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Factors That Affect The Global Positioning System And Global Navigation Satellite System In
An Urban And Forested Environment

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by
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ABSTRACT

Factors That Affect The Global Positioning System And Global Navigation Satellite System In An Urban And Forested Environment

by

Douglas Allen Ritchie

The purpose of this study was to evaluate the accuracy in real time measurements acquired from GPS and GLONASS satellite observations using RTK techniques in an urban and forested environment. To determine this accuracy, 2 data sets of 3-dimensional coordinates were created and compared at 14 stations situated at East Tennessee State University. One data set included coordinates determined by conventional land survey methods; the second was solved by RTK GPS-GLONASS. Once the magnitude of any deviation in the coordinate positions was determined, the contributions to the accuracies from cycle slips, multipath, satellite availability, PDOP, and fixed or float solutions were evaluated. Three points in the urban environment varied from the conventional data set. Multipath was assumed to be the major bias in these points. Seven points in the forested environment varied from the conventional data set. The use of float solutions and high PDOP may have caused this bias.
DEDICATION

I dedicate this work to my loving wife. May many years of blessed growth be granted to us during of life together and ever after.
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CHAPTER 1

INTRODUCTION

The most common technique land surveyors use to locate the features of objects and terrain found in an urban environment for topographical surveys is conventional land surveying techniques (Anderson & Mikhail, 1998). These techniques require the use of total stations and retrodirective prisms in order to determine the horizontal and vertical positions of the points in an urban environment. The use of the Global Positioning System (GPS) methods to determine a point’s location is becoming more available to land surveyors as the prices of GPS receivers and antennas are becoming more affordable (The International Trade Administration, Office of Telecommunications and, U.S. Department of Commerce, 1998).

Depending on the receivers and purpose of the survey, land surveyors use receivers with various techniques to collect GPS signals that determine a point’s location on earth (Anderson & Mikhail, 1998). The two observables, the pseudorange and the carrier-phase are observed, individually or together, to determine the location of a point. When observed together, the process is called code-phase differential GPS and is used in relative positioning techniques. Code-phase differential GPS is a form of relative positioning that uses the coarse acquisition code and precise code independently or together with the carrier phase (Anderson & Mikhail). Relative positioning methods use two or more receivers simultaneously to track the incoming signal from the same satellites (Anderson & Mikhail). Differencing is the difference between one receiver’s observable from another (Sickle, 1996).

GPS is not the only satellite navigation system in existence. The Russian Federation is developing and upgrading its Global Navigation Satellite System (GLONASS) (Polischuk et al., 2002). Each of these satellite navigation systems can independently determine a receiver’s
location over a point. However, improvements in receiver technology available on the market are allowing the simultaneous tracking of both GPS and the GLONASS satellites (Leick, 2004). Simultaneously tracking both GPS and GLONASS satellites increases the number of space vehicles available for receivers to track by juxtaposing both satellite constellations.

The incoming satellite signals broadcasted from both constellations are affected by atmospheric conditions during their trip to the earth. Weak satellite signals are easily affected by the localized surroundings and degrade the accuracy in a GPS-GLONASS receiver’s measurement (Seeber, 2003). GPS methods generally require an open horizon, 15 degrees above the receiver in order to reduce topographic refraction that can result in weak signals susceptible to cycle slips (Anderson & Mikhail, 1998). Areas with strong electromagnetic frequencies and reflective surfaces should also be avoided because they induce the effects of multipath and also cause cycle slips (Anderson & Mikhail). Cycle slips and multipath are two known sources of bias that affect both weak and strong satellite signals in a GPS-GLONASS observation (Gerdan, Coombe, & Takac, 1995).

Cycle slips and multipath are both undesirable in a satellite measurements because they affect the accuracy of a point determined by GPS & GLONASS signals. Multipath affects both pseudorange and carrier phase measurements (Teunissen, 1998). Multipath creates inaccurate measurements by causing the receiver to measure a longer or shorter pseudorange (Teunissen). Cycle slips only affect the carrier phase measurement determined by the receiver (Seeber, 2003). Cycle slips can occur for a few or for millions of cycles (Leick, 2004). Cycle slips cause receivers to lose track of the number of cycles received from the incoming satellite signal (Sickle, 1996). Losing track of the satellite signal creates a problem in determining the integer ambiguity resolution for the carrier phase measurements. The integer ambiguity resolution used
to determine a point’s position is lost when a cycle slip occurs and changes when, or if, the incoming signal is reacquired (Sickle). Multipath and cycle slips are both discussed in more detail in Chapter 2.

A typical urban and forested environment contains sources of multipath and cycle slips that degrade an incoming signal and create inaccurate measurements, creating difficulties in using GPS to locate land features in this environment (Nave, 1999). This study explored the affects of multipath and cycle slips on Real Time Kinematic GPS (RTK GPS) measurements by using code-phase differential GPS to collect coordinate data on fourteen points established in both an urban and forested area. The observations were performed to evaluate the accuracies of the GPS and GLONASS measurements to determine the benefits or usefulness this combination has for RTK topographic surveys in environments where severe to moderate cycle slips and multipath are expected. The data were compared to coordinates for the same points that were determined through conventional land surveying methods. The coordinates were referenced to the ETSU Geodetic Network located on the East Tennessee State University (ETSU) main campus in Johnson City, Tennessee. A comparison of the accuracy of the results between the two data sets was then made.

Statement of Problem

Exploring the contributions to accurate RTK GPS measurements provided additional research for a method of collecting data in urban and forested areas using satellite navigation systems. GPS-GLONASS satellites with RTK positioning methods were used to determine a point’s location in both an urban and forested environment. The accuracy of a point’s location derived from this method would also be influenced by sources of multipath and cycle slips. The
accuracy of the data collected in this topographic survey was compared to data acquired through conventional land surveying methods to determine how well this method for collecting data performed in both an urban and forested environment where multipath and cycle slips were expected.

“Surveying has to do with the determination of the relative spatial location of points on or near the surface of the earth” (Anderson & Mikhail, 1998, p. 3). The equipment used to perform the measurements, calculations, and storage of data changes with the technology that is available to land surveyors (Anderson & Mikhail). Receivers that track satellite signals from both GPS and GLONASS satellites are new technology available to land surveyors (Martin & Ladd, n.d.). The augmentation of the GPS signal with GLONASS would increase the number of satellites available for observations and increase the redundancy for each measurement (Martin & Ladd). In measurements made with satellite signals, “There is a direct link between the number of satellites observed and positional accuracy” (Martin & Ladd, n.d., Introduction, paragraph 2).

The purpose of this study was to evaluate the accuracy in real time measurements acquired from GPS and GLONASS satellite observations in a topographic survey using RTK relative positioning techniques in environments where cycle slips and multipath were expected. The factors that contributed to accurate and inaccurate RTK measurements were then determined and include: multipath, cycle slips, satellite availability, PDOP, and Fixed or Float solutions. These factors were addressed in the form of several research questions.
Research Questions

The following question for this study were addressed:

- Question 1: What are the differences in northings, eastings, and elevations for the urban environment?
- Question 2: What are the differences in northings, eastings, and elevations for the forested environment?
- Question 3: What effect does GLONASS have on RTK in an urban environment?
- Question 4: What effect does GLONASS have on RTK in a forested environment?
- Question 5: What effect does multipath, cycle slips, satellite availability, PDOP, and fixed or float solutions have in an urban environment?
- Question 6: What effect does multipath, cycle slips, satellite availability, PDOP, and fixed or float solutions have in a forested environment?

Assumptions

Several assumptions were made for this study. First, it assumed that ETSU contained an existing network of geodetic monuments located on the campus that could be used to orientate the conventional and GPS-GLONASS surveys to the same coordinate system. Second, the course established for the project was assumed to provide cycle slip and multipath that could be expected in a typical urban environment. Third, the course was assumed to adequately represent points in a typical urban environment. Fourth, the existing GLONASS satellite coverage for the observation window was assumed to be adequate during good GPS observation times. Fifth, the TOPCON HiPer Lite © receiver was assumed to correct bias from satellite position, satellite
timing, atmospheric, and oscillator errors for the RTK solutions (Anderson & Mikhail, 1998).

Sixth, the HiPer Lite © receiver was assumed to provide those adjusted solutions in real time.

**Limitations**

The study was limited to primarily to focusing on errors in the accuracy from satellite observation bias caused by multipath and cycle slips. The study was limited to the local topographic features found in the study area that would provide the multipath and cycle slip bias. The factors contributing to these two biases were expected to be generated from the localized features found at this site. These localized features included: the Department of Housing and Residence Life residential buildings (dormitories), the trees in the forested area, the asphalt in the J. L. Seehorn, Jr. Road, the asphalt in the parking area, the parked cars, and varying terrain elevations. The perimeter of the course was also limited in size to facilitate a conventional land survey. The size of the course restricted the study to a small number of sample data points that could be readily recollected. The size of the course also contained the study in a small geographic area. The correction for bias in the GPS-GLONASS satellite signals from satellite position, satellite timing, atmospheric, and oscillator errors was also dependent on the capability of the TOPCON © GPS-GLONASS receiver. The number of GLONASS satellites used for RTK measurements was also limited to what GLONASS satellites were available during an observation window that predicted low GPS PDOP values. Furthermore, number of operational satellites available in each constellation restricted the size of each satellite constellation available at the time of the GPS-GLONASS observations. The Positional Dilution of Precision (PDOP) was expected to achieve acceptable levels. The RTK equipment available at ETSU also
provided the study with one specific manufacture’s model and type. The major comparisons for the study were also limited to the data sets obtained by the conventional and RTK land surveys.

**Definition of Terms**

The following terms were defined for the purposes of this study.

**Accuracy** – “The closeness between measurements and their true values. The further a measurement is from its true value, the less accurate it is” (Anderson & Mikhail, 1998, p. 31).

**Ambiguity Float Solutions** – These solutions are “estimated as real values” (Seeber, 2003, p. 337) and provide accuracies that vary between meters to decimeters. The degree of accuracy depends on the length of observation time over a point. Fixed ambiguity solutions can achieve centimeter solutions. (Seeber).

**Carrier phase** – The carrier phase is the second GPS observable. The carrier phase is “a far more precise observable than the pseudorange” (Teunissen, 1998, p. 165). A GPS receiver compares the carrier phase received from a satellite signal to “the phase of a carrier generated by an” internal oscillator (p. 165). The carrier generated by the oscillator is constant, while the received carrier is fractional and constantly “changing in frequency due to the Doppler shift induced by the relative motion of the satellite” (p. 165). A partial cycle is known as a phase shift (Sickle, 1996). The complete carrier phase observable is the number of full and partial cycles that have passed between the satellite and receiver (Teunissen). However, a receiver can track the partial carrier wave but cannot identify one full cycle from another. This situation creates an unknown number of carrier wave cycles that pass between the satellite and receiver, known as the integer ambiguity (see below). The carrier phase is also referred to as “phase pseudorange” (Teunissen).
**Code-Phase Differential GPS** – GPS positioning technique that uses both navigation code and carrier phase observations with relative positioning methods to derive post-processed or real-time measurements (Anderson & Mikhail, 1998).

**Conventional Surveying Methods** – Conventional surveying methods is a method of surveying that uses a total station, and a retrodirective prism to locate a point’s position on the earth’s surface. The total station is an instrument capable of measuring both angles and distances. A retrodirective prism is a target capable of reflecting an electronic distance measurement signal-wave (Anderson & Mikhail, 1998)

**Cycle Slip** – A cycle slip is the temporary discontinuity in the lock a receiver has on a satellite signal during an observation (Anderson & Mikhail, 1998).

**Dilution of Precision (DOP)** – DOP is an expression used to describe the effect of good satellite geometry (Hofmann-Wellenhof, Lichtenegger, & Collins, 2001). Satellite geometry has an affect on the accuracy of a receiver’s position over a point (Leick, 2004). The quality of the solutions for a receiver’s position is affected by the geometry of the orbiting satellites position (Sickle, 1996).

**Easting** – The “X” coordinates in a state plane coordinate system (Anderson & Mikhail, 1998).

**Epoch** – An epoch is “a very short period of observation time, and is generally just a small part of a longer measurement” (Sickle, 1996, p. 47). When the receiver tracks at least four satellites, enough information in the navigation solution is available in each epoch to determine the receiver’s horizontal and vertical positions and to resolve satellite-receiver clock errors (Sickle).
**Integer Ambiguity Resolution** – The integer ambiguity resolution is the unknown total number of wavelengths that traveled from the satellite to the receiver in an incoming satellite signal. A receiver that tracks the carrier-phase for measurements can determine the fractional phase difference in the incoming satellite signals. A receiver does this by comparing the incoming signal to “a similar signal generated by the oscillator within the receiver” (Anderson & Mikhail, 1998, p. 710). However, the integer ambiguity resolution is unknown (Anderson & Mikhail). The incoming signal wavelength for the L1 and L2 carrier waves is 0.19 m and 0.24 m, respectively. The wavelengths for the both the coarse-acquisition code and the precise code are 300 hundred and 30 meters, respectively. The L1 and L2 carrier waves provide the sub decimeter measurement and the coarse acquisition and precise codes provide the decimeter to meter measurement.

**Kinematic Relative Positioning** – Kinematic relative positioning is a GPS surveying method that involves the occupation of one base receiver over a known reference point, such as a geodetic monument, and at least one roving receiver during observations (Anderson & Mikhail, 1998). Both base and roving receivers must continuously track and maintain lock on at least four common satellites in the receivers’ horizon. Initialization of the receivers is necessary to resolve the integer ambiguity resolution. Kinematic relative positioning is “restricted to areas that have a clear view of the horizon” and requires post-processing of all the field measurements (Anderson & Mikhail, p. 717).

**Multipath** – Satellite signals can enter the receiver from multiple paths (Hofmann-Wellenhof et al., 2001). This phenomenon occurs when a reflected satellite signal is received by the receiver’s antenna (Anderson & Mikhail, 1998). The satellite signal can reflect off a variety of surfaces located near and around the receiver. Algorithmic and statistical modeling cannot
eliminate this bias and only provide estimates for error solutions because multipath is dependent on the local surroundings at the receiver's location (Hofmann-Wellenhof et al.).

**Northing** – The “Y” coordinates in a state plane coordinate system (Anderson & Mikhail, 1998).

**Observation Window** – This is the time of day that offers optimal times for GPS observations. Optimal times are characterized as having adequate satellite availability and good satellite geometry (Hofmann-Wellenhof et al., 2001).

**On-the-fly (OTF)** – OTF consists of determining positional solutions for GPS roving, and base receivers by using software capable of on-the-fly ambiguity resolution “that permits very rapid estimation of the integer ambiguities” (Anderson & Mikhail, 1998, p. 718). On-the-fly solutions do not require initialization of receivers after a loss of satellite lock occurs. The algorithm for on-the-fly solutions uses combinations of pseudorange and carrier phase data (code and carrier phase) to solve the integer ambiguity resolution and uses statistical tests to “ensure reliability in estimated integers” (p. 718). These solutions require the tracking of at least five satellites (Anderson & Mikhail). On-the-fly solutions are used in RTK GPS and can provide centimeter accuracy (Anderson & Mikhail). On-the-fly solutions to the integer ambiguity is facilitated with many satellites present in the receiver’s horizon (Seeber, 2003)

**PDOP** – PDOP is a combination of the horizontal dilution of precision (HDOP) and the vertical dilution of precision (VDOP) (Anderson & Mikhail, 1998). PDOP is used to express satellite geometry. Low PDOP values are associated with good satellite positions in a receiver’s horizon. PDOP values “near three is associated with widely separated satellites and good positioning (Strang & Borre, 1997, p. 602).
**Precision** – “The closeness of repeated observations (or quantities derived from repeated sets of observations) to the sample mean (Leick, 2004, p. 95). It is also “defined as the degree of perfection obtained” (Federal Geodetic Control Committee [FGCC], 1975, p. 2).

**Pseudorange** – A pseudorange is the first GPS observable (Sickle, 1996). The pseudorange measurement is a time shift that “is the time elapsed between the instant a GPS signal leaves a satellite and the instant it arrives at a receiver” (Sickle, p. 18). The coarse-acquisition code and the precise code can both be used to measure a pseudorange. The precise code is more precise than the coarse-acquisition code (Hofmann-Wellenhof et al., 2001).

**Real-time Kinematic GPS (RTK GPS)** – RTK GPS is a kinematic relative positioning method that involves the use of a GPS base station placed over a known reference point that uses a radio or cellular communication to transmit real-time corrections for integer ambiguity resolutions to a remote receiver during observations over points (Anderson & Mikhail, 1998). The real-time corrections require on-the-fly solutions for integer ambiguities (Seeber, 2003). RTK GPS uses pseudorange and carrier phase data to solve integer ambiguity resolutions in observations (Seeber). The signal transmission from the base station to the remote receiver is affected by line of sight between the receivers and can be blocked by various obstructions. RTK GPS is also “another name for carrier-phase differential GPS” (Seeber, p. 336).

**Redundancy** – In this study, redundancy refers to the multiple number of incoming satellite signals that are tracked by a receiver.

**Urban Environment** – In this study, the urban environment is represented by a section of the East Tennessee State University campus.
Methodology

Four steps were undertaken to accomplish this study. First, information about GPS, GLONASS, and RTK positioning methods were reviewed in order to gain an understanding about the subject. Second, a field course was established at ETSU in order to provide an environment in an urban area where sources of multipath and cycle slips were present to affect the GPS and GLONASS satellite signals. Third, coordinates were determined for the fourteen points established in the field course by conventional surveying methods and RTK GPS-GLONASS relative positioning surveying methods. Fourth, the two data sets of coordinates for these fourteen points were compared to determine the variance of their positional accuracy. Fifth, an analysis of the contribution of multipath, cycle slips, satellite availability, PDOPs, and fixed and float solutions was performed.

The first step in the study was to acquire and review information from books, periodicals, and journals about satellite navigation systems. The first topic reviewed was literature on the GPS and GLONASS satellite constellations. Reviewing GPS and GLONASS literature was done in order to provide a brief synopsis of the satellite navigation systems and to determine the health of the GPS and GLONASS satellite constellations. Information about satellite geometry, specifically PDOP, was reviewed in order to identify good observation times for this study. Then, information about multipath and cycle slips was gathered in order to understand how these two sources of bias degraded the satellite signal. Understanding multipath and cycle slips helped with analyzing how the GPS-GLONASS accuracy varied from the values determined by the conventional land surveying method. Finally, RTK GPS positioning methods were reviewed in order to perform the GPS-GLONASS observations. Knowing the procedures for RTK GPS surveying assisted in minimizing the errors in the accuracy due to user error.
The second phase of this study consisted of establishing a course at ETSU where coordinate values were determined by conventional land surveying methods and RTK positioning methods. The course consisted of fourteen points that were located on the south side of ETSU’s campus. The course followed alongside the J.L. Seehorn, Jr. Road and the Clinchfield Railroad. This location was chosen because there are two distinct localized features in the vicinity. These two localized features were urban structures and a wooded hillside. The urban structures included ETSU’s Housing and Residence Life residential buildings, D.P. Culp University Center, asphalt roads, asphalt parking, and concrete sidewalks. The residential halls are brick buildings and the D.P. Culp University Center is a concrete building. The wooded area contained both deciduous and conifer trees that varied in height and diameter from small saplings to mature hardwoods. The location also had a large hill that was the major topographic feature and potential obstruction in the area. A chain link fence also follows along the north side of this hill.

