PERFORMANCE ASSESSMENT OF RELATIVE AND ABSOLUTE GNSS POSITIONING STRATEGIES UNDER DIFFERENT SKY VIEW CONDITIONS

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A dissertation submitted to the department of Geospatial Science and Technology (DGST) in partial fulfillment of the requirements for the award of bachelor of science in Geomatics (BSc. GM) at Ardhi University

CERTIFICATION

The undersigned certify that, they have proof read and hereby recommend for acceptance by the Ardhi University of a dissertation entitled "**Performance Assessment of Relative and Absolute GNSS Positioning Strategies Under Different Sky View Conditions**" in partial fulfillment of the requirement for the award of degree of Bachelor of Science in Geomatics of Ardhi University.

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DECLARATION AND COPYRIGHT

I, MAKAMBO JOSEPHAT hereby declare that, the contents of this dissertation are the results of my own findings through my study and investigation, and to the best of my knowledge, they have not been presented anywhere else as a dissertation for diploma, degree or any similar academic award in any institution of high learning.

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ACKNOWLEDGEMENT

First, I thank almighty God who gave me strength and wisdom for executing my dissertation research successfully. I would like to express here the very thanks to my dissertation supervisors Dr. Elifuraha Saria and Ms. Valerie Ayubu from Ardhi University who provided me the opportunity to perform such research, they instructed me the delicate methodologies so that to achieve research objectives. The completion of this research would be impossible if not dependent on the steadfast support and encouragement of my family and friends. The paid equal contributions to the study for which I always feel profound gratitude in my heart. I am indebted to a number of individuals who took time to share their experiences and skills on research work and sometimes provided me with relevant comment and advice for the research special mention must be made to key people including Mr. Kwimbere, Mr Hamphrey, Mr Lugomela, Mr. Mnzavas and Mr Henric. Special thanks to my classmate who help me during data collection and data processing.

DEDICATION

I dedicate this dissertation to my loving family whose words of encouragement and push for drive ring in my ears. Special dedication to my classmates and closely people who have supported me throughout the process, I will always appreciate all they have done.

ABSTRACT

This study presents a comprehensive assessment of the performance of relative and absolute GNSS positioning strategies under different skyview conditions. This research aimed at evaluating and compare the performance of relative and absolute GNSS positioning strategies under various sky view conditions. It focuses in investigating the accuracy and reliability of GNSS positioning techniques in three distinct skyview environments: open sky views, under tree canopies, and close proximity to tall buildings. The study focuses at evaluating the performance of relative and absolute positioning strategies in each of these scenarios. The study employs static GNSS data collected from points established under clear sky conditions as well as under clear satellite visibility (referred to as OPT 01 and OPT 02), points situated under tree canopies (FRT 01, FRT 02, and FRT 03), and points located near tall buildings (BLD 01, BLD 02, and BLD 03) all points were observed for the minimum of three hours. Data was collected in RINEX format and processed by Leica Infinity and RTKLIB. The decision to use two software tools, RTKLIB and Leica Infinity, was driven by the need to gain a comprehensive understanding of relative and absolute GNSS positioning performance under different sky view conditions. The obtained positions were assessed by comparing the coordinates of each point from both software in relative and absolute modes. The results show that in clear skyview conditions, the highest uncertainty in relative positioning was 0.004 meters, while for absolute positioning, it was 0.092 meters. However, under tree canopies, the highest uncertainty increased to 0.007 meters for relative positioning and 0.237 meters for absolute positioning. Similarly, when points were established close to tall buildings, the relative positioning uncertainty rose significantly to 0.407 meters, and the absolute positioning uncertainty was 0.282 meters. The findings of this research provide valuable insights into the performance of GNSS positioning methods under varying skyview conditions. The results can be of significant importance in enhancing the accuracy and reliability of GNSS-based positioning in challenging environments, such as urban areas and dense vegetation. The outcomes of this study can guide the development of improved GNSS positioning strategies to address the limitations posed by obstructed skyviews and lead to more precise location-based applications and services.

Keywords: Global Navigation Satellite System (GNSS), Relative and Absolute positioning

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ACRONYMS AND ABBREVIATIONS

DoD	Department of Defense
DOP	Dilution of Precision
DGPS	Differential Global Positioning System
GAMIT	GPS Analysis at Massachusetts Institute of Technology
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
IGS	International GNSS Service
PDOP	Position Dilution of Precision
PPP	Precise Point Positioning
RTK	Real Time Kinematic
RINEX	Receiver Independent Exchange Format
RMSE	Root Mean Square Error
SPP	Single Point Positioning
US	United States
TSH	Tanzania Shilling

CHAPTER ONE

INTRODUCTION

1.1 Background

Global Navigation Satellite System (GNSS) technologies have revolutionized the way positioning and navigation are conducted across various sectors, including surveying, mapping, agriculture, transportation, and geosciences. GNSS receivers utilize signals from multiple satellite constellations, such as GPS, GLONASS, Galileo, and BeiDou, to calculate accurate positions on Earth's surface. However, the performance of GNSS positioning can be significantly affected by the surrounding skyview conditions. Satellite navigation is critical in difficult scenarios such as urban canyons and mountainous areas, because many GNSS signals are blocked by natural and artificial obstacles or are strongly degraded. Currently Global Positioning System (GPS) is the most widespread GNSS, it is a space-based radio navigation system developed by the US Department of Defense (DoD) and is fully operative since 1994. (Kameran, 2010)

In urban environments and areas with dense vegetation, GNSS signals often encounter obstructions caused by tall buildings and tree canopies, leading to degraded satellite visibility and reduced signal strength. As a consequence, GNSS positioning in such challenging environments may suffer from increased inaccuracies, resulting in higher uncertainties in both relative and absolute positioning solutions. Consequently, it becomes essential to thoroughly assess the performance of GNSS positioning strategies under different skyview conditions to better understand their limitations and potential for improvement. (Joseph, 2012)

Despite the extensive use of GNSS in various fields, there is a critical need to comprehensively assess the performance of both relative and absolute positioning strategies under different skyview conditions. Such an assessment will help identify the strengths and limitations of each technique and provide valuable insights for optimizing positioning accuracy in challenging environments. Researchers need to set up experiments, collect data and analyze the results to assess the impact of different skyview conditions on both positioning method’s performance. In difficult scenarios it’s inevitable to find a position that has no limitation of signals especially in urban canyons and heavy forest. Figure 1.1 and figure 1.2 illustrate how GPS signals are blocked and refracted when positioning under urban canyons and in heavy forested areas (Awange, 2012)

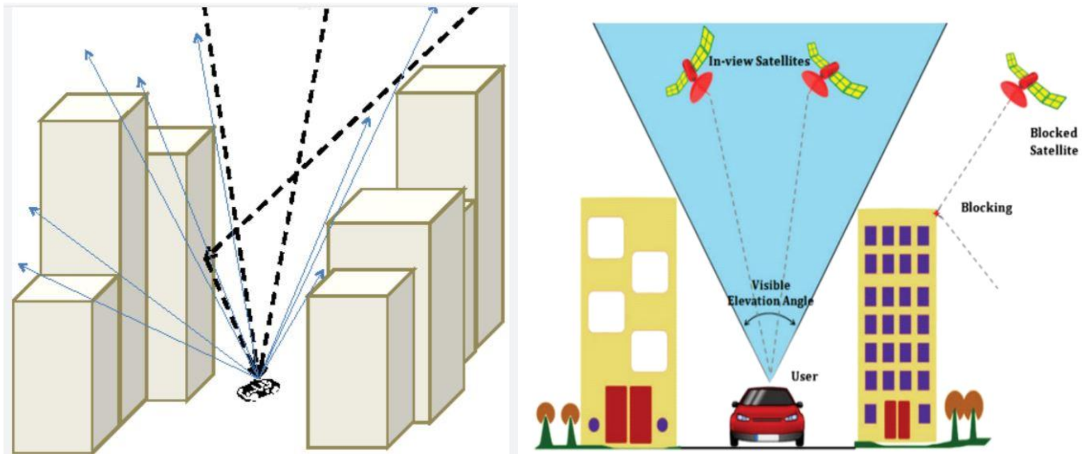

Figure 1.1: Satellite signal tracking under urban canyon. (Firdausah, 2014)

Figure 1.2: A part of road development under tree canopy where controls must be established during implementation of road dimensions (Springer, 2021)

1.1.1 Absolute Point Positioning

Absolute GNSS positioning aims to directly compute the geographic coordinates of a receiver without relying on nearby reference stations This is the positioning method which is independent from the influence of errors transferred from the reference station. In modeling PPP observations, beside the necessity of reference station, satellite clock corrections are not estimated, but assumed to be known. Satellite clock corrections are introduced into processing together with Earth orientation parameters and orbit information by precise products from e.g., IGS or CODE. Standard market GPS receiver using codes (Bayram, 2016).

1.1.2 Relative Point Positioning

Relative GNSS positioning involves determining the position of a receiver relative to the position of another nearby reference receiver. This technique requires both the reference and target receivers to track the same satellites simultaneously. The relative positioning approach is often employed in Real-Time Kinematic (RTK) and Differential GNSS (DGNSS) applications, which rely on a network of fixed reference stations to provide corrections to the target receiver. This method is based on information from reference stations with known coordinates. (William, 2002)

The performance of both relative and absolute positioning strategies can be significantly impacted by the availability of satellite signals in different skyview conditions. Under tree canopies, GNSS signals may be obstructed by foliage and suffer from multipath effects, leading to reduced positioning accuracy and increased positioning errors. In urban canyons, tall buildings can block direct satellite signals, causing signal blockages and reflections that further degrade the positioning performance. Conversely, in open skyview conditions, the absence of obstructions allows for a higher number of visible satellites and generally results in improved GNSS positioning accuracy

1.2 Previous studies

Previous studies have explored the impact of specific environmental conditions on GNSS positioning accuracy, such as urban environments with high-rise buildings and wooded areas with tree canopies. Two different related studies are;

1. Study Title: "Evaluation of GNSS Positioning Accuracy in Urban Environments with High-Rise Buildings". This study conducted by Smith et al. (2018) focused on assessing the performance of GNSS positioning techniques in urban environments with tall buildings. The researchers collected GNSS data in various locations within a dense urban area and compared the positioning accuracy under different conditions, including close proximity to tall buildings. Their findings highlighted the challenges posed by signal blockage and multipath effects, leading to reduced accuracy in such scenarios.

2. Study Title: "Impact of Tree Canopies on GNSS Positioning: An Experimental Analysis". In this study by Johnson et al. (2019), the authors investigated the effects of tree canopies on GNSS positioning accuracy in natural environments. They conducted field experiments in wooded areas with varying levels of tree cover and compared the results with open sky conditions. The research

revealed the significant degradation of GNSS performance under tree canopies due to signal attenuation and scattering, which resulted in positioning errors.

3. Study Title: "Performance Analysis of GNSS Positioning in Open Sky Conditions" (Brown et al., 2020), this study focused on evaluating GNSS positioning accuracy in open sky conditions, where the visibility of satellites is not obstructed by any significant structures. The research examined the effect of atmospheric conditions, satellite geometry, and receiver quality on the accuracy and precision of GNSS positioning under these favorable skyview conditions.

The three previously discussed related studies (Smith et al., 2018; Johnson et al., 2019; Brown et al., 2020) there is a lack of comprehensive research directly comparing the relative and absolute GNSS positioning strategies under these three distinct skyview conditions. This study aims to address this research gap by conducting a thorough performance assessment of relative and absolute GNSS positioning techniques in settings characterized by open sky views, tree canopies, and close proximity to tall buildings. By analyzing and comparing the positioning accuracy and reliability under these diverse skyview conditions, this research will provide valuable insights into the strengths and limitations of different GNSS positioning strategies.

1.3 Problem Statement

Despite the widespread use of Global Navigation Satellite System (GNSS) technologies for positioning applications, their performance can be significantly impacted under various environmental conditions. Previous studies have shown that GNSS positioning accuracy is affected by factors such as tree canopies, open sky views, and proximity to tall buildings. However, there is a lack of comprehensive research that directly compares the relative and absolute GNSS positioning strategies under these specific skyview conditions. This study seeks to fill this gap by conducting a comparative performance assessment of relative and absolute GNSS positioning techniques in environments characterized by tree canopies, open sky views, and close proximity to tall buildings. The findings of this research will contribute to a better understanding of the challenges posed by different skyview conditions and aid in optimizing GNSS positioning strategies for improved accuracy and reliability in urban and natural environments.

