 receiver tracks GPS satellites on both the L1 and L carrier frequencies to provide precise position data for land survey applications.

4.2.1 Parts of the Receiver

All operating controls, ports and connectors on the 5700 receiver are located on its four main panels as shown in Figure (4.1)

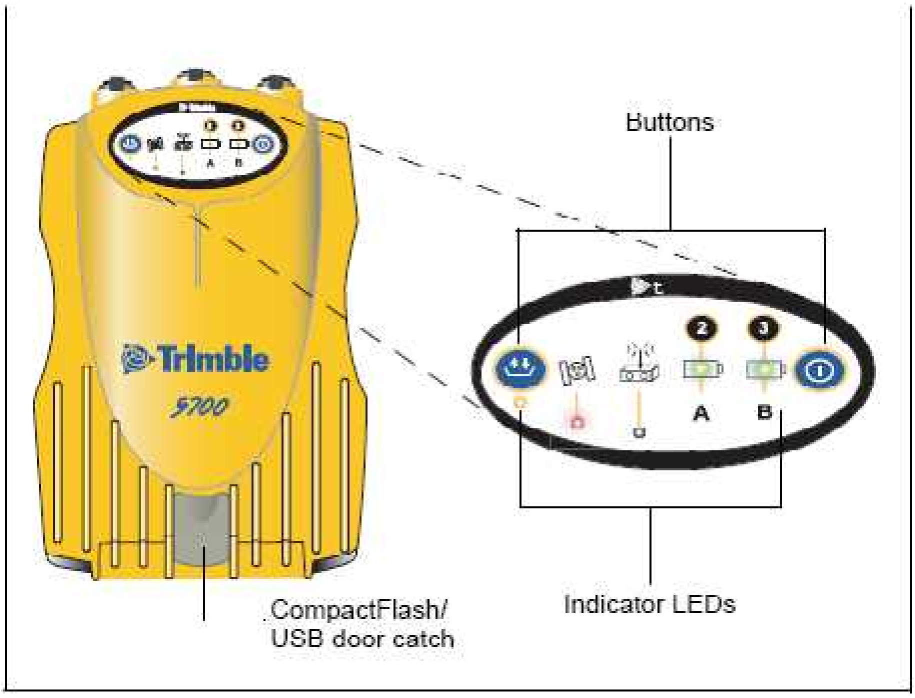


Figure (4.1): Panels on 5700 receiver

4.2.2 Setup Guidelines

Consider the following guidelines when setting up the 5700 receiver:

- **Environmental conditions**

Although the 5700 receiver has a waterproof housing, reasonable care should be taken to keep the unit dry. Avoid exposure to extreme environmental conditions, including:

- Water.
- Heat greater than 65° C (149° F)
- Cold less than - 40° (-40° F)
- Corrosive fluids and gases

Avoiding these conditions improves the 5700 receiver's performance and long-term reliability.

- **Sources of electrical interference**

Avoid the following sources of electrical and magnetic noise:

- Gasoline engines b (spark plugs).
- Televisions and PC monitors.
- Alternators and generators.
- Electric motors.
- Equipment with DC- to -AC converters.
- Fluorescent lights.
- Switching power supplies.

4.2.3 Post Processed Setup

For a post processed survey, you only need:

- the 5700 receiver
- A zephyr geodetic antenna .
- GPS antenna cable

Other requirement, as described below, is optional.

To setup the 5700 receiver for a post processed survey:

1. Setup the tripod with the tribrach and antenna adapter over the survey mark. Instead of the tripod, you can use a range pole with a bipod. However, Trimble recommends that you use a tripod for greater stability.
2. Mount the antenna on the tribrach adapter.
3. Use the tripod clip to hang the 5700 receiver on the tripod.
4. Connect the yellow GPS antenna cable to the zephyr antenna.
5. Connect the other end of the GPS antenna.

   Note Figure (4.2)

Figure (4.2): Post processed setup

4.2.4 Other System Components

- **Radios**

Radios are the most common data link for (RTK) real time kinematic surveying.

The 5700 receiver is available with an optional internal radio in either the 450 or 900 MHz UHF bands.

- **Antennas**

The 5700 receiver should normally be used with a zephyr geodetic antenna. These antennas have been designed specifically for use with the 5700 receiver.

Use Figure 4.3 as a guide for measuring the height of the zephyr and zephyr geodetic antennas. The zephyr antenna is designed to be measured to the top of the notch. The antennas. The zephyr geodetic (shown) has been designed to be measured to the bottom of the notch .note figure (4.3).

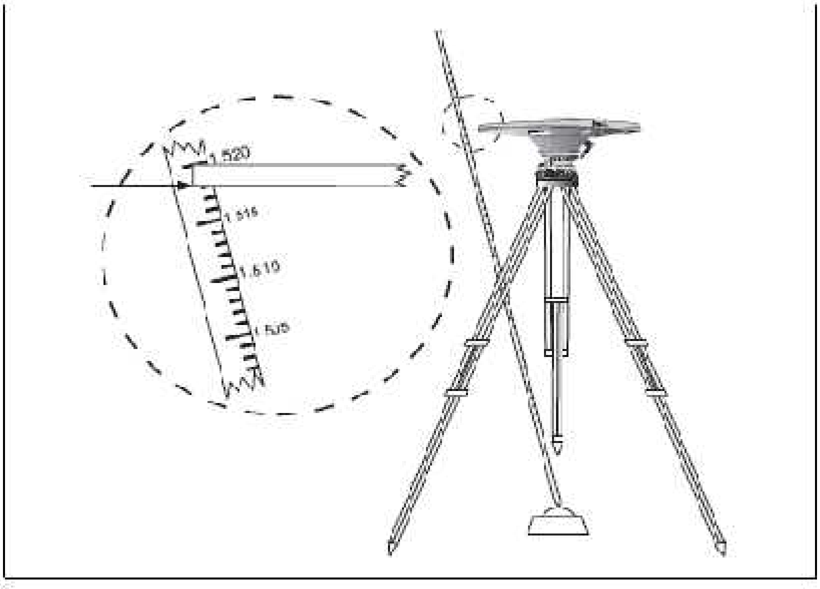


Figure (4.3): Measuring antenna height

4.3 Setup Receiver and Start RTK Survey and Static

For a post processed survey:

- Using 5700 receiver.
- A zephyr™ or zephyr geodetic antenna (trade name).
- A GPS antenna cable.
- Setup the tripod with the tribrach and antenna adapter over the survey mark.
- Use the tripod clip to hang the 5700 receiver on the tripod.
- Connect the yellow GPS antenna cable to the zephyr antenna.
- Connect the other end of the GPS antenna cable to the yellow port on the yellow port on the 5700 receiver.
- Connect a battery.
- Place the bracket against the pole at a comfortable height.
- Rotate the clamping screw on the bracket pole until tight.
- Place the controller into the cradle assembly and tighten the clamping mechanism.
- Any cables running down the pole should be run through the machined groove on the inside of the controller bracket.
- Position the controller in the preferred position for operation by pressing the spring-loaded release button in the cradle, pulling the assembly outward, and rotating the cradle assembly to the desired angle.
- Connect the other end of the cable to port on the 5700 receiver.
- Use the on/off button to switch the receiver.
- Turn on the controller survey.
- From the main menu on the controller, select (*configuration*).
- In the dialogue that appears , select survey styles , then from the (next step)
- Type field, select RTK, select start base receiver, Palestinian old grid, name point, code, and coordinate the base and antenna height.
- Start observation and store.

On returning to the office after completing a survey, transfer the field data to a computer that has the Trimble geomatics office™ software installed. You can then process the survey data in Trimble geomatics office to produce baselines and coordinates.

- Use the USB cable to connect the 5700 receiver to the computer.
- Start Trimble geomatics office.
- Transfer the data files to the computer using the Trimble data transfer utility.

Create a project:

- Select file / new project.
- In the *name* field of the dialogue that appears, enter the project name.
- From the *template* list, select a sample data option.
- In the new group, make sure that the *project* option is selected and then click *ok*.
- The project is created and the *project properties* dialogue appears.
- The measurements (values) in the field in each tab are derived from the sample data template.
- To close the *project properties* dialogue, click *ok.*

CHAPTER FIVE

FIELD MEASURMENTS AND DATA DESCRIPTION

5.1 Introduction

5.2 Positioning Trimble's Main Antenna

5.3 Network Establishment

5.4 Net work measurement

5.5 Real Time Kinematic Observations

5.6 Static Observations

5.7 Analysis of Fixed Baseline Measurements

5.8 Analysis of Repeat Baseline Measurements

5.9 Least Squares Adjustment of GPS Networks

CHAPTER FIVE

FIELD MEASURMENTS AND DATA DESCRIPTION

5.1 Introduction

In this section, some measurement of this project is outlined. The outgoing task for this project was to compare between accuracies according to changing some parameters in GPS instrument.

These parameters include time and mask angle, and the observing process was depending on changing these parameters to values that can affect on observations accuracy .The points observed by two methods:

1. Real time kinamatic (RTK) method.
2. Static method.

The measuring work flow had to be placed near by and inside the PPU which we selected two control points with fixed coordinates (A&B) then measuring the coordinates of other tree control points depending on these controls.(the base placed on A&B control points, and the rover placed on field controls (F , C ,& E)).

The idea was to place the antenna on controls A&B by relative positioning determination of coordinates of the points.

The network had been established inside PPU campus, and the comparison is between the accuracy of points depending on their horizontal and vertical standard deviations affected by changing time and mask parameters.

5.2 Positioning Trimble's Main Antenna

Two well defined points was used to decide the position of Trimble's antenna in Palestinian old grid system, the positioning was done using coordinate from previous studies and graduation projects in our university.

For each observation in this project the main instrument used is Trimble 5700 GPS which is offer in our university, the measuring operation classified into real time kinamatic and static methods, and we have to know that in real time kinamatic we have to connect radio between the base and the rover to send corrections immediately, but in static method it is not necessary.

5.3 Network Establishment

This section describes the procedure of gathering points in the frame network. The points where established in previous and we bring them from previous graduation projects.

5.4 Net Work Measurement

The antenna on the roof of the two PPU buildings (A&B) in Wadi Alhariia campus was positioned from three well-defined points in the near by region. The coordinates where in the Palestinian old grid system. The points were located in F, C, and E.

A 5700 rover collected data in each of the three points 5700 receiver with a Zephyr geodetic antenna simultaneously collected data throughout the measurements on the roof point.

5.5 Real Time Kinematic Observations

The network points were observed with normal radio RTK with three different time intervals: Instrument default time (8 seconds) and assigned time with (5seconds and 5 minutes) .and three mask angle Intervals: instrument default (13 degree) and assigned mask angles with (15, and 10 degrees).

These measurements were done in relation to the base station on the roof. All time and mask intervals were observed separately, with no correlation to each other.

During the observations the times and mask angles for all events were noted. This way the decision of what to compare is the root mean square error (especially in RTK method).

All measurements with time and mask parameters were done, simulating a normal Radio-RTK job, were three points should be positioned. The reason for measuring at three different (time and mask) intervals was to analyze the three points root mean square error, and the amount that it changes according to the time and mask parameters.

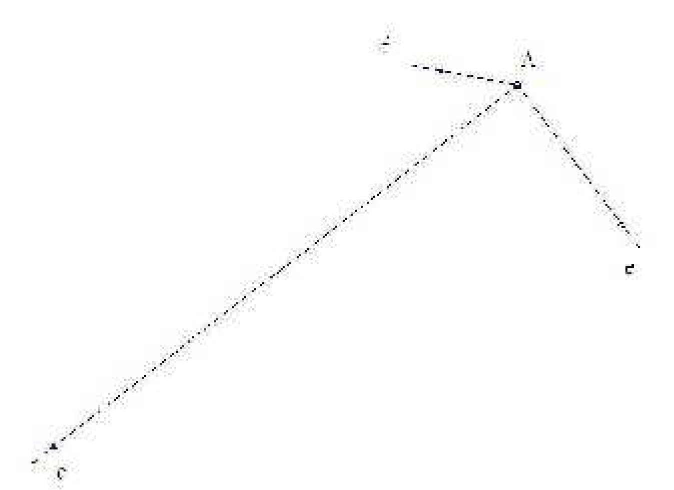


Figure (5.1): Network by RTK method.

5.5.1 Spatial Accuracy

RMSE is the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points.

Accuracy is reported in ground distances at the 95% confidence level. Accuracy reported at the 95%confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value.

The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product.

5.5.2 Accuracy Test Guidelines

According to the Spatial Data Transfer Standard (SDTS), accuracy testing by an independent source of higher accuracy is the preferred test for positional accuracy. Consequently, the NSSDA presents guidelines for accuracy testing by an independent source of higher accuracy. The independent source of higher accuracy shall the highest accuracy feasible and practicable to evaluate the accuracy of the dataset.

The data producer shall determine the geographic extent of testing. Horizontal accuracy shall be tested by comparing the planimetric coordinates of well-defined points3 in the dataset with coordinates of the same points from an independent source of higher accuracy. Vertical accuracy shall be tested by comparing the elevations in the dataset with elevations of the same points as determined from an independent source of higher accuracy.

Errors in recording or processing data, such as reversing signs or inconsistencies between the dataset and independent source of higher accuracy in coordinate reference system definition, must be corrected before computing the accuracy value.

A minimum of 3 check points have been tested, distributed to reflect the points accuracy of interest, and the distribution of error in the dataset.

5.5.3 Explanatory Comments

1. Horizontal Accuracy

Let:

RMSE_x = sqrt [(x data, i - x check, i) /n] ^{2}…………………………………….………… (5.1)

RMSE_y = sqrt [(y data, i - y check, i) /n] ^{2}………………...………………………… (5.2)

Where:

x data, i, y data, i are the coordinates of the i th check point in the dataset.

x check, i, y check, i are the coordinates of the i th check point in the independent source of higher accuracy.

n is the number of check points tested.

i is an integer ranging from 1 to n.