The features in this area provided two distinct halves for the course and allowed variations in the point’s locations. The first half was situated near the urban structures and is referred to as section one. These points were placed along the road, under overhead power and telephone lines, beside the parking lot, or near the sidewalks. These surfaces provided sources for multipath. These points were also free from overhead tree canopy. The second half of the course was established on and along the wooded hillside and is referred to as section two. In this area, some points were placed along the bottom of the hillside, and others were placed near the top of the hillside. The thickness of the woods and overhead canopy varied from point to point. The wooded section of the course was expected to have moderate to severe cycle slips.
The location of the course was also chosen because it allowed easy access to the ETSU Control Network. Both methods used the ETSU Control Network as a reference for the fourteen points. This reference system allowed a comparison of the point’s coordinate data in both horizontal and vertical directions. The horizontal control for this network was the Tennessee 83 State Plane Coordinate system. The North American Vertical Datum 1988 was used to establish vertical control. A table was created that showed the point’s position in the horizontal and vertical directions. Horizontal values were expressed as northings and eastings. Vertical directions were represented as elevations.

The third step of this study consisted of determining the horizontal and vertical positions of each point using conventional land surveying traverse and GPS-GLONASS topographic surveying methods. Conventional land surveying was a common method used by land surveyors to map land features in urban environments (Anderson & Mikhail, 1998). The horizontal and vertical positions were established by using a total station and retrodirective prism with traversing and side shots methods (Anderson & Mikhail). Conventional land surveying methods were used to determine point locations in all environments (Anderson & Mikhail). Thirteen points in the course were located by traversing, and one point was established with a side shot. All fourteen points were located directly with GPS-GLONASS topographic surveying methods. Satellite navigation systems were also used to determine the locations of points in a variety of environments (Anderson & Mikhail). However, observations were generally restricted to areas with open sky (Anderson & Mikhail). Despite the overhead tree canopy over several of the points, horizontal and vertical positions were established for each point.

The fourth step of this study performed the necessary data reductions for the conventional and RTK land surveys. The points collected in the conventional field survey were post-
processed using software currently available to the ETSU surveying and mapping department. The GPS-GLONASS surveying methods did not require post processing of the data. The RTK data were processed and corrected for errors in real time (Leick, 2004). The TOPCON® HiPer Lite Plus receiver processed and corrected the RTK data in real-time. The technical specification for this receiver was listed in Appendix A.

The fifth step of this study was to compare the values provided by the two data sets. The northing, easting, and vertical coordinate values for the points collected in the RTK GPS survey were compared and contrasted to the northing, easting, and vertical coordinate values for the points collected in the conventional land survey. Comparing the two data sets was done to determine the difference between the positional values of both coordinate sets in the course. Then, the contribution of multipath, cycle slips, satellite availability, PDOPs, and fixed and float solutions was performed to determine what combinations of these factors contributed to accurate positions. The accuracy of the GPS-GLONASS observations was then determined by how well they matched the accuracy of the conventional land survey. The level of accuracy for the conventional land survey met the accuracy specification in the Tennessee Statutes for Category I land survey. Meeting the accuracy specifications ensured that the points located in the conventional land survey were accurate and served as a reliable control group for comparison. Fifteen epochs were collected for each point in the RTK GPS survey. This was well in excess of the two epochs needed to acquire a position solution and correct for bias (Nave, 1999). The GPS base station’s location was established through the localization procedure used by the TOPCON® HiPer Lite Plus receiver. The localization of the GPS base station was better than seven millimeters at each point. The localization data showed that the base station was accurately positioned, despite the information that the rover collected.
Summary

Land surveyors used conventional land surveying positioning techniques to determine the positions of points in an urban environment. However, the use of conventional land surveying was restricted to the line of sight between the total station and reflective prism (Anderson & Mikhail, 1998). GPS methods of locating points was not dependent on line of sight but required an open sky horizon above the receiver in order to acquire and track incoming satellite signals (Anderson & Mikhail). An urban environment could contain many features, such as buildings, trees, and overhead utility lines that could obstruct the path of an incoming signal and cause loss of satellite lock. In addition, there are many reflective surfaces in an urban area that cause degradation to the GPS pseudorange due to multipath. Acquiring and tracking GLONASS satellite signals in addition to the GPS satellite signals might improve the RTK positioning methods in this cycle slip and multipath rich environment. In addition, the combination of cycle slips, multipath, satellite availability, PDOP, and fixed or float solutions are also factors that might contribute to the accuracy or inaccuracy of a point.
CHAPTER 2

REVIEW OF LITERATURE

Background

In order to perform the proposed study described in Chapter 1 of this thesis, several different topics were reviewed. This review of literature begins with a summary pertaining to GPS, GLONASS, and their constellations. Next, there is a discussion of how PDOP relates to accurate results derived from the incoming satellite signals. The errors attributed to multipath, cycle slips, and GPS-GLONASS augmentation are reviewed. This is followed by a summary of the relative positioning techniques used in RTK methods that are used to determine accurate and precise sub-centimeter measurements. The characteristics of the high accuracy RTK receivers and the steps taken in an RTK mission are discussed. The chapter closes by describing the characteristics of a GPS measurement augmented with GLONASS.

Introduction to GPS

The Navigation System with Time and Ranging Global Positioning System (NAVSTAR GPS) was “a satellite-based radio navigation system” that provided “precise three dimensional position, navigation, and time information to suitably equipped users” (Seeber, 2003, p. 211). GPS was the product of years of research and development that was initiated by the United States Department of Defense (DOD) in the 1950s to provide navigational information in all weather conditions across the globe (Anderson & Mikhail, 1998). In the early 21st century, GPS provided navigational support for both the civilian and military communities. GPS’s primarily function was to serve the military community; however, geodesists have used this system since
1983 to provide solutions to geodetic problems (Seeber). The satellites were operated and maintained by the U.S. DOD, which formed the control segment in GPS (Seeber). The control segment’s Master Control Station (MCS) was located near Colorado Springs, Colorado. Additional monitoring stations (MS) were situated in various locations around the world. According to Seeber, the MCS and assisting MS function to provided the following services:

1) Monitored and controlled the satellites and their orbits
2) Determined GPS system time
3) Predicted satellite ephemeris data and clock data and
4) Provided necessary updates to the navigation message

The GPS satellites broadcasted two pseudo-random noise codes (PRN), the coarse acquisition code and precise code, on two carrier frequencies in L-band radio spectrum (Anderson & Mikhail, 1998). The coarse acquisition code was solely modulated on the L-1 frequency, while the precise code was modulated on both L-1 and L-2 frequencies. These codes provided the raw data that receivers used to determine their horizontal and vertical positions, time measurements and corresponding velocities (Sickle, 1996). The coarse acquisition code provided navigational support for the Standard Positioning Service (SPS), which was utilized by the civilian community. The precise code provided the raw data used in the Precise Positioning Service (PPS), which was reserved for the DOD and other authorized users. PPS provided positional accuracies within 10 to 20 meters (Seeber, 2003). Until the Presidential decision on May 2, 2000, to deactivate Selective Availability (SA) permanently, positional accuracies of 100 meters or better were available with SPS. Once SA was deactivated, SPS provided accuracies comparable to the PPS. However, despite the use of SA to degrade SPS, civilian users of GPS
were able to achieve geodetic accuracies and precision using differential relative positioning techniques (Anderson & Mikhail)

The World Geodetic System (WGS), a geodetic datum, was developed by the DOD in the 1960s (Seeber, 2003). The first WGS geocentric terrestrial reference system was WGS 60 and was developed in 1960. Continuously being refined, as the DOD gathers more data, WGS advanced computational techniques, gathered more knowledge of the earth, and improved accuracies. As a result, the WGS 66, WGS 72 and the WGS 84 reference systems successively followed the WGS 60. The DOD employed the WGS as a reference system for GPS beginning on January 21, 1987 (Sickle, 1996). The geodetic datum that GPS used as a basis for a coordinate reference system was the World Geodetic System 1984 (WGS 84) (Seeber). WGS 84 was the direct coordinate system for GPS’s navigation message computation, but receivers could transform the WGS 84 coordinates to other reference systems such as the North American Datum 1983 (NAD 83) (Sickle).

GPS satellites employed GPS time (GPST) as a time reference system (Leick, 2004). GPST was within one microsecond of the coordinated universal time (UTC), monitored by the US Naval Observatory time scale (UTCUSNO). UTC consisted of the International Atomic Time (TAI), which is an integral number of seconds and leap seconds that are summed together and used as a time scale for precise astronomical applications (Anderson & Mikhail, 1998).

Introduction to GLONASS

The Russian Federation committed to updating and rebuilding the existing GLONASS constellation that was originally developed and maintained by the Soviet Union (Seeber, 2003). GLONASS was originally designed for military and civilian use (Seeber). This satellite system’s
primary military function was to serve as a navigation system for Soviet ballistic missiles (Lechner & Baumann, 2000). However, the Russian Federation declared that GLONASS would provide free navigation signals available for civilian use without the interference of selective availability (Seeber). GLONASS was also developed to provide 24 hour global navigational support in all weather conditions (Leick, 2004). The Russian Scientific-Research Institute of Space Industry and Russian Institute of Radionavigation and Time were both involved with the research and design of GLONASS’s satellites and their components (Polischuk et al., 2002). The Russian Military Space Forces served as the ground control segment that operated and managed GLONASS (Hoffman-Wellenhof, 2001). Located in Moscow, this ground control segment was known as the System Control Center. Additional control stations were located throughout the other areas of the former Soviet Union, but lacked global coverage (Seeber). These control stations were responsible for providing continuous support for the GLONASS satellites (Polischuk et al.).

GLONASS broadcasted two signals, the standard precision (SP) and high precision (HP) navigation signals (Seeber, 2003). The SP signal provided navigational support for the civilian community, while the HP signal was reserved for military use. The SP and HP signals contained navigation messages with all the necessary data a receiver needed to determine its horizontal and vertical positions and velocity (Seeber, 2003). The SP signal, referred to as the Channel of Standard Accuracy, could achieve a “horizontal positional accuracy of sixty meters”, and “vertical positional accuracy of seventy five meters” (Lechner & Baumann, 2000, p. 5). The HP signal, also called the Channel of High Accuracy, was used by the military and was developed to yield higher levels of positional accuracy. In addition to the navigational codes, GLONASS’s
carrier phase data could also provide positional solutions. GLONASS’s carrier phase data provided accurate and precise geodetic solutions (Seeber, 2003).

The radio-signal structure GLONASS used as a carrier wave was similar to the one used by GPS (Seeber, 2003). As with GPS, GLONASS also applied two carrier signals that broadcasted in the L-band range of the radio frequency spectrum (Seeber). The L-1 and L-2 frequencies transmitted the binary navigation code and message to the GLONASS receivers. The primary difference was that satellites shared the same L-1 and L-2 frequencies but broadcasted a different navigation code, while the GLONASS satellites shared the same navigation code but broadcasted at a different L-1 and L-2 radio frequency bandwidth (Seeber).

Due to the similarity of the frequency ranges, one antenna and common signal input amplifiers could receive the incoming signals from both systems; however, processing the signal required different techniques (Seeber, p. 385).

In addition to the differing L-band radio frequencies, there were two other differences in the GLONASS positioning techniques. One was the geographic reference system used as a geodetic datum (Seeber, 2003). The GLONASS satellites’ coordinate system determined receiver positions with the Parametry Zemli 1990 geodetic datum (PZ-90). This geodetic datum replaced the Soviet Geodetic System 1985 (SGS 85), previously used by GLONASS satellites. The PZ-90 geodetic datum also had a small difference in positional solutions, when compared to the WGS 84 system (Seeber). The other difference between the systems involved the system times used by GPS and GLONASS. GLONASS employed the UTC standard provided by the former Soviet Union (UTC SU) (Seeber). The offset between Moscow and Greenwich Time was 3 hours and GLONASS time also considered leap second in its calculations. Despite these and other differences between the navigation systems, receivers were available, that used both
navigation codes (Lechner & Baumann, 2000). Appendix B provided a table that shows technical differences between the satellite systems (Seeber).

The GPS Constellation

The GPS constellation was planned to have 24 operational satellites that broadcast carrier wave signals to a receiver on or above the earth (Anderson & Mikhail, 1998). Three of the satellites functioned as spares to ensure that a complete constellation was available for navigational support (Hofmann-Wellenhof et al., 2001). These satellites rapidly orbited the earth every 12 hours at an altitude of 20,200 km. Orbiting at this altitude reduced errors caused by gravitational pull and ionospheric delay (Leick, 2004). The satellites were evenly spaced in six orbital planes that were inclined at 55 degrees (Hofmann-Wellenhof et al., p. 335). These orbital patterns ensured that at least four satellites would be in a receiver’s horizon 24 hours a day from any location on earth (Hofmann-Wellenhof et al.). As of October 20, 2006, the current GPS constellation had 29 of the 30 satellites listed in operational status and in orbit around the earth. One satellite, SVN 15, was unusable due to a maintenance check and need for drift correction and had to be flown back into correct orbit. The GPS constellation’s current status could be found at the web address: http://tycho.usno.navy.mil/gpscurr.html. This website showed the status of each satellite and their names, orbital plane, launch dates, decommissioned dates, and other useful accompanying notes regarding the GPS constellation. The accompanying notes included limited information about the performance capabilities for the different models of satellites. Appendix C showed the current listing of available GPS satellites.

The constellation of GPS satellites evolved continuously and was refined with new technology to meet contemporary and future navigational needs. In 2006, there were six
different classes of GPS satellites that began with the Block I series. Eleven of these Block I satellites were launched between 1978 and 1985. Their successful launches, excellent lifespan, and reliable performance allowed the concept of a satellite navigation system to be realized (Leick, 2004). The Block II series, the second-generation GPS satellites, began to replace the Block I satellites in February 1989 (Leick). Twenty-eight Block II and IIA satellites were launched between 1989 and 1997 and created the modern GPS constellation and current orbital planes. The main difference between the Block I and II satellites was that the Block II series had SA and AS capabilities (Leick). Antispoofing was included in this series of satellites because it allowed the United States Military intentionally to deny access of the P code to any GPS receiver that tracked this code for surveying or navigational applications (Anderson & Mikhail, 1998). The Block IIA satellites were advanced compared to the Block II satellites and contained additional modifications, such as the ability to be tracked with laser ranging (Hofmann-Wellenhof et al., 2001).

The third generation GPS satellites were known as the Block IIR (replacement or replenishment) satellites and began to replace the Block II and Block IIA satellites with their first launch in July 1997. Thirteen of these satellites were launched and placed into orbit since 1997 (United States Naval Observatory, 2006). The Block IIR satellites had many additional features compared with the Block II and Block IIA series. The Block IIR satellites had inter-satellite tracking abilities and determined their own orbit autonomously. They also had the ability to measure ranges to other satellites and to ground control stations. These abilities allowed the satellites to run in an autonomous mode for 180 days and required less ground support (United States Naval Observatory). In the future, the Block IIR satellites are to be replaced by the Block IIR-M (modified) and Block IIF (follow on) satellites. The Block IIR-M satellites will broadcast
new civilian and military codes that will allow the manufacture of inexpensive dual frequency GPS receivers (Leick, 2004). Three Block IIR-M satellites were launched between September 2005 and November 2006 (United States Naval Observatory). The Block IIF satellites will broadcast a third signal wave on the L-5 carrier wave frequency (Leick). The first Block IIF satellite will be launched in 2007 (Hofmann-Wellenhof et al., 2001). In 2006, the GPS constellation consists of four of the six classes of satellites. They are the Block II, Block IIA, Block IIR, and Block IIR-M satellites.

The GLONASS Constellation

The GLONASS constellation went through different phases of development and decline since its first satellite launch in 1982. GLONASS satellites were originally deployed in three phases (Polischuk et al., 2002). Phase one consisted of the time when initial experimental tests were performed on the system in order to refine it for future use. During this time, four to six satellites were launched between the years 1983-1985.

Phase two occurred between the years 1986-1993 (Polischuk et al., 2002). After the experimental test flights were completed, the system began basic operation. Additional satellites were launched to build the constellation up to twelve operational satellites. In phase three, the Russian Federation completed its mission to create and develop a fully operational satellite navigation system. During the time between the years 1993-1995, GLONASS was in full operational status and had a complete constellation of 24 working satellites. However, this was the only period when the GLONASS constellation was at peak operational status. During 1996-1998, GLONASS was in operation but began declined due to lack of funding to continue
maintenance of the system. Slowly, the constellation was been reduced to a fraction of operational satellites.

Even though the constellation was only partially complete, the Russian Federation was determined to rebuild GLONASS to full operational status (Polischuk et al., 2002). In 2001, the Russian President and government passed a directive that would require unconditional financial support to maintain and redevelop GLONASS. This governmental order proposed a 10 year duration, or until 2011 to allow adequate time for complete system development. During this time, the GLONASS constellation and all supporting infrastructure would be rebuilt, including using updated satellites, refurbishing the ground control segment, gaining international support, and refining existing ground control reference networks.

The proposed GLONASS constellation would have 24 operational satellites, including 21 satellites to broadcast the navigation signal, and 3 spare satellites. These satellites would orbit the earth at an altitude of 19100 km in three orbital planes, 120 degrees in longitude apart (Polischuk et al., 2002). Eight satellites would be equally spaced in each plane and rapidly orbit the earth every 11 hours and 15 minutes. This orbital pattern was designed to ensure that 6 to 11 satellites would be visible in a receiver’s horizon from any position on earth. In addition, this orbital pattern allowed the satellites to pass over the monitoring stations located in the Russian Federation and provided better positioning results at higher latitudes (Hofmann-Wellenhof et al., 2001). The Russian Federation proposed a complete GLONASS constellation in 2011. In October of 2006, 16 satellites were in service and 13 were listed as usable. Updated information on the constellation was available at University of New Brunswick’s Department of Geodesy and Geomatics Engineering web address: http://gge.unb.ca/Resources/GLONASSConstellationStatus.txt. This website showed the current status of each satellite, the satellite names, launch
dates, decommissioned dates, and accompanying notes. Appendix D listed the GLONASS satellites available in October 2006.

The complete GLONASS constellation will consist of the GLONASS-M and GLONASS-K satellites (Polischuk et al., 2002). The GLONASS-M satellites will have a longer lifespan of 7 years and provide better performance. Eighteen of these satellites will be launched. These satellites will broadcast a stronger L-2 carrier wave and will provide a better navigation code. The improvements to the signals, clocks, and navigation codes will increase the positional accuracies from 60 meters to 30 meters for both horizontal and vertical positions. The GLONASS-K satellites will also be developed during this time. Twenty-four K series satellites will be developed and each will have a 10 year lifespan. These satellites will broadcast a third L-band carrier wave that will provide improved reliability and accuracy for navigational solutions. Positional accuracies for both the horizontal and vertical planes will be increased to five to eight meters. The GLONASS-K satellites will have the ability to “determine the divergence of the GLONASS system time scale with respect to the GPS system’s time scale and generation of corrections” (Polischuk et al., p. 157). Appendix B showed the technical differences for the GLONASS satellites.

**Dilution of Precision**

In order to collect reliable positioning data, receivers must track at least four satellites that are above “the observer’s mask angle for the simultaneous solution of the clock offset and three dimensions of the receiver’s position” (Sickle, 1996, p. 71). Signals from five or more satellites were required for kinematic positioning (Sickle). These satellites were in continuous motion and created a configuration of geometry in the receiver’s horizon. This configuration of
geometry of the satellites in the receiver’s horizon was a major factor that determined accuracy of a GPS measurement (Seeber, 2003). Dilution of Precision (DOP) was used to “describe the effect of receiver-satellite geometry on the accuracy of point positioning” (Leick, 2004, p. 251). DOPs “are still useful to identify a temporal weakness in geometry in kinematic applications, in particular in the presence of signal obstruction.” (Leick, p. 252).