1.4 Research Objectives

1.4.1 Main objective

The aim of this study was to make an assessment on the performance of both relative and absolute GNSS positioning strategies under different sky view conditions (difficult scenarios). The evaluation of the performance of these strategies were analyzed in terms of accuracy, precision and reliability of each point.

1.4.2 Specific Objectives

i. To compare the performance of relative and absolute GNSS positioning strategies under different sky view conditions
ii. To determine the suitability of each strategy under varying conditions which can affect the positioning accuracy
iii. To analyze the advantages and limitations of relative and absolute GNSS positioning strategies under difficult scenarios.

1.5 Scope and limitation of the research.

The scope of this study was to evaluate the performance of relative and absolute GNSS positioning strategies under different sky view conditions. The research involved collecting data from various locations of difficult scenarios and analyzing the accuracy, precision and reliability of the positioning strategies. The points were established around Ardhi university. Software used were RTKLIB and LEICA INFINITY.

1.6 Significance of the research.

The research provides valuable insights into the effectiveness of relative and absolute GNSS positioning strategies under varying sky view conditions. This information can be useful for professionals in the field of surveying, mapping and navigation as it can aid in selecting the appropriate positioning strategy for a given scenario. Furthermore, the research can also aid in development of new and improved GNSS positioning techniques particularly for areas with limited sky view.

1.7 Beneficiary of the study.

The beneficiaries of this research include professionals in the field of surveying, mapping and navigation as well as researchers and academics in the field of GNSS technology. The study can also be useful for government agencies involved in infrastructure planning and development particularly in areas with limited sky view. Moreover, the general public can also benefit from this research as it can aid in improving the accuracy of location-based services and navigation systems.

CHAPTER TWO

LITERATURE REVIEW

This chapter aims to provide a comprehensive overview by synthesizing the key findings from relevant studies. One crucial aspect in optimizing GNSS positioning accuracy lies in the choice between relative and absolute positioning techniques. While both methods have their merits, understanding their performance under different sky view conditions is imperative for ensuring dependable positioning outcomes. The performance of GNSS positioning strategies can be significantly influenced by various factors, including the sky view conditions encountered by satellite signals. Urban environments, dense tree canopies, and other obstructions may lead to signal attenuation and multipath interference, impacting the accuracy and reliability of GNSS-derived positions. Hence, conducting a comprehensive assessment of relative and absolute GNSS positioning under these diverse conditions is of utmost importance to enhance the robustness and applicability of GNSS-based systems.

2.1 GNSS Overview

A Global Navigation Satellite System (GNSS) refers to a global, satellite-based, all-weather, 24-hour operational radio-navigation and time transfer system which is designed to provide positioning, timing and navigation (PNT) services primarily for military as well as civilian applications. GNSS is the collective name for the US Navigation System with Timing and Ranging (NAVSTAR) Global Positioning System (GPS), the Russian Global Navigation Satellite System (GLONASS), European Galileo, and the Chinese BeiDou. (Bayram, 2016)

2.1.1 Global Positioning System

GPS consists, nominally, of a constellation of 24 operational satellites. This constellation, known as the initial operational capability (IOC), was completed in July 1993. The official IOC announcement, however, was made on December 8, 1993. To ensure continuous worldwide coverage, GPS satellites are arranged so that four satellites are placed in each of six orbital planes. With this constellation geometry, four to ten GPS satellites will be visible anywhere in the world, if an elevation angle of 15° is considered. only four satellites are needed to provide the positioning, or location, information. GPS satellite orbits are nearly circular (an elliptical shape with a maximum eccentricity is about 0.01), with an inclination of about 55° to the equator. The semimajor axis of a GPS orbit is about 26,560 km (i.e., the satellite altitude of about 20,200 km above the Earth's surface). The corresponding GPS orbital period is about 12 sidereal hours (~11 hours, 58 minutes). (El-Rabbany, 2002)

2.1.2 GPS Signals

Each GPS satellite transmits a microwave radio signal composed of two carrier frequencies (or sine waves) modulated by two digital codes and a navigation message. The two carrier frequencies are generated at 1,575.42 MHz (referred to as the L1 carrier) and 1,227.60 MHz (referred to as the L2 carrier). The corresponding carrier wavelengths are approximately 19 cm and 24.4 cm, respectively, which result from the relation between the carrier frequency and the speed of light in space. All of the GPS satellites transmit the same L1 and L2 carrier frequencies. The code modulation, however, is different for each satellite, which significantly minimizes the signal interference. The two GPS codes are called coarse acquisition (or C/A-code) and precision (or P-code). Each code consists of a stream of binary digits, zeros and ones, known as bits or chips. The codes are commonly known as Pseudorange noise (PRN) codes because they look like random signals (i.e., they are noise-like signals). Presently, the C/A-code is modulated onto the L1 carrier only, while the P-code is modulated onto both the L1 and the L2 carriers. This modulation is called biphase modulation, because the carrier phase is shifted by 180° when the code value changes from zero to one or from one to zero. The C/A-code is a stream of 1,023 binary digits (i.e., 1,023 zeros and ones) that repeats itself every millisecond. This means that the chipping rate of the C/A-code is 1.023 Mbps. In other words, the duration of one bit is approximately 1 ms, or equivalently 300m. Each satellite is assigned a unique C/A-code, which enables the GPS receivers to identify which satellite is transmitting a particular code. The C/A-code range measurement is relatively less precise compared with that of the P-code. It is, however, less complex and is available to all users. (Knippers, 2012)

The P-code is a very long sequence of binary digits that repeats itself after 266 days. It is also 10 times faster than the C/A-code (i.e., its rate is 10.23 Mbps). Multiplying the time it takes the P-code to repeat itself, 266 days, by its rate, 10.23 Mbps, tells us that the P-code is a stream of about 2.35 × 1014 chips! The 266-day-long code is divided into 38 segments; each is 1 week long. Of these, 32 segments are assigned to the various GPS satellites. That is, each satellite transmits a unique 1-week segment of the P-code, which is initialized every Saturday/Sunday midnight crossing. The remaining six segments are reserved for other uses. It is worth mentioning that a

GPS satellite is usually identified by its unique 1-week segment of the P-code. For example, a GPS satellite with an ID of PRN 20 refers to a GPS satellite that is assigned the twentieth-week segment of the PRN P-code. The P-code is designed primarily for military purposes. The GPS navigation message is a data stream added to both the L1 and the L2 carriers as binary biphase modulation at a low rate of 50 kbps. It consists of 25 frames of 1,500 bits each, or 37,500 bits in total. This means that the transmission of the complete navigation message takes 750 seconds, or 12.5 minutes. The navigation message contains, along with other information, the coordinates of the GPS satellites as a function of time, the satellite health status, the satellite clock correction, the satellite almanac, and atmospheric data. Each satellite transmits its own navigation message with information on the other satellites, such as the approximate location and health status (Misra & Enge, 2006). Figure 2.1 describes L1 and L2 GPS signals carrier and C/A code. (Knippers, 2012)

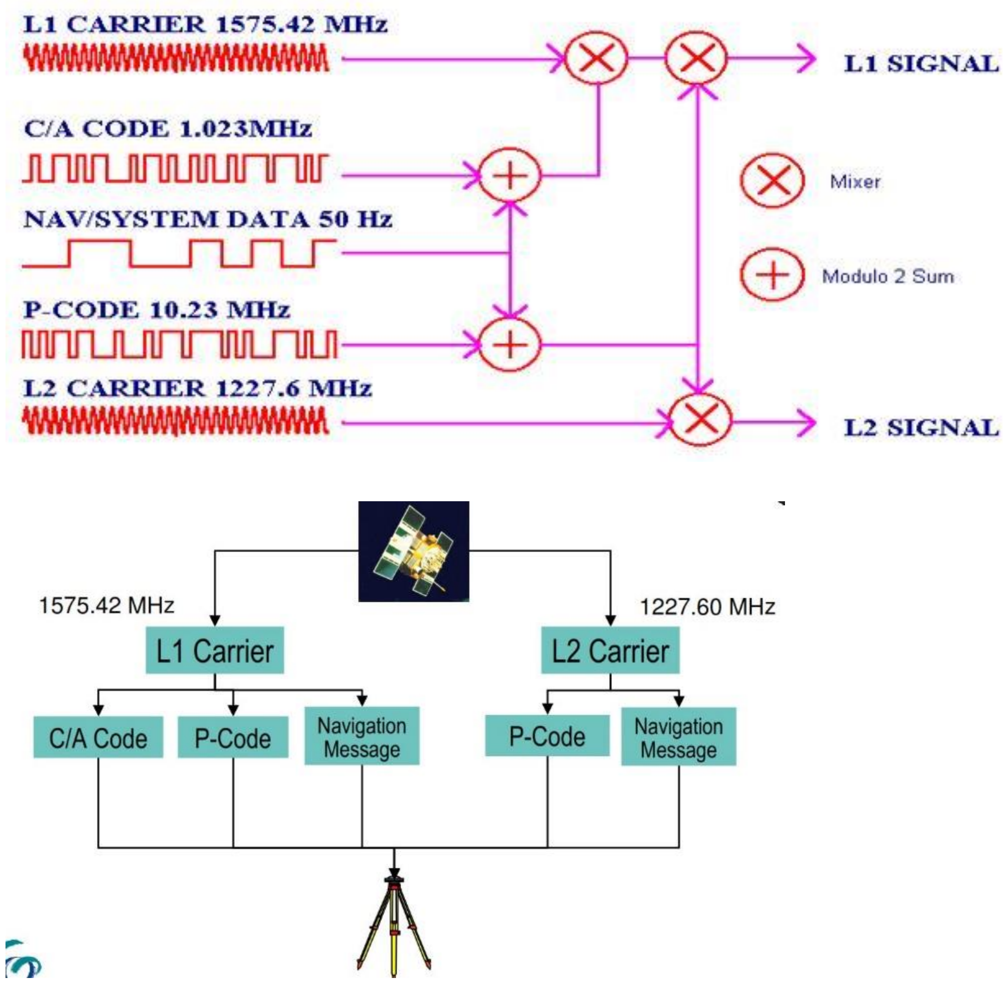

Figure 2.1 GPS Satellite Signal Structure (Knippers, 2012)

2.1.3 GPS Measurements

There are two types of range measurements: pseudo-range (code) and carrier-phase measurements.

The pseudo-range is the distance between the antenna phase centers of the satellite at the signal emission time and the receiver at the signal reception time. It is determined by multiplying the signal traveling time with the speed of light in a vacuum. The signal travelling time is the difference between the reception time at the receiver and the emission time at the satellite. Due to the fact that the receiver and satellite clocks are not perfectly synchronized to the GNSS system time, the pseudo-range measurement contains satellite and receiver clock offset errors (Misra & Enge, 2006)

The carrier-phase measurement is the phase difference between the signal's replica generated by the receiver and the signal received from the satellite at the instant of the measurement. The carrier-phase measurement is expressed as the sum of the fractional carrier-phase recorded by the receiver and an unknown integer number of phase cycles at the starting epoch between the satellite and the receiver. The unknown integer number of phase cycles is also known as an integer ambiguity and exists because the receiver has no way of knowing when the carrier wave left the satellite. The integer ambiguity will remain constant for a satellite, as tracking of that satellite is continued without a loss of lock. A loss of lock or a phase cycle slip will introduce a new unknown ambiguity. A cycle slip is a sudden jump in the carrier-phase observable, generally, by an integer number of cycles due to signal blockage by buildings, trees, severe ionospheric distortion etc. A cycle slip results in all subsequent measurements being offset by a constant integer number of cycles. Although the availability of the integer ambiguity and the cycle slips, the carrier-phase measurements are more accurate than pseudo-range measurements (Bernhard, 2001).

Satellite constellation

The accuracy with which positions are determined using GPS depends on two factors: the satellite configuration geometry, and the measurement accuracy equation 2.1 describes the position accuracy of a point. The usual term for GPS measurement accuracy is the user equivalent range error (UERE), which represents the combined effect of ephemeris uncertainties, propagation errors, clock and timing errors, and receiver noise. The effect of satellite configuration geometry is expressed by the dilution of precision (DOP) factor, which is the ratio of the positioning accuracy to the measurement accuracy

$\sigma = DOP^{*}\sigma_o$ …………………………………………………………………………………………….Eq 2.1

where σ is the measurement accuracy (standard deviation), and

σ_o, is the positioning accuracy (e.g., standard deviation in one coordinate).