Horizontal error at point i is defined as:

sqrt [(x data, i - x check, i) ^{2} +(y data, i - y check, i) ^{2}]

Horizontal RMSE is:

RMSE_r = sqrt [((x data, i - x check, i) ^{2} +(y data, i - y check, i) ^{2})/n]

= sqrt [RMSEx^2 + RMSEy^2] …………………………...…………………... (5.3)

2. Vertical Accuracy

Let:

$\mathrm{RMSE}_z = \mathrm{sqrt}\ [(z\ \mathrm{data}\ i - z\ \mathrm{check}\ i)\ /n]^2$ ………………….................................. (5.4)

Where

z data i is the vertical coordinate of the i th check point in the dataset.

z check i is the vertical coordinate of the i th check point in the independent source of higher accuracy.

n = the number of points being checked.

i is an integer from 1 to n.

Note: It is assumed that systematic errors have been eliminated as best as possible.

5.6 Static Observations

The only difference from ordinary Radio-RTK is how the correction data, from the base and the rover, is transferred. Radio-RTK uses a radio link and static stored in base and rover connection data in TGF (Trimble geomatics office) transferred into computer.

We measured three points by using this method, each of them was measured independently .the measurements were uncorrelated so we can easily compare time and mask parameters between them.

5.7 Analysis of Fixed Baseline Measurements

The GPS job specification often requires that baseline measurements be taken between base stations; these measurements can be used to confirm the accuracy of both the GPS measurement system and the known baseline lengths.

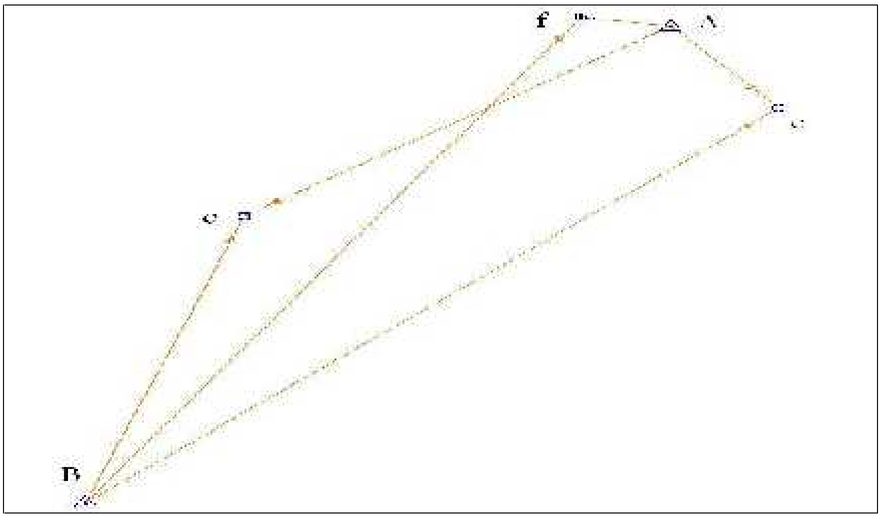


Figure (5.2): Network by static method.

If we assume that we have the X, Y, &Z coordinates to the base stations A&B

1. (measured by the electronic distance measurement-EDM instrument, with high accuracy) , then we can compute (X_{AB},Y_{AB}, Z_{AB}) and then the procedure can be.
2. Computing the coordinate differences between the two measured (using GPS) points (Δx_{ab}, Δy_{ab}, Δz_{ab}).
3. computing the absolute values of differences between the measured and the known baselines ($dx=\Delta X_{AB}-\Delta x_{ab}$, $dy=\Delta Y_{AB}-\Delta y_{ab}$, $dz=\Delta Z_{AB}-\Delta z_{ab}$)
4. computing the length of the baseline as :

$$AB = \sqrt{(XA - XB)^2 + (YA - YB)^2 + (ZA - ZB)^2} \quad \text{...} \quad (5.5)$$

Express the differences as computed in step (2) in parts per million, by dividing the differences by the length of the baseline computed in step (3); as:

ΔX-ppm = dX/AB * 1,000,000
ΔY-PPM = dY/AB*1,000,000 ………………………………………………………….. (5.6)
ΔZ-ppm = dZ/AB *1,000,000

Check the computed values for the ppm with the standard values.

5.8 Analysis of Repeat Baseline Measurements

Making repeated measurements of certain baselines can do removing blunders .The repeated measurements are taken at different observation sessions , and the results compared by finding the absolute differences in the two measurements and computing the ppm values .

Analysis of loop closures
GPS surveys consist of many interconnected closed loops, which from a network.

For each closed loop , the algebraic sum of the X components should equal zero, the same condition should exist also for the Y ,&Z components, large closing values within any closed loop indicate that either a blunder or a large error exist in one or more of the baselines of the loop .

It is important not to include any trivial baselines in these computations, because they can produce false accuracies for the loop.

To compute loop closing, the baseline components are added algebraically for that loop (ACBEA) as:

$$CX= \Delta XAC+ \Delta XCB+ \Delta XBE+ \Delta XEA$$
$$CY=\Delta YAC+ \Delta YCB+ \Delta YBE+ \Delta YEA \quad \text{……………………………………...…………} \quad (7.5)$$
$$CZ== \Delta ZAC+ \Delta ZCB+ \Delta ZBE+ \Delta ZEA$$

To compute the total length (lc) of the disclosure:

$$lc= \sqrt{(CX)^2+(CY)^2+(CZ)^2} \quad \text{……………………………….……………………} \quad (8.5)$$

And then we can find the closure ppm ratio by dividing (CX, CY, and CZ) by (lc) and then compare them with the standard values.

5.9 Least Squares Adjustment of GPS Networks

As noted earlier, because GPS networks contain redundant measurements, they must be adjusted to make all coordinate differences consistent. In applying least squares to the problem of adjusting baselines in GPS network, observation equations are written that relate station coordinates to the observed coordinate differences and their residual error. To illustrate the procedure, consider of figure (5.2).For line AF of this figure, an observation equation can be written for each measured baseline component as:

$$\begin{aligned} X_F &= X_A + \Delta X_{AF} + V_{X_{AF}} \\ Y_F &= Y_A + \Delta Y_{AF} + V_{Y_{AF}} \\ Z_F &= Z_A + \Delta Z_{AF} + V_{Z_{AF}} \end{aligned} \quad \text{…………………………………………………… (9.5)}$$

Similarly, the observation equations for the baseline components of remaining lines are:

For line AC:

$$\begin{aligned} X_C &= X_A + \Delta X_{AC} + V_{X_{AC}} \\ Y_C &= Y_A + \Delta Y_{AC} + V_{Y_{AC}} \\ Z_C &= Z_A + \Delta Z_{AC} + V_{Z_{AC}} \end{aligned} \quad \text{…………………………………………………… (10.5)}$$

For line AE:

$$\begin{aligned} X_E &= X_A + \Delta X_{AE} + V_{X_{AE}} \\ Y_E &= Y_A + \Delta Y_{AE} + V_{Y_{AE}} \\ Z_E &= Z_A + \Delta Z_{AE} + V_{Z_{AE}} \end{aligned} \quad \text{…………………………………………………… (11.5)}$$

For line BF:

$$\begin{aligned} X_F &= X_B + \Delta X_{BF} + V_{X_{BF}} \\ Y_F &= Y_B + \Delta Y_{BF} + V_{Y_{BF}} \\ Z_F &= Z_B + \Delta Z_{BF} + V_{Z_{BF}} \end{aligned} \quad \text{……………………………..…………...… (12.5)}$$

For line BC:

$$\begin{aligned} X_C &= X_B + \Delta X_{BC} + V_{X_{BC}} \\ Y_C &= Y_B + \Delta Y_{BC} + V_{Y_{BC}} \\ Z_C &= Z_B + \Delta Z_{BC} + V_{Z_{BC}} \end{aligned} \quad \text{…………………………………..…………..... (13.5)}$$

For line BE:

$$\begin{aligned} X_E &= X_B + \Delta X_{BE} + V_{X_{BE}} \\ Y_E &= Y_B + \Delta Y_{BE} + V_{Y_{BE}} \\ Z_E &= Z_B + \Delta Z_{BE} + V_{Z_{BE}} \end{aligned} \quad \text{…………………………….…………………. (14.5)}$$

Observation equations of the form above would be written for all measured baseline in any figure. For figure (5.2) there were a total of 6 measured baselines, so the number of observation equations that can be developed is (18).Also, each of stations F, C and E has three unknown coordinates, for a total of 9 unknowns in the network. Thus there are {18-9=9} redundant observations in the network. The 18 observation equations can be expressed in matrix form as:

$AX=L+V$ ……………………………………………………..……….…….. (15.5)

If the observation equations for adjusting the network of figure (5.2) are written in the same order that the measurements are listed in tables (see appendices), the A, X,L,W, and V matrices would be.

Coefficient matrix similar to that in differential leveling, however, weight matrix has off-diagonal elements since baseline measurements are indirect observations.

Formulate (A) matrix:

The elements of the (A) matrix are coefficients of observation equations:

$$A = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Formulate (X), (L), and (V)

X matrix: is the unknowns

L matrix: is the observation

V matrix: are the residuals

$$X = \begin{bmatrix} X_C \\ Y_C \\ Z_C \\ X_F \\ Y_F \\ Z_F \\ X_E \\ Y_E \\ Z_E \\ \\ \\ \end{bmatrix} \quad L = \begin{bmatrix} X_A + \Delta X_{AC} \\ Y_A + \Delta Y_{AC} \\ Z_A + \Delta Z_{AC} \\ XA + \Delta X_{AF} \\ YA + \Delta YAF \\ ZA + \Delta ZAF \\ X_A + \Delta X_{AE} \\ Y_A + \Delta Y_{AE} \\ Z_A + \Delta Z_{AE} \\ \vdots \\ \vdots \\ X_B + \Delta X_{BE} \\ Y_B + \Delta Y_{BE} \\ Z_B + \Delta Z_{BE} \end{bmatrix} \quad V = \begin{bmatrix} V_{X_{AC}} \\ V_{Y_{AC}} \\ V_{Z_{AC}} \\ V_{X_{AF}} \\ V_{X_{AF}} \\ V_{Z_{AF}} \\ V_{X_{AE}} \\ V_{Y_{AE}} \\ V_{Z_{AE}} \\ \vdots \\ \vdots \\ V_{X_{BE}} \\ V_{Y_{BE}} \\ V_{Z_{BE}} \end{bmatrix}$$

Weight matrix

By definition W $=\Sigma^{-1}$

In this problem covariance matrix is:

$$\Sigma=\begin{bmatrix}
\pm_{X_{AF}}^{2} & \pm_{XY_{AF}} & \pm_{XZ_{AF}} & 0 & 0 & 0 & 0 & 0 & 0 & \cdots & 0 & 0 & 0 \\
\pm_{XY_{AF}} & \pm_{Y_{AF}}^{2} & \pm_{YZ_{AF}} & 0 & 0 & 0 & 0 & 0 & 0 & & 0 & 0 & 0 \\
\pm_{XZ_{AF}} & \pm_{YZ_{AF}} & \pm_{Z_{AF}}^{2} & 0 & 0 & 0 & 0 & 0 & 0 & & 0 & 0 & 0 \\
0 & 0 & 0 & \pm_{X_{AC}}^{2} & \pm_{XY_{AC}} & \pm_{XZ_{AC}} & 0 & 0 & 0 & & 0 & 0 & 0 \\
0 & 0 & 0 & \pm_{XY_{AC}} & \pm_{Y_{AC}}^{2} & \pm_{YZ_{AC}} & 0 & 0 & 0 & & 0 & 0 & 0 \\
0 & 0 & 0 & \pm_{XZ_{AC}} & \pm_{YZ_{AC}} & \pm_{Z_{AC}}^{2} & 0 & 0 & 0 & & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \pm_{X_{AE}}^{2} & \pm_{XY_{AE}} & \pm_{XZ_{AE}} & & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \pm_{XY_{AE}} & \pm_{Y_{AE}}^{2} & \pm_{YZ_{AE}} & & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & \pm_{XZ_{AE}} & \pm_{YZ_{AE}} & \pm_{Z_{AE}}^{2} & & 0 & 0 & 0 \\
\vdots & & & & & & & & & \ddots & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \pm_{X_{BE}}^{2} & \pm_{XY_{BE}} & \pm_{XZ_{BE}} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \pm_{XY_{BE}} & \pm_{Y_{BE}}^{2} & \pm_{YZ_{BE}} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & \pm_{XZ_{BE}} & \pm_{YZ_{BE}} & \pm_{Z_{BE}}^{2}
\end{bmatrix}$$

CHAPTER SIX

CALCULATIONS

6.1 Positioning of Trimble's main antenna

6.2 Calculation Diagrams

CHAPTER SIX

CALCULATIONS

6.1 Positioning of Trimble's Main Antenna

The results and data from the positioning of Trimble's main antenna are shown in the subsections below:

6.1.1 Known Coordinate

Table (6.1): (A& B) Stations Coordinates, and Field Survey Coordinates

Point name	Northing	Easting	Elevation
A	1101824.189	158807.533	915.662
B	1101505.006	158568.374	916.074
F	1101830.465	158770.361	899.563
C	1101697.105	158633.130	888.740
E	11011769.849	158851.165	896.240

These coordinates are received from previous graduation project, and measured by using electronic distance measurement-EDM instrument.

The coordinates are for our purposes considered error-free and fixed before the net-adjustment in least square solution.