Geometric dilution of precision (GDOP) described the “uncertainty that may be expected in the three position coordinates (x, y, z) and the clock offset from a particular configuration of satellites” (Sickle, 1996, p. 71). Poor satellite geometry resulted when satellites were clustered together in the horizon. High PDOP values reflected poor satellite geometry (Sickle). Position dilution of precision (PDOP) expressed the degree of uncertainty in the solution for a receiver’s position (Sickle). PDOP was the combination of horizontal dilution of precision (HDOP) and vertical dilution of precision (VDOP). Ideal satellite geometry for four orbiting satellites in the receiver’s horizon was with only one satellite above the receiver and the others distributed 120 degrees “from one another in azimuth near the horizon” (Sickle, p. 71). A large number of satellites spread out above the receiver would reduce PDOP values (Sickle). This ideal scenario was described as satellites that form a widely spaced inverted triangle above the GPS receiver. GDOP and PDOP values of two and three were expected in situations with good observational conditions with a complete and operational constellation of satellites (Seeber, 2003). A PDOP value of three was “associated with widely separated satellites and good positioning” (Strang & Borre, 1997, p. 602)

The degree of DOP values determined the length of time during acceptable DOP needed to collect satellite signal data over a point. Accuracy was achieved with low DOP values. When DOP values were high, longer observation times were needed to achieve accurate measurements
Sickle, 1996). Short observation times were possible by simultaneously tracking five or more satellites that had good geometry in the horizon and low DOP values (Sickle). This combination yielded adequate accuracy results for the receiver’s position measurements (Sickle). DOP values could be determined in advance before the GPS survey during pre-mission planning (Leick, 2004). Software with satellite ephemeris data could predict the positions of satellites at a given time in the day for the approximate receiver location (Sickle). The observation times could then be planned for the times of day that had low DOP values.

**Multipath, Cycle Slips and GPS-GLONASS Errors**

The course established for this study was set in an area that placed points in locations where multipath and cycle slips errors were expected. These two error sources were targeted to evaluate how well the GPS-GLONASS combination assisted in determining a point’s position used in RTK kinematic techniques. These errors affected both GPS and GLONASS satellite signals. This discussion also contains information about errors brought into a measurement from the combination of these two navigation systems.

Satellite signals could enter the GPS antenna from reflected surfaces (Seeber, 2003). These reflected signals traveled indirect paths to the antenna and resulted in a longer signal length than direct signal waves (Leick, 2004). This biasness was called multipath and was a dominant source of error that affected the accuracy in satellite signal measurements in both GPS and GLONASS (Teunissen & Kleusberg, 1998). The sources of multipath varied from point to point because it was dependent on the local features found around the point and the position of the satellites during the observation (Gerdan et al., 1995). Extreme amounts of multipath could cause a loss in satellite lock, and might produce a cycle slip (Seeber). Multipath also reduced
signal-to-noise ratios (SNR) values in the satellite signals. Signals that were affected by multipath had lower SNRs than healthy satellite signals (Gerdan et al.).

Multipath affected both the code and carrier wave measurements (Seeber, 2003). The effects of multipath were much greater for code measurements than carrier phase measurements (Hofmann-Wellenhof et al., 2001). The magnitudes of errors were different for the precise code and coarse acquisition code. The precise code could contain errors from several decimeters to several meters. The error could be as great as one hundred meters in coarse acquisition code observations (Seeber). Multipath had a different effect on carrier phase measurements and produced an error of several centimeters in carrier phase observations (Seeber). There, multipath produced a phase shift that varied as the satellite geometry changed in the receiver’s horizon. The error increased and decreased as the satellites orbited above the receiver. This cyclic behavior could be observed and minimized through long observational sessions; however, this was not possible in brief observation times typical in kinematic surveying methods (Seeber). Multipath affected the phase shift of both the L1 and L2 signals. Multipath could create horizontal errors up to 5 centimeters or more and vertical errors up to fifteen centimeters or more in combined L1 and L2 carrier phase measurements.

There were techniques that could be used to reduce the effects of multipath. First, the antenna design determined how much multipath affected the measurement. Antennas with choke rings and digital filtering were more adept at minimizing multipath (Seeber, 2003). Users could become aware of potential sources of multipath and learn to be wary of environments and structures, such as chain-link fences, that were known sources of multipath (Hofmann-Wellenhof et al., 2001). Receivers and software design were also a factor in minimizing the effects of multipath. Receivers that provided an option for selecting narrow frequency bandwidths allowed
better SNRs (Sickle, 1996). However, this reduced the ability of the receiver to track satellites, and makes the carrier phase more prone to cycle slips (Sickle).

Another way multipath could be reduced was avoiding using observables received from satellites that were low on the horizon. The signals broadcasted from satellites low on the horizon were weak and more prone to having higher levels of multipath bias (Leick, 2004). These signals were also present as low SNR (Gerdan et al., 1995). Using a mask angle of 15 to 20 degrees off the horizon aided in avoiding this situation (Sickle, 1996). Multipath could be reduced during a long observation session for a point; however, this was not possible in kinematic surveying methods (Seeber, 2003). For RTK land surveying, it was important to minimize the effects of multipath and to avoid the sources during short observations, especially for control stations (Seeber).

In addition to multipath, static, and RTK receivers that use carrier phase measurements were subject to bias from cycle slips (Hofmann-Wellenhof et al., 2001). Cycle slips did not affect coded pseudorange measurements (Sickle, 1996). A cycle slip occurred “when a receiver loses phase lock of the satellite signal” (Seeber, 2003, p. 277). Cycle slips in kinematic surveying are caused by a variety of sources. Any physical object that obstructs the signal path to the receiver will cause a cycle slip. Sources of obstructions include buildings, trees, and terrain. Interference to the signal, inclined antennas, and incorrect signal processing also create cycle slips. The number of missed cycles may be small or very large. A slip of several million cycles may occur in an observation (Seeber). A cycle slip causes the receiver to lose its resolution of the integer ambiguity solution during for carrier phase measurements. If a loss of the integer ambiguity resolution occurred, the receiver must be reinitialized in order to proceed with the carrier phase measurements.
Receivers handled cycle slips in two phases: cycle slip detection and cycle slip repair or cycle slip fixing. In cycle slip detection, the receiver used built-in algorithms to determine the presence of cycle slips and to flag data containing missing cycles in observation data (Seeber, 2003). Multi-channel receivers detected a cycle slip within 20 milliseconds of it occurrence (Seeber). Cycle slips were also detected by algorithms that used the Doppler shift to evaluate the carrier phase difference for each successive epoch and then applied a time interval (Hofmann-Wellenhof et al., 2001). Cycle slips were repaired during data editing and data processing, either automatically or interactively (Seeber). Cycle slips could be repaired interactively during post data processing; however, this was not possible for true RTK GPS surveying (Seeber). True RTK GPS surveying required an automatic solution for the missing cycles to be determined in real time. This allowed true “on-the-fly” positioning (Seeber).

Receivers repaired cycle slips in real time by using the following methods. First, receivers must track and have continuous lock on five or more satellites to determine a positional solution and to provide the redundancy in satellite signal data. The receiver employed the redundant satellite signal data to reconstruct the missing number of carrier cycles after the receiver reestablished connection (Seeber, 2003). Second, the receiver must be a dual-frequency receiver that acquired signal data from the L1 and L2 carrier waves. Third, if a low-noise code receiver was used, it could combine the code and carrier beat phase data and compare the “unambiguous code result” to phase measurements and immediately removed the cycle slips (Seeber).

Receivers that had the ability to keep better lock on satellites were less prone to cycle slips (Seeber, 2003). However, when cycle slips occurred and the number of tracked satellites was less than five, there are methods used in kinematic GPS that could force ambiguity
solutions. First, the roving receiver could be reinitialized to resolve the phase ambiguity. Receivers might use sophisticated algorithms to solve a new integer ambiguity “on-the-fly” after the loss of lock. “For each cycle slip, a new ambiguity parameter is simply introduced into the adjustment” (Seeber, p. 281). Dual frequency receivers that tracked the L1 and L2 carrier waves determined a new integer ambiguity by analyzing the ionospheric residuals and using them with Kalman filtering to determine and repair the gap in cycles.

Interference, diffraction, and foliage attenuation also affected and degraded the incoming GPS signals. Interference was produced by nearby radio frequencies located within close proximity to the GPS antenna. Radio frequencies affected the receiver’s ability to track the L2 signal more than the L1 signal (Seeber, 2003). Interference affected the GPS signals in several ways. First, it decreased the SNR ratios that increased the susceptibility of the antenna to multipath. Interference also disrupted the receiver’s ability to acquire and track the GPS signal. Strong interference caused cycle slips. The sources of interfering radio frequencies included VHF, UHF, and TV transmitters. Interference was also produced by amateur radio transmissions that broadcasted at a frequency close to the L2 frequency. Aviation radar installations created interference with the incoming signal. Weak satellite signals broadcasted from satellites low on the receiver’s horizon were more prone to the effects from interference. The effects of high voltage power cables were insignificant. To help minimize the effects of interference, GPS receiver should be set at least 10 meters away from electrical transmitters (Seeber).

Diffraction produced a problem in kinematic GPS positioning (Seeber, 2003). It occurred when the path of a direct satellite signal was blocked from the receiver while reflected signals were not also blocked. Diffraction errors occurred when the GPS receiver tracked the indirect signal instead of the direct signal. The diffracted signal produced a carrier phase error from
several centimeters to decimeters because it traveled a longer path to the receiver. Diffracted signals could be detected by inspection of SNRs (Seeber).

The vegetation and trees in an area degraded the satellite signal. This effect was called foliage attenuation and influenced both base and rover receivers (Seeber, 2003). The magnitude of this error was varied by the type of vegetation and the receiver’s ability to track the satellite signal.

The GLONASS navigation codes are also broadcasted on the L1 and L2 frequency bands and were subject to the same error bias as GPS (Seeber, 2003). These errors were resolved with data processing (Seeber). Receivers that tracked both the GPS and GLONASS navigation codes also corrected for the difference between the two geodetic datums and time base used as a reference in each navigation system. Receiver measurements were not affected by selective availability (SA); SA was deactivated for GPS on May 2, 2000 (Seeber). Furthermore, anti-spoofing (AS) did not affect GLONASS (Hofmann-Wellenhof et al., 2001).

Kinematic and RTK Positioning Techniques

Kinematic surveying, a method of GPS positioning that land surveyors used, determined the locations of features in an urban environment. This method of surveying involved one moving receiver that occupied different points of interest for short observation times (Sickle, 1996). The observation time can be varied from a few seconds to several minutes (Anderson & Mikhail, 1998). The rapid succession of point-to-point observations allowed kinematic surveying methods to be a productive land surveying technique.

Several different methods implemented kinematic surveying. One kinematic application, called rapid static technique, required at least two receivers, a base station and a roving receiver.
(Sickle, 1996). The base station receiver served as a reference marker for the roving receiver. The base station was usually placed over a known reference marker, while the roving receiver moved in succession over different points of interest. This stop-and-go technique was used in kinematic relative positioning (Hofmann-Wellenhof et al., 2001).

The locations of points determined by kinematic relative positioning methods were adjusted and corrected by post-processing the data after the observations were collected or in real time, while the observations were taking place (Anderson & Mikhail, 1998). If the point data were needed in real time, a radio link, set up at the base station, broadcasted the satellite signal data to the roving receiver. This technique of kinematic relative positioning was called real-time kinematic positioning (RTK GPS) (Hofmann-Wellenhof et al., 2001). RTK GPS was an accurate method for determining the position of a point of interest with short observation times (Seeber, 2003).

In Seeber’s (2003) work, *Satellite Geodesy*, he referred to RTK surveying as carrier-phase differential GPS. Anderson and Mikhail (1998) called the process code-phase differential GPS. Code-phase differential GPS used both the pseudorange data and carrier phase data to provide the solutions for measurements to determine a point’s position. Overall, this was the best method used to gather the most precise data for RTK positioning techniques (Hofmann-Wellenhof et al., 2001). Code-phase differential GPS provided solutions with reliable measurements with centimeter levels of accuracies for each point within several kilometers of distance (Seeber). However, the use of proper equipment and procedures for observing satellites was required in order to provide these accurate measurements.

As mentioned above, carrier-phase differential GPS used both the pseudorange and carrier phase data to determine coordinates of a point. Typically, the dual frequency receivers
using both the precise code and coarse acquisition code without carrier phase data worked for navigation purposes (Seeber, 2003). “Generally speaking, the accuracy of code ranges is at the meter level, whereas the accuracy of carrier phases is in the millimeter range” (Hofmann-Wellenhof, et al., 2001, p. 133). The accuracy of pseudorange was improved by using narrow code correlators or by implementing smoothing techniques for epochs of data (Hofmann-Wellenhof et al.). A precise measurement for kinematic positioning usually “implies the use of carrier phase data as the basic observable” (Seeber, p. 290). Either single frequency or dual-frequency receivers were employed in carrier-phase differential positioning techniques (Seeber, p. 336). The dual frequency receivers that tracked both the L1 and L2 carrier waves provided a quicker and more reliable solution to the ambiguity resolution for the carrier phase (Seeber). These receivers offered features that were typically used by geodetic receivers (Strang & Borre, 1997).

**RTK Receivers**

One main characteristic of RTK positioning techniques was the use of “highly integrated instrumentation” to achieve centimeter levels of accuracy for short distances (Seeber, 2003). The receivers used for RTK positioning had to possess the sophisticated technology and software capable of providing real-time corrected solutions for the location of each point in a survey. The base station had to be capable of transmitting pseudorange and carrier phase data to a roving receiver that could provide the real-time corrections required for the incoming satellite signals while in motion (Seeber). The real-time solutions for the ambiguity resolution at the roving station are performed “on-the-fly” (OTF). The most sophisticated receivers had the software capability to perform OTF ambiguity resolutions for the carrier phase at the base station without
the process of initialization (Anderson & Mikhail, 1998). This was the most advanced form of kinematic positioning that could be used with RTK techniques (Hofmann-Wellenhof et al., 2001).

As mentioned previously, both single and dual frequency receivers could be used in RTK positioning, but receivers with dual frequency capabilities resolved the carrier phase’s integer ambiguity resolution faster than single frequency receivers (Seeber, 2003). The dual frequency receiver also eliminated the “ionospheric refraction by the ionosphere-free combination of the two carrier phases” (Hofmann-Wellenhof et al., 2001, p. 145). These receivers were designed to have a fast data sampling rate and large amounts of storage in order to increase the ability to detect and repair cycle slips during kinematic surveying (Hofmann-Wellenhof et al.). RTK receivers also required enough channels in order to track multiple satellite signals (Sickle, 1996). Channels in the receiver are used to separate the multiple incoming satellite signals’ radio frequencies that are collected by the receiver’s antenna (Sickle). Each separate channel sorts a particular satellite signal. A minimum of four channels was necessary to provide redundant satellite data (Hofmann-Wellenhof et al.). Twelve channels were typical; however, a receiver can have up to 40 channels (Sickle).

**RTK Positioning Missions**

Satellite observation missions were generally conducted in three phases: planning, observing, and post-mission processing (Sickle, 1996). Planning a satellite observation mission was carried out with pre-mission planning, required in order to allow the observations to take place smoothly and to avoid costly mistakes (Sickle). The first step in pre-mission planning determined what accuracy standards and specifications were required for the survey (Anderson
& Mikhail, 1998). The accuracy standards were established by the Federal Geographic Data Committee (FGDC) and classified as first, second, and third order and are required by the Tennessee Statures for GPS land surveys (Standards of Practice, 0820-2-.07, 1999).

The second step determined what reference system and reference markers would be needed for the survey (Sickle, 1996). The reference system defined how the coordinates were determined for the reference markers and varied between differing systems (Seeber, 2003). A conversion of data could be required, depending on the uses for the observation data. Reference markers “should be of a higher-order survey than the one being performed” (Anderson & Mikhail, 1998, p. 731). The location of the reference markers should also be evaluated to provide adequate horizontal and vertical control for the proposed observations (Sickle). The reference markers should be near the proposed project and contain the features that need to be located at the site. Ideally, the reference markers should fall at the corners of the project and contain an internal reference marker. The accessibility to these reference markers should also be considered since many may be placed in areas that are difficult to reach (Sickle). These reference markers could be located in a variety of locations that may be far from roads, under trees, on private property, or on mountains and building tops (Sickle).

The third step in pre-mission planning determined when good observation windows were available for the day (Sickle, 1996). Observation windows were times in the day that offered maximum satellite coverage with good satellite geometry (Hofmann-Wellenhof et al., 2001). These are the times of day that provided the low PDOP values needed for accurate satellite observations. Accompanying features for observation windows were sky (polar) plots and obstruction surveys (Anderson & Mikhail, 1998). Sky plots were performed for known points where observations would take place, such as reference markers. The sky plot showed the
courses of the orbiting satellites as they tracked across the horizon above the receiver (Sickle). The azimuths and elevation of each satellite were displayed on a 360 degree plot with accompanying zenith positions. The obstruction survey could be conducted with a magnetic compass and either a clinometer or theodolite (Anderson & Mikhail). This equipment sketched out the obstructions that surrounded the reference marker. The obstructions are topographical features that might block the incoming satellite signal and create potential cycle slips. These obstructions were then overlaid on the sky plot and aided in determining optimal observation widows for known reference markers. Site reconnaissance determined if the site for the proposed survey was adequate for satellite positioning (Sickle). The site should have a clear line of site and be free from obstructions 15 to 20 degrees above the horizon. The site should also be free from potential sources of multipath.

The final step for pre-mission planning included understanding the proper satellite positioning procedures and having knowledge of the equipment. Surveying procedures were varied and depended on the capability of the receivers and the purpose for the survey. The users of the receivers had to know the principles for static and kinematic positioning techniques and the capabilities of their receivers in order to execute an observation mission properly (Sickle, 1996). This was necessary in order to achieve the intended accuracy for the positions of the points located in the survey (Sickle). After the steps for the pre-mission planning were completed and the receivers were charged and gathered, the user was ready to perform the observation mission.

Once the pre-mission planning was completed, the observation mission was ready to take place. The carrier phase data served as the main observable in code-phase differential positioning because it yielded higher positional accuracy than the code pseudorange measurements (Seeber,
2003). When carrier phase differential techniques were used in RTK relative positioning techniques, both receivers continuously tracked five common satellites (Hofmann-Wellenhof et al., 2001). In addition, this method required the user to set up the base station over a known reference marker and to initialize the receiver before performing the RTK survey (Hofmann-Wellenhof et al.).

Initialization was the process of resolving the integer ambiguities of the carrier phase before beginning the survey (Hofmann-Wellenhof et al., 2001). The carrier phase integer ambiguity was usually resolved after several epochs and could take as little as 1 or 2 minutes for receivers with dual frequency capabilities (Hofmann-Wellenhof et al.). During initialization, the receiver determined the reference marker’s millimeter position in a few seconds (Sickle, 1996). However, determining the unknown distance in meters takes more time. Once the base station was initialized and the carrier phase integer ambiguity resolution was performed, the base station was ready to transmit the incoming satellite signal data to the roving receiver in real time (Seeber, 2003).

The carrier phase integer ambiguities at the roving receiver were determined in real time by performing OTF solutions (Seeber, 2003). OTF “ambiguity resolution is the relative surveying technique that permits very rapid estimation of the integer ambiguities” in kinematic positioning (Anderson & Mikhail, 1998, p. 718). If the receiver did not have OTF capabilities and the receiver lost its lock on the incoming signal, the roving receiver had to re-initialize over a known reference point to resolve the ambiguity resolution (Sickle, 1996). The roving receiver would also need to be re-initialized if the number of observed satellites dropped below four, the problem created by cycle slips (Seeber).
After initialization, the roving receiver was moved momentarily over each point for 2 minutes or less in successive observations to determine each point’s coordinate position for the survey (Sickle, 1996). Ideally, each point had been located when conditions for the survey were favorable. These favorable conditions generally required “continuous reception from five satellites by both base and rover” receiver, low SNRs, no multipath, and low PDOP (Anderson & Mikhail, 1998, p. 957; Hofmann-Wellenhof et al., 2001). When these conditions were present, the roving receiver accurately determined a point’s location with one epoch of data (Seeber, 2003). When the conditions were not favorable, more epochs were needed to determine a reliable integer ambiguity solution (Hofmann-Wellenhof et al.). An observation could also last for several epochs to give the receiver more time to average the data for accurate results (Hofmann-Wellenhof et al.).