DOP is a scalar representing the contribution of the configuration geometry to the positioning accuracy. There are many varieties of DOP, depending on what particular coordinate, or combinations of coordinates. The more common DOPs are: VDOP*σ_o is the standard deviation in height (Vertical), HDOP*σ_o is the accuracy in 2D Horizontal position, PDOP*σ_o is the accuracy in 3D Position, TDOP*σ_o is the standard deviation in Time, HTDOP*σ_o is the accuracy in Horizontal position and Time, GDOP*σ_o is the accuracy in 3D position, and time (Geometrical). Since GPS satellites orbit the Earth on six different orbital paths, during the course of every day the number of satellites overhead changes as the satellites move. This affects the accuracy of the GPS measurements as represented by the PDOP. The geometry of the Satellite Visibility is expressed as Dilution of Precision (DOP). DOP is expressed as a numeric value < 4 yield excellent precision, 5 to 7 are acceptable and > 7 yield poor precision. With current ephemeris file mission planning software such as TBC, SKI Pro, GNSS solutions Planning software can be used to generate charts showing the number of satellites available and the quality of their arrangement over any selected period of time. This enables the users to plan their GPS work to coincide with the optimal satellite conditions. Figure2.2 illustrates an example of some satellite geometry. (Ahmet, 2016)

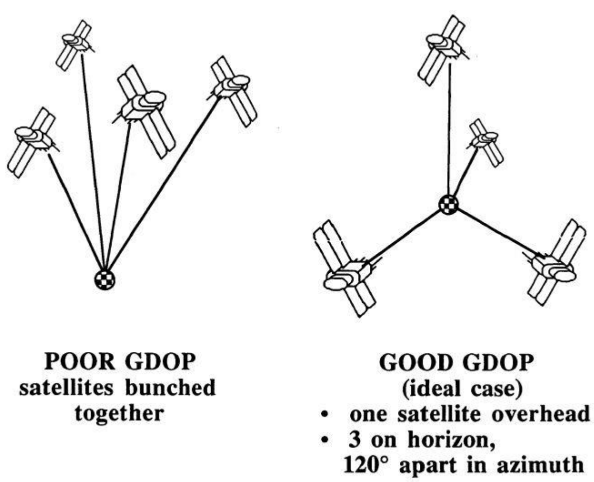

Figure 2.2: A figure showing some satellite geometry during positioning (Ahmet, 2016).

GPS signals: The basic concept of GNSS positioning is based on measuring the ranges between the satellites and a GNSS receiver and applying the multilateration concept which is determining a position by knowing the distances from at least four known points. However, these range measurements are affected by some error sources, such as the satellite and receiver clock errors, satellite ephemeris error and atmospheric errors (Daniel, 2015)

Pseudo-range is the distance between the antenna phase centers of the satellite at the signal emission time and the receiver at the signal reception time or is the time shift required to line up a replica of the code generated in the receiver with the received code from the satellite multiplied by the speed of light. Figure 2.3 illustrate the signal of a pseudorange from satellite on space to receiver on the ground. Ideally the time shift is the difference between the time of signal reception (measured in the receiver time frame) and the time of emission (measured in the satellite time frame). In fact, the two-time frames will be different, which introduces a bias into the measurement. These biased time delay measurements are thus referred to as pseudo-ranges its illustrated in equation 2.2. (David, 1987).

The pseudorange (L) is given by

$$L = (N+\Delta\Phi)\lambda + c\delta t + \Delta^{ion} + \Delta^{trop} + et\ al \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad Eq\ 2.2$$

L = pseudorange, is the distance between satellite and receiver

N = full wavelengths

$\Delta\Phi$ = partial phase (phase shift)

λ = carrier wavelength

δt = clock error

c = speed of light

et al = remaining errors like phase center antenna offset

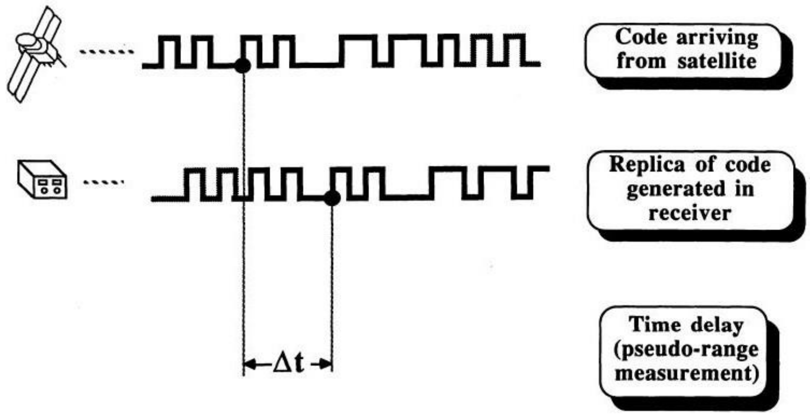

Figure 2.3: A figure showing Pseudo-Range Measurement signals from satellite to receiver (David, 1987)

Carrier beat phase is the phase difference between the signal's replica generated by the receiver and the signal received from the satellite at the instant of the measurement. Figure 2.4 describe the carrier beat signal how it is transmitted from satellite to receiver. A loss of lock or a phase cycle slip will introduce a new unknown ambiguity. A cycle slip is a sudden jump in the carrier-phase observable, generally, by an integer number of cycles due to signal blockage by buildings, trees, severe ionospheric distortion etc. A cycle slip results in all subsequent measurements being offset by a constant integer number of cycles (David, 1987). Carrier phase measurement defined by equation 2.3 is a technique to measure the range (distance) of a satellite by determine the number of cycles of the (sine-shaped) radio signal between sender and receiver

$$\Phi^S_R(T_R) = \Phi_R(T_R) - \Phi^S(T^S) + N + n_\Phi \quad \ldots\ldots \text{Eq 2.3}$$

$\Phi^S_R(T_R)$ = Total Phase between Satellite and Receiver

$\Phi_R(T_R)$ = Phase taken in Receiver at (T_R) time

$\Phi^S(T^S)$ = Phase taken in Satellite at (T^S) time

N = Ambiguity

n_Φ = Noise factor

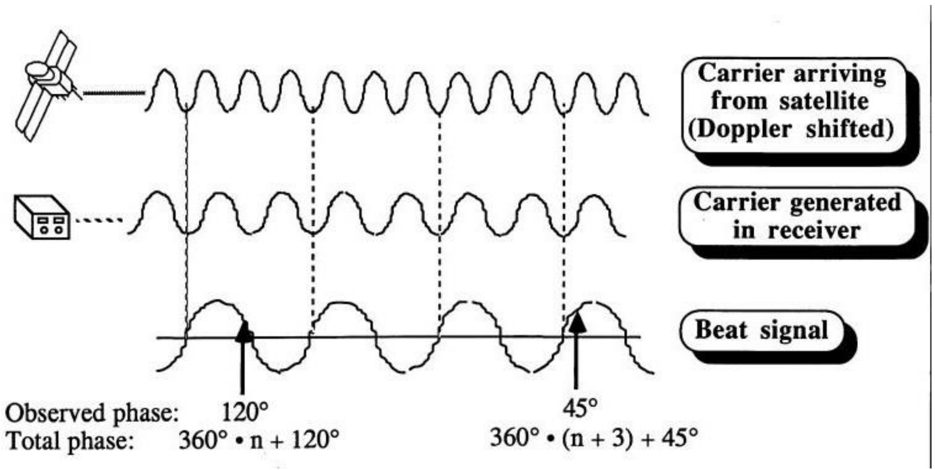

Figure 2.4: A figure showing Carrier beat phase Measurement signals from satellite to receiver (David, 1987)

Sources of errors in GNSS positioning including Ambiguity information (integer ambiguity), error in the range measurement (position error), satellite–receiver geometry (Satellite constellation), accuracy of the satellite ephemerides, effect of atmospheric refraction, multipath environment at the receivers, Relativistic corrections, Satellite Antenna Phase Center Offset. These errors can be eliminated by the use of Kalman filter is an optimal recursive estimator that minimizes the mean square error of the estimated parameters using a priori knowledge about system and measurement models and also their corresponding stochastic models. Kalman Filter consists of two major steps. The first one is the prediction, and the second one is the update. Equation 2.4 and equation 2.5 describe the system and measurement models. In the prediction step, the forward state vector and its covariance matrix are predicted using the system model and the current updated state vector and its covariance matrix. In the update step, these predicted state vector and its covariance matrix are updated with the new measurements (Msogoya, 2015)

- System Model

$x_k = F_{k-1}x_{k-1} + w_{k-1}\ ,\ w_{k-1} \sim N(0, Q_{k-1})$ …………………..………………Eq 2.4

- Measurement Model

$z_k = H_k x_k + \ _k \sim N(0, R_k)$ ……………………………………………………………Eq 2.5

Where

xk - State vector at epoch k

$Fk-1$ - Transition matrix at epoch k-1

$xk-1$ - State vector at epoch k-1

$wk-1$ - System noise vector at epoch k-1

$Qk-1$ - Covariance matrix of system noise vector at epoch k-1

zk - Measurement vector at epoch k

Hk - Design matrix at epoch k

vk - Measurement noise vector at epoch k

Rk - Covariance matrix of measurement noise vector at epoch k

Single Differencing, single difference is obtained by differencing the simultaneous measurements of the rover and the reference station from one satellite Code phases described in equation 2.6

$$\Delta PR = \Delta R + \Delta d_{ion} + \Delta d_{trop} + \mathcal{E}_{CD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq\ 2.6$$

Carrier Phases (error in measuring carrier range) is obtained by using equation 2.7

$$\nabla\Phi = \nabla R + \nabla d_{ion} + \nabla d_{trop} + \nabla \delta n + \mathcal{E}_{\Phi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq\ 2.7$$

In relative measurements, the receiver – receiver difference is used eliminate or reduce: satellite orbit and clock errors, ionosphere and troposphere refraction does not affect on receiver clock errors, near-receiver errors like multipath or antenna phase center variation. Double Differencing illustrated by equation 2.8, A double difference is obtained by subtracting two single differences Code phases

$$\nabla\Delta PR = \nabla\Delta R + \nabla\Delta d_{ion} + \nabla\Delta d_{trop} + \mathcal{E}_{CD} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq\ 2.8$$

Carrier Phases described by equation 2.9 (error in measuring carrier range)

$$\nabla\Delta\Phi = \nabla\Delta R + \nabla\Delta d_{ion} + \nabla\Delta d_{trop} + \nabla\Delta\delta n + \mathcal{E}_{\Phi} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. Eq\ 2.9$$

Eliminates receiver clock errors, Ionosphere and troposphere errors getting smaller, Integer ambiguities remain, Double difference is widely used for GNSS computation. Triple Differencing Constructed from differences between receivers, satellites and time at two different epochs. No cycle ambiguity and it's good for cycle slip removal and orbit determination.

Error in measuring pseudo range

$$\delta\nabla\Delta\Phi = \delta\nabla\Delta R - \delta\Delta d_{ion} + \delta\Delta d_{trop} + \varepsilon_{\Phi} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots Eq\ 2.10$$

Eliminates the integer ambiguity, used for seeking and estimating the cycle slips in phase observations, Noise is increased, therefore not used for final computations. Equation 2.10 illustrate error in pseudorange.

The Use of Choke Ring Antenna and Dual Frequency Receivers**,** Choke ring antennas are notable for their ability to reject multipath signals from a source. Since the path that a signal takes from a transmitter to receiver can be used to measure the distance between the two, this makes it highly suited for GPS and radar applications**.** Dual-frequency minimizes errors caused by the ionosphere and troposphere, which contain ionized particles that have effect on signals and disrupt them. Ionospheric scintillation occurs when the signals from the satellite pass through the atmosphere; they encounter zones of air that contain high levels of extra electrons, causing the signals to be deflected and delayed. Mapping functions. Mapping functions and models like Niell Mapping Function (NMF), based on temporal changes and geographic location rather than on surface meteorological parameters. Vienna Mapping Function 1 (VMF1), for tropospheric products and forms a source of consistent troposphere delays models for all space geodetic techniques. Global Mapping Function (GMF) based on data from the global ECMWF numerical weather model (Joseph, 2012).