6.1.2 Field Measurements and RMS Calculations

6.1.2.1 Instrument Default Parameters

In this section we measured the three assigned points in field (PPU campus) the points are (F, C, and E) observed by the instrument default parameters, and the measuring method divided into two classes:

a. RTK default
b. Static default

And the observed values which gained from field measurements as follows:

Table (6.2): RTK Default Observation

Point name	Northing	Easting	Elevation
F	1101830.547	158770.636	899.557
C	1101697.107	158633.130	888.736
E	1101769.838	158851.158	896.239

Table (6.3): Static Default Observation

Point name	Northing	Easting	Elevation
F	1101830.554	158770.648	899.555
C	1101697.105	158633.137	888.730
E	1101769.826	158851.175	896.235

6.1.2.2 Time Parameters

In this section we measured the three assigned points in field (PPU campus) the points are (F, C, and E) observed by changing the time parameter, and the measuring method divided into two classes:

a. RTK (5min and 5sec)
b. Static (15min and 5min)

Now we will find the root mean square error of the observations below, and find the horizontal and vertical accuracies, the results are as follows:

Table (6.4): RTK Default Observation

Point name	Northing	Easting	Elevation
F	1101830.547	158770.636	899.557
C	1101697.107	158633.130	888.736
E	1101769.838	158851.158	896.239

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.011225

RMSE $_{(E)}$ = 0.00860

RMSE $_{(R)}$ = 0.014143

2) Vertical RMSE:

RMSE $_{(H)}$ = 0.0072801

Table (6.5): RTK Time= 5Min

Point name	**Northing**	**Easting**	**Elevation**
F	1101830.550	158770.638	899.555
C	1101697.112	158633.128	888.734
E	1101769.831	158851.158	896.244

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.011387

RMSE $_{(E)}$ = 0.0058309

RMSE $_{(R)}$ = 0.01279

2) Vertical RMSE:

RMSE $_{(H)}$ =0.006557

Table (6.6): RTK Time=5 Sec

Point name	**Northing**	**Easting**	**Elevation**
F	1101830.544	158770.634	899.578
C	1101697.098	158633.135	888.750
E	1101769.837	158851.153	896.190

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.00559

RMSE $_{(E)}$ = 0.00251

RMSE $_{(R)}$ = 0.001340

2) Vertical RMSE:

RMSE $_{(H)}$ =0.02562

Table (6.7): Static Time = 15Min

Point name	Northing	Easting	Elevation
F	1101830.547	158770.637	899.555
C	1101697.092	158633.136	888.732
E	1101769.826	158851.150	896.232

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.00854

RMSE $_{(E)}$ = 0.01558

RMSE $_{(R)}$ = 0.01771

2) Vertical RMSE:

RMSE $_{(H)}$ = 0.00249

Table (6.8): Static Time = 5 Min

Point name	Northing	Easting	Elevation
F	1101830.465	158770.546	899.549
C	1101697.769	158633.219	888.721
E	1101769.745	158851.068	896.048

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.39649

RMSE $_{(E)}$ = 0.08739

RMSE $_{(R)}$ = 0.09596

2) Vertical RMSE:

RMSE $_{(H)}$ = 0.10705

6.1.2.3 Mask Angle Parameter

In this section we measured the three assigned points in field (PPU campus) the points are (F, C, and E) observed by changing the mask angle parameter, and the measuring method divided into two classes:

c. RTK (10˚ and 15˚)
d. Static (10˚ and 15˚)

Table (6.9): RTK Mask= 10˚

Point name	Northing	Easting	Elevation
F	1101830.546	158770.640	899.547
C	1101697.107	158633.147	888.734
E	1101769.839	158851.124	896.228

1) Horizontal RMSE:

$RMSE_{(N)} = 0.00588$

$RMSE_{(E)} = 0.0172$

$RMSE_{(R)} = 0.01817$

2) Vertical RMSE:

$RMSE_{(H)} = 0.0125$

Table (6.10): RTK Mask = 15˚

Point name	Northing	Easting	Elevation
F	1101830.533	158770.650	899.551
C	1101697.097	158633.126	888.733
E	1101769.831	158851.143	896.235

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.01362

RMSE $_{(E)}$ = 0.016416

RMSE $_{(R)}$ = 0.02133

2) Vertical RMSE:

RMSE $_{(H)}$ = 0.01087

Table (6.11): Static Mask = 10˚

Point name	Northing	Easting	Elevation
F	1101830.549	158770.635	899.566
C	1101697.103	158633.141	888.734
E	1101769.831	158851.125	896.269

1) Horizontal RMSE:

RMSE $_{(N)}$ = 0.00707

RMSE $_{(E)}$ = 0.02390

RMSE $_{(R)}$ = 0.02492

2) Vertical RMSE:

RMSE $_{(H)}$ =0.02176

Table (6.12): Static Mask = 15˚

Point name	**Northing**	**Easting**	**Elevation**
F	1101830.639	158770.478	899.010
C	1101697.768	158633.219	888.870
E	1101769.592	158851.643	896.118

1) Horizontal RMSE:

$\text{RMSE}_{(N)} = 0.41668$

$\text{RMSE}_{(E)} = 0.30283$

$\text{RMSE}_{(R)} = 0.51510$

2) Vertical RMSE:

$\text{RMSE}_{(H)} = 0.33119$

- The observations are made with a Trimble 5700 receiver, and the antenna heights are measured to the bottom of antenna mount.
- Appendix show static observations and there network calculations.

6.1.3 Calculations of Standard Deviation of the Network

6.1.3.1 Default Calculations

After applying Least squares (see appendix), the computed reference variance by static method of instrument default parameters:

$V^TWV = 0.749690714$

Computed $\boxed{S_0 = \sqrt{\left(\frac{V^T * W * V}{M - N}\right)}}$ ……………………………..………………… (6.1)

R = m-n

Where m: number of equations
N: number of unknowns
R: degrees of freedom

So= 0.288615606

Computed standard deviation static of instrument default parameters in station (A):

$Sxf = So\ \sqrt{Qxixi}\ = 0.288615606 * \sqrt{2.36*10^{-6}} = 4.43379707*10^{-4}$

$Syf = So\sqrt{Qyiyi}\ = 0.288615606 * \sqrt{9.59*10^{-7}} = 2.826370647*10^{-4}$

$Szf = So\sqrt{Qzizi}\ = 0.288615606 * \sqrt{7.33*10^{-7}} = 2.470994609*10^{-4}$

$Sxc = So\ \sqrt{Qxixi}\ = 0.288615606 * \sqrt{2.04*10^{-6}} = 4.122255387*10^{-4}$

$Syc= So\sqrt{Qyiyi}\ = 0.288615606 * \sqrt{1.23*10^{-6}} = 0.3200901915*10^{-4}$

$Szc = So\sqrt{Qzizi}\ = 0.288615606 * \sqrt{1.51*10^{-6}} = 3.546567943*10^{-4}$

$Sxe = So\ \sqrt{Qxixi}\ = 0.288615606 * \sqrt{5.03*10^{-6}} = 6.472973113*10^{-4}$

$Sye= So\sqrt{Qyiyi}\ = 0.288615606 * \sqrt{5.02*10^{-6}} = 6.466535545*10^{-4}$

$Sze = So\sqrt{Qzizi}\ = 0.288615606 * \sqrt{3.11*10^{-6}} = 5.089791652*10^{-4}$

Table(6.13):Standard Deviation Static of Instrument Default Parameters in Station(A)

Point	**Name**	**Easting(X)**	**Northing(Y)**	**Elevation(Z)**
1	**F**	4.43379707 E-04	2.826370647E-04	2.470994609 E-04
2	**C**	4.122255387 E-04	0.3200901915 E-04	3.546567943E-04
3	**E**	6.472973113 E-04	5.089791652 E-04	5.089791652 E-04

Computed standard deviation static of instrument default parameters in station (B):

Sxf = So $\sqrt{Qxixi}$ = 0.288615606 * $\sqrt{3.50*10^{-6}} = 5.399503571*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.288615606 * $\sqrt{3.62*10^{-6}} = 5.491286409*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.288615606 * $\sqrt{2.46*10^{-6}} = 4.5267589*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ = 0.288615606 * $\sqrt{5.16*10^{-6}} = 6.556086295*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.288615606 * $\sqrt{1.93*10^{-6}} = 4.0095766141*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.288615606 * $\sqrt{2.68*10^{-6}} = 4.724841101*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.288615606 * $\sqrt{3.13*10^{-6}} = 5.106131314*10^{-4}$

Sye= So $\sqrt{Qyiyi}$ = 0.288615606 * $\sqrt{2.36*10^{-6}} = 4.43379707*10^{-4}$

Sze = So $\sqrt{Qzizi}$ = 0.288615606 * $\sqrt{3.14*10^{-6}} = 5.114281568*10^{-4}$

Table(6.14):Standard Deviation Static of Instrument Default Parameters in Station (B):

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	5.399503571 E-04	5.491286409 E-04	4.5267589 E-04
2	**C**	6.556086295 E-04	4.0095766141 E-04	4.724841101 E-04
3	**E**	5.106131314 E-04	4.43379707 E-04	5.114281568 E-04

Computed average standard deviation static of instrument default parameters in stations A&B:

Sxf= $\dfrac{4.43379707*10^{-4}+5.399503571*10^{-4}}{2}$ = 4.916650321E-4

Syf= $\dfrac{2.826370647*10^{-4}+5.491286409*10^{-4}}{2}$ = 4.158828528E-4

Szf= $\dfrac{2.470994609*10^{-4}+4.5267589*10^{-4}}{2}$ = 3.498876755E-4

$$Sxc= \frac{4.122255387*10^{-4}+6.556086295*10^{-4}}{2} = 5.339170841E-4$$

$$Syc= \frac{0.3200901915*10^{-4}+4.0095766141*10^{-4}}{2} = 2.164833403E-4$$

$$Szc= \frac{3.543567943*10^{-4}+4.724841101*10^{-4}}{2} = 4.134204522E-4$$

$$Sxe= \frac{6.472973113*10^{-4}+5.106131314*10^{-4}}{2} = 5.789552214E-4$$

$$Sye= \frac{6.466535545*10^{-4}+4.43379707*10^{-4}}{2} = 5.450166308E-4$$

$$S_{ze}= \frac{5.089791652*10^{-4}+5.114281568*10^{-4}}{2} = 5.10203661E-4$$

Table(6.15): Average Standard Deviation Static of Instrument Default Parameters

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	4.916650321 E-04	4.158828528E-04	3.498876755E-04
2	**C**	5.339170841 E-04	2.164833403 E-04	4.134204522 E-04
3	**E**	5.789552214 E-04	5.450166308 E-04	5.10203661 E-04

Computed horizontal standard error for points F, C, & E of static of instrument default parameters:

Horizontal standard error = $\sqrt{(SX)^2+(Sy)^2}$

Horizontal standard:

$$F= \sqrt{\left(4.916650321*10^{-4}\right)^2+\left(4.158828528*10^{-4}\right)^2} = 6.439666537E-4$$

$$C = \sqrt{\left(5.339170841*10^{-4}\right)^2+\left(2.164833403*10^{-4}\right)^2} = 5.761358254\ E-4$$

$$E = \sqrt{\left(5.789552214*10^{-4}\right)^2+\left(5.450166308*10^{-4}\right)^2} = 7.951303517\ E-4$$

Computed vertical standard error for points F, C, &E of static of instrument default parameters:

Vertical standard error = $\sqrt{(Sz)^2}$

Vertical standard error F = $\sqrt{(3.498876755*10^{-4})^2}$ = 3.498876755E-04

Vertical standard error C = $\sqrt{(4.134204522*10^{-4})}$ = 4.134204522 E-04

Vertical standard error E = $\sqrt{(5.10203661*10^{-4}}$) = 5.10203661 E-04

Table(6.16):Horizontal and Vertical Standard Error in Static of Instrument Default Parameters

Point	Name	Horizontal	Vertical
1	**F**	6.439666537E-4	3.498876755E-04
2	**C**	5.761358254 E-4	4.134204522 E-04
3	**E**	7.951303517 E-4	5.10203661 E-04

6.1.3.2 Time 15 minutes Calculations

After applying Least Squares (see appendix), the computed reference variance by static method at time =15 minutes as follows:

V^TWV= 0.211661368

So= 0.153355566

Computed standard deviation static 15 minutes in station A:

Sxf = So $\sqrt{Qxixi}$ = 0.153355566* $\sqrt{2.36*10^{-6}} = 2.355892907*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.153355566* $\sqrt{9.59*10^{-7}}$ =$1.529716966*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.153355566* $\sqrt{5.48*10^{-5}}$ =$1.135245587*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ 0.153355566* $\sqrt{3.69*10^{-6}} = 2.945864225*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.153355566* $\sqrt{1.44*10^{-6}} = 1.840266792*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.153355566* $\sqrt{1.45*10^{-6}} = 1.846645552*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.153355566* $\sqrt{4.93*10^{-6}} = 3.405046153*10^{-4}$

Sye= So $\sqrt{Qyiyi}$ = 0.153355566* $\sqrt{4.83*10^{-6}} = 3.370335296*10^{-4}$

Sze = So $\sqrt{Qzizi}$ = 0.153355566* $\sqrt{3.08*10^{-6}} = 2.691379261*10^{-4}$

Table (6.17): Standard Deviation Static 15 Minutes in Station A

Point	**Name**	**Easting(X)**	**Northing(Y)**	**Elevation(Z)**
1	**F**	2.355892907 E-04	1.529716966 E-04	1.135245587 E-03
2	**C**	2.945864225 E-04	1.840266792 E-04	1.846645552 E-04
3	**E**	3.405046153 E-04	3.370335296 E-04	2.691379261 E-04