Post-processing GPS-GLONASS positioning data included procedures that used the computerized operations and algorithms that corrected the satellite data for their inherent biases to determine the true range measurements between the satellites and receivers (Sickle, 1996). However, in RTK surveys, the simultaneous observations of both the base and roving receivers were combined and processed in real time (Hofmann-Wellenhof et al., 2001). The roving receiver completed this process with internal software. The algorithms the software used were dependent on the manufactures and varied among different types of receivers and their intended uses (Seeber, 2003). These algorithms generally doubled differencing solutions provided by relative positioning techniques with ambiguity fixing techniques (Leick, 2004). Generally, post-processing RTK data included creating a data file, downloading point data, and blunder detection (Hofmann-Wellenhof et al.).
Some models of modern receivers offered the technology and software necessary to track both GPS and GLONASS satellite signals. These receivers also had the ability and channels to track and process both GPS and GLONASS carrier phase data. This allowed GPS measurements to be augmented by the signals broadcasted by the GLONASS constellation. With both complete constellations, 12 to 16 satellites would be available for simultaneous coverage from any location on the earth (Seeber, 2003). These constellations could be used in code-phase relative positioning methods. Dual frequency receivers also had the capability to track both navigation system’s navigation codes and signal frequencies (Seeber). These receivers also have the ability to correct for bias in the GLONASS signals and navigation codes (Seeber). The method to correct the bias in GLONASS signals was similar to the methods used in GPS (Seeber). The receivers also corrected for the different geodetic datum and system times used by each navigation system (Habrich, Curtner, & Rotbacher, 1999). In turn, these signals and navigation codes could supplement GPS to determine coordinates for a point. The extra signal assisted with the receiver’s ability to determine better positional accuracy and improved the integrity of the measurement (Lechner & Baumann, 2000). In addition, using GLONASS provided new methods for detecting and repairing cycle slip (Lechner & Baumann). However, at least two GLONASS satellites had to be tracked in order to correct for the difference in GPS and GLONASS time (Seeber). This correction had to be made in order for GLONASS to contribute in GPS positioning solutions.
CHAPTER 3

METHODS AND PROCEDURES

**Background**

This project collected two sets of coordinate and elevation data for a course that consisted of 14 points. One set of coordinates was determined with conventional land surveying methods and the second set was determined with RTK land surveying methods using both GPS and GLONASS satellites. Originally, three data sets of coordinate values were planned for this study. The three data sets would have included, conventional land surveying coordinates, GPS coordinates, and GPS-GLONASS coordinates. The study planned to use the conventional land surveying coordinate set as a control group, and then compared the results from the GPS and GPS-GLONASS data sets. However, there were not enough GLONASS satellites available in the receiver’s horizon over several points during the RTK survey to make any significant contribution from a GPS-GLONASS solution. A decision was made to reject the GPS data set and to solely use GPS-GLONASS satellite data and just note which points had the GLONASS satellites and which did not.

Two static GPS surveys were also performed to supplement the conventional land survey and RTK GPS-GLONASS land survey. The first static survey was performed to collect cycle slip information for the incoming GPS satellite signals; the static receivers lacked the capability to track satellites in the GLONASS constellation. This data accompanied the sky plot surveys to determine which incoming satellite signals were blocked by the obstructions surrounding the roving receiver during the successive observations for each station. The second static GPS survey was conducted to provide additional positional information for stations A, B, and C.
This information was used for further comparison between the conventional land survey, and the RTK GPS-GLONASS land survey.

A code-phase differential GPS-GLONASS mission using RTK relative positioning techniques was chosen for the kinematic survey because this technique is used by land surveyors to provide the most accurate GPS surveys in real time (Anderson & Mikhail, 1998). Surveyors use RTK GPS to perform construction layout and topographical surveys (Anderson & Mikhail). The conventional survey was performed as a control group due to its nature of being immune to multipath and cycle slip errors, while the RTK survey is not. The conventional surveying equipment was the chosen represented equipment because it was commonly used in construction layout and topographical surveys. A closed loop traverse was performed using conventional surveying techniques. The RTK GPS-GLONASS survey was then performed to gather positional data on fourteen points that were located by the conventional survey.

Fourteen points were established to create a course that could be located by each of the surveying methods listed above. Some points were placed in areas where reflective surfaces and obstructions were expected to interfere with the GPS and GLONASS signals. According to Leick (2004), reflective surfaces included features such as the ground, buildings, trees, hills, and rooftops all contribute to multipath. Seeber (2003) said that physical obstructions to weak satellite signals were a common cause of cycle slips in a kinematic survey, such as tree canopy, tree trunks, and buildings that block the satellite signals and created cycle slips. The assumptions were that these features would degrade or entirely block the satellite signals and yield an inaccurate measurement. Typically, errors are mitigated in static and kinematic GPS with post processing techniques. However, the RTK receiver adjusted and corrected data in real time without post processing procedures.
The two data sets of coordinates and elevations for the fourteen field stations were used for comparison. Each GPS-GLONASS point’s coordinate and elevation data was compared to the point’s data determined by the conventional land survey to help identify inaccurate GPS-GLONASS measurements. If the GPS-GLONASS point’s position varied from the coordinate data established by the conventional land survey, the point was determined to be an inaccurate measurement. Then, the point was further evaluated to identify if it was affected by multipath and cycle slips. The environment around each point was evaluated to determine if multipath was a potential source of bias in the GPS-GLONASS measurement. If the localized features around the point were known potential sources of multipath, then it was decided that multipath affected the incoming satellite signal. Cycle slips were detected by evaluating carrier waves that were collected from each satellite in a static GPS survey. If the incoming satellite signals showed sources of cycle slips, it was then determined that cycle slips affected the solution of the integer ambiguity and created a biased positional solution. Each network of control points were also individually compared to the accuracy standards for a survey performed in an urban environment. These accuracy standards are provided by the Tennessee Statures and Federal Geodetic Control Committee (FGCC) and are also discussed later in this chapter.

The equipment used in the conventional and RTK land survey was provided by ETSU. ETSU has both conventional and RTK surveying equipment that is comparable to equipment used by practicing surveyors in the land surveying profession. This conventional equipment included a total station, electronic data recorder, and retrodirective prisms with supporting tripods and tribrachs. The RTK equipment included a base and roving receivers with antenna mounts. The base station was mounted on top of a fixed two-meter tripod, while the roving
receiver was mounted onto a two-meter graphite rod with supporting bipod. Both the conventional and RTK equipment is discussed in more detail later in this chapter.

Fourteen Point Course

A course consisting of 14 points was established along the southern perimeter of East Tennessee State University’s (ETSU) campus and was shown in Appendix E. This course ran along J.L. Seehorn, Jr. Road and the Clinchfield Railroad. The predominant local site features along the J.L. Seehorn, Jr. Road included three story buildings, a concrete sidewalk, grassy yards, an asphalt road, asphalt parking, overhead power and telephone lines, utility power poles, and large mature trees. The sky’s horizon along J.L. Seehorn, Jr. Rd. for this section of campus was open and not constricted by any forested tree canopy. This area was referred to as section one for the study. The principal site feature along and south of the Clinchfield Railroad included forest turf, a chain link fence, a forested area, tree canopy, and large mature trees. This area also had a major topographical feature in the form of a hill that was approximately 40 feet high. This area was called section two. This contrast of physical site features provided two distinguished characteristics for the course situated in this location. Section one had more urban features and an open sky horizon; Section two was forested with tree canopy that obstructed the overhead horizon. Multipath and cycle slips were expected in both sections; however, multipath should be greater in the section one while cycle slips should be the predominant error in section two.

These points were placed throughout the area to establish the field points and traverse stations for use in the course and were identified by the first 14 letters of the alphabet. The points were set to be inter-visible for the conventional land survey. Six of the points fell in section one under open sky. These were points A, B, C, L, M, and N. Four of these points,
points A, B, C and N, were in areas with little physical obstructions. These points should have
been only be affected by multipath. Point L and M were located under residential power lines
and telephone lines. These points might have had electrical interference that may have cause a
cycle slip in addition to multipath. One point, C, was placed to be the furthest from the base
station. Points L, M, and N were also placed close to the base station receiver and had a clear
horizon. These points were relatively unobstructed by large trees, buildings, or hills. The radio
transmission from the base station receiver also had a clear line of sight to the roving receiver.
Eight of the points fell in the Section 2 in the forested area. These points are D, E, F, G, H, I, J,
and K. Two of these points, H and I, were placed near the summit of the hill while the rest of
these points fell along the toe of the hill. The hill obstructed a significant part of the horizon for
points D and K. Point D’s horizon was block up to 50 degrees in the zenith between north
azimuth 120 degrees and north azimuth 230 of its horizon. The horizon for point K was
obstructed up 30 degrees in the zenith between north 190 degrees and north 250 degrees of its
horizon. This hill obstructed at least 20 degrees for part of the horizon for the remainder of these
points. In addition to the hill, a large tree was located by point K. Point F was placed near a
chain link fence, which was a known source of multipath (Hofmann-Wellenhof et al., 2001).
The remaining points were located in areas and were surrounded by trees and heavy tree
canopies.

Sky Plot and Obstruction Survey

A sky plot for an obstruction survey described in Chapter 2 for each point was performed.
Obstruction surveys were performed to identify the physical obstacles and satellite visibility
around each point (Anderson & Mikhail, 1998). All obstruction surveys were used to assist in
determining which points were most likely to be affected by cycle slips. The obstruction survey showed that points D-K had an obstructed horizon and were all expected to have multiple cycle. Points A, B, C, L, M, and N each had an open horizon.

The location of each physical obstruction was determined by a magnetic compass, clinometer, and theodolite. The magnetic compass was used to orientate the theodolite to magnetic north. The theodolite was then used to orient each obstruction in the sky plot’s horizontal plane. The clinometer and theodolite were both used to determine the altitude or zenith angular obstruction. Each obstruction or tree cluster with a width two arc degrees and larger was then sketched onto the sky plot. General comments on the thickness of the overhead tree canopy in the forested section of the course were then included in the obstruction survey.

**ETSU Geodetic Control Network**

The ETSU Geodetic Control Network was used as a reference system for the coordinates determined in the conventional and GPS-GLONASS land survey. This reference system used the Tennessee 83 State Plane Coordinate system for horizontal control and the North American Vertical Datum 1989 (NAVD 1989) for vertical control. The unit of distance measurements for these systems was given in meters. As suggested by Maune, (1996), a new GPS survey should be referenced to at least three control stations. Sickle (1996) suggests that a new GPS survey should include a minimum of four control station when elevations are involved in the survey. This GPS-GLONASS survey was referenced to four existing control stations within the ETSU Geodetic Control Network. These stations were Lewis, Andrews, and Ottinger, and Williams.
Conventional Land Survey

A conventional land survey was performed to create a horizontal and vertical control network with coordinate and elevation data that were used as a basis of comparison of data for the GPS coordinates. Each point was included in a closed traverse loop by conventional surveying equipment. A closed loop traverse consists of a traverse that closes on itself and has the shape of a multisided polygon. The angles and distances measured in the traverse were reduced to rectangular coordinates that are represented in northings (Y) and eastings (X) (Wirshing, 1985). A closed traverse allowed different geometric and arithmetic checks and provided an indicator on the quality of the traverse data. The closed traverse also allowed errors in the measured angles and distances to be adjusted and corrected through post-processing techniques. Post-processing could include a least squares or compass rule adjustment to correct the coordinate values at each point. One geometric check included determining the traverse’s total angular misclosure by summing up each interior angle and comparing it to the sum of a mathematically closed polygon. An arithmetic check was used to determine the total error in the northing and easting directions. This total error was used to calculate the ratio of misclosure or the relative accuracy ratio for the traverse. This ratio of misclosure was the ratio between the total error and the total length of the survey. If blunders or gross systematic errors were present in the angle and distance measurements, the error ratio will be large (Anderson & Mikhail, 1998, p. 409). This ratio was used to classify the traverse to different relative accuracy ratios provided by accuracy specifications that were established by state and federal regulatory legislations. For example, the Tennessee Statutes for Category I land surveys required that an unadjusted closed traverse have a positional closure to be at least 1:10,000 for linear errors. The equipment,
accuracy standard, field procedure, and results for this survey were described in the following sections.

**Conventional Surveying Equipment**

The conventional land survey was performed with a total station and supplemental traverse equipment. A TOPCON© GTS 311 total station was used to measure the angles, distances, and elevations for the study. This instrument had the ability to measure angles within two seconds of arc. A Tripod Data Systems (TDS) Recon© data collector was used to electronically record and store the angular and distance measurements. This data collector was a handheld computer that contained software specifically designed for land surveying uses. Both the TOPCON© GTS 311 and TDS Recon© were instruments commonly used by land surveyors to perform conventional land surveys. Supplemental equipment included two retrodirective prisms, three tripods, tribrachs, and tribrach adapters. This equipment was not typically used to locate topographical features for a land survey. Instead, it was used to assist in accurately locating traverse control points in a three-dimensional traverse when repeated angle measurements and double centering methods were planned for locating control points in a traverse (Anderson & Mikhail, 1998). The retrodirective prisms were used to reflect the total station’s intensity-modulated light beam back to its electronic distance measurement (EDM) equipment. The tripods provided a stable surface for the retrodirective prisms and assisted in centering them over the control point. The tribrachs and tribrach adapters were used to mount the retrodirective prisms on the tripod.
Accuracy Standards for the Conventional Survey

The horizontal control element for the conventional land survey was designed to meet the criteria for the Tennessee Statutes for Category I land surveys. This standard stated that linear error for the unadjusted closed traverse loop was not to exceed 1 foot per 10,000 feet. This category was used for Urban and Subdivision areas (0820-3-.05 Accuracy of Surveys). This standard is also the same as the accuracy specifications for a third-order class I survey established in the Specifications to Support Classification, Standards of Accuracy, and General Specifications of Geodetic Control Surveys (FGCC, 1975). This standard was for local horizontal control in moderate and low land value areas. The field procedure and methods used to meet the accuracy requirements of this standard was described in the following section.

Conventional Land Survey Field Procedure

In order to achieve horizontal coordinates and elevations for each station, a three-dimensional closed loop traverse was measured for the study. This allowed a geometric check for the horizontal angles measured between each control station and also evaluated the accuracy for the coordinate data with a ratio of misclosure (Anderson & Mikhail, 1998). The ratio of misclosure was required to be at least 1:10,000 for the data set determined by the conventional land survey. All but one point was included within the closed loop during the traverse. Point C was located with a side shot. Side shots were made to control stations Lewis, Andrews, and Ottinger and to establish geodetic control coordinates. All side shots were adjusted to the traverse data.

The total station was used to measure horizontal angles, zenith angles, and distances between each pair of points. Direct and reverse measurements for doubled angles were
performed at each station. Any doubled angle that exceeded 10 arc seconds was rejected and a new measurement was taken. Measuring direct and reversed angles allowed a check for any blunder in the angular measurements and cancelled systematic instrumental errors. Doubling angles also increased the precision of the angular measure (Anderson & Mikhail, 1998).

The Recon data collector was used to electronically record and store the raw and coordinate point data. The height of instrument was measured and recorded for each instrument set up, and the height of prism was measured and recorded for each backsight and foresight. A retrodistance prism was set up on the tripods and centered over each point. After the data were collected, they were then downloaded and processed for errors. The final adjusted coordinates are displayed as northing and eastings and were translated and rotated to the Tennessee State Plane Coordinate System 1983. The elevation data were referenced to NAD83. The misclosure data for the closed traverse were shown in Table 1. The compass rule was used to adjust the misclosure for the closed traverse. The unadjusted closure was 1:18,712 and met the Tennessee Statutes for Category I land surveys.

Table 1

*Conventional Land Survey Closed Traverse Misclosure Data*

<table>
<thead>
<tr>
<th></th>
<th>Unadjusted</th>
<th>Adjusted</th>
</tr>
</thead>
<tbody>
<tr>
<td>Misclosure error distance</td>
<td>0.075 m</td>
<td>0.000 m</td>
</tr>
<tr>
<td>Precision</td>
<td>1:18,712</td>
<td>Perfect</td>
</tr>
</tbody>
</table>
GPS-GLONASS Land Survey

A GPS-GLONASS RTK topographic survey was performed to create a horizontal and vertical network that had measurements for control stations whose accuracies were expected to be degraded by multipath and cycle slip bias. As mentioned above, this data set was compared to the conventional survey network to determine which points were influenced by multipath and cycle slips.

The RTK GPS-GLONASS mission was performed using code-phase differential techniques. This was a relative positioning method that uses a dual frequency receiver to track the coarse acquisition and precise code along with carrier phase in order to determine each of the 14 point’s positional solution. This included the use of a base station, situated over a known reference station that transmitted the incoming satellite data to a roving receiver in real time. The roving receiver was used to locate each point in the course. The horizontal and vertical solutions for each point are shown below. The equipment, accuracy standard, and field methods are discussed in the following sections.

GPS-GLONASS Equipment

A TOPCON© HiPer Lite Plus was used to perform the RTK GPS-GLONASS topographic survey. This system included two dual frequency receivers and allowed relative
positioning using both a base receiver and a roving receiver. This equipment was capable of RTK performance and tracked L1 and L2 signals from both GPS and GLONASS satellites. The receivers also tracked carrier phase data from both satellite constellations. The receivers had enough channels to separate the incoming satellite signals from both constellations. The base station used a 915 MHz spread spectrum radio to transmit data to the roving receiver up to one and a half miles away. It used Bluetooth® wireless technology instead of cable connections. This system can achieve RTK horizontal accuracies of 10mm + 1.0ppm and vertical accuracies of 15mm +1ppm. This receiver can be upgraded to track the GALILEO satellites when this navigation system was operational (Hayes Instrument, 2007). Additional equipment included the antenna mounts for the base station and roving receivers.

**Accuracy Standards for the GPS-GLONASS Survey**

The accuracy of the points determined by the RTK GPS-GLONASS land survey was compared to the classification standards listed in the FGCC Geometric and Geodetic Accuracy Standards and Specifications for Using GPS Relative Positioning Techniques, as required by Tennesse Statute 0820-2-.07. The FGCC specified “Six “orders” of geometric relative positioning (Federal Geodetic Control Committee [FDCC], 1989, p. 5). This GPS-GLONASS control network was designed to meet the Order C 3 line-length dependent error of 1:10,000 (FGCC, p. 5).

The PDOP values for each measurement were also monitored and recorded to determine the quality of the incoming satellite based on the overhead satellite geometry. Fifteen epochs of data were collected at each point to allow extra observation time to determine its position. “An epoch is a short period of the observation time from each satellite and contains enough
information to solve the location of a point” (Sickle, 1996, p. 47). “Two epochs were necessary to overcome any biases” in the code measurement (Nave, 1999, p. 34). Under favorable conditions, one epoch of data was needed for the roving receiver to accurately determine a point’s location (Seeber, 2003, p. 337).

**GPS-GLONASS Field Procedure**

The GPS-GLONASS mission followed the procedures and methods outlined above in Chapter 2. Pre-mission planning, an observation, and post-survey mission computations were conducted. The pre-mission planning began by determining when a good observation window was available for the RTK survey. Unfortunately, almanac data for the GLONASS satellites were unavailable, due to the restriction of available equipment at ETSU. ETSU’s Surveying and Mapping Science program did not have the available RHINEX software to transfer the GLONASS almanac from the TOPCON receivers into the Trimble software. In addition, the Trimble Geomatics Office software did not work directly with the TOPCON© HiPer Lite Plus receivers. As a result, the pre-planning observation window was restricted to the availability of good satellite geometry and position for the GPS constellation and the availability of the GLONASS satellites remained unknown.