2.2 Methods of GPS Positioning

Static GPS surveying is a positioning technique that depends on the carrier-phase measurements. It employs one or more stationary receivers simultaneously tracking the same satellites. The observation, or occupation, time varies from about 20 minutes to a few hours, depending on the purpose of the project. The measurements are usually taken at a recording interval of 15 or 20 seconds, or one sample measurement every 15 or 20 seconds. After completing the field measurements, the collected data is downloaded from the receivers into the PC for processing.

Fast (rapid) static: Fast, or rapid, static surveying is a carrier-phase based relative positioning technique similar to static GPS surveying. That is, it employs two or more receivers simultaneously tracking the same satellites. The rover receiver collects data for a period of about 2 to 10 minutes. Once the rover receiver has collected the data, the user moves to the following point with unknown coordinates and repeats the procedures. It should be pointed out that, while moving, the rover receiver may be turned off. Due to the relatively short occupation time for the rover receiver, the recording interval is reduced to 5 seconds. (El-Rabbany, 2002)

Stop-and-go GPS surveying is another carrier-phase-based relative positioning technique. It also employs two or more GPS receivers simultaneously tracking the same satellites a base receiver that remains stationary over the known point and one or more rover receivers. The rover receiver travels between the unknown points, and makes a brief stop at each point to collect the GPS data. The data is usually collected at a 1- to 2-second recording rate for a period of about 30 seconds per each stop.

RTK GPS surveying: In this method, the base receiver remains stationary over the known point and is attached to a radio transmitter. The rover receiver is normally carried in a backpack and is attached to a radio receiver. Similar to the conventional kinematic GPS method, a data rate as high as 1 Hz (one sample per second) is required. The base receiver measurements and coordinates are transmitted to the rover receiver through the communication (radio). The built-in software in a rover receiver combines and processes the GPS measurements collected at both the base and the rover receivers to obtain the rover coordinates (El-Rabbany, 2002)

2.3 Strategies of GPS Positioning

There only two methods which are used GPS positioning which are relative and absolute techniques to obtain positioning, navigation and timing systems for many years.

2.3.1 Precise Point Positioning

Precise Point Positioning (PPP) is another popular positioning method, which uses publicly available Global Navigation Satellite System (GNSS) precise orbit and clock products provided by International GNSS Service (IGS) to improve the positioning accuracy with only a single GNSS receiver. In modeling PPP observations, beside the necessity of reference station, satellite clock corrections are not estimated, but assumed to be known. Satellite clock corrections are introduced into processing together with Earth orientation parameters and orbit information by precise products from e.g., IGS or CODE. Standard market GPS receiver using code observations in standalone mode accuracy can be up to a few centimeters. Therefore, estimated parameters are station clock corrections, troposphere parameters and coordinates (Ahmet, 2016).

2.3.2 Relative Point Positioning

Since the beginning of GNSS positioning most accurate and common in use is relative (differential) positioning. This method is based on information from a reference station or group of reference stations with known coordinates. By observation's differentiation most errors are reduced so this method is more precise than absolute positioning after taking into account the reference station's error. The best known and most commonly used differential positioning method is RTK (Real Time Kinematic) technique. Static measurements within a millimeter accuracy can be achieved for respectively long sessions length and short vectors. For extremely short baselines (several hundred meters) in a 24-hours session, the accuracy could be less than a millimeter. Relative positioning affected by satellite geometry, bad satellite constellation yields poor accuracy (William, 2002)

2.4 GPS Source of errors and their mitigations

Satellite Orbit and Clock Errors: The satellite orbits should be known for any arbitrary epoch to be able to obtain Positioning, Navigation and Timing (PNT) information using GNSS. These satellite orbits can be obtained from the broadcast orbits or the precise orbits (Bernhard, 2001). The satellite orbit error is the difference between its actual and predicted orbits. In DGPS, the satellite orbit errors are significantly mitigated by differencing techniques. However, the mitigation success depends on the separation between the reference and rover stations. In PPP, the satellite orbit errors are mitigated using the precise orbits to be able to provide high positioning accuracy. Note that the precise orbits can also be used for DGPS to increase the positioning accuracy. The satellite clock error refers to the offset between GNSS reference time and satellite clock time due to a lack of synchronization of the satellite clock with respect to GNSS reference time. The satellite clock error can be mitigated using the broadcast clock corrections in the navigation messages with the precision of 7 nanoseconds, or precise clock corrections with precision of about 0.1 nanoseconds depending on the latency from IGS (Misra & Enge, 2006).

Tropospheric Delay is the layer of the atmosphere from the surface of the earth up to 40 km. It can be separated into dry (0-40 km) and wet (0-11km) components. The dry component consists of dry gas molecules and represents about 90% of the total tropospheric error while the wet component consists of the water molecules and represents about 10% of the total tropospheric error. The troposphere is a non-dispersive medium for the frequencies below 15 GHZ and delays both code and carrier-phase measurements. Therefore, it cannot be eliminated by using dual-frequency measurements. The dry tropospheric error can be modeled successfully at zenith direction, but the wet tropospheric error cannot be modeled easily due to the irregular variation of the water molecules over time. (El-Rabbany, 2002)

Satellite Antenna Phase Center Offset The pseudorange and carrier-phase measurements refer to the distance between satellite and receiver antenna phase centers. Broadcast orbits are given for these satellite antenna centers, while precise orbits refer to satellites' center of mass due to force models used for satellite orbit modeling. The offset between the satellite antenna center and the satellite center of mass can be obtained from ANTEX files provided by IGS in the satellite body-fixed coordinate system with respect to the satellite center of mass. In order to apply the satellite antenna phase center offset correction to carrier-phase measurements, first, satellite PCO offset vector in the satellite body-fixed coordinate system is converted to the Earth-centered Earth-fixed (ECEF) coordinate system and then it is projected into the satellite-receiver direction as follows (Subirana, 2013).

Receiver Clock Error The receivers are generally equipped with the inexpensive crystal clocks which are not set exactly to GNSS reference time and also, they can drift easily over time. This offset between the GNSS reference time and the receiver time is called the receiver clock error. In PPP, it can be mitigated by estimating as an unknown parameter, while in DGPS, it can be eliminated by the between satellite differences techniques without depending on the separation between the reference and rover stations. Multipath and Noise The multipath is the phenomenon of a signal reaching a GNSS antenna via two or more paths. The maximum multipath error could be approximately half the code chip length and one-quarter of carrier-phase wavelength. The effects of multipath cannot be removed through modeling or by differencing techniques. However, its effect may be decreased by using a choke ring antenna which can decrease the multipath error and setting up this antenna away from reflecting objects. In addition, the satellites at low elevations angles could be discarded by setting an elevation cutoff angle.

2.5 GPS signal propagation under different sky view

Sky view refers to the amount of visible sky unobstructed by buildings, trees, or other obstructions, which can affect the availability and quality of satellite signals used for GNSS positioning. The concepts of under tree canopy, under urban canyon, and open sky can be related to GPS positioning as they can affect the accuracy and availability of GPS signals. (Joseph, 2012)

2.5.1 Open sky

Open sky is an area on the surface of the Earth where the horizon is visible in all quadrants where there are no physical barriers or obstructions above the observer. In open areas with an unobstructed view of the sky, GNSS receivers can receive signals directly from multiple satellites. This condition typically provides favorable positioning accuracy, as there are minimal signal blockages and multipath effects. This can create a sense of vastness, freedom, and possibility. GPS positioning works best when there is an unobstructed view of the sky, as the GPS signals are transmitted by satellites that orbit the earth. (Joseph, 2012)

2.5.2 Tree canopy

Tree canopy refers to the part of the point/area surrounded by the branches, leaves, and trunks of trees. This can create a sense of shelter, intimacy, and tranquility forming a kind of ceiling. In wooded or forested areas, tree canopies can obstruct the GNSS signals, leading to signal attenuation and scattering. The presence of dense foliage can cause significant challenges for accurate positioning, especially in situations where clear line-of-sight to the satellites is obstructed. The measured pseudorange reaching the receiver ends up being longer than the actual pseudorange, had the signal travelled directly. (Daniel, 2015)

2.5.3 Urban canyon

Urban canyon is a portion surrounded by tall buildings and narrow streets. This can create a sense of confinement, noise, and chaos. Urban environments with tall buildings can cause signal blockage and multipath interference. The tall structures may obstruct the direct path between the GNSS receiver and the satellites, leading to reduced positioning accuracy and increased susceptibility to signal reflections. GPS positioning can also be affected by the presence of tall buildings and narrow streets, which can create an urban canyon effect that obstructs the GPS signals. In urban areas, the presence of buildings and tall structures contribute greatly to the multipath effect. Multipath errors can be avoided by placing the receiver in a place without reflective or refractive surfaces. (Awange, 2012)

2.7 The Current Research

The performance of Global Navigation Satellite System (GNSS) positioning strategies has been a subject of extensive research, particularly concerning their accuracy and reliability under varying sky view conditions. Urban environments present unique challenges due to the presence of high-rise buildings and narrow streets, leading to what is commonly referred to as "urban canyons. These conditions significantly impact the visibility of GNSS satellites, potentially degrading the positioning accuracy and precision. The primary objective of this current research study is to evaluate and compare the performance of relative and absolute GNSS positioning strategies in varying environments. By conducting an in-depth analysis, the study aims to shed light on the strengths and limitations of both approaches, considering the constraints posed by limited sky view in urban and forest settings.

Drawing from the insights gained from previous research, the current study adopts a comprehensive approach to evaluate GNSS positioning performance under all three conditions. By conducting experiments in representative urban canyon locations, forested areas with dense tree canopies, and open-sky environments, the research aims to systematically compare the relative and absolute GNSS positioning strategies. Synthesizing findings from previous studies and incorporating a multi-condition approach in the current research enhances the significance of the study. The outcomes of this research will aid in determining the most suitable positioning strategies for specific applications, especially in areas where GNSS performance may be compromised, and will also offer recommendations for enhancing the accuracy and reliability of GNSS positioning in challenging environments

CHAPTER THREE

METHODOLOGY

This chapter presents a series of field experiments carried out in representative urban canyon locations, tree canopies and open sky locations. Utilizing a GNSS receiver capable of collecting raw satellite observations, data were collected under different sky view conditions, including scenarios with obstructed satellite visibility. The study focused on two main positioning strategies: relative positioning (baseline processing) and absolute positioning (precise point positioning).

3.1 Reconnaissance

Reconnaissance refers to the process of gathering information about the area of interest before conducting the actual study. This was done by visiting the site, surveying the area and to collect data essential for pre-analysis. During reconnaissance data were collected under different conditions like open sky, under tree canopy and close to tall buildings where GPS signals behave differently. Reconnaissance in this research was very important because the objective of the research was to investigate the performance relative and absolute GNSS positioning strategies in varying conditions. Therefore, these difficult scenarios must be determined before execution of the research.

3.2 Pre-analysis

Analysis of components, measurements of a survey project before the project is actually undertaken. This was done by ensuring all controls were established on the required condition that fitted on the criteria, specifications and guidelines to be undertaken in order to achieve the research objectives. Under this study pre-analysis was done by selecting suitable instruments like GPS receivers and processing software i.e., Leica Infinity and RTKLIB, budget and extensive research in order to achieve the stated goals of the research.

3.3 Control extension

Control extension refers to the process of extending an existing control network to cover a larger area or project site. This was done by establishing new control points that were tied to the existing control network through GPS surveying techniques, to create a larger network of reference points. A control network is a network, often of triangles, which are measured exactly by techniques of terrestrial surveying or by space techniques that are used to provide a consistent and accurate spatial reference for positioning and mapping. Control network design involves determining the optimal configuration and placement of control points within a project site or geographic region. Through this study the control network figure 3.1 was designed by selecting the appropriate number of control points, determining the spacing and distribution of control points, and establishing the accuracy requirements for the control network. Control network design is important for ensuring that the control network is accurate, reliable, and consistent across the entire project site or geographic region. A designed network is shown on the figure 3.1.