Computed standard deviation static 15 minutes in station B:

Sxf = So $\sqrt{Qxixi}$ = 0.153355566* $\sqrt{4.01*10^{-6}} = 3.070942816*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.153355566* $\sqrt{3.30*10^{-6}} = 2.785842202*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.153355566* $\sqrt{2.15*10^{-6}} = 2.248634001*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ = 0.153355566* $\sqrt{4.58*10^{-6}} = 3.281952432*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.153355566* $\sqrt{1.65*10^{-5}} = 6.229332539*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.153355566* $\sqrt{2.49*10^{-6}} = 2.419910014*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.153355566* $\sqrt{2.99*10^{-6}} = 2.65176563*10^{-4}$

Sye= So $\sqrt{Qyiyi}$ = 0.153355566* $\sqrt{3.06*10^{-6}} = 2.682626784*10^{-4}$

Sze = So $\sqrt{Qzizi}$ = 0.153355566* $\sqrt{3.14*10^{-6}} = 2.717467553*10^{-4}$

Table (6.18): Standard Deviation Static 15 Minutes in Station B

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	3.070942816 E-04	2.785842202 E-04	2.248634001 E-04
2	**C**	3.281952432 E-04	6.229332539 E-04	2.419910014 E-04
3	**E**	2.65176563 E-04	2.682626784 E-04	2.717467553 E-04

Computed average standard deviation static 15 minutes in stations A&B:

$$Sxf= \frac{3.355892907*10^{-4}+3.070942816*10^{-4}}{2} = 3.213417862E-4$$

$$Syf= \frac{1.529716966*10^{-4}+2.785842202*10^{-4}}{2} = 2.157779493E-4$$

$$Szf= \frac{1.135245587*10^{-4}+2.248634001*10^{-4}}{2} = 1.691939794E-4$$

$$Sxc= \frac{2.945864225*10^{-4}+3.281952432*10^{-4}}{2} = 3.113908329E-4$$

$$Syc= \frac{1.840266792*10^{-4}+6.229332539*10^{-4}}{2} = 4.034799666E-4$$

$$Szc= \frac{1.846645552*10^{-4}+2.419910014*10^{-4}}{2} = 2.133277783E-4$$

$$Sxe= \frac{3.405046153*10^{-4}+2.65176563*10^{-4}}{2} = 3.028405892E-4$$

$$Sye= \frac{1.840266792*10^{-4}+2.682626784*10^{-4}}{2} = 2.261446788E-4$$

$$Sze= \frac{2.691379261*10^{-4}+2.717467553*10^{-4}}{2} = 2.704263008E-4$$

Table (6.19): Average Standard Deviation Static 15 Minutes

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	3.213417862E-04	2.157779493E-04	1.691939794E-04
2	**C**	3.113908329E-04	4.034799666E-04	2.133277783E-04
3	**E**	3.028405892E-04	2.261446788E-04	2.704263008E-04

Computed horizontal standard error for points F, C, & E of static time = 15 minutes:

Horizontal standard error = $\sqrt{(SX)^2 + (Sy)^2}$ ………………………….………….. (6.3)

Horizontal standard:

F= $\sqrt{\left(3.213417862 * 10^{-4}\right)^2 + \left(2.157779493 * 10^{-4}\right)^2}$ = 3.870667328E-4

C = $\sqrt{\left(3.113908329 * 10^{-4}\right)^2 + \left(4.034799666 * 10^{-4}\right)^2}$ = 5.096668856 E-4

E = $\sqrt{\left(3.028405892 * 10^{-4}\right)^2 + \left(2.261446788 * 10^{-4}\right)^2}$ = 3.779601069 E-4

Computed vertical standard error for points F, C, &E of static time = 15 minutes:

Vertical standard error = $\sqrt{(Sz)^2}$ …………………………………………………… (6.4)

Vertical standard error F = $\sqrt{(1.691939794 * 10^{-4})^2}$ = 1.691939794E-04

Vertical standard error C = $\sqrt{(2.133277783 * 10^{-4})^2}$ = 2.133277783E-04

Vertical standard error E = $\sqrt{(2.704263008E * 10^{-4})^2}$ = 2.704263008E E-04

Table (6.20): Horizontal and Vertical Standard Error in Static Time = 15 Minutes

Point	Name	Horizontal	Vertical
1	**F**	3.870667328E-4	1.691939794E-04
2	**C**	5.0966,68856E-4	2.133277783E-04
3	**E**	3.779601069 E-4	2.704263008E E-04

6.1.3.3 Time 5 minutes Calculations

After applying Least Squares (see appendix), the computed reference variance by static method at time = 5 minutes as follows:

$V^TWV = 2.799863576$

So= 0.557759762

Computed standard deviation static 5 minutes in station A:

Sxf = So $\sqrt{Qxixi}$ = 0.557759762* $\sqrt{2.9037*10^{-6}} = 9.504363819*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.557759762* $\sqrt{2.006*10^{-6}} = 7.89973721*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.557759762* $\sqrt{2.830*10^{-6}} = 9.382971515*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ = 0.557759762* $\sqrt{2.377*10^{-6}} = 8.59927368*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.557759762* $\sqrt{1.5409*10^{-6}} = 6.923638874*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.557759762* $\sqrt{1.819*10^{-6}} = 7.522523093*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.557759762* $\sqrt{4.793*10^{-6}} = 1.221099054*10^{-3}$

Sye= So $\sqrt{Qyiyi}$ = 0.557759762* $\sqrt{3.4063*10^{-6}} = 1.2941058*10^{-3}$

Sze = So $\sqrt{Qzizi}$ = 0.557759762* $\sqrt{4.9994*10^{-6}} = 1.247101437*10^{-3}$

Table (6.21): Standard Deviation Static 5 Minutes in Station A

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	9.504363819 E-04	7.89973721 E-04	9.382971515 E-04
2	**C**	8.59927368 E-04	6.923638874 E-04	7.522523093 E-04
3	**E**	1.221099054 E-03	1.2941058 E-03	1.247101437 E-03

Computed standard deviation static 5 minutes in station B:

Sxf = So $\sqrt{Qxixi}$ = 0.557759762* $\sqrt{1.7542*10^{-7}} = 2.33607474*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.557759762* $\sqrt{1.127*10^{-7}} = 1.872445294*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.557759762* $\sqrt{1.398*10^{-7}} = 2.085454725*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ = 0.557759762* $\sqrt{1.991*10^{-7}} = 2.488758808*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.557759762* $\sqrt{1.4106*10^{-7}} = 2.094831616*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.557759762* $\sqrt{2.1215*10^{-7}} = 2.56872442*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.557759762* $\sqrt{2.221*10^{-7}} = 2.628581575*10^{-4}$

Sye= So $\sqrt{Qyiyi}$ 0.557759762* $\sqrt{1.365*10^{-7}} = 2.060693996*10^{-4}$

Sze = So $\sqrt{Qzizi}$ = 0.557759762* $\sqrt{1.5445*10^{-7}} = 2.192002961*10^{-4}$

Table (6.22): Standard Deviation Static 5 Minutes in Station B

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	2.33607474 E-04	1.872445294 E-04	2.085454725 E-04
2	**C**	2.488758808 E-04	2.094831616 E-04	2.56872442 E-04
3	**E**	2.628581575 E-04	2.060693996 E-04	2.192002961 E-04

Computed average standard deviation static 5 minutes in stations A&B:

Sxf= $\dfrac{9.504363819*10^{-4} + 2.33607474*10^{-4}}{2}$ = 5.92021928E-4

Syf= $\dfrac{7.89973721*10^{-4} + 1.872445294*10^{-4}}{2}$ = 4.862095075E-4

Szf= $\dfrac{9.382971515*10^{-4} + 2.085454725*10^{-4}}{2}$ = 5.73421312E-4

$$Sxc=\frac{8.59927368*10^{-4}+2.488758808*10^{-4}}{2} = 5.544016244E\text{-}4$$

$$Syc=\frac{6.923638874*10^{-4}+2.094831616*10^{-4}}{2} = 4.509235245E\text{-}4$$

$$Szc=\frac{7.522523093*10^{-4}+2.56872442*10^{-4}}{2} = 5.045623757E\text{-}4$$

$$Sxe=\frac{1.221099054*10^{-3}+2.628581575*10^{-4}}{2} = 7.419786058E\text{-}4$$

$$Sye=\frac{1.2941058*10^{-3}+2.060693996*10^{-4}}{2} = 7.500875998E\text{-}4$$

$$Sze=\frac{1.247101437*10^{-3}+2.192002961*10^{-4}}{2} = 7.331508531E\text{-}4$$

Table (6.23): Average Standard Deviation Static 5 Minutes

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	5.92021928E-04	4.862095075E-04	5.73421312E-04
2	**C**	5.544016244E-04	4.509235245E-04	5.045623757E-04
3	**E**	7.419786058E-04	7.500875998E-04	7.331508531E-04

Computed horizontal standard error for points F, C, & E of static time = 5 minutes:

Horizontal standard error = $\sqrt{(SX)^2+(Sy)^2}$

Horizontal standard:

$$F=\sqrt{\left(5.92021928*10^{-4}\right)^2+\left(4.862095075*10^{-4}\right)^2} = 7.660872329E\text{-}4$$

$$C=\sqrt{\left(5.544016244*10^{-4}\right)^2+\left(4.509235245*10^{-4}\right)^2} = 7.146280054\ E\text{-}4$$

$$E=\sqrt{\left(7.419786058*10^{-4}\right)^2+\left(7.50087599*10^{-4}\right)^2} = 1.055065712\ E\text{-}3$$

Computed vertical standard error for points F, C, &E of static time = 5 minutes:

Vertical standard error = $\sqrt{(Sz)^2}$

Vertical standard error F = $\sqrt{(5.73421312*10^{-4})^2}$ = 5.73421312E-04

Vertical standard error C = $\sqrt{(5.045623757*10^{-4})}$ = 5.045623757E-04

Vertical standard error E = $\sqrt{(7.33150853*10^{-4)}}$ = 7.33150853E-04

Table (6.24): Horizontal and Vertical Standard Error in Static Time = 5 Minutes

Point	Name	Horizontal	Vertical
1	**F**	7.660872329E-4	5.73421312E-04
2	**C**	7.146280054 E-4	5.045623757E-04
3	**E**	1.055065712 E-3	7.33150853E-04

6.1.3.4 Mask Angle 15° Calculations

After applying Least Squares (see appendix), the computed reference variance by static method at mask =15° as follows:

V^TWV = 0.016493171

So = 0.04280858

Computed standard deviation static mask=15 degrees in station A:

Sxf = So $\sqrt{Qxixi}$ = 0.04280858* $\sqrt{2.25*10^{-5}} = 2.030589243*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.04280858* $\sqrt{1.94*10^{-5}} = 1.885522361*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.04280858* $\sqrt{2.39*10^{-5}} = 2.92809859*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ = 0.04280858* $\sqrt{1.31*10^{-5}} = 1.549410412*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.04280858* $\sqrt{8.51*10^{-5}} = 3.949077003*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.04280858* $\sqrt{0.06*10^{-5}} = 0.3315938348*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.04280858* $\sqrt{2.99*10^{-5}} = 2.340811359*10^{-4}$

Sye= So $\sqrt{Qyiyi}$ = 0.04280858* $\sqrt{2.10*10^{-5}} = 1.961735582*10^{-4}$

Sze = So $\sqrt{Qzizi}$ = 0.04280858* $\sqrt{3.03*10^{-5}} = 2.356416941*10^{-4}$

Table (6.25): Standard Deviation Static Mask= 15 Degrees in Station A

Point	**Name**	**Easting(X)**	**Northing(Y)**	**Elevation(Z)**
1	**F**	2.030589243 E-4	1.885522361 E-4	2.92809859 E-4
2	**C**	1.549410412 E-4	3.949077003 E-4	0.3315938348 E-4
3	**E**	2.340811359 E-4	1.961735582 E-4	2.356416941 E-4

Computed standard deviation static mask= 15 degrees in station B:

Sxf = So $\sqrt{Qxixi}$ = 0.04280858* $\sqrt{6.14*10^{-5}} = 3.354401223*10^{-4}$

Syf = So $\sqrt{Qyiyi}$ = 0.04280858* $\sqrt{4.30*10^{-5}} = 2.8071446317*10^{-4}$

Szf = So $\sqrt{Qzizi}$ = 0.04280858* $\sqrt{3.13*10^{-5}} = 2.394986065*10^{-4}$

Sxc = So $\sqrt{Qxixi}$ = 0.04280858* $\sqrt{4.70*10^{-5}} = 2.934808384*10^{-4}$

Syc= So $\sqrt{Qyiyi}$ = 0.04280858* $\sqrt{1.41*10^{-5}} = 1.607460754*10^{-4}$

Szc = So $\sqrt{Qzizi}$ = 0.04280858* $\sqrt{1.85*10^{-5}} = 1.841266647*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = 0.04280858* $\sqrt{4.50*10^{-5}} = 2.871686847*10^{-4}$

Sye= So $\sqrt{Qyiyi}$ = 0.04280858* $\sqrt{4.66*10^{-5}} = 2.922293153*10^{-4}$

Sze = So $\sqrt{Qzizi}$ = 0.04280858* $\sqrt{3.53*10^{-5}} = 2.543420544*10^{-4}$

Table (6.26): Standard Deviation Static Mask = 15 Degrees in Station B

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	3.354401223 E-4	2.8071446317 E-4	2.394986065 E-4
2	**C**	2.934808384 E-4	1.607460754 E-4	1.841266647 E-4
3	**E**	2.871686847 E-4	2.92223153 E-4	2.543420544 E-4

Computed average standard deviation static mask= 15 degrees in stations A&B:

Sxf= $\frac{2.030589243*10^{-4}+3.354401223*10^{-4}}{2}$ = 2.692495233E-4

Syf= $\frac{1.885522361*10^{-4}+2.8071446317*10^{-4}}{2}$ = 2.346333496E-4

Szf= $\frac{2.92809859*10^{-4}+2.39486065*10^{-4}}{2}$ = 2.66147962E-4

Sxc= $\frac{1.549410412*10^{-4}+2.934808384*10^{-4}}{2}$ = 2.242109398E-4

Syc= $\frac{3.949077003*10^{-4}+1.607460754*10^{-4}}{2}$ = 2.778268879E-4

Szc= $\frac{0.3315938348*10^{-4}+1.841266647*10^{-4}}{2}$ = 1.086430241E-4

Sxe= $\frac{2.340811359*10^{-4}+2.871686847*10^{-4}}{2}$ = 2.606249103E-4

Sye= $\frac{1.961735582*10^{-4}+2.92223153*10^{-4}}{2}$ = 2.441983556E-4

Sze= $\frac{2.356416941*10^{-4}+2.543420544*10^{-4}}{2}$ = 2.449918743E-4

Table (6.27): Average Standard Deviation Static Mask = 15 Degrees

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	2.692495233 E-04	2.346333496 E-04	2.66147962 E-04
2	**C**	2.242109398 E-04	2.778268879 E-04	1.086430241 E-04
3	**E**	2.606249103 E-04	2.441983556 E-04	2.449918743 E-04

Computed horizontal standard error for points F, C, & E of static time = 15 minutes:

Horizontal standard error = $\sqrt{(SX)^2 + (Sy)^2}$

Horizontal standard:

F= $\sqrt{\left(2.692495233 * 10^{-4}\right)^2 + \left(2.346333496 * 10^{-4}\right)^2}$ = 3.571387889 E-4

C = $\sqrt{\left(2.242109398 * 10^{-4}\right)^2 + \left(2.778268879 * 10^{-4}\right)^2}$ = 3.570130602 E-4

E = $\sqrt{\left(2.606249103 * 10^{-4}\right)^2 + \left(2.441983556 * 10^{-4}\right)^2}$ = 3.571528815 E-4

Computed vertical standard error for points F, C, &E of static time = 15 minutes:

Vertical standard error = $\sqrt{(Sz)^2}$

Vertical standard error F = $\sqrt{(2.66147962 * 10^{-4})^2}$ = 2.66147962 E-04

Vertical standard error C = $\sqrt{(1.086430241 * 10^{-4})}$ = 1.086430241 E-04

Vertical standard error E = $\sqrt{(2.449918743 * 10^{-4)}}$ = 2.449918743 E-04

Table 6.28: Horizontal and Vertical Standard Error in Static Mask = 15 Degrees

Point	Name	Horizontal	Vertical
1	**F**	3.571387889 E-4	2.66147962 E-04
2	**C**	3.570130602 E-4	1.086430241 E-04
3	**E**	3.571528815 E-4	2.449918743 E-04

6.1.2.5 Mask Angle 10° Calculations

After applying Least Squares (see appendix), the computed reference variance by static method mask angle=10° as follow:

$V^TWV= 6.664301942$

So = 0.862436

Computed standard deviation static mask angle=10° in station A:

$Sxf = So \sqrt{Qxixi} = 0.862436* \sqrt{2.345*10^{-7}} = 4.176363583*10^{-4}$

$Syf = So\sqrt{Qyiyi} = 0.862436* \sqrt{1.0236*10^{-7}} = 2.759256125*10^{-4}$

$Szf = So\sqrt{Qzizi} = 0.862436* \sqrt{2.683*10^{-7}} = 4.467218683*10^{-4}$

$Sxc = So \sqrt{Qxixi} = 0.862436* \sqrt{1.00235*10^{-7}} = 2.730464749*10^{-4}$

$Syc= So\sqrt{Qyiyi}\ 0.862436* \sqrt{9.4356*10^{-8}} = 2.649181036*10^{-4}$

$Szc = So\sqrt{Qzizi} = 0.862436* \sqrt{1.826*10^{-8}} =1.165406036*10^{-4}$

$Sxe = So \sqrt{Qxixi} = 0.862436* \sqrt{1.834*10^{-8}} =1.167956162*10^{-4}$

$Sye= So\sqrt{Qyiyi} = 0.862436* \sqrt{2.457*10^{-8}} =1.351852956*10^{-4}$

$Sze = So\sqrt{Qzizi} = 0.862436* \sqrt{2.0396*10^{-7}} =3.894927501*10^{-4}$

Table (6.29): Standard Deviation Static mask Angle = 10° in Station A

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	4.176363583 E-04	2.759256125 E-04	4.467218683 E-04
2	**C**	2.730464749 E-04	2.649181036 E-04	1.165406036 -04
3	**E**	1.167956162 E-04	1.351852956 E-04	3.894927501 E-04

Computed standard deviation static mask angle = 10° in station B:

Sxf = So $\sqrt{Qxixi}$ = = 0.862436* $\sqrt{8.147*10^{-6}} = 2.854295009*10^{-3}$

Syf = So $\sqrt{Qyiyi}$ = = 0.862436* $\sqrt{8.306*10^{-6}} = 2.485551923*10^{-3}$

Szf = So $\sqrt{Qzizi}$ = = 0.862436* $\sqrt{4.986*10^{-6}} = 1.925763778*10^{-3}$

Sxc = So $\sqrt{Qxixi}$ = = 0.862436* $\sqrt{5.66*10^{-6}} = 2.051800315*10^{-3}$

Syc= So $\sqrt{Qyiyi}$ = = 0.862436* $\sqrt{5.148*10^{-5}} = 6.1879470737*10^{-3}$

Szc = So $\sqrt{Qzizi}$ = = 0.862436* $\sqrt{1.284*10^{-6}} = 9.772583469*10^{-4}$

Sxe = So $\sqrt{Qxixi}$ = = 0.862436* $\sqrt{6.040*10^{-5}} = 6.702631542*10^{-3}$

Sye= So $\sqrt{Qyiyi}$ = = 0.862436* $\sqrt{6.664*10^{-6}} = 2.226354772*10^{-3}$

Sze = So $\sqrt{Qzizi}$ = 0.862436* $\sqrt{6.342*10^{-6}} = 2.171900521*10^{-3}$

Table (6.30): Standard Deviation Static Mask Angle = 10° in Station B

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	2.854295009 E-03	2.485551923 E-03	1.925763778 E-03
2	**C**	2.051800315 E-03	6.1879470737 E-03	9.772583469 E-04
3	**E**	6.702631542 E-03	2.226354772 E-03	2.171900521 E-03

Computed average standard deviation static mask angle = 10° in stations A&B:

$$\text{Sxf}=\frac{4.176363583*10^{-4}+2.854295009*10^{-3}}{2} = 1.635962737\text{E-}3$$

$$\text{Syf}=\frac{2.759256125*10^{-4}+2.485551923*10^{-3}}{2} = 1.380738772\text{E-}3$$

$$\text{Szf}=\frac{4.467218683*10^{-4}+1.925763778*10^{-3}}{2} = 1.186242823\text{E-}3$$

$$\text{Sxc}=\frac{2.730464749*10^{-4}+2.051800315*10^{-3}}{2} = 1.162423395\text{E-}3$$

$$\text{Syc}=\frac{2.649181036*10^{-4}+6.1879470737*10^{-3}}{2} = 3.226432588\text{E-}3$$

$$\text{Szc}=\frac{1.165406036*10^{-4}+9772583469*10^{-4}}{2} = 5.468994753*\text{E-}4$$

$$\text{Sxe}=\frac{1.167956162*10^{-4}+6.702631542*10^{-3}}{2} = 3.409713579\text{E-}3$$

$$\text{Sye}=\frac{1.351852956*10^{-4}+6.1879470737*10^{-3}}{2} = 3.161566184\text{E-}3$$

$$\text{Sze}=\frac{3.894927501*10^{-4}+2.171900521*10^{-3}}{2} = 1.280696636\text{E-}3$$

Table (6.31): Average Standard Deviation Static Mask Angle = 10°

Point	Name	Easting(X)	Northing(Y)	Elevation(Z)
1	**F**	1.635962737E-03	1.380738772E-03	1.186242823E-03
2	**C**	1.162423395E-03	3.226432588E-03	5.468994753E-04
3	**E**	3.409713579E-03	3.161566184E-03	1.280696636E-03

Computed horizontal standard error for points F, C, & E of static time = 15 minutes:

Horizontal standard error = $\sqrt{(SX)^2+(Sy)^2}$

Horizontal standard:

F= $\sqrt{(1.635962737*10^{-3})^2+(1.380738772*10^{-3})^2}$ = 2.140750717E-3

C = $\sqrt{(1.162423395*10^{-3})^2+(3.226432588*10^{-3})^2}$ = 3.429445384 E-3

E = $\sqrt{(3.409713579*10^{-3})^2+(3.161566184*10^{-3})^2}$ = 4.649908325 E-4

Computed vertical standard error for points F, C, &E of static mask angle = 10°:

Vertical standard error = $\sqrt{(Sz)^2}$

Vertical standard error F = $\sqrt{(1.186242823*10^{-3})^2}$ = 1.186242823 E-03

Vertical standard error C = $\sqrt{(5.468994753*10^{-4})}$ = 5.468994753E-04

Vertical standard error E = $\sqrt{(1.2806966361*10^{-3)}}$ = 1.280696636E-03

Table (6.32): Horizontal and Vertical Standard Error in Static Mask Angle = 10°

Point	Name	Horizontal	Vertical
1	**F**	2.140750717E-3	1.186242823 E-04
2	**C**	3.429445384 E-3	5.468994753E-04
3	**E**	4.649908325 E-4	1.280696636E-03

6.2 Calculation Diagrams

6.2.1 Time Accuracy

This section shows data for the standard deviations at each point. The data for the deviations are presented in tables and diagrams.

6.2.1.1 Curve of RTK Horizontal Error

The horizontal standard error for RTK observations are in this section presented in diagrams for each point separately where X-axis denotes different measuring times:
1= 5 seconds, 2 = 8 seconds, 3 = 5 minutes .And the Y-axis denotes the RMS (Root Mean square error)

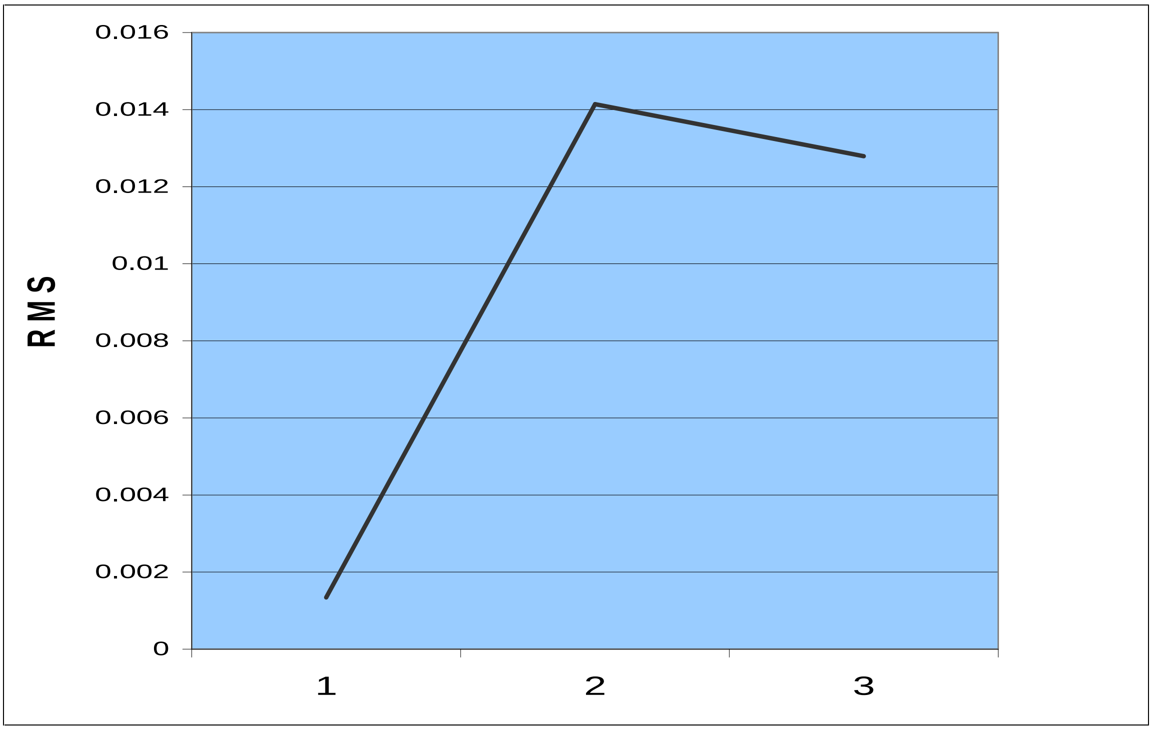


Figure (6.1): Horizontal standard error for RTK time

(1= 5 sec, 2=8 secs, 3=5 min)

6.2.1.2 Curve of RTK Vertical Error

The Vertical standard error for RTK observations are in this section presented in diagrams for each point separately where X-axis denotes different measuring times:

1= 5 seconds, 2 = 8 seconds, 3 = 5 minutes .And the Y-axis denotes the RMS (Root Mean square error)