A Trimble single frequency static receiver was used to collect the GPS satellite almanac data at the course’s approximate latitude and longitude position. These data were downloaded into Trimble Geomatics Office software and then analyzed to determine what time of day provided the best opportunity for the GPS satellites and good geometry to perform the RTK survey. At least five available satellites were needed and PDOP values less than four were desired. PDOP values of four or less were chosen because these numbers represented satellites
that were spread out across the receiver’s horizon in a good position for the survey (Strang & Borre, 1997). The proposed day for the RTK survey was October 23, 2006. PDOP values that were four and better were possible during the entire day except at 3:00 PM. The PDOP values increased to six for an hour at this time in the day due to a drop in the existing satellite coverage. A good observation window was determined to be available during the entire day except at 3:00 PM.

The four reference markers chosen for the RTK survey were Lewis, Andrews, Ottinger, and Williams. These control stations were close to the course, but did not encompass the 14 points. Their relative distances were comparable to the length of the course. These points were very accessible and free from any overhead and surrounding obstructions. The reference stations were also part of a precise campus geodetic control network, which met Second Order Class I conventional standards. The accuracy standards used for the RTK survey were selected to meet the conventional second order class II 1:10,000 standard.

The observation mission began by preparing the roving receiver for the survey and establishing its parameters for the RTK survey of the 14 points in the course. The first parameter established was restricting the observed satellites to a 15 degree mask angle. The other parameters included setting up the receiver parity, height of antennas, baud rates, and epoch counts. As mentioned above, one epoch contained enough data for a receiver to determine a point’s location. Fifteen epochs were used in this survey to provide a redundancy of 14 additional epochs. Fixed solutions were also used whenever possible. However, float and fixed or float solutions were accepted when a fixed solution was unattainable. The receiver was set to track GLONASS satellites in order to incorporate the GLONASS data into the solutions for each point.
Once the parameters for the roving receiver were established for the survey, the base station receiver was then prepared for the survey. The base station receiver was placed near the course at an elevated position where the receiver had a good horizon. This location was also close to several stations in both sections one and two. This location was in the west parking lot of the First Tennessee Regional Health building. The base station collected signals from both GPS and GLONASS satellites and broadcasted a corrected positional signal to the roving receiver.

After the base station was set up in the parking lot, it was then initialized during a process called localization. Localization was the process used by TOPCON© HiPer Lite Plus system to establish the coordinate system and initialize the base station receiver. The base station for this survey was localized by referencing Lewis, Williams, and Ottinger.

The roving receiver was used throughout the course to collect GPS-GLONASS coordinate data for each point. The roving receiver was placed over each station and collected 15 epochs of data for each point. If a fixed solution was not determined, a float or fixed or float solution was accepted. Each point’s measurement was noted and recorded as being based on a fixed or float solution. The radio link between the base station and roving receiver was monitored throughout the survey in order to ensure that a radio link was established with each receiver. This transmission was a concern during the survey because the strength of signal might have decreased at some points due to the physical obstacles located in the vicinity of the course. These obstacles included large trees, the forest, buildings, and the hill. In addition to maintaining radio link, the total number of satellites in the horizon was recorded. The number of GPS and GLONASS satellites that contributed to the measurement was also recorded. The
PDOP values for the combined HDOP and VDOP were also individually recorded. This information was provided in Table 3.

The post-observation mission for the RTK survey included downloading the collected data into the drafting software for comparison and analysis with the conventional survey data. The comparisons and analysis of the GPS-GLONASS RTK survey data to the conventional survey data was then made and reported. This report was discussed in the Chapter 4 of this study.

**Static GPS Survey for Cycle Slip Data**

A static GPS survey mission was made to in addition to the RTK survey solely to collect cycle slip information. Six Trimble© 4600 single frequency receivers were used to observe the incoming satellite signals over each point. The static survey was performed during the same observation window at approximately the same time in order to collect incoming satellite signals from a GPS constellation that was similar to the constellation present at the time of the RTK survey. The Trimble© receiver successfully tracked and recorded signal data from the same number of satellites as were recorded during the RTK survey. For example, station B and C each tracked seven GPS satellites during both the RTK and static survey; stations E and G each tracked six satellites each during the RTK and static survey.

A 20 minute observation session was initially planned for each observation session. The observation times for the static survey at stations D, I, and M were 10 minutes or less due to a problem with the static receiver. The static receiver prematurely shut itself off early during the observation session for these stations. However, enough data were collected to determine if the incoming satellite signals for these stations contained cycle slips. This problem did not occur for
the other observation sessions and the static receivers collected at least 20 minutes of data at the remaining stations.

After these observation data were collected they were downloaded into Trimble Geomatics Office© to determine what satellites signals were affected by cycle slip data. Any individual signal that showed an occurrence of a loss of satellite lock between the receiver and satellite was noted. The incoming satellite signals for the points set up in the urban area were not affected by cycle slips. However, the incoming satellite signals for the points set up in the forested area had zero to severe cycle slips present in the observed satellite data. Table 2 showed the satellite signals that were affected by cycle slips for each station. This table was created from the information provided by the Trimble Geomatics Office© software. This software provided a graphical output that displayed the number of tracked satellites, their corresponding space vehicle number, the satellite signal, and length of time the signal was tracked. Cycle slips appeared as breaks in time in the displayed signal. The breaks in time began from the moment the signal was lost and lasted until it was reacquired.

Table 2

*Satellite Signals Affected and Unaffected by Cycle Slips*

<table>
<thead>
<tr>
<th>Station</th>
<th>Cycle slips</th>
<th>Affected satellite signals</th>
<th>Unaffected satellite signals</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>Yes</td>
<td>SV 11</td>
<td>SV 8</td>
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<td></td>
<td></td>
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<td>E</td>
<td>Yes</td>
<td>SV 19</td>
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<td>SV 28</td>
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</tr>
</tbody>
</table>
Results of the Conventional and GPS-GLONASS Surveys

Table 3 showed the results of the conventional traverse and RTK GPS-GLONASS topographical survey. Each station’s name and section the station was located in is provided. The northing, easting, and elevation that were determined by each surveying method formed the first three columns of the table. The differences between these coordinate values and elevations were listed in column three. Columns four and five listed what stations contained cycle slip and multipath errors. Columns six and seven tabulated how many GPS and GLONASS satellites were tracked and the corresponding PDOP values. This table noted whether the ambiguity resolution for each station’s RTK coordinates and elevations was based on a fixed or float solution in column six. Finally, the last column in the table described the local features that surrounded each point.
Table 3

*Results of Conventional Traverse and RTK GPS-GLONASS Survey*

<table>
<thead>
<tr>
<th>Station</th>
<th>Conventional surveying (meters)</th>
<th>RTK GPS surveying (meters)</th>
<th>Differences (meters)</th>
<th>Cycle slips</th>
<th>Multipath</th>
<th>Satellites present</th>
<th>PDOP</th>
<th>Fixed or float</th>
<th>Local point features</th>
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<tbody>
<tr>
<td>A</td>
<td></td>
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<td>N 224335.116</td>
<td>E 926152.608</td>
<td>E 531.390</td>
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<td>Building, road, sidewalk, grass</td>
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<td>Sec. 1</td>
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<td>E 533.126</td>
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</table>
Table 3 (continued)

<table>
<thead>
<tr>
<th>Station</th>
<th>Conventional surveying (meters)</th>
<th>RTK GPS surveying (meters)</th>
<th>Differences (meters)</th>
<th>Cycle slips</th>
<th>Multipath Satellites present</th>
<th>PDOP</th>
<th>Fixed or float</th>
<th>Local point features</th>
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<td>N 224377.223 E 926360.852 El 531.775</td>
<td>N 0.309</td>
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<td>Yes</td>
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<td>N 224304.023 E 926418.117 El 560.312</td>
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<td>3.6 Float</td>
<td>Forest, dense canopy, hill top</td>
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</tbody>
</table>
Table 3 (continued)

<table>
<thead>
<tr>
<th>Station</th>
<th>Conventional surveying (meters)</th>
<th>RTK GPS surveying (meters)</th>
<th>Differences (meters)</th>
<th>Cycle slips</th>
<th>Multipath</th>
<th>Satellites present</th>
<th>PDOP</th>
<th>Fixed or float</th>
<th>Local point features</th>
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<td>N 224422.960 E 926509.296 El 533.995</td>
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<td>Maybe</td>
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<td>N 224464.086 E 926482.671 El 529.420</td>
<td>N 0.124 E –0.015 El 0.151</td>
<td>No</td>
<td>Maybe</td>
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<td>2.1</td>
<td>Fixed</td>
<td>Grass, overhead power/telephone lines, building</td>
</tr>
<tr>
<td>N Sec. 1</td>
<td>N 224511.230 E 926421.465 El 524.716</td>
<td>N 224511.136 E 926421.440 El 524.482</td>
<td>N 0.094 E 0.025 El 0.234</td>
<td>No</td>
<td>Maybe</td>
<td>US: 7 RU: 0</td>
<td>2.1</td>
<td>Fixed</td>
<td>Road, parking lot, parked cars, building, sidewalk, grass</td>
</tr>
</tbody>
</table>
Table 3 (continued)

Legend

Sec.: Section  
N: Northing  
E: Easting  
El: Elevation  
US: GPS satellites  
RU: GLONASS satellites

Resurvey for Stations A, B, and C with Static GPS

An additional static GPS survey using the Trimble© 4600 single frequency receivers was performed on December 15, 2007. The purpose of this static GPS survey was to collect additional coordinate data for comparison for points A, B, and C of the course. These additional coordinates were used to assist in determining whether multipath was present in the RTK measurements for points A, B, and C or if a blunder existed in the conventional land survey at this location. Control station Lewis was used as a reference station to orientate this static survey. Four Trimble© 4600 single frequency receivers were used to simultaneously collect the satellite data. The static survey occurred during an observation window with PDOPs that were comparable to the RTK GPS survey. Each receiver collected a minimum of 30 minutes of satellite data from the L-1 signal frequency. This information was processed using the Trimble Geomatics Office© software. Table 4 presented the coordinate values for the conventional, RTK GPS, and static GPS surveys and listed the differences between these data sets.
Table 4

Results of the Static GPS Land Survey for Stations A, B, and C

<table>
<thead>
<tr>
<th>Station</th>
<th>Conventional surveying (meters)</th>
<th>RTK GPS surveying (meters)</th>
<th>Static GPS surveying (meters)</th>
<th>Difference b/n conv. and static (meters)</th>
<th>Difference b/n RTK and static (meters)</th>
<th>Difference b/n conv. and RTK (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>N 224335.116 E 926152.608 El 531.390</td>
<td>N 224334.465 E 926153.149 El 536.302</td>
<td>N 224334.976 E 926152.750 El 531.349</td>
<td>N 0.140 E –0.142 El 0.041</td>
<td>N –0.511 E 0.399 El –4.912</td>
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</tr>
<tr>
<td>B</td>
<td>N 224214.894 E 926036.121 El 533.126</td>
<td>N 224214.312 E 926036.612 El 538.132</td>
<td>N 224214.821 E 926036.213 El 533.183</td>
<td>N 0.073 E –0.092 El –0.057</td>
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<td>N –0.484 E 0.417 El –5.000</td>
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</table>

Legend

Conv.: Conventional Land Survey

Sec.: Section

N: Northing

E: Easting

El: Elevation
CHAPTER 4

DATA ANALYSIS AND CONCLUSION

Background

As described in Chapter 3, two techniques for land surveying were used to locate 14 points that were separated into two different sections in a course. The three-dimensional coordinate values were listed in Table 3 in Chapter 3. The two sections for this study contained two different topographical environments. Section one contained an urban area and while section two was forested. The analysis of data for this study began by comparing the differences in the three-dimensional positions for each station located in section one and two. These differences were analyzed to answer the two following questions:

Question 1: What are the differences in northings, eastings, and elevations for the urban environment?

Question 2: What are the differences in northings, eastings, and elevations for the forested environment?

A figure and accompanying table for the differences in coordinate values and elevations were created for each section to assist with analyzing and comparing the data. The figures provided a visual representation for the differences in each station. This assisted in identifying the different elements of each point that were close to the three-dimensional coordinate value for the conventional survey’s data set. The tables provided the numerical values for each station. Each station’s horizontal differences were displayed as northings and easting. The vertical differences were shown as elevations. Each difference was compared by determining which points were within 10 centimeters, a half a meter, a meter, a meter and a half, two meters, and
greater than two meters. The stations with the greatest and smallest differences in northing,
eastings, and elevations were noted. A fourth column was created to show the total horizontal
linear error between the northing and eastings for each point. The distance formula 
\[ (\Delta N^2) + (\Delta E^2) ]^{1/2} \]
was used to calculate the linear error between the differences of the northing and
 easting coordinates. The stations with the smallest linear error were determined to have the most
accurate and reliable horizontal positions of the RTK data set. The accuracies and inaccuracies
were based on the extent of these differences in the horizontal linear errors and vertical errors
were summarized in the concluding remarks for these two questions.

After determining points in each section that were accurate or inaccurate, the additional
data for each station were analyzed. The additional data included: the number of satellites
collected; whether multipath or cycle slips had an effect on the station’s accuracy; how many
satellites in each constellation were tracked; the observation’s PDOP value; and whether the
measurement was based on a fixed or float solution. This information was also placed in tabular
form to assist with analyzing how these different elements contributed to the accuracy of the
measurement at each point. These data were analyzed to answer the following questions:

- **Question 3:** What effect does GLONASS have on RTK in an urban environment?
- **Question 4:** What effect does GLONASS have on RTK in a forested environment?
- **Question 5:** What effect does multipath, cycle slips, PDOP, and fixed or float solutions
  have in an urban environment?
- **Question 6:** What effect does multipath, cycle slips, PDOP, and fixed or float solutions
  have in a forested environment?

Each question was answered by forming a conclusion that was based on the data analysis for
each section.
Question 1

*What are the differences in northings, eastings, and elevations for the urban environment?*

**Data Analysis**

Stations A, B, C, L, M, and N were in section one, the urban environment. This section contained three-story residential buildings, a concrete sidewalk, grass yards, an asphalt road, asphalt parking, and parked automobiles. These urban features were all commonly known to be potential sources of multipath (Seeber, 2003). The satellite signals may potentially reflect off the horizontal, vertical, and inclined surfaces of these features into the GPS receiver (Seeber). Occurrences of severe cycle slips were not an issue in section one because the obstruction surveys and static GPS land surveys that were performed showed that the stations in this area were free from overhead tree canopies and had an open horizon. Overhead residential power and telephone lines were also in the vicinity of these stations.

Figure 1 illustrated the differences in meters between the conventional land survey and the RTK land survey for each point’s northing, eastings, and elevations in section one (see Figure 1). The values for these differences were provided in Table 5 (see Table 5). The values in Figure 1 and Table 5 both demonstrated that stations A, B, and C each had the largest differences in positional locations for section one. The elevation differences for A, B, and C was over four and a half meters. The elevation differences for stations B and C each reached five meters. The northings for stations A, B, and C each were greater than half a meter. The difference in easting for point A also was greater than half a meter. Station B and C’s easting position was almost a half meter different from the conventional data set. B and C were one centimeter and five centimeters short of the half-meter mark. The environment around these
stations included rooftops, brick walls, concrete sidewalks, asphalt surfaces, parked automobiles, grass yards, and overhead utilities.

Stations L, M, and N each had the least horizontal linear errors and elevation differences in section one. The elevation difference for stations L, M, and N were all within 25 centimeters from their respective elevation in conventional data set. The differences in the northing positions for stations L, M, and N were all within half a meter. The northings for stations L and M were each less than 13 centimeters. Station N’s northing position was within 10 centimeters of its position in the conventional data set. The differences in eastings for these three points were all within 10 centimeters. The difference in station L’s easting position did not differ from its position in the conventional data set. The local features found predominately around these points included concrete sidewalks, asphalt surfaces, parked automobiles, grass yards, and overhead utilities.

Table 5

Section One: Tabulated Differences in Northings, Eastings and Elevations Between the Conventional and RTK Land Surveys

<table>
<thead>
<tr>
<th>Station</th>
<th>Northing (meters)</th>
<th>Easting (meters)</th>
<th>Elevation (meters)</th>
<th>Linear error (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.651</td>
<td>-0.541</td>
<td>-4.912</td>
<td>0.846</td>
</tr>
<tr>
<td>B</td>
<td>0.582</td>
<td>-0.491</td>
<td>-5.006</td>
<td>0.761</td>
</tr>
<tr>
<td>C</td>
<td>0.595</td>
<td>-0.451</td>
<td>-5.000</td>
<td>0.747</td>
</tr>
<tr>
<td>L</td>
<td>0.111</td>
<td>0.000</td>
<td>0.158</td>
<td>0.111</td>
</tr>
<tr>
<td>M</td>
<td>0.124</td>
<td>-0.015</td>
<td>0.151</td>
<td>0.125</td>
</tr>
<tr>
<td>N</td>
<td>0.094</td>
<td>0.025</td>
<td>0.234</td>
<td>0.097</td>
</tr>
</tbody>
</table>
Conclusion

As stated by Seeber (2003), RTK carrier-phase differential GPS methods provided reliable solutions for measurements with centimeter levels of accuracies under favorable conditions. Favorable conditions included: a clear horizon, no electromagnetic interference, no natural or man-made reflective surfaces, low signal-to-noise ratios, low PDOPS, the continuous tracking of five common satellites for the base and roving receivers (Anderson & Mikhail, 1998). Reliable positional solutions were apparent for stations L, M, and N. These three stations each had positional accuracies that were expected out of RTK GPS. The greatest horizontal linear error of these three stations was in station M, which had a linear error of 12.5 centimeters. Stations L and N each had linear errors of 11.1 and 9.7 centimeters respectively. The elevations for each of these stations were all less than 24 centimeters. Every station in section one had an
open horizon. Stations L and M were each located under residential overhead utilities. Points A, B, and C all had larger difference in their horizontal and vertical positions. The difference in elevations for stations A, B, and C were very large and averaged at almost five meters. The horizontal linear error for was greater than half a meter for each point. These stations were also located under open sky and had few physical obstructions surrounding the points. The contributions of multipath, cycle slips, poor PDOP, or float solutions in determining these reliable and unreliable positional solutions were analyzed and discussed in Question 5.

**Differences in Coordinates for Section Two**

**Question 2**

*What are the differences in northings, eastings, and elevations for the forested environment?*

**Data Analysis**

Points D, E, F, G, H, I, J, and K were in section two, the forested environment. This environment included forest turf, a chain link fence, a forested area, tree canopy, and large mature trees. The stations were also placed along the bottom and near the crest of a hill approximately forty feet high. Multiple cycle slips were expected in this section because these stations were situated on a hillside within the forested area, which may obstruct the incoming signal (Sickle, 1996). These cycle slips were revealed in the static GPS land survey that was performed and discussed in Chapter 3. The chain link fence was a concern because it was a known source of multipath (Hofmann-Wellenhof et al., 2001).

The northings, eastings and elevations for the RTK land survey each had varying levels of positional differences when compared to the conventional land survey and are shown in Table 6 and displayed in Figure 2. The difference in elevations was discussed first in range from the
least positional difference to the greatest. None of the elevations for this data set were within 10 centimeters of elevations in the conventional data set. Station H was the only point within half a meter of the coinciding positional values in the conventional data set. Station D was within a meter of its common position in the conventional data set. Stations I and J were within a meter and a half. Stations E and K were within two meters. Stations F and G were greater than two meters of their positions determined by the conventional land survey. Station F was also had the greatest error with a difference of nearly five meters.