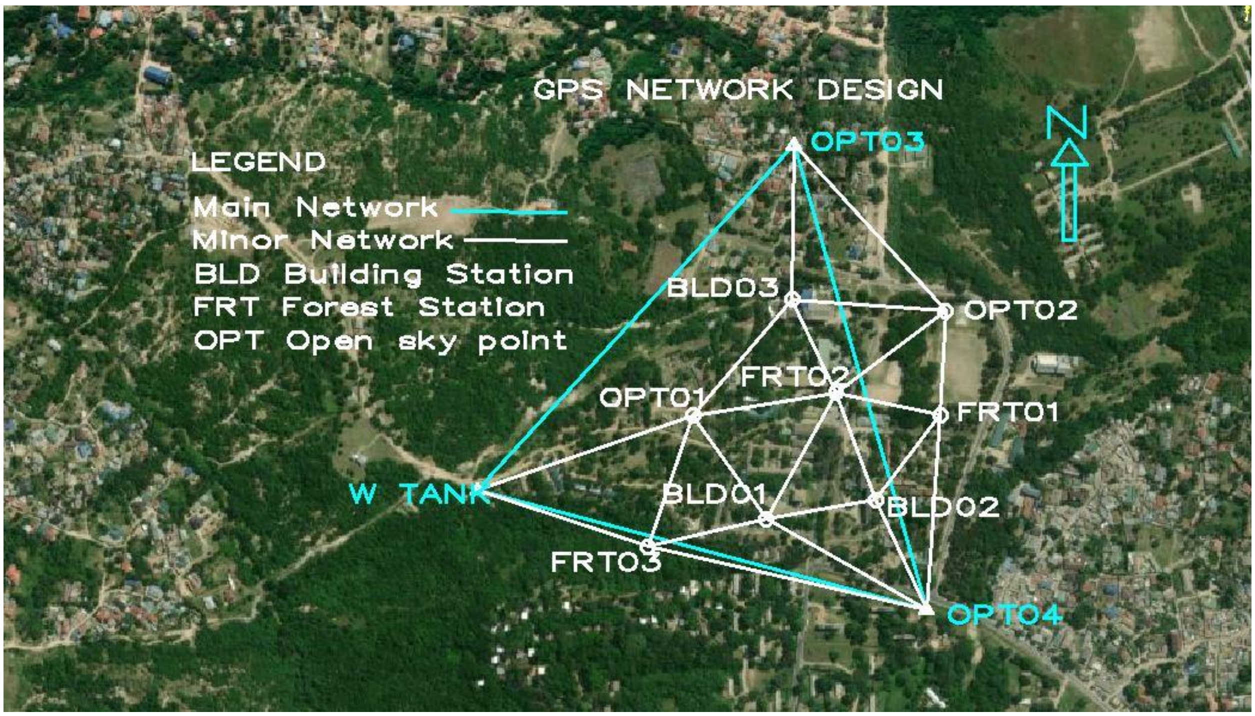

Figure 3.1: Network designed in part of ARU for extension of controls

From figure 3.1 two new points OPT 03 and OPT 04 were tied to the existing point and formed the main network described by cyan color. The other remaining points were tied to the main network and formed a minor network defined by white color. This was done in order to have enough controls so that the objective of the research to be achieved. The figure 3.1 explains points which were established for the purpose of assessing GPS positioning strategies under different sky view conditions. The points named BLD were established close to tall building, OPT on open space and FRT under tree canopy.

Criteria considered for the network designed

New controls were established under varying scenarios which have sufficient or weak signals arriving from satellite to receiver. The included angles of the triangle are greater than 30 degrees and less than 330 degrees, the vertices of the triangle being the control points, most of the baseline are shorter, the short the baseline the high precision, all baseline are less than 2 kilometers and each vertex of a triangle is tied to at least one existing (reference) point. The triangles in figure 3.1 are only for space technique because the purpose of the research was to assess the performance of relative and absolute GNSS positioning strategies under difficult scenarios where the GPS signals are sufficient or degraded. Ill conditioning in GPS measurements can occur when there is insufficient information available to accurately determine the position of a receiver. This can happen due to a number of factors, such as a poor geometry of the satellite constellation, weak signal strength, atmospheric interference, or poor receiver hardware. When the GPS system is ill-conditioned, the measurements become more uncertain and less precise, leading to errors in the calculation of position. The new points were established at least five meters from the tall building so that the sky can be visible in one part and the other part obstructed and those under tree canopy were established under tall tree(s) so that one part or top part can be visible. Table 3.1 describe the location of each station in a particular scenario.

Table 3.1: Description of points under different sky view

Station	Location	Description
BLD 01	Close to administration block	Moderate sky view, the horizon cannot be seen in both sides
BLD 02	Close to High-cost hostel	
BLD 03	Close to New building block	Bad sky as observed from the earth's surface
FRT 01	Under tree canopy	
FRT 02	Under tree canopy	
FRT 03	Under tree canopy	Moderate sky view
OPT 01	Clear sky view	Good sky, no obstruction of GPS signals
OPT 02	Clear sky view	

3.4 Data Collection

Data were observed by static method at a sampling rate of 0.1 seconds with occupation time of three hours using GPS receivers from different stations which were established around Ardhi campus. A total of eight points were used to investigate on the two positioning strategies in achieving the main goal of the research. After observation, data were downloaded in Rinex format for post processing.

3.5 Quality Check

Quality check was done by using Teqc software in order to assess the quality of each point. Satellite visibility tracking of each point are attached in the appendix 1. Quality check was performed by taking the ratio between complete observations and possible/expected observations. Table 3.1 describes the percentage of each station and it was obtained by using the equation 3.1.

$$\textit{Quality Check} = \frac{\textit{Complete Observations}}{\textit{Possible Observations}}\ x\ 100\% \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\textit{Eq 3.1}$$

Table 3.2: Quality Check of the control points

Station	Possible Observations	Complete Observations	Rejected	Percentage (%)
BLD 01	221903	157551	64352	71
BLD 02	293687	196770	96917	67
BLD 03	287351	169537	117814	59
FRT 01	403883	391767	12116	97
FRT 02	346197	321963	24234	93
FRT 03	385225	369816	15409	96
OPT 01	834290	825947	8343	99
OPT 02	689175	668500	20675	97

3.6 Data Processing

During data post processing, two software were used depending on the positioning strategies in assessing their reliability, accuracy and precision of each point. The two-software used are Leica infinity and RTKLIB, each software has two processing modes, single point positioning (SSP) and baseline processing (Differential positioning) their processing strategies are indicated in table 3.3. Total of eleven points were used during data processing, three reference points and eight unknown points. In Leica infinity software all points were processed at once, whereby only independent baselines were processed. For Rtklib software, it involved processing one baseline i.e., one fixed control point and one unknown point. For absolute positioning all unknown points were processed without any reference points. The processing strategies of each software are described in table 3.3 the table explains the requirements of each software during processing which include data that are used during post processing in both differential mode and single point positioning

Instruments (software)

RTKLIB: An Open-Source Program Package for GNSS Positioning. It supports standard and precise positioning algorithms. It has many library functions and models for GNSS data processing (Takasu, 2015)

LEICA INFINITY**:** An Open-Source Program Package for GNSS Positioning. It supports both single point positioning (SPP) and differential positioning (DGPS). It has a download option for acquiring required sources for post processing and adjustment including ephemeris, parameters, Antex and navigation files (Hansen, 2022).

The processing strategy of each software are described in table 3.3. It describes the requirements of each software in both absolute and relative modes of processing.

Table 3.3: Describe the processing strategies of each software

Processing mode	REQUIREMENTS	
	RTKLIB (Takasu, 2015)	Leica Infinity (Hansen, 2022)
Absolute Positioning	Observation file of a rover	Observation files of rovers
	Navigation file	Navigation files
	Ephemeris	Ephemeris
		Coordinate system
Relative Positioning	Observation file of rover	Observation files of rovers and base
	Observation of base	Navigation files
	Navigation file	Ephemeris
	Ephemeris	Coordinate system

Two different software RTKLIB and Leica Infinity were used during data post processing. The study used different software to ensure that a comprehensive assessment to be performed in order to achieve the aimed objectives. The use of only one software could not attain a quantitative investigation on the performance of relative and absolute GNSS positioning under tree canopies, urban canyons and in clear sky. The use of different software means the study will not assess the performance of positioning strategies only but also will make a quantitative assessment on the processing software use to achieve the research objectives. In other hands, the decision to use two software tools, RTKLIB and Leica Infinity, was driven by the need to gain a comprehensive understanding of relative and absolute GNSS positioning performance under different sky view conditions, as well as to ensure robustness and accuracy in the analysis through cross-validation and accounting for software-specific limitations

CHAPTER FOUR

RESULTS, ANALYSIS AND DISCUSSIONS

This chapter mainly focuses on the results obtained from this research. The results are required to meet the objectives of the study. The research outputs include the tables showing the coordinates of each station and figures showing the accuracy, precision and reliability of the station coordinates.

4.1 RESULTS

Data was collected under different scenarios with the same occupation time, GPS signal tracking were different at each station because the points were located in different sky views. Some points were located on clear view, other points on moderate sky view and other points under bad sky view of the sky, these categories are indicated in the table 4.1.

Figure 4.1 illustrates how the network was processed by using Leica Infinity. Leica Infinity process only non-trivial baseline (a baseline between reference station and unknown station).

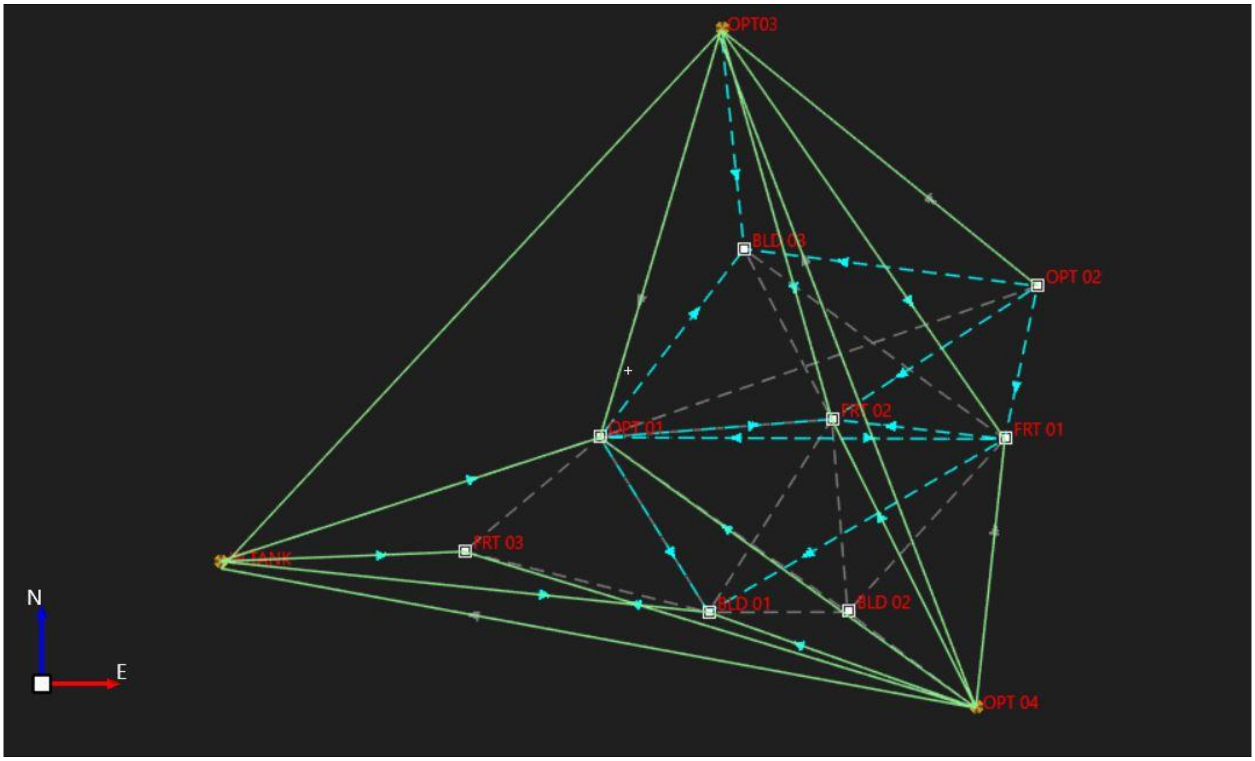

Figure 4.1: A processed network by using Leica Infinity

From figure 4.1 the full lines are non-trivial and were processed while doted lines are trivial line between unknown stations. All points were processed from at least one known station except one point named BLD 03 where differential positioning was not possible due to too fewer independent fixes of a rover. Network adjustment report is attached on appendix 2. Table 4.3 and table 4.4 they describe the results showing projected coordinates and their uncertainty for relative positioning by using the two software RTKLIB and Leica Infinity.