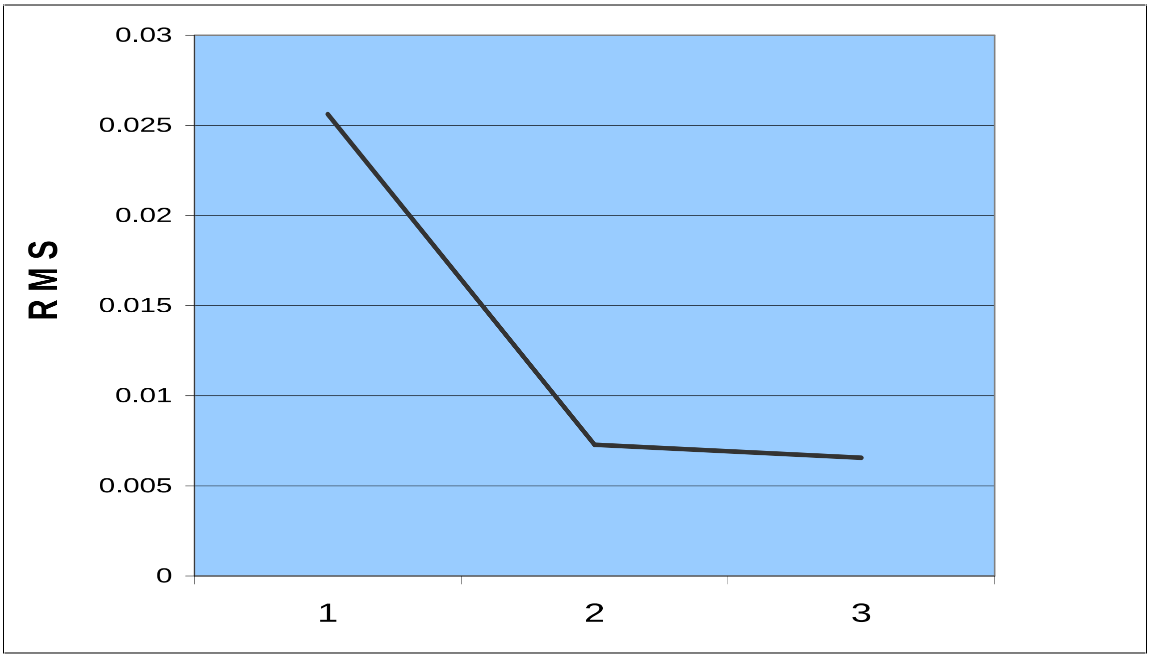


Figure (6.2): Vertical standard error for RTK time

(1= 5 sec, 2=8 sec, 3=5 min)

6.2.1.3 Curves of Static Horizontal Standard Error

The horizontal standard error for static observations are in this section presented in diagrams for each point separately where X-axis denotes different measuring times :

1= 5 minutes, 2 = 8 minutes, 3= 15 minutes .And the Y-axis denotes the standard error.

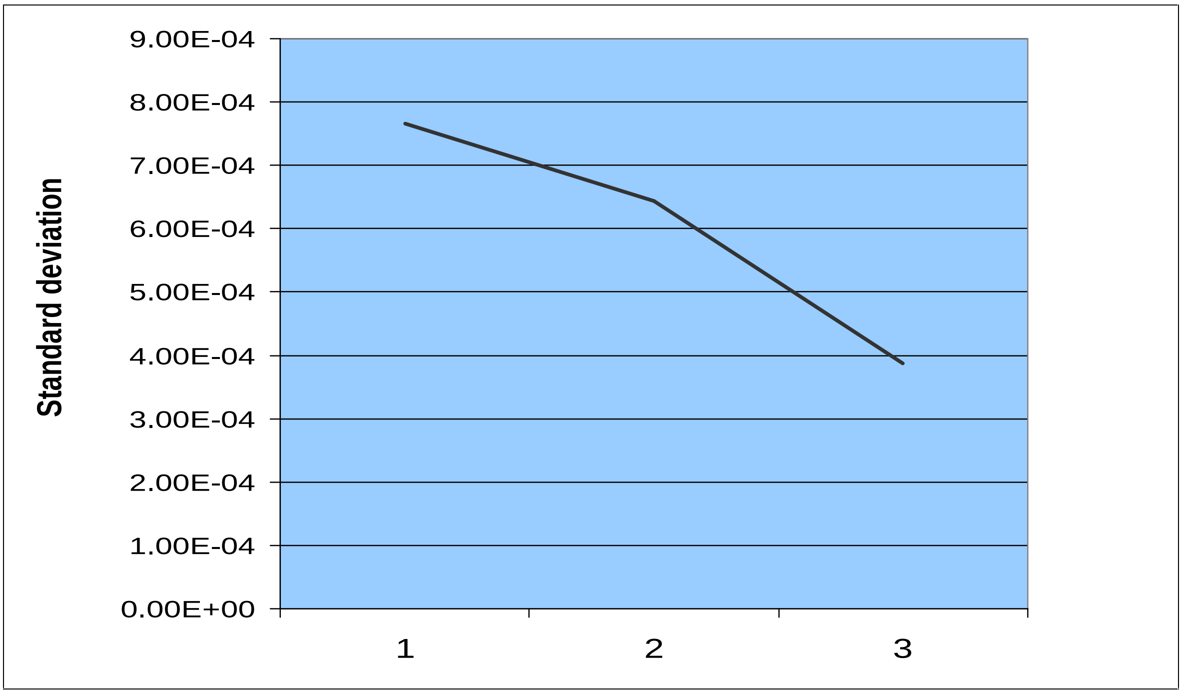


Figure (6.3): Horizontal Standard Error for Static Point (F)

(1=5min, 2=8min, 3= 15 min)

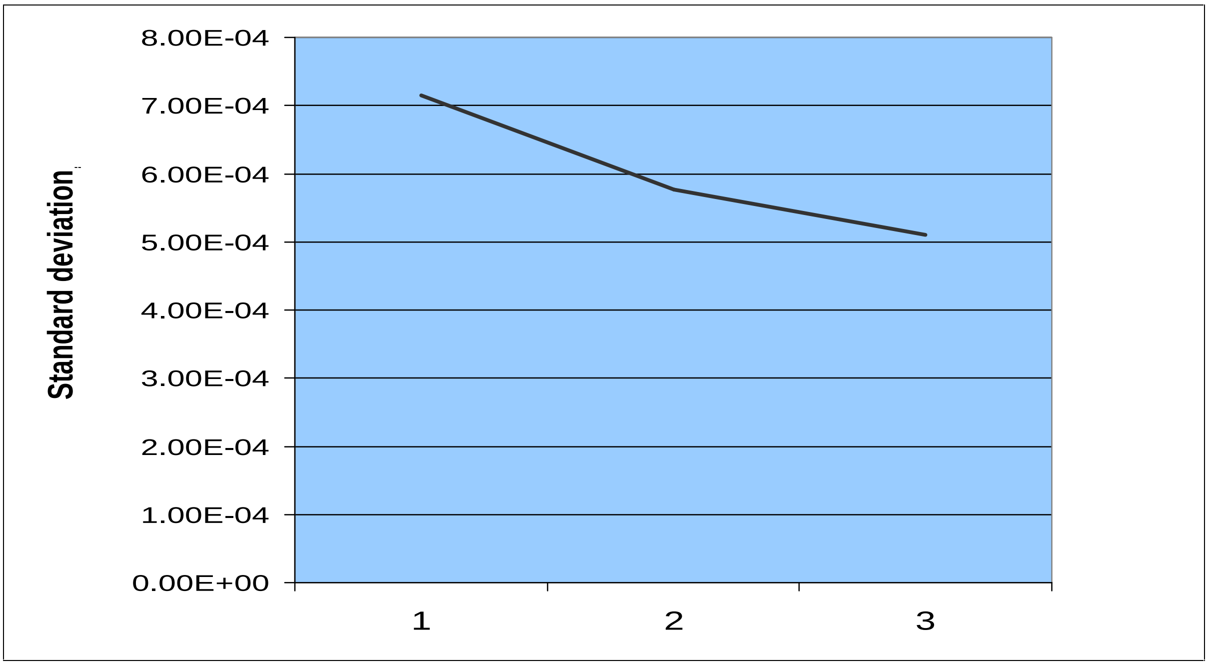


Figure (6.4): Horizontal standard error for static point (C)

(1=5min, 2=8min, 3= 15min)

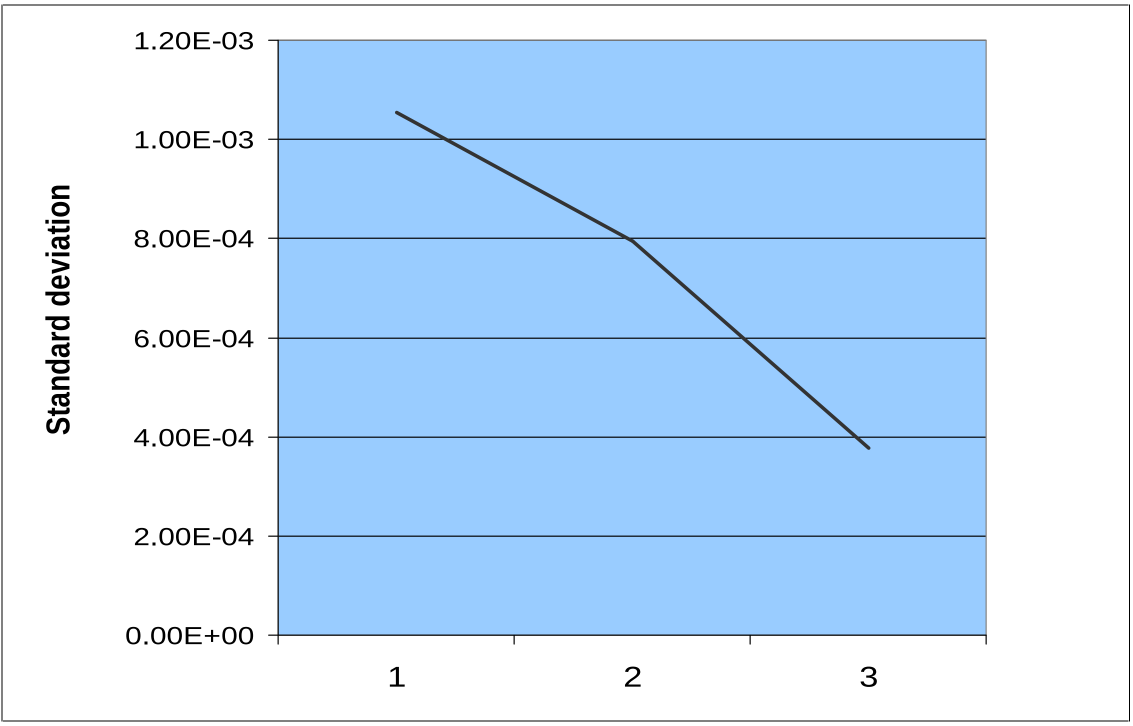


Figure (6.5): Horizontal Standard Error for Static Point (E)

(1= 5 min, 2 = 8 min, 3= 15 min)

6.2.1.4 Curves of Static Vertical Standard Error

The vertical standard errors for static in this section are presented in diagrams for each point separately, where X-axis denotes different measuring times:

1= 5 minutes, 2= 8 minutes, 3= 15 minutes .And the Y axis denotes the standard error.

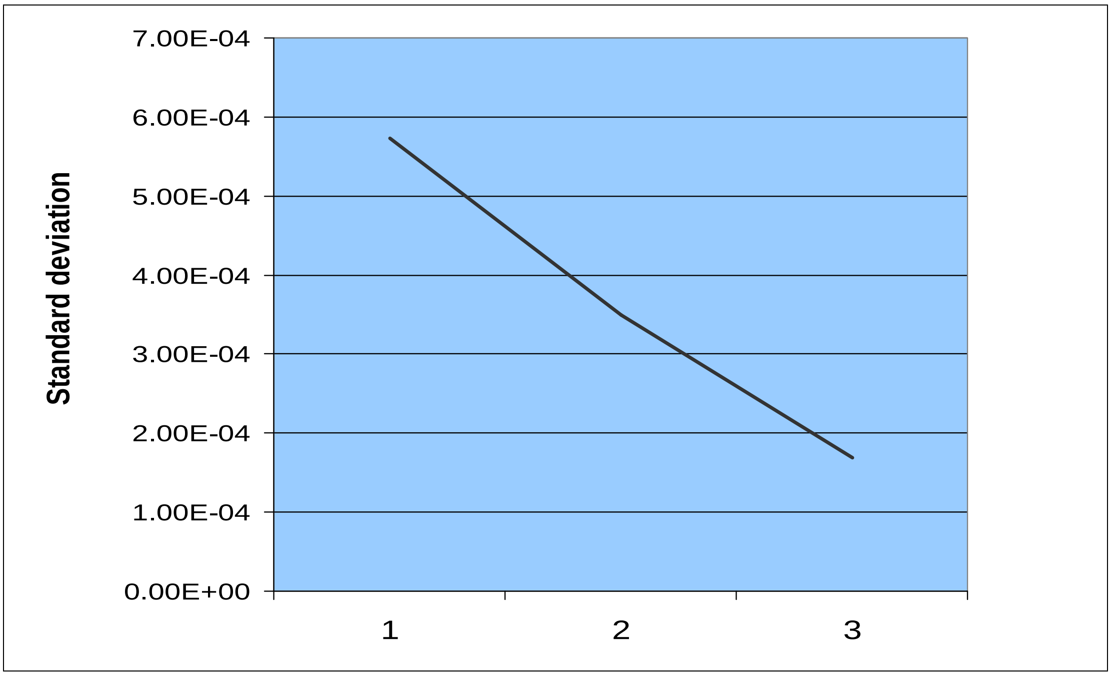


Figure (6.6): Vertical Standard Error for Static Point (F)

(1= 5 min, 2= 8 min, 3= 15 min)