The eastings were grouped together and discussed from the least differences to the greatest. The eastings for stations G, H, and I were each within 10 centimeters of the measurements performed in the conventional land survey. The eastings for stations F, E, and K were all within half a meter of the eastings in the conventional land survey. The eastings for stations D and J were both about half a meter different and were the only two stations in the data set that were positioned further east in the easting position.

Station D’s northing position was the only point within 10 centimeters of its position determined by the conventional survey. Stations F, G, H, and J were all within half a meter of the same locations determined by the traverse. Station I was within a meter and station K was within two meters of the positions determined by the traverse.
Table 6

Section Two: Tabulated Differences in Northings, Eastings and Elevations Between the Conventional and RTK Land Surveys

<table>
<thead>
<tr>
<th>Station</th>
<th>Northing (meters)</th>
<th>Easting (meters)</th>
<th>Elevation (meters)</th>
<th>Liner error (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>0.010</td>
<td>-0.510</td>
<td>0.740</td>
<td>0.510</td>
</tr>
<tr>
<td>E</td>
<td>-0.486</td>
<td>0.378</td>
<td>-1.894</td>
<td>0.616</td>
</tr>
<tr>
<td>F</td>
<td>0.216</td>
<td>0.381</td>
<td>-4.862</td>
<td>0.438</td>
</tr>
<tr>
<td>G</td>
<td>0.309</td>
<td>0.017</td>
<td>-2.129</td>
<td>0.309</td>
</tr>
<tr>
<td>H</td>
<td>0.104</td>
<td>0.010</td>
<td>0.266</td>
<td>0.104</td>
</tr>
<tr>
<td>I</td>
<td>-0.776</td>
<td>0.078</td>
<td>-1.210</td>
<td>0.780</td>
</tr>
<tr>
<td>J</td>
<td>0.268</td>
<td>-0.577</td>
<td>-1.131</td>
<td>0.636</td>
</tr>
<tr>
<td>K</td>
<td>1.980</td>
<td>0.194</td>
<td>-1.634</td>
<td>1.989</td>
</tr>
</tbody>
</table>

Figure 2. Section Two: Graphical Differences in Northings, Eastings and Elevations Between the Conventional and RTK Land Surveys.
Conclusion

Station H was the most accurate and reliable point in both horizontal and vertical planes for this data set. H’s horizontal location was within a centimeter for the easting and almost within 10 centimeters for the northing when compared to the conventional land survey. The horizontal linear error for point H was 10.4 centimeters and only slightly greater than the linear error for station N in section one. Station H’s linear error was also less than stations L and M. Similar to stations L, M, and N, the elevation was also the least accurate value for station H. The roving receiver achieved this solution within the forested environment, and under tree canopy. However, station H was situated near the summit of the hill. Stations G and F each had the second and third most accurate linear errors of 30.9 and 43.8 centimeters respectively. These values were achieved while these stations were located near the toe of the hillside and when their horizon was partially obstructed by the hillside. The remaining points had linear errors greater than half meter. Station K had a linear error that was 1.989 meters, which was the greatest in this data set.

With the exceptions of stations H and D, the elevations for each of these stations exceeded 1 meter. Station F had the largest elevation difference from the conventional data set. Station F’s elevation differed by 4.862 meters, which was similar to the elevation differences seen in stations A, B, and C of section 1. The location of station F and K may have been a factor in contributing to these values. Station F was placed near a chain link fence and was also near the base of the hill. Part of station K’s horizon was also significantly blocked by the hill and a large mature tree. These points in the forested environment were all surrounded by trees and under tree canopy. Every point except H and I were placed near the toe of the hill. Despite this environment, the linear errors for the stations in section two, with the exceptions of stations I and
K, were all smaller than the linear errors for station A, B, and C. The contributions of multipath, cycle slips, poor PDOP, or float solutions in determining these reliable and unreliable positional solutions were analyzed and discussed in Question 6.

**Contributions of GLONASS**

*Question 3*

*What effect does GLONASS have on RTK in an urban environment?*

**Data Analysis**

The number of GPS and GLONASS satellites tracked during the GPS-GLONASS RTK topographic survey in section one was displayed in Figure 3. This figure showed that only two GLONASS satellites were tracked during the observations for points A and B. Points C, L, M, and N did not acquire a lock on any GLONASS satellites. Table 5 showed the difference in the northings, eastings, and elevations for each point in section one.

*Figure 3. Section One: The Number of GPS and GLONASS Satellites Tracked by the RTK Roving Receiver.*
Conclusion

As mentioned earlier, two GLONASS satellites were needed to provide a contributing positional solution for measurements using both satellite navigation systems (Seeber, 2003). As shown above in Figure 3, only two points in section one tracked enough GLONASS satellites to assist in providing a positional solution. The GLONASS satellites assisted in determining a measurement for points A and B; however, the errors for these points averaged 0.616 m in the northing, and average –0.516 m in the easting, and –4.959 m for the elevations. Point C also had differences in northings, eastings, and elevation values that were similar in range to both points A and B. These difference in northings, eastings, and elevations for A, B and C was among the largest in section one and among the largest for the total data set as shown in Table 5. Points L, M, and N of section one all had small differences in the northings, eastings, and elevations. These differences represented the smallest of all the points and did not use any GLONASS satellites in the calculations for positional solutions. Therefore, at this time, GLONASS did not have any noticeable effect on RTK measurements in an urban environment.

Question 4

What effect does GLONASS have on RTK in a forested environment?

Data Analysis

The number of GLONASS satellites that were tracked during the RTK GPS-GLONASS observations for the eight points in section two was shown in Figure 4. All but one station in this section tracked a GLONASS satellite. Station H was the only point that did not acquire lock on a GLONASS satellite signal. Table 6, listed the differences in northings, eastings, and elevations at each point.
Conclusion

As mentioned above, two GLONASS satellites were required to contribute to a GPS-GLONASS positional solution. As a result, none of the points in section two had a solution that was assisted by GLONASS satellite signal. Station H was the most accurately determined point in section two and was the only point that did not track any GLONASS satellites. Based on these data, GLONASS did not assist in the accuracy of the measurements or in providing a solution for the stations in section two.
Contributions of Multipath, Cycle Slips, Satellite Availability, PDOP, and Fixed or Float Solutions

Question 5

What effect does multipath, cycle slips, satellite availability, PDOP, and fixed or float solutions have in an urban environment?

Data Analysis

Table 7 showed each station and its difference in position compared to its location determined by the conventional traverse. This table also showed if there were cycle slips or multipath observed in the measurement. This table also showed how many satellites were tracked during the observation, the PDOP value for the satellite constellation, and whether the position was based on a fixed or floats solutions. Stations A, B, and C were all shown to be the most displaced points in this data set. These three points each tracked seven GPS satellites with PDOP values that ranged from 3.0 to 3.3. The ambiguity resolution was also based on a fixed solution. There was no cycle slips present in the signal data. However, these observations contained multipath. Stations L, M, and N also tracked seven GPS satellites and had a PDOP value of 2.1. The ambiguity resolutions were also based on a fixed solution. These observations contained no sources of cycle slips or multipath in the solutions for these points.
Table 7

Section One: Coordinate Differences and Cycle Slips, Multipath, Satellite

Availability, PDOP and Fixed or Float Solutions

<table>
<thead>
<tr>
<th>Station</th>
<th>Differences (meters)</th>
<th>Linear error (meters)</th>
<th>Cycle slips</th>
<th>Multipath</th>
<th>Satellites present</th>
<th>PDOP</th>
<th>Fixed or float</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>N 0.651</td>
<td>E -0.541</td>
<td>0.846</td>
<td>No</td>
<td>Yes</td>
<td>US: 7 RU: 2</td>
<td>3.3 Fixed</td>
</tr>
<tr>
<td></td>
<td>El -4.912</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 0.582</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>E -0.491</td>
<td>0.761</td>
<td>No</td>
<td>Yes</td>
<td>US: 7 RU: 2</td>
<td>3.0 Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>El -5.006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 0.595</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>E -0.451</td>
<td>0.747</td>
<td>No</td>
<td>Yes</td>
<td>US: 7 RU: 0</td>
<td>3.2 Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>El -5.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 0.111</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>E -0.000</td>
<td>0.111</td>
<td>No</td>
<td>Maybe</td>
<td>US: 7 RU: 0</td>
<td>2.1 Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>El 0.158</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 0.124</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>E -0.015</td>
<td>0.125</td>
<td>No</td>
<td>Maybe</td>
<td>US: 7 RU: 0</td>
<td>2.1 Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>El 0.151</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N 0.094</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>E 0.025</td>
<td>0.097</td>
<td>No</td>
<td>Maybe</td>
<td>US: 7 RU: 0</td>
<td>2.1 Fixed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>El 0.234</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend

Sec.: Section

N: Northing

E: Easting
Table 7 (continued)

Legend

El: Elevation

US: GPS satellites

RU: GLONASS satellites

Conclusion

The effect that multipath, cycle slips, satellite availability, PDOP, and fixed or float solutions have in an urban environment is discussed in the following.

Cycle slips- The incoming satellite signals were unobstructed during each observation for the stations in sections one. Cycle slips were not present during the observations for the points in section one and had no effect on the positional solutions.

Multipath- Anderson and Mikhail (1998) said that multipath was the largest contributor to errors in kinematic GPS surveys. Varying amounts of multipath were probably present in each solution for the stations in section one. Large amounts of multipath may have been present in the incoming signals at stations A, B, and C during the RTK GPS-GLONASS topographic survey. The building walls, rooftops, asphalt surfaces, concrete sidewalks, grass yards, and parked automobiles may have created a large multipath bias for these three stations. Stations L, M, and N probably contained some multipath in its solutions because there were reflective surfaces around these stations; but these stations were further from building features such as walls and rooftops. The lack of these features may have reduced the levels of multipath around these points and allowed the roving receiver to determine a more accurate positional solution at these stations.
Satellite Availability- The roving receiver tracked seven satellites for each observation over the stations during the RTK survey in section one. This exceeds the minimum requirements for RTK GPS positioning and was necessary for favorable GPS conditions (Anderson & Mikhail, 1998).

PDOP- The PDOP values for these points were all 3.3 or lower. These low values represented a good distribution of satellites across the receiver’s horizon and were necessary for achieving good positional solutions and favorable GPS conditions (Strang & Borre, 1997).

Fixed or Float solutions- The integer ambiguity resolution was based on a fixed solution for each station in section one. As mentioned above, cycle slips did not occur for these points. As a result, the integer ambiguity did not need re-solved by the GPS receiver and remained constant during the RTK survey. This ensured good data quality for the positional solutions that were determined during the RTK observations (Seeber, 2003).

Hofmann-Wellenhof et al. (2001) stated that accurate RTK GPS measurements for points were determined while performing the land survey in favorable conditions. He described these conditions as no multipath, low PDOPs, low signal-to-noise ratios (SNR), and the tracking of at least five common satellites that had good satellite geometry and positions by both the base and roving receiver. SNRs were not observed during this survey and possibly could have contributed to the multipath effect. Hofmann-Wellenhof et al. (2001) also stated that when these favorable conditions were present, observation times as short as one epoch could accurately measure the position of a point. These favorable conditions were apparent in stations L, M, and N, and these points had the smallest variance in horizontal and vertical positions compared with their locations determined by the conventional traverse. These points each had a fixed ambiguity solution, no cycle slips, low PDOPs, and good satellite availability and distribution. Multipath
was assumed to be present but was not severe enough to yield unreliable positional solutions.

Stations L, M, and N may have acquired additional horizontal error from the rotation and translation of the conventional data set to the East Tennessee State University’s (ETSU) Geodetic network. Reliable RTK GPS solutions were not determined at these stations at stations A, B, and C. Severe multipath was assumed to be present in the solutions for these stations because the other conditions for reliable RTK GPS solutions were met.

Stations L, M, and N may have had better positional solutions because they were closer to the base station receiver. Every point was within the mile and half range of base station’s transmitter, but the roving receiver may have received a more robust and unobstructed transmission signal at stations L, M, and N. Point C was the furthest station from the base at a distance of 553.384 meters. The transmission signal from the base station to stations A, B, and C may have been obstructed by the relief in the ground topography, such as the hill, or by the forest described in section two. This degraded signal may have affected the roving receiver’s ability to completely mitigate multipath at these stations.

Question 6

What effect does multipath, cycle slips, satellite availability, PDOP, and fixed or float solutions have in a forested environment?

Data Analysis

Table 8 was similar to Table 7, only it applied to the stations in section two. Station H was determined to have the most reliable position determined by RTK GPS-GLONASS positioning methods. Stations D, E, F, G, I, J, and K will be discussed first because these points were determined to have the greatest variance in horizontal and vertical positions when
compared to the conventional traverse data set. Stations D and E each tracked five GPS satellites and had PDOP values of 3.3 and 4.6 respectively. Stations F, G, I, J, and K tracked six GPS satellites and had PDOP values that ranged between 3.0 to 6.6. Station G was the point that had the PDOP of 6.6. All of these stations based the ambiguity resolution on a float value. Cycle slips also affected these stations, and multipath may have had a small effect on the measurements. Both cycle slips and multipath affected the measurement at station K; this was also the most inaccurate measurement in section two. Station H was the only point in this data set that had a linear error that was near 10 centimeters. Station H also tracked six GPS satellites and had a PDOP of 3.2. This station was also affected by cycle slips and may have had small amounts of multipath. However, the ambiguity resolution was based on a fixed solution.

Table 8

*Section Two: Coordinate Differences and Cycle Slips, Multipath, Satellite Availability, PDOP and Fixed or Float Solutions*

<table>
<thead>
<tr>
<th>Station</th>
<th>Differences (meters)</th>
<th>Linear error (meters)</th>
<th>Cycle slips</th>
<th>Multipath</th>
<th>Satellites present</th>
<th>PDOP</th>
<th>Fixed or float</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>N 0.010</td>
<td>E -0.510</td>
<td>0.510</td>
<td>Yes</td>
<td>Maybe</td>
<td>US: 5 RU: 1</td>
<td>3.3 Float</td>
</tr>
<tr>
<td></td>
<td>E 0.740</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>E 0.378</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>US: 5 RU: 1</td>
<td>4.6 Float</td>
</tr>
<tr>
<td></td>
<td>N -0.486</td>
<td>E 0.616</td>
<td></td>
<td>Yes</td>
<td>Maybe</td>
<td></td>
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<tr>
<td></td>
<td>E -1.894</td>
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<td></td>
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<td></td>
</tr>
</tbody>
</table>
Table 8 (continued)

<table>
<thead>
<tr>
<th>Station</th>
<th>Differences (meters)</th>
<th>Average error (meters)</th>
<th>Cycle slips</th>
<th>Multipath</th>
<th>Satellites present</th>
<th>PDOP</th>
<th>Fixed or float</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N  0.216</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>E  0.381</td>
<td>0.438</td>
<td>Yes</td>
<td>Yes</td>
<td>US: 6 RU: 1</td>
<td>3.0</td>
<td>Float</td>
</tr>
<tr>
<td></td>
<td>El -4.862</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N  0.309</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>E  0.017</td>
<td>0.309</td>
<td>Yes</td>
<td>Maybe</td>
<td>US: 6 RU: 1</td>
<td>6.6</td>
<td>Float</td>
</tr>
<tr>
<td></td>
<td>El -2.129</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>N  0.104</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>E  0.010</td>
<td>0.104</td>
<td>Yes</td>
<td>Maybe</td>
<td>US: 6 RU: 0</td>
<td>3.2</td>
<td>Fixed</td>
</tr>
<tr>
<td></td>
<td>El 0.266</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>N -0.776</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>I</td>
<td>E  0.078</td>
<td>0.780</td>
<td>Yes</td>
<td>Maybe</td>
<td>US: 6 RU: 1</td>
<td>3.6</td>
<td>Float</td>
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<tr>
<td></td>
<td>El -1.210</td>
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<tr>
<td></td>
<td>N  0.268</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>J</td>
<td>E -0.577</td>
<td>0.636</td>
<td>Yes</td>
<td>Maybe</td>
<td>US: 6 RU: 1</td>
<td>3.9</td>
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<tr>
<td></td>
<td>N  1.980</td>
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<tr>
<td>K</td>
<td>E  0.194</td>
<td>1.989</td>
<td>Yes</td>
<td>Maybe</td>
<td>US: 6 RU: 1</td>
<td>4.1</td>
<td>Float</td>
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<td></td>
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<td></td>
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Legend
Sec.: Section
N: Northing
E: Easting
El: Elevation
US: GPS satellites
RU: GLONASS satellites
Conclusion

The effect that multipath, cycle slips, satellite availability, PDOP, and fixed or float solutions have in an urban environment is discussed in the following.

Cycle slips- Satellite signals that travel through areas that are heavily obstructed from the natural or urban features are prone to cycle slips during a GPS survey (Anderson & Mikhail, 1998). The forested environment created many obstructions that produced cycle slips in the satellite signals for each observation for the stations section two. Cycle slips degrade the quality of data received by a GPS receiver (Seeber, 2003). These cycle slips may have degraded the quality of the satellite signal received by the roving receiver and may have affected the receiver's ability to determine reliable positional solutions by requiring multiple resolutions for the ambiguity solution (Seeber). This may have been a significant contributing factor for station K, due to point K’s close proximity to a mature tree and its location near the toe of the hill’s slope.

Multipath- The stations in the forested environment of section two were further from potential sources of multipath that were found in the urban environment for the stations described in section one. However, these stations may still contain multipath bias because trees can produce multipath (Hofmann-Wellenhof et al., 2001). Station F was placed near a known potential source of multipath, a chain link fence (Hofmann-Wellenhof et al.). This may have created the larger difference in station F’s vertical position when compared to the conventional land survey than the other points.

Satellite availability- Despite the overhead tree canopy and trees found in the forested environment, the roving receiver was able to track enough satellites to determine a RTK GPS positional solution during the RTK GPS observation. The simultaneous resolution of the satellites signals from a minimum number of five satellites by both the base and roving receiver
was required for performing RTK GPS surveys in favorable conditions (Anderson & Mikhail, 1998). The RTK GPS positional solutions for stations D and E were determined from five satellites. The roving receiver tracked six GPS satellites at stations F, G, H, I, J, and K.

PDOP- Strang and Borre (1997) said that a PDOP value near three “is associated with widely separated satellites and good positioning” (p. 602). Hofmann-Wellenhof et al. (2001) state that “compared to the static mode, the accuracy in the kinematic mode is worse mainly due to multipath and DOP variations” (p. 320). The roving receiver was able to achieve favorable PDOP values within the forested environment for four of the stations in section two. These stations were D, F, H, I, and J. The PDOP values for these stations were 3.3, 3.0, 3.2, 3.6, and 3.9 respectively. These stations had the best PDOP values for this section and, with the exception of stations F and H, achieved linear errors greater than half a meter. However, station F’s linear error was 0.438 meters. Stations E and K had PDOP of 4.6 and 4.1 respectively. Station E also had a linear error greater than half a meter while station K’s linear error was near 2 meters. The highest PDOP value was recorded at station G and was 6.6. Despite this high PDOP value, this station had the second smallest linear error of this data set. Excepting station H, these high PDOP values may have contributed to the larger positional differences for this data set.

Fixed or Float solutions- As mentioned above, the roving receiver had difficulties in maintaining a constant lock on the GPS signals in the forested environment during the observations over each station. The cycle slips create difficulties for the receiver in resolving the integer ambiguity for the carrier phase (Seeber, 2003). As a result, only float solutions were achieved for all but one station in section two during the RTK GPS land survey. This appeared to be a significant source of bias in the deviation of these stations from the conventional land
survey. Station H was the only point where a fixed solution was determined. In addition, station H also had the most reliable positional solution section two.