Table 4.1: Projected coordinates in WGS84 of relative positioning using RTKLIB

Station	Northing (meter)	Easting (meter)	Uncertainty (meter)	
			Northing	Easting
BLD 01	9252039.292	523631.555	0.073	0.063
BLD 02	9252039.126	523763.032	0.091	0.101
BLD 03	9252380.610	523661.293	0.112	0.207
FRT 01	9252195.584	523917.636	0.709	0.241
FRT 02	9252220.198	523750.266	0.173	0.354
FRT 03	9252097.909	523399.845	0.090	0.053
OPT 01	9252202.088	523530.167	0.009	0.007
OPT 02	9252345.800	523945.517	0.010	0.016

Table 4.2: Projected coordinates in WGS84 of relative positioning processed using Leica Infinity

Station	Northing (meter)	Easting (meter)	Uncertainty (meter)	
			Northing (m)	Easting (m)
BLD 01	9252039.317	523631.557	0.095	0.075
BLD 02	9252038.790	523762.908	0.407	0.396
BLD 03	Differential positioning was not possible (too less fixes)			
FRT 01	9252200.391	523914.500	0.004	0.004
FRT 02	9252220.290	523750.437	0.007	0.007
FRT 03	9252097.913	523399.855	0.005	0.004
OPT 01	9252202.088	523530.168	0.003	0.002
OPT 02	9252345.781	523945.543	0.004	0.005

From table 4.1 and table 4.2, the two software which used to process the collected data, Leica infinity provided better results than RTKLIB in most of the stations. For points which were established under clear view with good satellite visibility (named OPT 01 and OPT 02) and those established under tree canopy named FRT 01, FRT 02 and FRT 03 the highest uncertainty was 0.007m while for points which were established close to building named BLD 01, BLD 02 and BLD 03 the highest uncertainty for RTKLIB was 0.100m and for Leica Infinity was 0.407m this signifies that RTKLIB is more superior than Leica Infinity for points that were established close to tall building. Furthermore, Leica Infinity is not suitable for points close to tall buildings this has been proved by a point named BLD 03 the software failed to process the baseline due to fewer independent fixes of a rover. Table 4.3 describe the compared projected coordinates in relative positioning.

Table 4.3: Comparison of the projected coordinates in WGS84 by relative positioning using RTKLIB and Leica Infinity

	RTKLIB		LEICA INFINITY		DIFFERENCE	
Station	Northing (meter)	Easting (meter)	Northing (meter)	Easting (meter)	ΔN (meter)	ΔE (meter)
BLD 01	9252039.292	523631.555	9252039.317	523631.557	-0.025	-0.002
BLD 02	9252039.126	523763.032	9252038.790	523762.908	1.752	1.130
BLD 03	9252380.610	523661.293				
FRT 01	9252195.584	523917.636	9252200.391	523914.500	-4.807	3.136
FRT 02	9252220.198	523750.266	9252220.290	523750.437	-0.092	-0.171
FRT 03	9252097.909	523399.845	9252097.913	523399.855	-0.004	-0.040
OPT 01	9252202.088	523530.167	9252202.088	523530.168	-0.000	-0.001
OPT 02	9252345.800	523945.517	9252345.781	523945.543	0.019	-0.026

Table 4.4 and 4.5 explain the results of the projected coordinates and their uncertainty for absolute positioning by using the two software RTKLIB and Leica Infinity.

Table 4.4: Projected coordinates in WGS84 in absolute positioning using RTKLIB

Station	Northing (meter)	Easting (meter)	Uncertainty (meter)	
			Northing	Easting

BLD 01	9252032.434	523631.740	0.763	1.009
BLD 02	9252034.018	523764.038	0.612	0.333
BLD 03	9252381.357	523654.214	0.884	0.983
FRT 01	9252199.002	523913.849	0.370	0.590
FRT 02	9252215.524	523746.570	0.164	0.213
FRT 03	9252093.159	523401.705	0.141	0.183
OPT 01	9252202.085	523529.775	0.139	0.098
OPT 02	9252344.202	523944.774	0.163	0.149

Table 4.5: Projected coordinates in WGS84 in absolute positioning using Leica Infinity

Station	Northing (meter)	Easting (meter)	Uncertainty (meter)	
			Northing (m)	Easting (m)
BLD 01	9252036.832	523631.225	0.282	0.229
BLD 02	9252038.243	523763.607	0.073	0.098
BLD 03	9252380.954	523661.402	0.110	0.144
FRT 01	9252198.155	523914.385	0.165	0.154
FRT 02	9252218.127	523749.773	0.237	0.235
FRT 03	9252098.486	523401.126	0.117	0.120
OPT 01	9252201.045	523531.163	0.092	0.038
OPT 02	9252345.137	523945.178	0.079	0.081

Considering table 4.4 and table 4.5 the uncertainty of each station seems to vary in both software used to process the data. Under this scenario Leica Infinity performed better than RTKLIB under all scenarios, for points established on clear sky view, under tree canopy and close to tall buildings. The maximum uncertainty for points under clear sky view was 0.092 for Leica Infinity and 0.163 for RTKLIB, for points on moderate conditions named BLD 01, BLD 02 and FRT 03 the maximum uncertainty was 0.282m for Leica Infinity and 0.763m for RTKLIB and for points under bad sky view named BLD 03, FRT 01 and FRT 02 maximum uncertainty was 0.494m for Leica Infinity and 0.983m for RTKLIB. Under single point positioning Leica Infinity performed better than RTKLB under all assessed conditions. Table 4.6 describe the comparison of the projected coordinate between RTKLIB and Leica Infinity in single point positioning mode.

Table 4.6: Comparison of the projected coordinates in WGS84 in absolute positioning using RTKLIB and Leica Infinity

Station	RTKLIB		LEICA INFINITY		DIFFERENCE	
	Northing (meter)	Easting (meter)	Northing (meter)	Easting (meter)	ΔN (meter)	ΔE (meter)
BLD 01	9252032.434	523631.740	9252032.832	523631.225	-0.398	0.515
BLD 02	9252034.018	523764.038	9252035.243	523763.607	-1.225	0.431
BLD 03	9252381.357	523654.214	9252380.954	523655.402	0.403	-1.188
FRT 01	9252199.002	523913.849	9252198.155	523914.385	0.847	-0.536
FRT 02	9252215.524	523746.570	9252215.127	523747.773	0.397	-1.203
FRT 03	9252093.159	523401.705	9252093.486	523401.126	-0.327	0.579
OPT 01	9252202.085	523529.775	9252201.045	523530.163	1.04	-0.388
OPT 02	9252344.202	523944.774	9252345.137	523945.178	-0.935	-0.404

Figure 4.2, figure 4.3, figure 4.4 and figure 4.5 illustrate the uncertainty of northing and easting of each station processed by using all software used which are Leica Infinity and RTKLIB in both positioning strategies relative and absolute. The comparison was made in order to achieve the objectives of this research. Comparing the processing strategies in order to determine the suitability and limitation of each approach when positioning under different sky view conditions and finally to propose the best positioning strategies under these varying scenarios