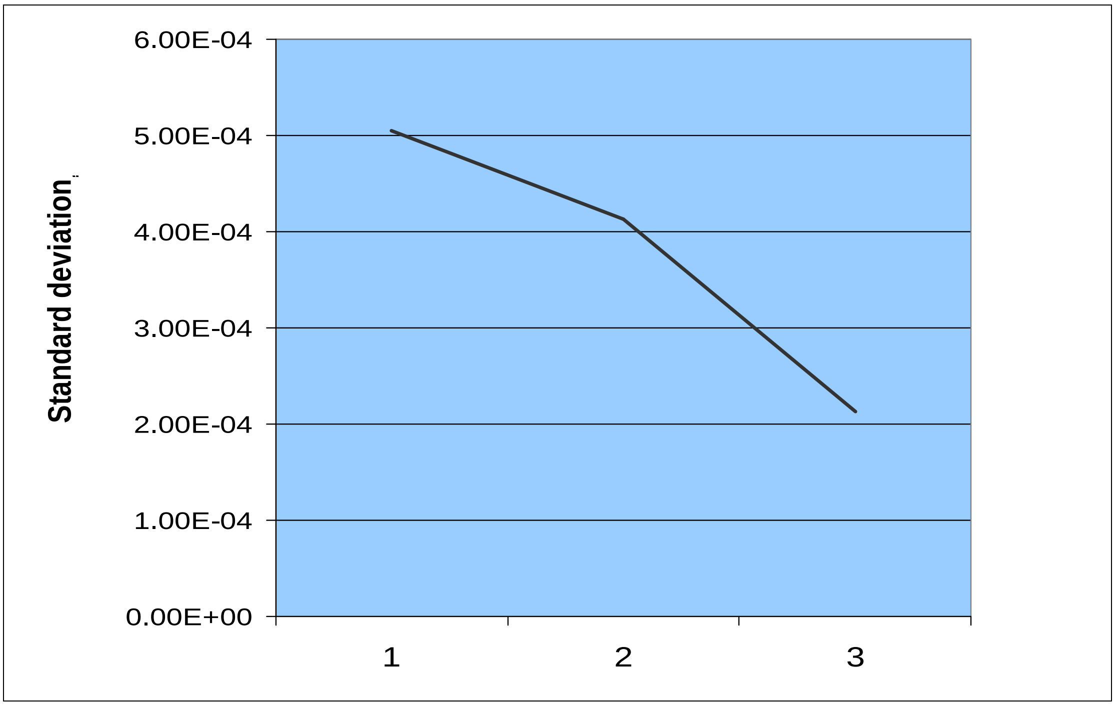


Figure (6.7): Vertical Standard Error in Static Point (C)

(1= 5 min, 2= 8 min, 3= 15 min)

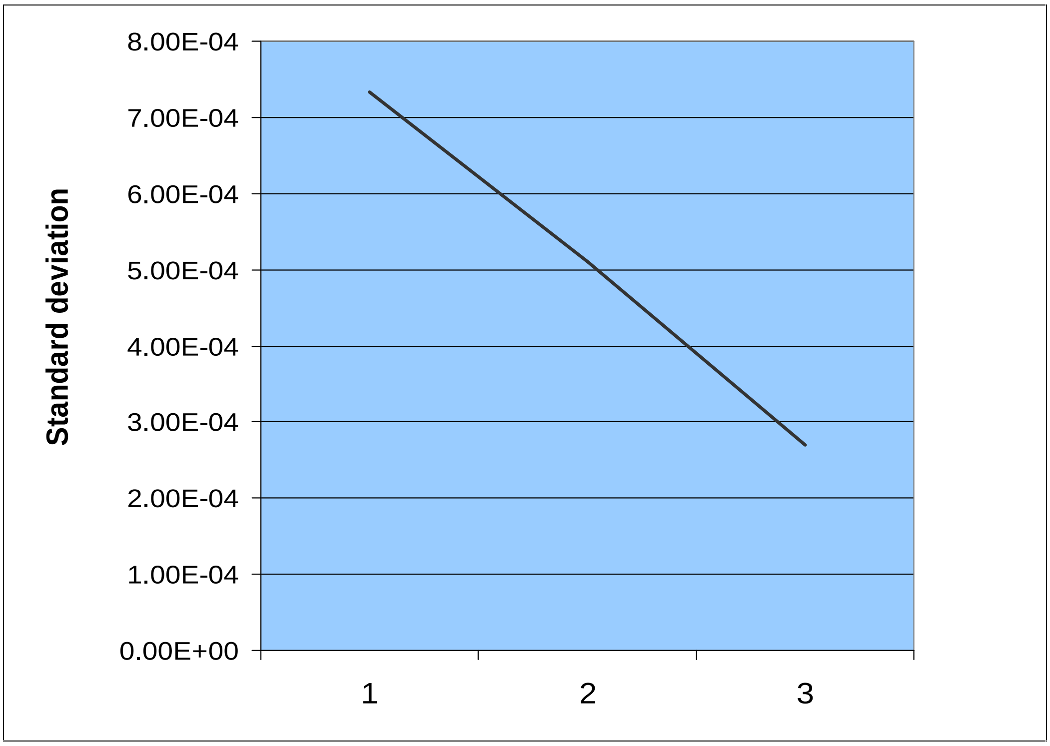


Figure (6.8): Vertical Standard Error in Static Point (E)

(1= 5 min, 2= 8 min, 3= 15 min)

6.2.2 Mask Angle Accuracy

This section shows data for the standard deviations at each point. The data for the deviations are presented in tables and diagrams.

6.2.2.1 Curve of RTK Horizontal Error

The horizontal standard error for RTK observations are in this section presented in diagrams for each point separately where X-axis denotes different measuring times:
1= 10°, 2 = 13°, 3 = 15° .And the Y-axis denotes the RMS (Root Mean square error)

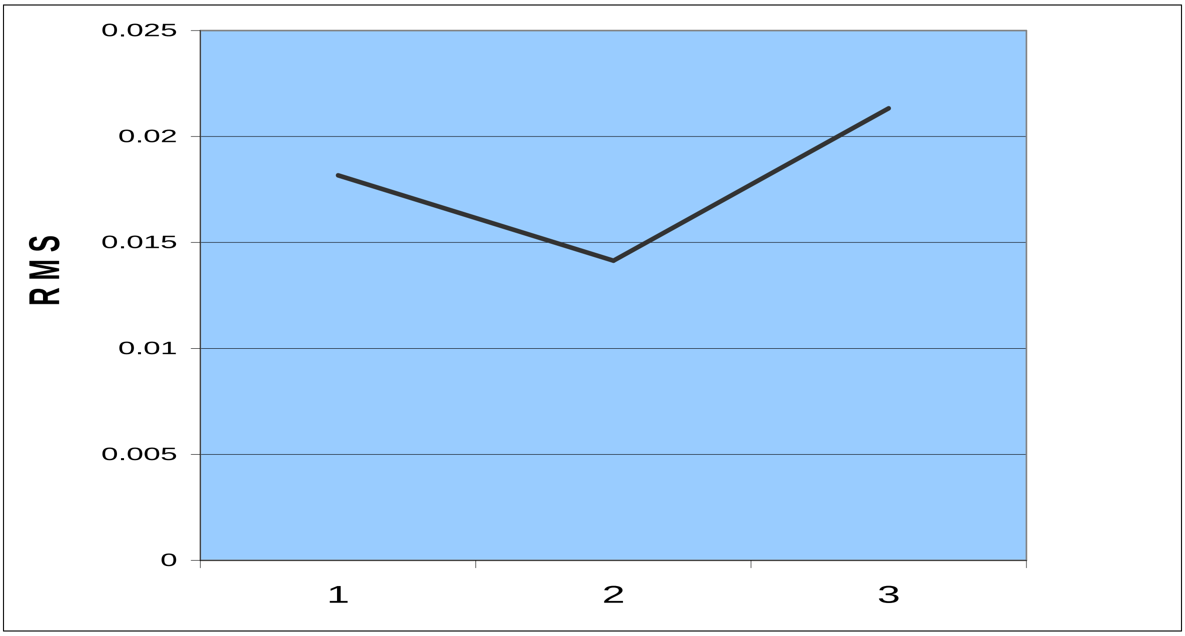


Figure (6.9): Horizontal Standard Error for RTK Mask Angle

(1= 10°, 2 = 13°, 3 = 15°)

6.2.2.2 Curve of RTK Vertical Error

The vertical standard error for RTK observations are in this section presented in diagrams for each point separately where X-axis denotes different measuring times:

1= 10°, 2 = 13°, 3 = 15° .And the Y-axis denotes the RMS (Root Mean square error)

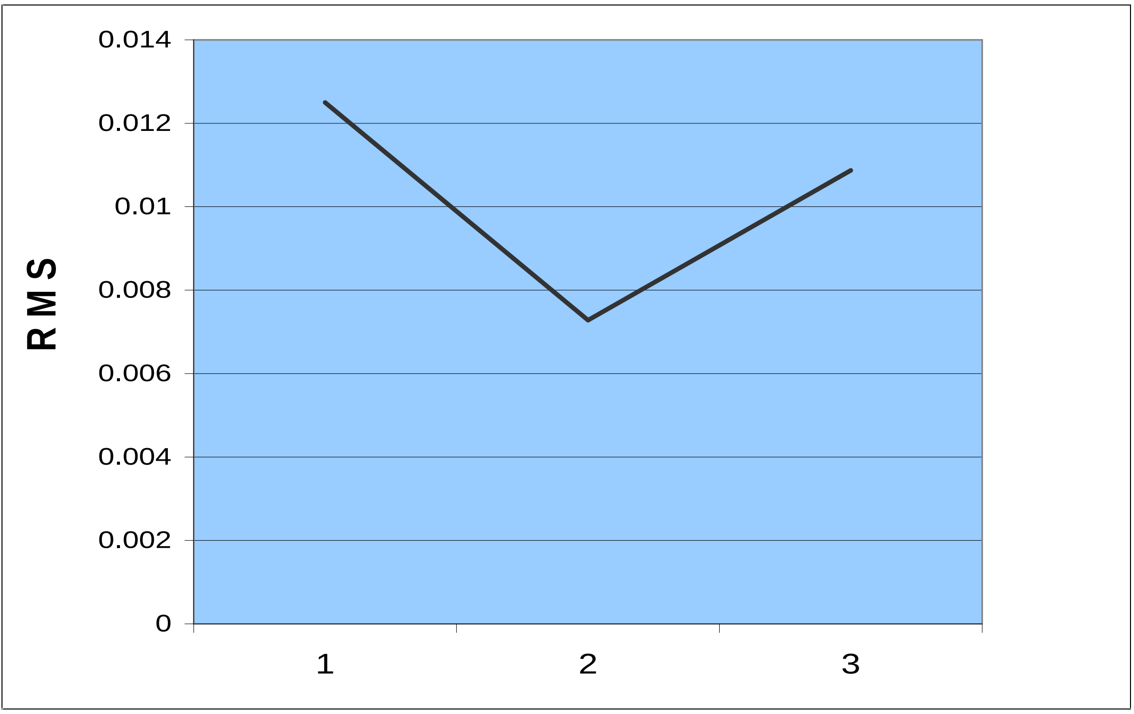


Figure (6.10): Vertical Standard Error for RTK Mask Angle

(1= 10°, 2 = 13°, 3 = 15°)

6.2.2.3 Curves of Static Horizontal Standard Error

The horizontal standard error for static observations are in this section presented in diagrams for each point separately where X-axis denotes different mask angles :
1= 10 degrees, 2 = 13 degrees, 3= 15 degrees .And the Y-axis denotes the standard error.

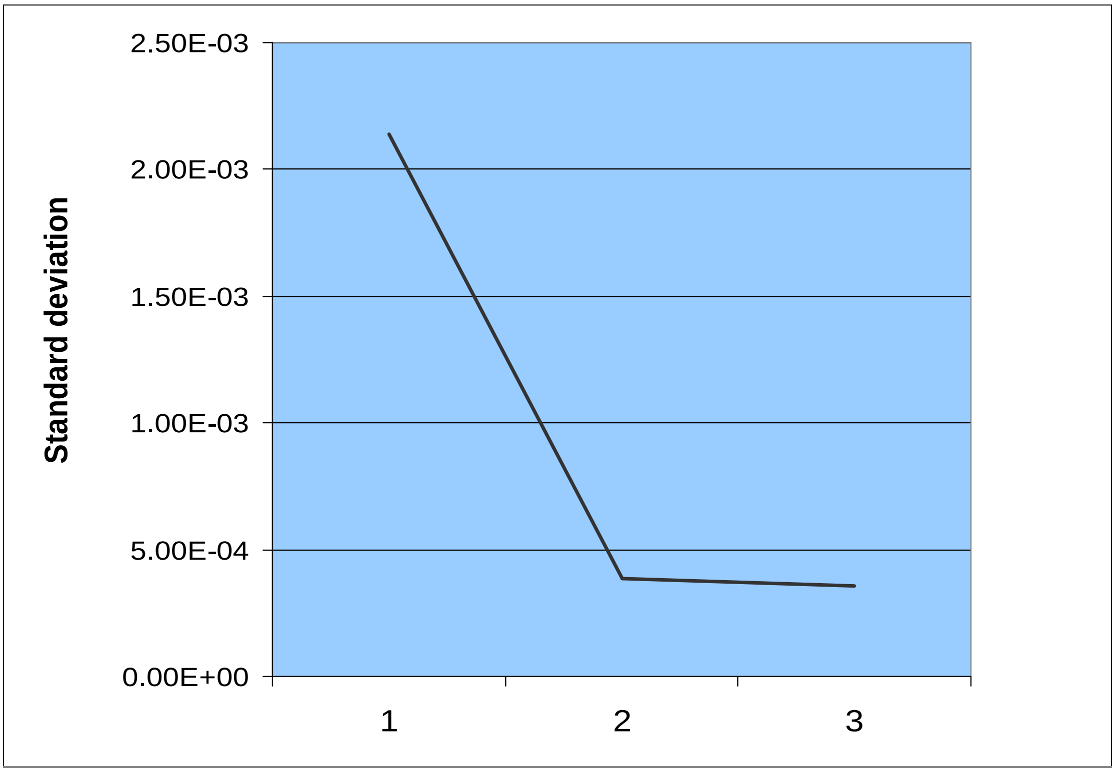


Figure (6.11): Horizontal Standard Error in Static Point (F)