As mentioned above by Hofmann-Wellenhof et al. (2001), reliable and accurate GPS data can be determined with short observation times with favorable conditions. The favorable conditions were described by Hofmann-Wellenhof et al. as no multipath, low PDOPs, low signal-to-noise ratios (SNR), and the tracking of at least five common satellites with good satellite geometry and positions by both the base and roving receiver. Multipath may have degraded the elevation positional solution for station F because this station was near a chain link fence. The PDOP values were good for five of these stations. However, excepting station H, several of these points had linear errors greater than half a meter and elevation differences exceeding 1 meter. Despite the trees and forest canopy, the roving receiver was able to lock onto at least five satellites during the time allotted for observation sessions. However, the points in this section were observed in an environment that caused multiple cycle slips in the GPS carrier wave.

Seeber (2003) stated that the resolution of the ambiguity was critical in achieving accurate measurements using the carrier phase measurements. Seeber also said that the resolved integer ambiguity was what guaranteed the accurate measurements with short observation times for relative positioning methods. Three problems that create difficulty in resolving the ambiguity solution included cycle slips, low number of tracked satellites, and short observation times (Seeber). Two of these conditions were present in section two: poor data quality caused by cycle slips and short observation times. As discussed earlier, when a cycle slip occurred, the ambiguity resolution was lost and had to be resolved. Topographic surveys generally require short observation times for locating the features at the site. These short observation times may
not have provided enough time in the forested environment to determine a fixed ambiguity resolution. Every point except station H was not able to determine a fixed solution within 15 epochs. Station H was the only point the roving receiver was able to determine a fixed solution for and was the most accurate point located in section two. H’s linear error was common to stations L, M, and N in section one. The use of float solutions and short observation times may have contributed to the differences in horizontal and vertical positions for these stations in section two.

Resurvey of Stations A, B, and C by Static GPS

As mentioned in Chapter 3, a separate static GPS survey was performed to provide additional coordinates for comparison for points A, B, and C. The purpose of this static survey was primarily to identify if a blunder existed in the positions in stations A, B, and C that were determined by the conventional survey. The static GPS land survey was also less affected by multipath because it used the carrier phase and not the navigation code (Hofmann-Wellenhof et al., 2001). The coordinate data acquired by the static GPS land survey was compared to the coordinate data for stations A, B, and C determined by both the conventional land survey and the RTK GPS land survey. This was performed to verify that the conventional land survey accurately located the stations in the fourteen point course with respect to the ETSU Geodetic Control Network and that the errors present in the coordinates for A, B, and C were derived during the occupancy of these points by the roving receiver in the RTK GPS land survey.

Table 9 listed the differences in between the coordinate values of the conventional land survey and static GPS survey for these three points. The differences in the horizontal linear errors for the coordinates between the two data sets for points A, B, and C listed in Table 9.
Station A had the largest linear error and varied the most in its northing and easting positions and the least in elevation by 14, 14.2, and 4.1 centimeters respectively. Station B also differed the most in its northing and easting coordinates and each were within 10 centimeters of the conventional data set. Station B’s linear error was 11.7 centimeters with and elevation difference of 5.7 centimeters. Station C had the smallest linear error and deviated the most from the conventional data set in its northing coordinate but was within five centimeters in both the easting and elevation. Stations A and B each varied the most in the easting position, while Station C had the deviated the most in its northing position.

### Table 9

**Differences Between Northing, Easting and Elevation Between Conventional Land Survey and Static GPS Survey**

<table>
<thead>
<tr>
<th>Station</th>
<th>Northing (meters)</th>
<th>Easting (meters)</th>
<th>Elevation (meters)</th>
<th>Linear error (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.140</td>
<td>-0.142</td>
<td>0.041</td>
<td>0.199</td>
</tr>
<tr>
<td>B</td>
<td>0.073</td>
<td>-0.092</td>
<td>-0.057</td>
<td>0.117</td>
</tr>
<tr>
<td>C</td>
<td>0.111</td>
<td>-0.034</td>
<td>-0.048</td>
<td>0.116</td>
</tr>
</tbody>
</table>

Table 10 listed the differences for these coordinates between the RTK GPS survey and the static GPS survey. The RTK coordinates also had larger horizontal and vertical differences when compared to the coordinates determined by the static GPS survey. This was similar to the results listed above in Table 5 when the RTK data set was compared to the conventional land survey above. The horizontal linear errors were greater than half a meter for stations A, B, and C. The largest differences for each station were found in the elevations and were greater than
4.949 meters. The second largest differences were found in the northing positions and were 0.484 meters or greater. The easting position deviated by 0.399 meters or more.

### Table 10

**Differences Between Northing, Easting, and Elevation Between RTK GPS Survey and Static GPS Survey**

<table>
<thead>
<tr>
<th>Station</th>
<th>Northing (meters)</th>
<th>Easting (meters)</th>
<th>Elevation (meters)</th>
<th>Linear error (meters)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-0.511</td>
<td>0.399</td>
<td>4.953</td>
<td>0.648</td>
</tr>
<tr>
<td>B</td>
<td>-0.509</td>
<td>0.399</td>
<td>4.949</td>
<td>0.647</td>
</tr>
<tr>
<td>C</td>
<td>-0.484</td>
<td>0.417</td>
<td>4.955</td>
<td>0.639</td>
</tr>
</tbody>
</table>

### Conclusion

The horizontal linear error differences for the coordinate sets between the conventional land survey and static GPS survey each are within 12 centimeter for stations B and C. The linear error was 19.9 centimeters for station A. The positions of stations A, B, and C for the conventional land survey’s and static GPS survey’s data sets are within close proximity to each other. This showed that no blunders existed in the conventional land survey at these stations. When the static GPS coordinates for these stations were compared to the positions of these stations determined by the RTK GPS coordinates, the RTK GPS data set continued to have the largest deviation in coordinate values. The differences the northings and eastings between the static GPS and RTK GPS land surveys were smaller than the differences between the conventional and RTK GPS land surveys. However, the elevations measured by the RTK GPS land survey were nearly five meters different from both the conventional and static land surveys.
This may have resulted because the static survey solely used carrier phase measurements and was subjected to smaller multipath bias (Hofmann-Wellenhof et al., 2001). The larger deviations in the positions of stations A, B, and C determined by the RTK GPS land survey appeared to be caused by multipath. Further analysis, or a re-survey of these stations by each land survey methods may be needed in order to positively identify the factors that caused the deviation of the RTK GPS land survey.

**Conclusion**

There were not enough GLONASS satellites present at the time of the survey to make any significant difference with the RTK measurements made at each station. This was due to the status of the current GLONASS constellation. However, as stated by Polischuk et al. (2002), the GLONASS constellation was planned to be at complete operational status in 2011. With a fully operational status, GLONASS may contribute to positioning methods and may be more apt to augment the existing GPS constellation. A fully operations GLONASS constellation may also improve satellite availability and lower PDOP values.

Kim and Langley (n.d.) said that unprocessed cycle slips and missed cycle slips were the number one leading cause of error in measurements using the carrier phase. Detection and repair depended on the algorithms of the receiver’s software. Research on processing satellite signal data was aimed at improving algorithms and the methods they use to detect cycle slips faster for repair. As stated by Seeber (2003), the cycle slip detection and repair by the RTK receiver was essential for determining accurate GPS positioning. The float solutions used to determine the positions of stations, D, E, F, G, I, J, and K in section two possibly contributed to the deviations in these stations from the conventional survey.
As in *The performance of RTK-GPS for surveying under challenging environmental conditions*, Lee and Ge (2006) also demonstrated that RTK positioning techniques had a weakness due to obstruction of the satellite signals. These obstructions included features such as buildings, trees, and tree canopies. They stated that usage of RTK positioning methods was dependent on the intended applications and the error tolerance required by these applications. This was also consistent to the findings in a United States Forestry Service (2004) GPS test performed under heavy canopy under the direction of Rodriguez. His tests showed that longer observation times were required to get point solutions due to the tree canopy and topographical obstructions. Their recommendations suggested ensuring the observations were being performed when the constellations are in an orbit above the receiver in unobstructed skies and above the masked horizon. The short observation times of the stations and weakened satellite signals in section two may have contributed to their deviations from their positions acquired by the conventional land survey.

The affects of multipath and cycle slips may be reduced with the modernization of GPS. According to Kubo, Yasuda, Kawano, Ono, and Uratani (n.d.), the third civil frequency, the L5 signal, may increase a GPS receiver’s performance for precise positioning using carrier phase data. Their experiments used GPS signal wave simulators and a receiver that can track the L5 signal and used it with the existing L1 and L2 frequency signals. This receiver had improved performance in two ways. First, the receiver yielded better positional accuracies with DGPS and RTK in urban areas with severe multipath. Second, they demonstrated that the receiver’s ability to resolve the ambiguity resolution for RTK land surveying improved. Receivers that can track the proposed L5 frequency will be expected to be available for civilian use. When this happens, RTK methods will be tested for applications of RTK surveying in environments that previously
restricted or limited its use. A more robust satellite signal and additional satellite signal may have reduced the multipath bias that may have been present in stations A, B, and C in section one. In addition, as the RTK receivers’ capability to resolve the ambiguity resolutions continues to improve, they may be able to provide data that is more reliable in environments where cycle slips may be expected.

Recommendations for Continued Research

As stated by Hofmann-Wellenhof et al. (2001), kinematic surveying was affected more by the bias created by dilution of precision and multipath than static surveying. Three factors that contributed to the differences in the RTK solutions from the conventional data set in this study appeared to be multipath, PDOP, and float solutions. This study suggests that multipath was the main contribution of bias in four of the stations observed by RTK positioning methods. These stations were A, B, C, and F. This study also showed that PDOP might have reduced the reliability in several stations, such as stations E, G, and K. The deviations in the positions in the majority of the stations in section two may have resulted from the float solutions that were used to determine the station’s positions in the course.

Future research should include identifying methods that surveyors can use to minimize the contributions of multipath, dilution of precision, and float solutions in RTK land survey. This research can include RTK methods that combine the GPS and GLONASS constellations for RTK land surveys. Combining these constellations will increase the satellite availability, which may provide better PDOP during observations, reduce multipath, and yield fixed solutions in environments where RTK land surveying produces unreliable solutions. Second, a new civilian signal will be available through GPS as the GPS network undergoes modernization. This robust
signal may increase a receiver’s ability to track the GPS signals in areas with obstructions from urban infrastructure or forests. Research should be pursued when this new signal becomes available for civilian use.

As discussed in Chapter 2, local vegetation has an effect called foliage attenuation that degrades the GPS-GLONASS signals. Furthermore, different types of vegetation had different effects on these signals. Future research on the contributions of these effects from deciduous and pines would be useful as GPS begins to be used in wooded areas and forests for topographical and wetland surveys.

One desired result of this study was to provide additional research on identifying the factors that contribute to reliable RTK measurements in and urban and forested environments to assist RTK users in gathering positional data in these environments. This topic should be continued because there are land surveyors who own RTK equipment but do not apply it to regular surveying tasks. This may be from a lack of readily identifying the different environments that RTK methods can be applied to or from a lack of understanding the factors that contribute to reliable positional data. Additional research should be conducted to produce useful and understandable information that land surveyors can use to help them understand the capabilities and applications of RTK surveying methods to assist with the productivity and efficiency in their businesses and practice. Understanding and applying this technology will allow land surveyors to continue at being in the forefront of this growing technology in their communities across the globe.
REFERENCES


newest global information utility. Retrieved October 23, 2006, from:


http://www.sciencedirect.com/science


Martin, W., & Ladd, J. (n.d.). GPS + GLONASS surveying post-processed and real-time


APPENDICIES

APPENDIX A

TOPCON Hiper Lite Plus © Technical Specification

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Tracking</td>
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</tr>
<tr>
<td>Tracking Channels, standard</td>
<td>40 L1 GPS (20 GPS L1 + L2 on Cinderella Days)</td>
</tr>
<tr>
<td>Tracking Channels, optional</td>
<td>20 GPS L1+ L2 (GD), GPS L1 + GLONASS (GG)</td>
</tr>
<tr>
<td></td>
<td>20 GPS L1 + L2 + GLONASS (GGD)</td>
</tr>
<tr>
<td>Signals Tracked</td>
<td>L1/L2 C/A-code and P-code, Carrier phase, GLONASS</td>
</tr>
<tr>
<td>Channels</td>
<td>40</td>
</tr>
<tr>
<td>Performance</td>
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</tr>
<tr>
<td>V: 5mm + 0.5ppm</td>
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</tr>
<tr>
<td>RTK</td>
<td>H: 10mm + 1ppm</td>
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<td>V: 15mm + 1ppm</td>
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<td>Ground Plane</td>
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## APPENDIX B

Technical Differences For The GLONASS And GPS Satellite Systems

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<thead>
<tr>
<th>Component</th>
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<th>GPS</th>
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<tr>
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<td></td>
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<tr>
<td>Control Segment</td>
<td>Military Space Force</td>
<td>Department of Defense</td>
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<tr>
<td>Tracking network</td>
<td>Global</td>
<td>Regional</td>
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<tr>
<td>Number of Satellites in</td>
<td>21 + 3 orbiting spares</td>
<td>21 + 3 orbiting spares</td>
</tr>
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<tr>
<td>Number of orbital planes</td>
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<td>Inclination</td>
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<td>55°</td>
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<tr>
<td>Orbital altitude</td>
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<td>Orbital radius</td>
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<td>26,560 km</td>
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<td>Orbital period</td>
<td>11 hours 15 minutes</td>
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<td>Satellite Spacing</td>
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<td>Even</td>
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<td>Ephemeris representation</td>
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<td>Keplerian elements and</td>
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<tr>
<td></td>
<td>velocity, acceleration in</td>
<td>interpolation coefficients</td>
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<td></td>
<td>the ECEF Cartesian system)</td>
<td></td>
</tr>
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<td>Geodetic datum</td>
<td>PZ-90</td>
<td>WGS 84</td>
</tr>
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<td>Time base</td>
<td>GLONASS system time</td>
<td>GPS system time</td>
</tr>
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<td>Related system time</td>
<td>UTC(SU)</td>
<td>UTC(USNO)</td>
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<td>Almanac transmission</td>
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<td>1.575 MHz</td>
</tr>
<tr>
<td>Frequency band L2</td>
<td>1.246 – 1.256 MHz</td>
<td>1.228 MHz</td>
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<td>C/A-code on L1</td>
</tr>
<tr>
<td></td>
<td>P-code on L1, L2</td>
<td>P-code on L1, L2</td>
</tr>
<tr>
<td>Code type</td>
<td>PRN sequence</td>
<td>Gold code</td>
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APPENDIX B (continued)

<table>
<thead>
<tr>
<th>Component</th>
<th>GLONASS</th>
<th>GPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Signal Structure</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Code frequency C/A-</td>
<td>0.511 MHz</td>
<td>1.023 MHz</td>
</tr>
<tr>
<td>code</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Code frequency P-code</td>
<td>5.11 MHz</td>
<td>10.23 MHz</td>
</tr>
<tr>
<td>Clock data</td>
<td>Clock offset frequency offset</td>
<td>Clock offset frequency offset and rate</td>
</tr>
</tbody>
</table>

APPENDIX C

Orbiting GPS Satellites For October 2006

<table>
<thead>
<tr>
<th>SVN</th>
<th>Model</th>
<th>Plane</th>
<th>Launch date</th>
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<td>II-9</td>
<td>D5</td>
<td>Oct. 1, 1990</td>
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<tr>
<td>24</td>
<td>IIA-11</td>
<td>D6</td>
<td>Jul. 4, 1991</td>
</tr>
<tr>
<td>25</td>
<td>IIA-12</td>
<td>A5</td>
<td>Feb. 23, 1992</td>
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<tr>
<td>26</td>
<td>IIA-14</td>
<td>F2</td>
<td>Jul. 7, 1992</td>
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<td>27</td>
<td>IIA-15</td>
<td>A4</td>
<td>Sep. 9, 1992</td>
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<tr>
<td>32</td>
<td>IIA-16</td>
<td>F6</td>
<td>Nov. 22, 1992</td>
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<td>37</td>
<td>IIA-20</td>
<td>C5</td>
<td>May 13, 1993</td>
</tr>
<tr>
<td>35</td>
<td>IIA-22</td>
<td>B4</td>
<td>Aug. 30, 1993</td>
</tr>
<tr>
<td>34</td>
<td>IIA-23</td>
<td>D4</td>
<td>Oct. 26, 1993</td>
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<td>36</td>
<td>IIA-24</td>
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<td>IIA-28</td>
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<td>43</td>
<td>IIR-2</td>
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<td>46</td>
<td>IIR-3</td>
<td>D2</td>
<td>Oct. 7, 1999</td>
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<td>51</td>
<td>IIR-4</td>
<td>E1</td>
<td>May 11, 2000</td>
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<td>IIR-5</td>
<td>B3</td>
<td>Jul. 16, 2000</td>
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<td>41</td>
<td>IIR-6</td>
<td>F1</td>
<td>Nov. 10, 2000</td>
</tr>
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<td>54</td>
<td>IIR-7</td>
<td>E4</td>
<td>Jan. 30, 2001</td>
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<td>56</td>
<td>IIR-8</td>
<td>B1</td>
<td>Jan. 29, 2003</td>
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<td>45</td>
<td>IIR-9</td>
<td>D3</td>
<td>Mar. 31, 2003</td>
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<td>47</td>
<td>IIR-10</td>
<td>E2</td>
<td>Dec. 21, 2003</td>
</tr>
<tr>
<td>59</td>
<td>IIR-11</td>
<td>C3</td>
<td>Mar. 20, 2004</td>
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APPENDIX C (continued)

<table>
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<th>SVN</th>
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<th>Launch date</th>
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<td>60</td>
<td>IIR-12</td>
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<td>61</td>
<td>IIR-13</td>
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<td>Nov. 6, 2004</td>
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<td>IIR-14M</td>
<td>C4</td>
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<td>52</td>
<td>IIR-15M</td>
<td>A2</td>
<td>Sep. 25, 2006</td>
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</table>

APPENDIX D

Orbiting GLONASS Satellites For October 2006

<table>
<thead>
<tr>
<th>Russian Space Force Numbers</th>
<th>Model</th>
<th>Orbital Plane</th>
<th>Launch Date</th>
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<td>OK</td>
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<td>787</td>
<td>GLONASS</td>
<td>3</td>
<td>Oct. 13, 2000</td>
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<td>GLONASS</td>
<td>1</td>
<td>Dec. 1, 2001</td>
<td>OK</td>
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<td>Dec. 1, 2001</td>
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<td>GLONASS M</td>
<td>3</td>
<td>Dec. 25, 2005</td>
<td>OK</td>
</tr>
</tbody>
</table>

APPENDIX E

Fourteen Point Course

APPENDIX F

Conventional Land Survey Raw Data

JB, NMdr-tripod, DT08-10-2003, TM20:40:25
JB, NMdr2-tripod, DT08-06-2003, TM10:59:28
MO, AD0, UN1, SF1.0, EC0, EO0.0, AU0

SP, PN1, N 5000.0, E 5000.0, EL100.0, --Start

--Activating Total Station: Topcon GPT Series (Pulse Laser) [m], COM1, 1200 baud, even parity

OC, OP1, N 5000.0, E 5000.0, EL100.0, --Start

LS, HI1.58, HR1.545

BK, OP1, BP0, BS90.0000, BC0.0000

--BS Circle check : angular err= 0.0000

SS, OP1, FP14, AR0.0000, ZE91.1300, SD321.429, --N

OC, OP1, N 5000.0, E 5000.0, EL100.0, --Start

BK, OP1, BP14, BS90.0000, BC0.0000

--BS check 1 – 14: ZE91.1300, SD321.426, HD err= -0.002999, VD err= 0.000064

--BS Circle check : angular err= 0.0000

OC, OP1, N 5000.0, E 5000.0, EL100.0, --Start

BK, OP1, BP14, BS90.0000, BC0.0000

--BS check 1 – 14: ZE91.1300, SD321.427, HD err= -0.002, VD err= 0.000042

--BS Circle check : angular err= 0.0000

LS, HI1.58, HR1.488
RD,BD 1:0.0000

--BS zenith: 91.1255, slope dist: 321.428

RB,OP1,BP14,AR0.0000,ZE91.1255,SD321.428,HR1.488,--N

RD,FD 1:167.2115

RD,ZD 1:89.2615

MD,SD 1:167.405

RF,OP1,FP2,AR167.2115,ZE89.2615,SD167.405,HR1.488,--B

RD,BV 1:179.5955

RD,FV 1:347.2120

--RD,ZV 1:270.3330

--Not shooting reverse distances.