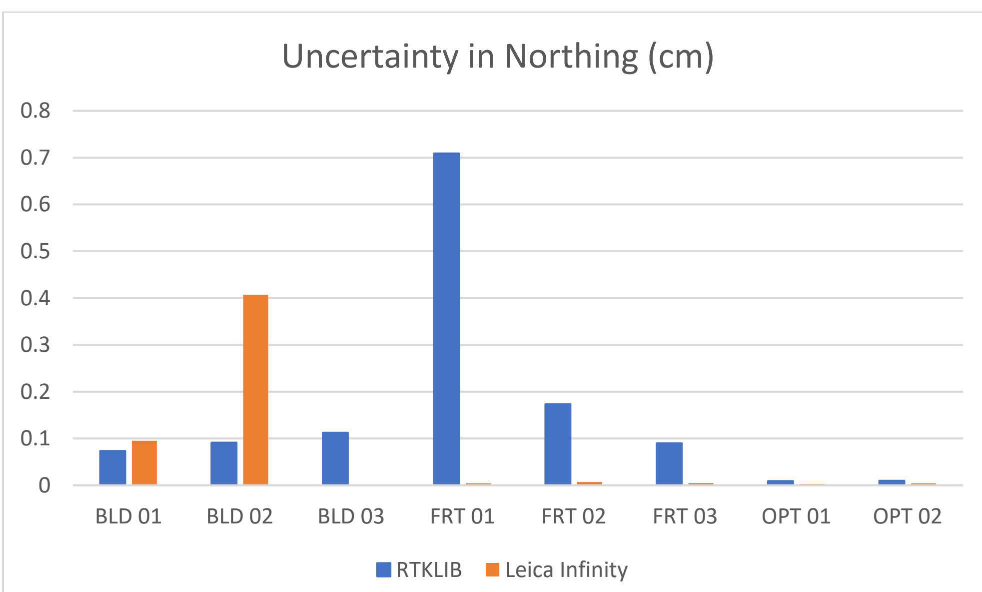

Figure 4.2: Comparison of uncertainties for relative positioning in Northing

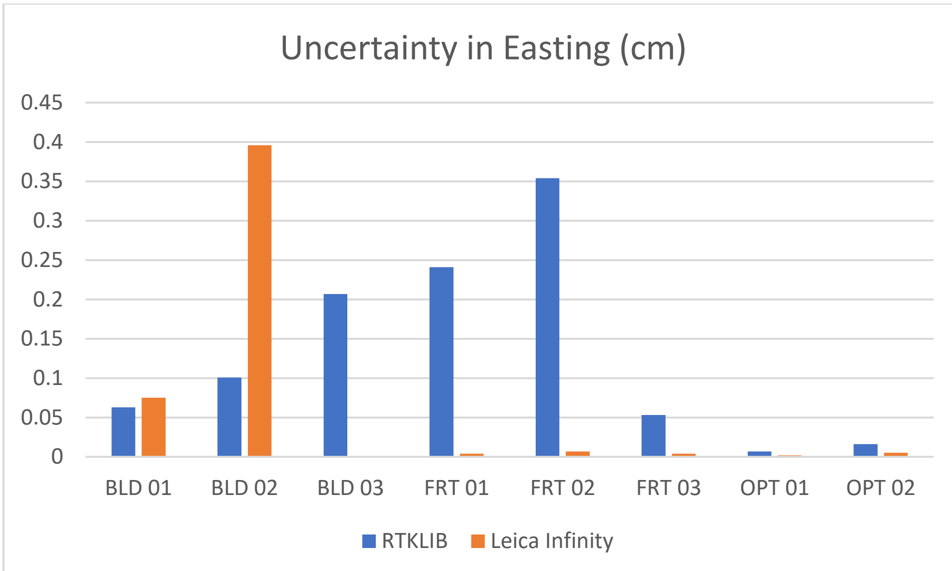

Figure 4.3: Comparison of uncertainties for relative positioning in Easting

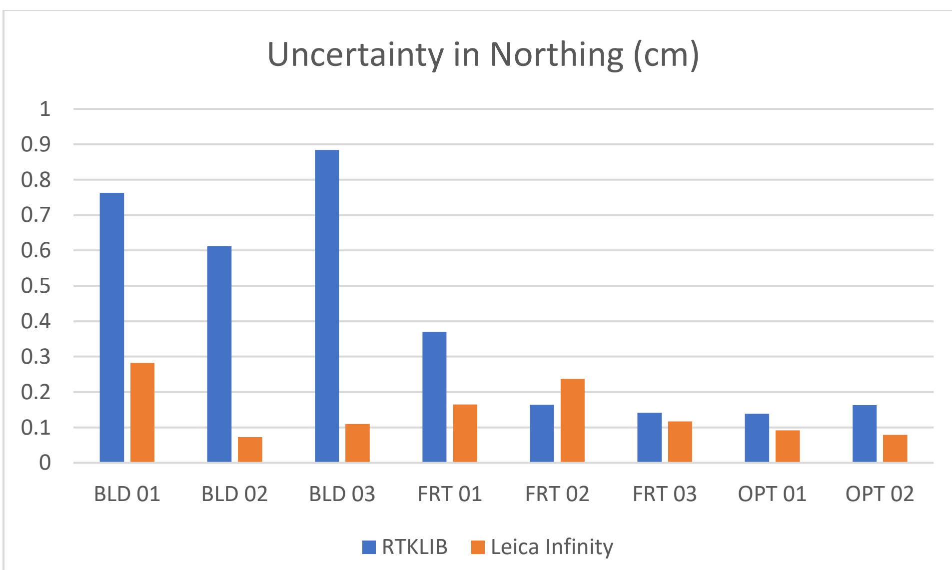

Figure 4.4: Comparison of uncertainties for absolute positioning in Northing

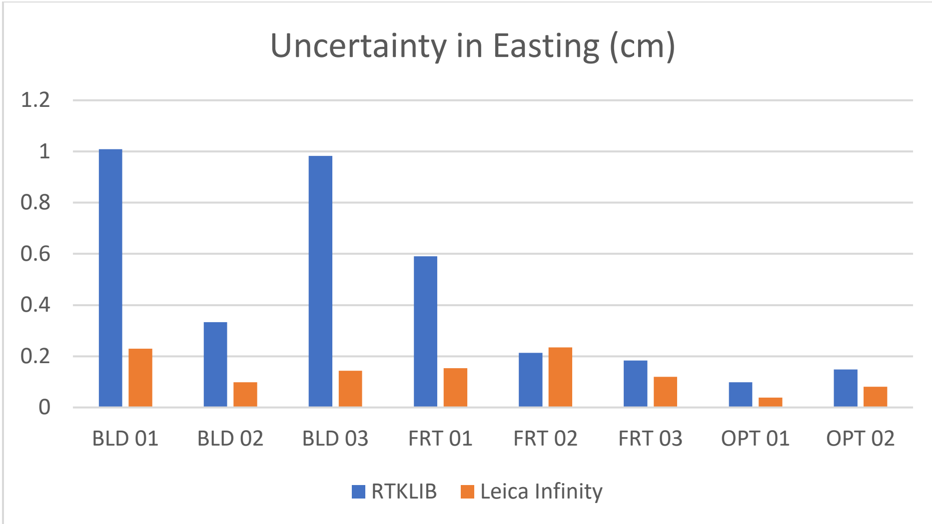

Figure 4.5: Comparison of uncertainties for absolute positioning in Easting

The results of the study indicate varying performances for relative and absolute GNSS positioning strategies across different sky view conditions. Table 4.7 illustrates the compared coordinates obtained after post processing in both processing modes relative and absolute.

Table 4.7: Comparison of the projected coordinates in WGS84 between relative and absolute positioning

	Relative Positioning		Single Point Positioning		Difference	
Station	Northing(m)	Easting(m)	Northing(m)	Easting(m)	ΔN	ΔE
BLD 01	9252039	523631.6	9252037	523631.225	2.46	0.33
BLD 02	9252039	523763	9252038	523763.607	0.883	-0.575
BLD 03	9252381	523661.3	9252381	523661.402	-0.344	-0.109
FRT 01	9252200	523914.5	9252198	523914.385	2.236	0.115
FRT 02	9252220	523750.4	9252218	523749.773	2.163	0.664
FRT 03	9252098	523399.9	9252098	523401.126	-0.573	-1.271
OPT 01	9252202	523530.2	9252201	523531.163	1.043	-0.995
OPT 02	9252346	523945.5	9252345	523945.178	0.644	0.365

4.2: ANALYSIS AND DISCUSSIONS

This research study not only comparing the performance of relative and absolute positioning strategies under different sky view conditions but also provide a quantitative assessment of two software packages RTKLIB and Leica Infinity. The quantitative assessment of the two software package reinforces the recommendation of utilizing Leica Infinity for GNSS data processing in scenarios where high accuracy and robustness are required. However, it is worth noting that the choice of software may depend on specific project requirements, budget constraints and the expertise of the user. In addition to these findings a quantitative assessment was conducted to compare the performance of the two software packages used in data processing RTKLIB and Leica Infinity. The quantitative assessment demonstrated that Leica Infinity exhibited superior performance compared to RTKLIB. Several factors contribute to this conclusion first, Leica infinity incorporates advanced algorithms and processing techniques that optimize the positioning results in high accuracy and reliability. Secondly Leica infinity provide a more user friendly and intuitive interface making it easier to handle and analyses the GNSS data. Furthermore, Leica Infinity offers a seamless integration with Leica GNSS receivers, providing enhanced compatibility and synergy between the hardware and the software components

For points which were established under moderate conditions which are BLD 01, FRT 01 and FRT 02, relative positioning performed better than single point positioning especially when using Leica Infinity software although they provided high value of uncertainty. For points under clear sky view conditions which are OPT 01 and OPT 02 differential positioning performed better than absolute as shown in table 4.4 the maximum uncertainty is 7mm for relative positioning and 0.093m for absolute positioning. Under bad sky view conditions especially BLD 03 and BLD 02 relative positioning did not perform better when compared to absolute positioning this was assessed by their uncertainty. The maximum uncertainty for relative positioning was 0.207m by using RTKLIB and the maximum uncertainty for absolute positioning is 0.144m.

The results of the study in table 4.7 indicates varying performances for relative and absolute GNSS positioning strategies across different sky view conditions. In open sky view areas, relative positioning demonstrated superior accuracy compared to absolute positioning. The relative method effectively mitigated multipath effects and signal obstructions, leading to more reliable and accurate positioning solutions. Under tree canopy cover, where GNSS signals experienced severe blockages, relative positioning outperformed absolute positioning due to its ability to leverage baseline vectors between satellite signals. The observed performance trends can be attributed to the different principles underlying relative and absolute positioning strategies. Relative positioning relies on the measurement of baseline vectors between receivers, reducing the impact of common errors in both receiver units. This property makes it highly advantageous in obstructed environments, such as under tree canopies. On the other hand, absolute positioning is heavily dependent on the availability of a sufficient number of visible satellites with good geometry. As a result, it performed relatively better in areas close to tall structures where signal obstructions were minimized, enabling more favorable satellite visibility and geometry.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The performance assessment of relative and absolute GNSS positioning strategies revealed that relative positioning performed better in scenarios with open sky view and under tree canopies due to its ability to mitigate signal blockages and multipath effects. Conversely, absolute positioning demonstrated better performance in areas close to tall structures, where satellite visibility was less obstructed. These findings offer valuable insights for GNSS users and professionals, enabling them to choose the most suitable positioning strategy based on the specific environmental conditions.

A comprehensive assessment on the performance of relative and absolute GNSS positioning strategies under different sky view conditions was conducted. A network of controls that was designed in part of Ardhi University contained eight points, where three were established under tree canopy (named FRT), other three points under tall buildings (named BLD) and two points were on open sky. The research confirms that differential positioning provided better results to points which were located in clear view when compared to single point positioning. Points close to tall building Single Point Positioning performed better than differential GPS, since in some points under tree canopy and urban canyon, differential positioning was not possible to process the data and obtain the results due to insufficient GPS signals tracked. For points that agree to produce results under tree canopy and urban canyon by differential positioning they produce large value of uncertainty when compared with Single Point Positioning this signifies that DGPS provide less accuracy when compared with absolute positioning. The performance of relative and absolute GNSS positioning under varying conditions and their accuracies are quite different since these positions have insufficient signals which make differential positioning impossible in some cases when signals tracked are very few. The possible solution under these scenarios is to use Absolute GPS positioning strategy rather than Differential GPS positioning on areas that seem to have insufficient GPS signals.

This research study not only compares the performance of relative and absolute positioning strategies under different sky view conditions but also provide a quantitative assessment of two software packages RTKLIB and Leica Infinity. The findings indicate that Leica Infinity offers superior performance in terms of accuracy, reliability, user friendliness and integration capability.

5.2 Recommendations

The performance of relative and absolute GPS positioning under different sky view conditions seems to behave differently at each station. One limitation of this study was the sample size of data points, which may not encompass all possible scenarios. Additionally, variations in environmental factors and GNSS receiver models could influence the results. Future research should consider expanding the study to include a larger dataset from diverse geographic locations and multiple GNSS receiver. From the results and conclusions obtained above, the following recommendations are being made;

i. Further research should be extended especially now we have different GNSS receivers like South receivers, Kolida receivers and CHCN receivers.
ii. The research must be extended to other GNSS positioning modes like GLONASS, BEIDOU, QZSS and GALILEO. Since this research based only in GPS positioning.
iii. The occupation time for data collection must be increased up to 6 or more hours so that to determine the trend of the data when the time increases so that we have enough data that can support the application of different software during data processing like GAMIT which is known for providing accurate and precise data for differential positioning.

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APPENDICES

APPENDIX 1. Describes Satellite Visibility of Each Point

APPENDIX 2. Illustrates Network Adjustment Report

APPENDIX 1

```
 SV+-----|-------------------|-------------------|-------------------|------+ SV
 25|IIIIII----------___________                                               | 25
 29|Loo-II-IIIIoooIIIIIIIIIIIII-----------__________                           | 29
 16|-----------------------IIIIooooooooooooooooIooo----oooooooooooooooooooooo| 16
  2|------------------------------------------------------IIIooooooooooooooooo|  2
 10|----I--I-----I-I-------------------------------_________________________| 10
 26|-IIIooooooooooooIoooIooooooooooooooooooooIooo-MIMoooooIooooooooooooooo| 26
 28|LoooooooooooooooIoooIooooooooooooooooooooIooo-MIMooooooooooooooooooooo| 28
 31|LoooooooooooooooIoooIooooooooooooooooooooIooo-MI-oooooooooooooooooooo| 31
 32|LoooooooooooooooIoooIooooooooooooooooooooIooo--IMIIIoIIIIIII-I-I--M---| 32
 27|  __________------------------------------------MIIMIIIII2oIooooooooooo| 27
  8|                         _________-----------------------I-----------|  8
  4|                                              _________-----------oooooo|  4
R12|L~~~~~~~~~~------                                                      |R12
R 1|L~~~~~~~~~~~~~-I-----------                                            |R 1
R13|L~~I~~~~~~~~~~~~~I~~~-~~~II~~~-~~~~~-I---------                        |R13
R 2|L~~~~~~~~~~~~~~~~-~~~I~~~~~~~~~~IIII--M------------------              |R 2
R 3|               --M~~~M~~~~~~~~~~~~~~~~~~~~~~I~~~-M-M~~~~-I---------------|R 3
R23|               ----cc-cccccccccccccccc--ccc-c-------c--c-cc-c-cccccccc--|R23
R24|                                   ----------~~~-M-M~~~~~~~~~~~~~~~~~~~~~~|R24
R 4|                                                       -L~~~~~~~~~~~~~~~~|R 4
-dn|534434544554767588766665554455555555677777776654445433333444344344454555|-dn
+dn|5556566666677789a-977-77777555656557999988 8-777----65558865656555555566|+dn
+10|eeeeeeeeeeeffffgggggfffffffeeeeeeeefggffffffffedddddddffeeeeeeeeeffffff|+10
Pos| ooooooooooooooooooooooooooooooooooooooooooo o oooooooooooooooooooooooo|Pos
Clk|                ^   ^                    ^   ^^^^                        |Clk
   +-----|-------------------|-------------------|-------------------|------+
12:42:06.000                                                       16:18:02.500
2023 May 11                                                         2023 May 11
```

Satellite visibility of BLD 01 station close to tall building

```
 SV+---------------------|-----------------------|----------------------|---+ SV
 31|LooooII Moooo2IIIoIIooooIoooooooI2IoooIIIoIooooooooooooooooooo---------I| 31
 29|LooooIIIoIoooooooooooooooooooooooooooooooIIoooIo                        | 29
 16|Loooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo---------L| 16
 32|LoooooooooooooooooooooooooooooooooooooooooooooooooooooooooIII---------L| 32
 26|Loooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo---------L| 26
 28|LooooIoooooooooooooooooIoooooooooooooooooooooooooooooooooooooo---------L| 28
 10|LoooooooooooooooooooooooooooooooooooooooooooooooooooooooooooI---------I| 10
 27|                                Looooooooooooooooooooooooooooo---------L| 27
  2|                                                              ---------L|  2
R12|LNNNNNNNNNNN                                                           |R12
R13|LNNNNNNNNNNNNNNNNNNNNNNNNNNNLLLNLLNN             LLNLLLL    ----       |R13
R 1|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNLNNLNLNLN                      |R 1
R 2|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN--------L|R 2
R 3|                           LNLNNNNLNNNNNNNNNNNNNNNNNNNNNNNNNNN--------L|R 3
R23|                                                              ---------L|R23
R24|                                                              ---------L|R24
Obs|bbbbbbbabbbbaaaaaaaaaaaaaaabbbbbbccccbbbbbbbbbbba9aaaaaaa99998         c|Obs
Clk|-                                                             ^^^^^^^^^^|Clk
   +---------------------|-----------------------|----------------------|---+
12:02:34.500                                                    15:34:17.500
2023 May 11                                                      2023 May 11

*********************
QC of RINEX  file(s) : BLD02
*********************
```