(1=10°, 2=13°, 3= 15°)

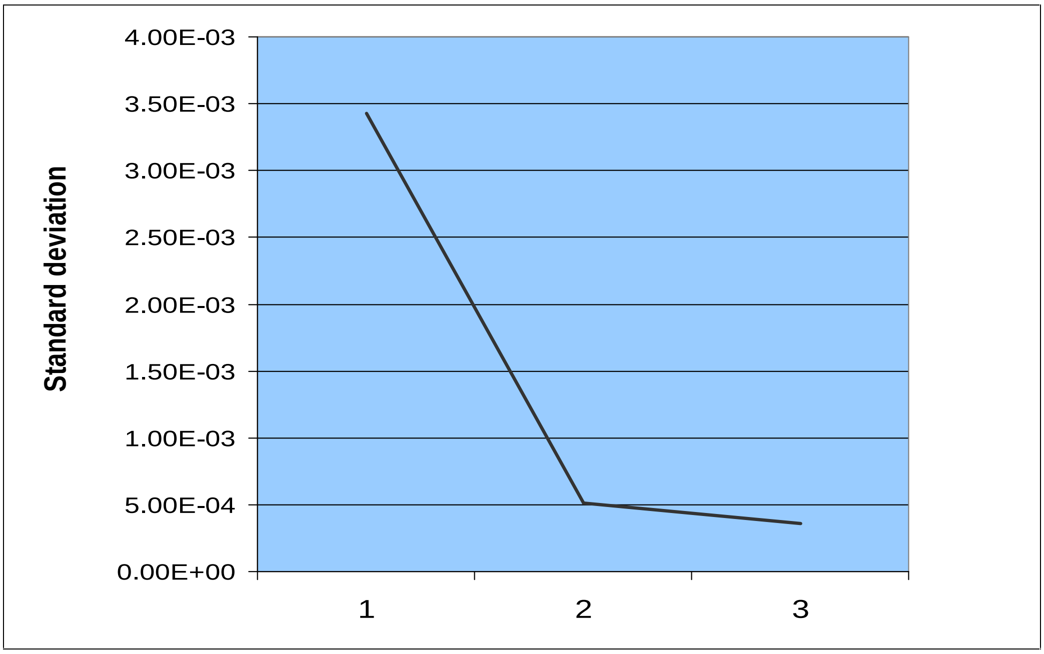


Figure (6.12): Horizontal Standard Error in Static Point (C)

(1=10°, 2=13°, 3=15°)

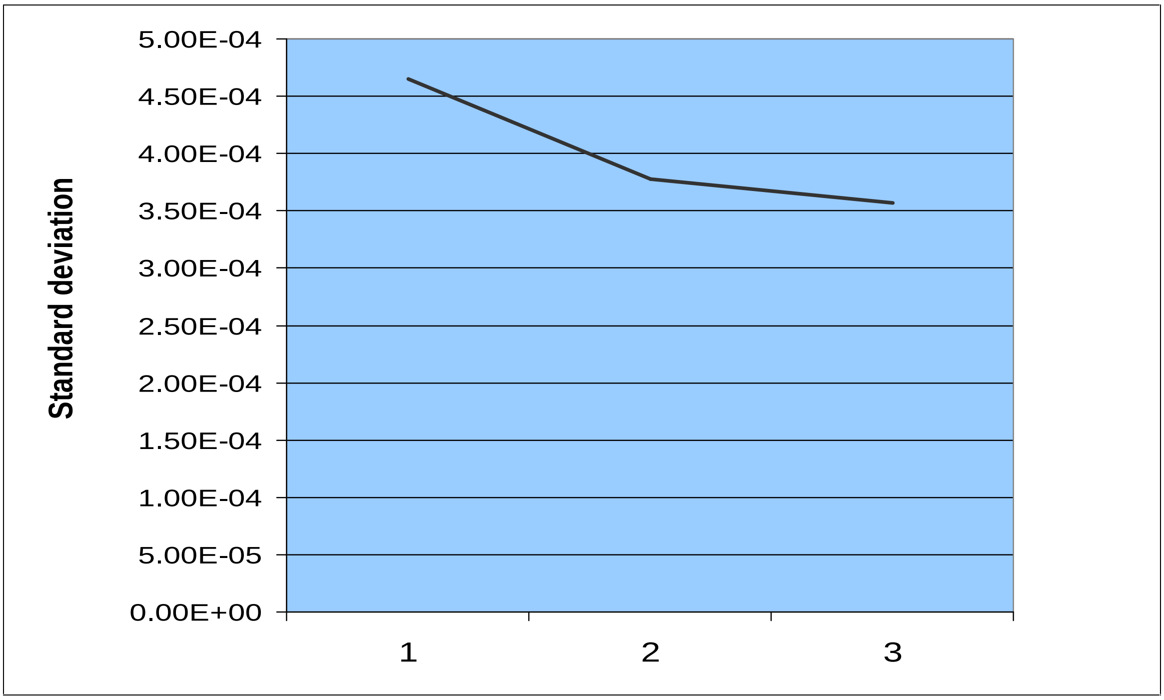


Figure (6.13): Horizontal Standard Error in Static Point (E)

(1=10°,2=13°,3= 15°)

6.2.2.4 Curves of Static Vertical Standard Error

The vertical standard errors for static in this section are presented in diagrams for each point separately , where X-axis denotes different measured mask angles:

1= 10 degrees, 2 = 13 degrees, 3= 15 degrees .And the Y-axis denotes the standard error.

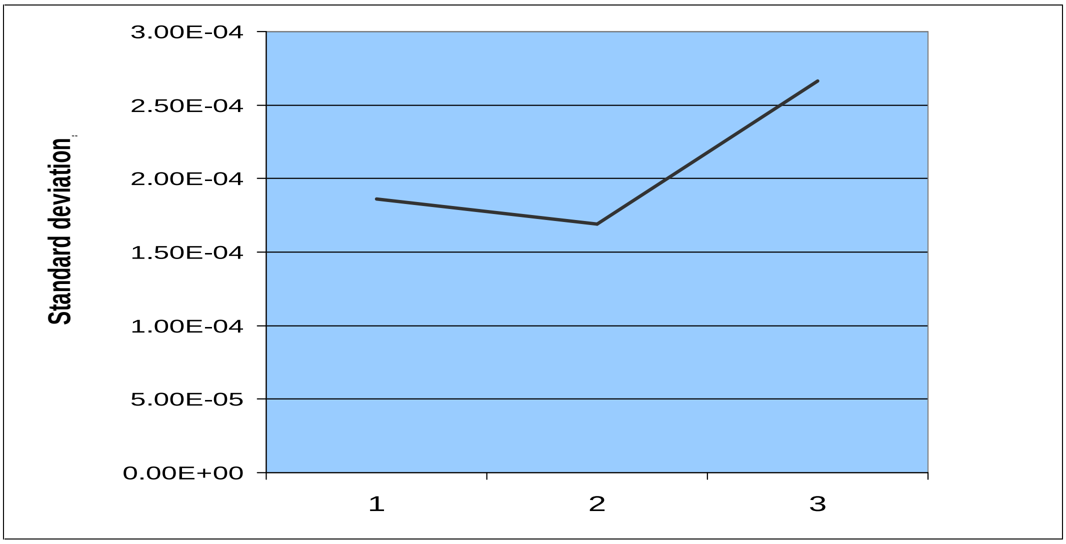


Figure (6.14): Vertical Standard Error in Static Point (F)

(1=10°,2=13°,3=15°)

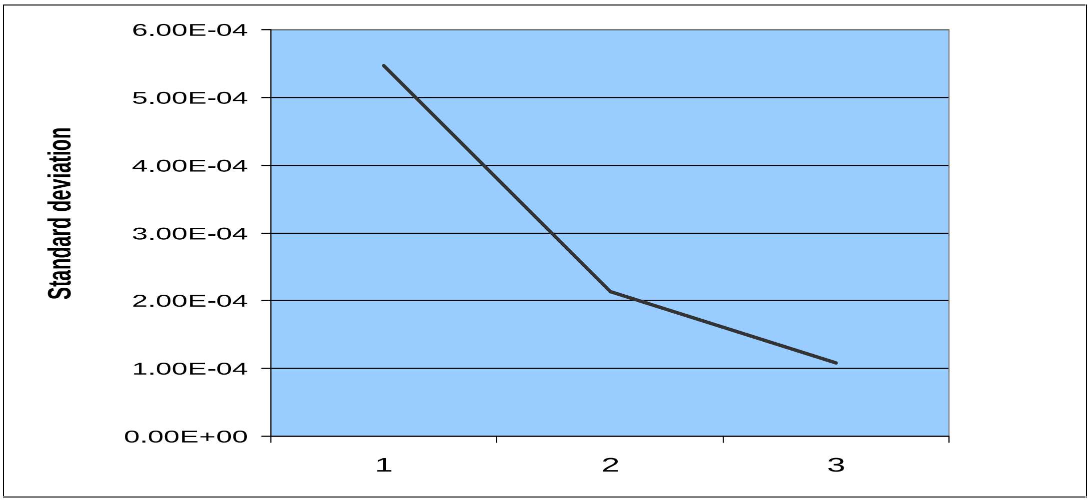


Figure 6.15: Vertical Standard Error in Static Point (C)

(1=10°,2=13°,3=15°)

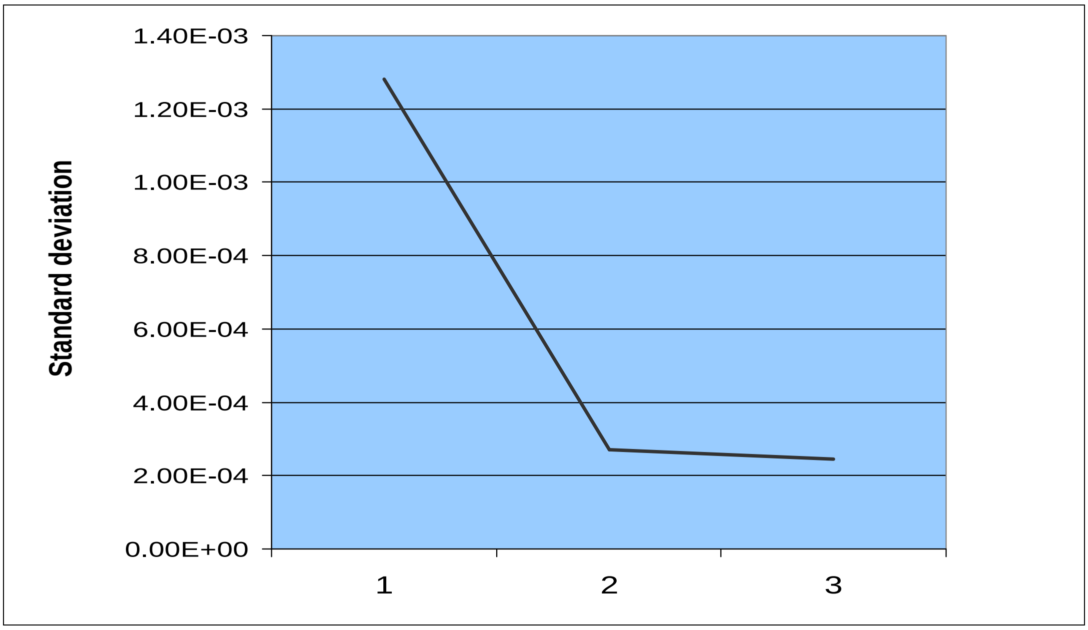


Figure (6.16): Vertical Standard Error in Static Point (E)

(1=10°,2=13°,3= 15°)

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

7.2 Recommendations

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

7.1 Conclusions

This chapter outlines a summary of the main conclusions made in this project.
Amore detailed discussion could be read in chapter six.

1. Static method is more accurate than RTK method.
2. When GPS time increased, the horizontal and vertical standard error of the observed points decreased, so that the accuracy increased.
3. When GPS mask angle increased, the horizontal and vertical standard error of the observed points decreased, so that the accuracy increased.
4. In static method, figures show a little difference in standard error between 13 degrees and 15 degrees , but 15 degrees still more accurate than 13 degrees ,because 15 degrees mask angle limits a number of satellite that transmit signals .
5. Some points show different results ,because of the observing circumstances were different .

7.2 Recommendations

1. Increasing GPS measuring time as much as possible (depend on the goals and specifications of the project) to get high accurate observations.

2. Increasing GPS mask angle from 13 degrees to 15 degrees to get high accurate observations, but needs more observations

3. Using GPS in project surveying of road geometry with RTK method.

4. we recommend to complete the project in larger number of points, and larger points distribution, in addition to play more parameters as Baseline length, DoP and Number of satellites.

APPENDIX

Appendix shows the calculation procedure by Least square solution for all points.

1. **Static Default Calculations.**
2. **Static Time(15 minutes) Calculations.**
3. **Static Time (5 minutes) Calculations**
4. **Static Mask angle (15 degrees) Calculations**
5. **Static Mask angle (10 degrees) Calculations**

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