Satellite visibility of BLD 02 station close to building

```
  SV+---------------|--------------------------------|-----------------------+ SV
  25|IIIIIIo III--MII---M-I-MIIIMI I   IIIIIIII----II----------------------II| 25
  18|LoIIIIIIIIIII----------II III                                           | 18
  28|Looooooooo-II-II--III-MIIIIIIIIIIIIIII------III  III-------I--------1o| 28
  23|Looooooooo-LL-L---5-L-Looooooooooooooooooo----MooooooooooooooooI------    | 23
  10|Looooooooo-ML-M---M-M-5ooooooooooooooooooo----MooooooooooooooooI-------LI| 10
  29|       Looo-L-------LIIII II II LII-----LI-----I  L----------II-------Lo| 29
  26|                      -LIIIIIIooIIIIooIIoI----MIIoooooooooooooI--------I| 26
  32|                                                  Loo I2LIIIIII-------Mo| 32
  31|                                                                      Io| 31
 R11|LNNNNNNNLLN-L------                                                     |R11
 R12|LNNNNNNNNNNNLLNLN--LNLNLNNNNNNNNNNNNNNNNNNN---LNNNNNNNNNNNNLLLN-------LN|R12
 R 1|                    -LNLNNNNNNNNNNLNLLLLNL-----     LLL     LLL-------LN|R 1
 R13|                                          ----LNNNNNNNNNNNNNNNN------ LL|R13
 R 2|                                                              --------LN|R 2
 Obs|77777777887665555  5465887887776777777776664   77656786766666797       aa|Obs
 Clk|-         ^^^^^^^^^^^^^                  ^^^^^               ^^^^^^^^^ |Clk
    +---------------|--------------------------------|-----------------------+
09:31:37.500                                                           12:42:04.500
2023 May 11                                                             2023 May 11
```

Satellite visibility of BLD 03 station close to tall building

```
  SV+---------------|---------------|---------------|----------------|-------+ SV
   5|LooIooILI                                                              |  5
  24|LooooooooooIooIIIIIL                                                   | 24
  15|LoooooooooooooIMIooIIoIMIoooooo                                        | 15
  18|LooooooooooIIoIIIIIIIIIIIIIIIIMIIIIIII                                 | 18
  12|Looooooooooooooooooooooooooooooooooooooooo                             | 12
  25|IIoIIoIooooIoooooooooooooooooooooooooooooooooooIoIooIIIIIIIII          | 25
  23|LoooooooooooooooooooooooooooooooooooooooooooIIIIIoIIIIIIIIIIIIIILIII   | 23
  10|        LIoooooooooooooooooooooooooooooooooooooooooooooooIIoooIIIIIIooII| 10
  28|           IIIIIooooooooooooIoooooIoooooooooooIoooooooooooIIooooILIooooIo| 28
  29|                           LMILoIIIMIoooooooooooIoooooooooI2ooIoooooooooo| 29
  32|                               LoIIoooooooooooooooooooooooIIoooooooooooIo| 32
  26|                                    L M---LIIIIIIIIIIIoooIIoooooooooooIo| 26
  31|                                                     IIIIIIIIIIIIIooIIoo| 31
  16|                                                           III MIIIIIIoI| 16
 Obs|7777777777778888888877777777888778888988777777777777777888888999888887777|Obs
 Clk|-                                                        ^^             |Clk
    +---------------|---------------|---------------|----------------|-------+
09:03:11.500                                                       13:29:21.500
2023 May 11                                                         2023 May 11

*********************
QC of RINEX  file(s) : FRT01
*********************
```

Satellite visibility of FRT 01 station under tree canopy

```
 SV+---------|------------|-------------|------------|-------------|-------+ SV
  5|IIL                                                                     |  5
 24|LooooIooooIIo                                                           | 24
 15|Looooooooooooooooooooo                                                  | 15
 18|LoooooooooooooooIIoIIIoIooIIIo                                          | 18
 12|LooIoooooooooooooooooIIIIIIIIII                                         | 12
 25|IIIIIIIIIIIIIIIIIIoIIoIoIIoooooIIIIIIIIIIIIIIIIII                       | 25
 23|LooooIIIIIIooIoIoIIoIoIIIIIIIIIIIIIIIIooIoIIIIIIIIIIIII                 | 23
 10|   IIoIIoooooooooooooooIIIoooooooIIooIoooooo-IooooIIIIIIIIIIIIIIIIIIIM  | 10
 28|   IIIIIIIILIIIoIIoIIIIIIoIooIooooIooooooII-IIIIoooooIooIoooIIIooIIIIII| 28
 29|                   IIIIIIIIIIIoIIIIIoIIIoIo-IooooooooIoooIIoooIII       | 29
 32|                       LIIIIoooooooooooooIooIIIIIIIIIIIIIoIoIoILIIIIIIIII| 32
 26|                          IIIIIIIIoooooooooo-IoooooIoIIIIIIIoIIIIoooooooo| 26
 31|                                        LIIIIoooooooooooIIooooIoooooooooIo| 31
 16|                                             IIIIIoooooooooooooooooooooooo| 16
 27|                                                            LIIIooIIIIII| 27
  2|                                                                      LI|  2
Obs|77788888888888777777887787899888877777777888889999998887777778888887777777|Obs
Clk|                                           ^^                           |Clk
   +---------|------------|-------------|------------|-------------|-------+
09:20:53.000                                                    14:32:13.500
2023 May 11                                                      2023 May 11

**********************
QC of RINEX  file(s) : FRT02
**********************
```

Satellite visibility of FRT O2 under tree canopy

```
 SV+----------------------|---------------------------------|---------------+ SV
 24|Loo                                                                     | 24
 15|Looooooooo                                                              | 15
 18|LoooIIIIIIIIIIII                        IIIIIIIII                       | 18
 12|Looooooooooooooooooo                                                    | 12
 25|LoooooooooooooooooooooooooooooIoII                                      | 25
 23|LooooooooooooooooooooooooooooooooIIII                                   | 23
 10|LoooooooooooooooooooooooooooooooooooooooooIIIoIIIIIo2Io                 | 10
 28|LoooooooIIooIIIIoIooIIIIIIIIIIIoooooooooIooooooooooooooooooooooooooooooooo| 28
 29|        IooooooooooooooooooooooooooooooooooLooooooI                     | 29
 32|            IIIIoooooooooooooooooooooooooooooooooooooooooooooooooooooIoIII| 32
 26|             IIIooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 26
 31|                            LIIooIIIIMILIMLIooooooooooooooooooooooooooooooo| 31
 16|                             Loooooooooooooooooooooooooooooooooooooooooooo| 16
 27|                                          LIIIIIIoooooooooooooooooooooooo| 27
  2|                                            LooIIIIIIoooooooooooooooooooo|  2
  8|                                                      LIIIIIIooooooooooo|  8
  4|                                                                 IIIIIII|  4
 21|                                                                       I| 21
R 7|LNNNN                                                                   |R 7
R11|LNNNNNNNNNNNNNNNNN                                                      |R11
R 8|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN                                         |R 8
R12|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN                                 |R12
R 1|  LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNLLL               |R 1
R13|            LNNNNNNNNNNNNNNNNNNNNNNNNNNNLLLLLLLLLLLLLLLNNLLLLLLL        |R13
R 2|                     LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNLNNLNNNN  |R 2
R23|                                         LLNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R23
R 3|                                          LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R 3
R24|                                               LLLNNNNNNNNNNNNNNNNNNNNNNNN|R24
R17|                                                             LNNLNNNNNNN|R17
R 4|                                                               LLLNNLLNN|R 4
R14|                                                                   LLNNL|R14
Obs|ccdccbbbbcbbceeeddcbbcccccccdeddddccbba9abcdeeefffeedcddeeeeeeeffffgggfg|Obs
Clk|-                                                                       |Clk
   +----------------------|---------------------------------|---------------+
10:00:04.500                                                    16:20:24.000
2023 May 11                                                      2023 May 11

*********************
QC of RINEX  file(s) : OPT01
*********************
```

Satellite visibility of OPT 01 clear sky view

```
 SV+-------------------|----------------------|---------------------|--------+ SV
 10|III5---------------______________________________________________________| 10
 16|LooooooooooooooooooooI-ooooooooooooooooooooooooIIIIIoooooooooooooooooooooI| 16
 18|---------------IIIIoIooIIoIIoIooooooIoooooooooooIoo---------------------| 18
 26|LIooooooIIooIoooIoIoIIIIIoIIIoIIIII---MIIIIIIIIIoIoIIoooooooooooooooooooI| 26
 27|LoooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooI| 27
 28|LoooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooI| 28
  2|Looooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo|  2
 31|LIIIIIoIoIooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo| 31
 32|LoooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooI| 32
  8|---------IIooooIoIooIoIIoooIIoIIIooooooooooooooooooIIooooooIooooooooooooI|  8
  4|                    ____________________-----------------------IIIIIIIII|  4
R 2|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNLNNNNLNLNNNN  |R 2
R 3|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNL|R 3
R23|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNLNNNNNNNNNN|R23
R24|LNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNNN|R24
R17|                                       LLNNNLNLNNLLNNNNNNNNNNNNNNNNNNNNNL|R17
R 4|                                       LLLLLLNLNNLLNNLNLLNLNLNNNNNLLNNLL |R 4
R14|                                                             LLNNLNNLLNLL|R14
-dn|7666777666666655544444444444444444444455565577777777778888877788888677555|-dn
+dn|7877887777666766665455554444454444445577788888877787888888888899889788867|+dn
+10|bbaaaaaaaaaaaaa99999999999999999999999999aaaaaaaaaaaaaaaaaaaaaaaaaaaaaaaa|+10
Pos| oooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooooo|Pos
Clk|                                                                         |Clk
   +-------------------|----------------------|---------------------|--------+
14:34:18.500                                                       16:11:21.000
2023 May 11                                                         2023 May 11

*********************
QC of RINEX  file(s) : 0859131o34.23o
input RnxNAV file(s) : 0859131o34.23n
*********************
```

Satellite visibility of FRT 03 under tree canopy

```
 SV+---|------------------|------------------|-------------------|----------+ SV
  5|IoooooIooooooo                                                           |  5
 24|LoooooooooooooooIIIIIIIII 2o                                               | 24
 15|IooooIoooooooooooooooIIIMooooIoIooIoIIIMo                                  | 15
 18|LooooooooooooooooooooooooooooooooooooooooooooIIIIII --                     | 18
 12|LIooooooooooooooooooooooooooooooooooooooooooooooIIIo-M                     | 12
 23|Looooooooooooooooooooooooooooooooooooooooooooooooooo-Moooooooo-IooooooooI| 23
 25|Looooooooooooooooooooooooooooooooooooooooooooooooooo-Zoooooooo-LooooooIII| 25
 10|              IIoooooooooooooooooooooooooooooooooooo-Ioooooooo-Iooooooooo| 10
 28|               Looooooooooooooooooooooooooooooooooooo-5oooooooo-5ooooooooo| 28
 29|                                      LILoooLooooooo-2ooILoIoo2-MIIoIIIII| 29
 32|                                           LooIooooo-2oooooooo-Iooooooooo| 32
 26|                                               LIoIo-Loooooooo-Iooooooooo| 26
 31|                                                                   Looooo| 31
Obs|7777777777777778888888888878877777777788777888899998887777777776777888888|Obs
Clk|                                                    ^^        ^^         |Clk
   +---|------------------|------------------|-------------------|----------+
08:50:22.000                                                       12:33:11.000
2023 May 11                                                         2023 May 11

*********************
QC of RINEX  file(s) : OPT02
*********************
```

Satellite visibility of OPT 01 station under clear sky view