--Horizontal Angle Error: 0.0010

--Zenith Angle Error: 0.0000

--Horizontal Angle Error compares to the average: 0.0000

--Zenith Angle Error compares to the average: 0.0000

--Slope Distance Error compares to the average: 0.0

TR,OP1,FP2,AR167.2120,ZE89.2615,SD167.405,--B

OC,OP2,N 4963.356779,E 4836.662903,EL101.735468,--B

BK,OP2,BP1,BS77.2120,BC0.0000

LS,HI1.449,HR1.488

OC,OP2,N 4963.356779,E 4836.662903,EL101.735468,--B

BK,OP2,BP1,BS77.2120,BC0.0000

--BS check 2 – 1:ZE90.3320,SD167.405639,HD err= 0.000837, VD err= 0.073283
--BS Circle check : angular err= 0.0000
LS,HI1.449,HR1.464
RD,BD 1:0.0000
--BS zenith: 90.3320, slope dist: 167.404115
RB,OP2,BP1,AR0.0000,ZE90.3320,SD167.404115,HR1.464,--Start
RD,FD 1:104.4900
RD,ZD 1:85.0910
MD,SD 1:92.970282
RF,OP2,FP3,AR104.4900,ZE85.0910,SD92.970282,HR1.464,--nail
RD,BV 1:180.0005
RD,FV 1:284.4900
--RD,ZV 1:274.5030
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0005
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0
--Traverse later to point: 3
LS,HI1.449,HR1.435
SS,OP2,FP15,AR248.5710,ZE96.4455,SD28.055372,--Liews
SS,OP2,FP16,AR275.2840,ZE95.5315,SD135.90602,--Andrews
LS,HI1.449,HR1.464
SS, OP2, FP3, AR 104.4858, ZE 85.0910, SD 92.970282, --nail
LS, HI 1.449, HR 1.435
OC, OP3, N 4870.785526, E 4833.152743, EL 109.576374, --nail
BK, OP3, BP2, BS 2.1018, BC 0.0000
OC, OP3, N 4870.785526, E 4833.152743, EL 109.576374, --nail
LS, HI 1.53, HR 1.435
BK, OP3, BP2, BS 2.1018, BC 0.0000
-- HR at Backsight: 1.488
-- BS check 3 – 2: ZE 94.5305, SD 92.979426, HD err= 0.003949, VD err= -0.034408
-- BS Circle check: angular err= 0.0000
-- BS check 3 – 2: ZE 94.5300, SD 92.982, HD err= 0.006706, VD err= -0.032382
-- BS Circle check: angular err= 0.0000
OC, OP3, N 4870.785526, E 4833.152743, EL 109.576374, --nail
LS, HI 1.527, HR 1.435
BK, OP3, BP2, BS 2.1018, BC 0.0000
-- HR at Backsight: 1.488
-- BS check 3 – 2: ZE 94.5255, SD 92.977, HD err= 0.001916, VD err= -0.03271
-- BS Circle check: angular err= 0.0250
-- RD, BD 1:0.0000
-- BS zenith: , slope dist:
-- RB, OP3, BP2, AR 0.0000, ZE, SD, HR 1.488, --B
-- RD, FD 1:0.0000
-- RD, ZD 1:
--MD,SD 1:
--RF,OP3,FP,AR0.0000,ZE,SD,HR1.435,--
--RD,BV 1:180.0000
--BS zenith: , slope dist:
--RB,OP3,BP2,AR180.0000,ZE,SD,HR1.488,--B
--RD,FV 1:180.0000
--RD,ZV 1:
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0000
--Zenith Angle Error: 0.0000
RD,BD 1:0.0000
--BS zenith: 94.5300, slope dist: 92.982
RB,OP3,BP2,AR0.0000,ZE94.5300,SD92.982,HR1.488,--B
RD,FD 1:88.0205
RD,ZD 1:90.0245
MD,SD 1:133.716
RF,OP3,FP4,AR88.0205,ZE90.0245,SD133.716,HR1.435,--D
RD,BV 1:179.5955
RD,FV 1:268.0210
--RD,ZV 1:269.5655
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0010
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0

-- Traverse later to point: 4

SS, OP3, FP17, AR242.4810, ZE79.5930, SD14.996, -- C

OC, OP3, N 4870.785526, E 4833.152743, EL109.576374, -- nail

LS, HI1.606, HR1.435

BK, OP3, BP2, BS2.1018, BC0.0000

-- BS check 3 – 2: ZE90.0445, SD133.717, HD err= 41.079094, VD err= 7.827147
-- BS Circle check : angular err= 0.0000

OC, OP4, N 4870.300943, E 4966.867822, EL109.561409, -- D

BK, OP4, BP3, BS270.1228, BC0.0000

-- BS check 4 – 3: ZE90.0445, SD133.717, HD err= 0.000915, VD err= -0.028724
-- BS Circle check : angular err= 0.0000

OC, OP4, N 4870.300943, E 4966.867822, EL109.561409, -- D

BK, OP4, BP3, BS270.1228, BC0.0000

-- BS check 4 – 3: ZE90.0445, SD133.718, HD err= 0.001915, VD err= -0.028726
-- BS Circle check : angular err= 0.0000

-- RD, BD 1:0.0000
-- BS zenith: 90.0445, slope dist: 133.717

-- RB, OP4, BP3, AR0.0000, ZE90.0445, SD133.717, HR1.435, -- nail

-- RD, FD 1:161.3100
-- RD, ZD 1:89.5250
--MD,SD 1:85.044
--RF,OP4,FP18,AR161.3100,ZE89.5250,SD85.044,HR1.435,--TR
--RD,BV 1:180.0045
--RD,FV 1:341.3015
--RD,ZV 1:270.0620

--Not shooting reverse distances.
--Horizontal Angle Error: 0.0130
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0048
--Zenith Angle Error compares to the average: 0.0015
--Slope Distance Error compares to the average: 0.001

RD,BD 1:359.5955
--BS zenith: 90.0415, slope dist: 133.719

RB,OP4,BP3,AR359.5955,ZE90.0415,SD133.719,HR1.435,--nail
RD,FD 1:161.3110
RD,ZD 1:89.5305

MD,SD 1:85.043
RF,OP4,FP18,AR161.3110,ZE89.5305,SD85.043,HR1.435,--TR
RD,BV 1:180.0045
RD,FV 1:341.3135
--RD,ZV 1:270.0650

--Not shooting reverse distances.
--Horizontal Angle Error: 0.0025
--Zenith Angle Error: 0.0000

--Horizontal Angle Error compares to the average: 0.0000

--Zenith Angle Error compares to the average: 0.0000

--Slope Distance Error compares to the average: 0.0

LS, HI1.606, HR1.485

TR, OP4, FP18, AR161.3103, ZE89.5305, SD85.043, --TR

OC, OP18, N 4896.968516, E 5047.621293, EL109.853514, --TR

BK, OP18, BP4, BS251.4330, BC0.0000

OC, OP18, N 4896.968516, E 5047.621293, EL109.853514, --TR

LS, HI1.552, HR1.485

BK, OP18, BP4, BS251.4330, BC0.0000

--HR at Backsight: 1.545

--BS check 18 – 4: ZE90.0845, SD85.043, HD err= -0.000103, VD err= 0.082647

--BS Circle check: angular err= 0.0000

LS, HI1.552, HR1.496

RD, BD 1:0.0000

--BS zenith: 90.0845, slope dist: 85.044

RB, OP18, BP4, AR0.0000, ZE90.0845, SD85.044, HR1.545, --D

RD, FD 1:179.1100

RD, ZD 1:94.4955

MD, SD 1:97.415

RF, OP18, FP6, AR179.1100, ZE94.4955, SD97.415, HR1.496, --F

RD, BV 1:180.0005
RD,FV 1:359.1100
--RD,ZV 1:265.0950
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0005
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0
--Traverse later to point: 6
SS,OP18,FP6,AR179.1058,ZE94.4955,SD97.415,--F
OC,OP6,N 4928.718933,E 5139.350576,EL101.703916,--F
LS,HI1.562,HR1.496
BK,OP6,BP18,BS250.5428,BC0.0000
--HR at backsight: 1.545
--BS check 6 – 18:ZE85.1825,SD97.405,HD err= 0.009639, VD err= -0.163143
--BS Circle check: angular err= 0.0000
RD,BD 1:0.0000
--BS zenith: 85.1825, slope dist: 97.405
RB,OP6,BP18,AR0.0000,ZE85.1825,SD97.405,HR1.545,--TR
RD,FD 1:206.2730
RD,ZD 1:93.2605
MD,SD 1:58.66
RF,OP6,FP7,AR206.2730,ZE93.2605,SD58.66,HR1.496,--G
RD,BV 1:179.5955
RD,FV 1:26.2730
--RD,ZV 1:266.3335
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0005
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0
TR,OP6,FP7,AR206.2733,ZE93.2605,SD58.66,--G
OC,OP7,N 4921.211138,E 5197.421891,EL98.255518,--G
BK,OP7,BP6,BS277.2200,BC0.0000
--HR at Backsight: 1.545
OC,OP7,N 4921.211138,E 5197.421891,EL98.255518,--G
LS,HI1.555,HR1.496
BK,OP7,BP6,BS277.2200,BC0.0000
--HR at Backsight: 1.495
--BS check 7 – 6:ZE86.3700,SD58.654305,HD err= -0.002556, VD err= 0.073145
--BS Circle check : angular err= 0.0000
--BS check 7 – 6:ZE86.3700,SD58.654,HD err= -0.002861, VD err= 0.073127
--BS Circle check : angular err= 0.0000
LS,HI1.555,HR1.458
RD,BD 1:0.0000
--BS zenith: 86.3700, slope dist: 58.655

RB,OP7,BP6,AR0.0000,ZE86.3700,SD58.655,HR1.495,--F

RD,FD 1:279.3840

RD,ZD 1:67.3220

MD,SD 1:72.297

RF,OP7,FP8,AR279.3840,ZE67.3220,SD72.297,HR1.458,--H

RD,BV 1:179.5955

RD,FV 1:99.3835

--RD,ZV 1:292.2725

--Not shooting reverse distances.

--Horizontal Angle Error: 0.0000

--Zenith Angle Error: 0.0000

--Horizontal Angle Error compares to the average: 0.0000

--Zenith Angle Error compares to the average: 0.0000

--Slope Distance Error compares to the average: 0.0

TR,OP7,FP8,AR279.3840,ZE67.3220,SD72.297,--H

OC,OP8,N 4857.321833,E 5177.875422,EL125.97404,--H

BK,OP8,BP7,BS17.0040,BC0.0000

--HR at Backsight: 1.495

LS,HI1.521,HR1.458

OC,OP8,N 4857.321833,E 5177.875422,EL125.97404,--H

BK,OP8,BP7,BS17.0040,BC0.0000

--HR at Backsight: 1.495
--BS check 8 – 7:ZE112.3010,SD72.339,HD err= 0.018698, VD err= 0.058345
--BS Circle check : angular err= 0.0000
OC,OP8,N 4857.321833,E 5177.875422,EL125.97404,--H
BK,OP8,BP7,BS17.0040,BC0.0000
--HR at backsight: 1.495
--BS check 8 – 7:ZE112.3010,SD72.347,HD err= 0.026088, VD err= 0.055283
--BS Circle check : angular err= 0.0000
RD,BD 1:0.0000
--BS zenith: 112.3010, slope dist: 72.342
RB,OP8,BP7,AR0.0000,ZE112.3010,SD72.342,HR1.495,--G
RD,FD 1:120.5755
RD,ZD 1:87.3640
MD,SD 1:39.978
RF,OP8,FP9,AR120.5755,ZE87.3640,SD39.978,HR1.458,--I
RD,BV 1:180.0005
RD,FV 1:300.5750
--RD,ZV 1:272.2300
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0010
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0
LS, HI1.512, HR1.45

TR, OP8, FP9, AR120.5750, ZE87.3640, SD39.978, --I

OC, OP9, N 4827.649874, E 5204.615627, EL127.711399, --I

BK, OP9, BP8, BS317.5830, BC0.0000

-- HR at Backsight: 1.495

LS, HI1.512, HR1.45

OC, OP9, N 4827.649874, E 5204.615627, EL127.711399, --I

BK, OP9, BP8, BS317.5830, BC0.0000

-- HR at Backsight: 1.458

-- BS check 9 – 8: ZE92.3510, SD39.983744, HD err= -0.000234, VD err= -0.012741

-- BS Circle check : angular err= 0.0000

LS, HI1.512, HR1.502

RD, BD 1:0.0005

-- BS zenith: 92.3510, slope dist: 39.985

RB, OP9, BP8, AR0.0005, ZE92.3510, SD39.985, HR1.458, --H

RD, FD 1:108.4255

RD, ZD 1:109.5515

MD, SD 1:65.52

RF, OP9, FP10, AR108.4255, ZE109.5515, SD65.52, HR1.502, --J

RD, BV 1:180.0005

RD, FV 1:288.4255

-- RD, ZV 1:250.0425

-- Not shooting reverse distances.
--Horizontal Angle Error: 0.0000
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0

TR,OP9,FP10,AR108.4250,ZE109.5515,SD65.52,--J

OC,OP10,N 4852.026276,E 5261.186798,EL105.397331,--J

BK,OP10,BP9,BS246.4120,BC0.0000

--HR at Backsight: 1.458

LS,HI1.559,HR1.502

OC,OP10,N 4852.026276,E 5261.186798,EL105.397331,--J

BK,OP10,BP9,BS246.4120,BC0.0000

--HR at Backsight: 1.45

--BS check 10 – 9:ZE70.1115,SD65.481,HD err= 0.005408, VD err= -0.010729

--BS Circle check : angular err= 0.0000

LS,HI1.559,HR1.505

RD,BD 1:0.0000

--BS zenith: 70.1115, slope dist: 65.481

RB,OP10,BP9,AR0.0000,ZE70.1115,SD65.481,HR1.45,--I

RD,FD 1:275.5820

RD,ZD 1:87.2800

MD,SD 1:49.976

RF,OP10,FP11,AR275.5820,ZE87.2800,SD49.976,HR1.505,--K
RD,BV 1:179.5950
RD,FV 1:95.5820
--RD,ZV 1:272.3135
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0010
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0
TR,OP10,FP11,AR275.5825,ZE87.2800,SD49.976,--K
OC,OP11,N 4804.367511,E 5276.065076,EL107.660301,--K
BK,OP11,BP10,BS342.3945,BC0.0000
--HR at Backsight: 1.45
LS,HI1.563,HR1.505
OC,OP11,N 4804.367511,E 5276.065076,EL107.660301,--K
BK,OP11,BP10,BS342.3945,BC0.0000
--HR at Backsight: 1.502
--BS check 11 – 10:ZE92.4250,SD49.975,HD err= -0.008208, VD err= -0.042276
--BS Circle check : angular err= 0.0000
LS,HI1.563,HR1.469
RD,BD 1:0.0000
--BS zenith: 92.4310, slope dist: 49.979
RB,OP11,BP10,AR0.0000,ZE92.4310,SD49.979,HR1.502,--J
RD,FD 1:61.0730
RD,ZD 1:92.4825
MD,SD 1:101.934
RF,OP11,FP12,AR61.0730,ZE92.4825,SD101.934,HR1.469,--L
RD,BV 1:180.0000
RD,FV 1:241.0730
--RD,ZV 1:267.1115
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0000
--Zenith Angle Error: 0.0000
--Horizontal Angle Error compares to the average: 0.0000
--Zenith Angle Error compares to the average: 0.0000
--Slope Distance Error compares to the average: 0.0
TR,OP11,FP12,AR61.0730,ZE92.4825,SD101.934,--L
OC,OP12,N 4877.866519,E 5346.517316,EL102.762508,--L
BK,OP12,BP11,BS223.4715,BC0.0000
--HR at Backsight: 1.502
LS,HI1.535,HR1.469
OC,OP12,N 4877.866519,E 5346.517316,EL102.762508,--L
BK,OP12,BP11,BS223.4715,BC0.0000
--HR at Backsight: 1.505
--BS check 12 – 11:ZE87.1440,SD101.927,HD err= -0.002556, VD err= 0.032346
--BS Circle check: angular err= 0.0000
LS, HI 1.535, HR 1.425
-- RD, BD 1:0.0000
-- BS zenith: 87.1440, slope dist: 101.927
-- RB, OP 12, BP 11, AR 0.0000, ZE 87.1440, SD 101.927, HR 1.505, -- K
-- RD, FD 1:136.3255
-- RD, ZD 1:95.2825
-- MD, SD 1:49.233
-- RF, OP 12, FP 13, AR 136.3255, ZE 95.2825, SD 49.233, HR 1.425, -- M
-- RD, BV 1:179.5955
-- RD, FV 1:316.3305
-- RD, ZV 1:264.3125
-- Not shooting reverse distances.
-- Horizontal Angle Error: 0.0015
-- Zenith Angle Error: 0.0000
-- Horizontal Angle Error compares to the average: 0.0000
-- Zenith Angle Error compares to the average: 0.0020
-- Slope Distance Error compares to the average: 0.0
RD, BD 1:0.0025
-- BS zenith: 87.1430, slope dist: 101.929
RB, OP 12, BP 11, AR 0.0025, ZE 87.1430, SD 101.929, HR 1.505, -- K
RD, FD 1:136.3325
RD, ZD 1:95.2805
MD, SD 1:49.233
RF, OP12, FP13, AR136.3325, ZE95.2805, SD49.233, HR1.425, --M
RD, BV 1:180.0020
RD, FV 1:316.3325
-- RD, ZV 1:264.3140
-- Not shooting reverse distances.
-- Horizontal Angle Error: 0.0005
-- Zenith Angle Error: 0.0000
-- Horizontal Angle Error compares to the average: 0.0000
-- Zenith Angle Error compares to the average: 0.0000
-- Slope Distance Error compares to the average: 0.0
TR, OP12, FP13, AR136.3303, ZE95.2805, SD49.233, --M
OC, OP13, N 4926.874629, E 5346.806595, EL98.181058, --M
BK, OP13, BP12, BS180.2018, BC0.0000
-- HR at Backsight: 1.505
LS, HI 1.487, HR1.425
OC, OP13, N 4926.874629, E 5346.806595, EL98.181058, --M
BK, OP13, BP12, BS180.2018, BC0.0000
-- HR at Backsight: 1.505
-- BS check 13 – 12: ZE84.4255, SD49.22225, HD err= 0.004057, VD err= -0.065831
-- BS Circle check: angular err= 0.0000
LS, HI 1.487, HR1.488
-- RD, BD 1:0.0000
-- BS zenith: 84.4300, slope dist: 49.22225
--RB,OP13,BP12,AR0.0000,ZE84.4300,SD49.22225,HR1.505,--L
--RD,FD 1:0.0000
--RD,ZD 1:
--MD,SD 1:
--RF,OP13,FP,AR0.0000,ZE,SD,HR1.488,--
--RD,BV 1:180.0000
--BS zenith: , slope dist:
--RB,OP13,BP12,AR180.0000,ZE,SD,HR1.505,--L
--RD,FV 1:180.0000
--RD,ZV 1:
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0000
--Zenith Angle Error: 0.0000
RD,BD 1:0.0000
--BS zenith: 84.4300, slope dist: 49.22225
RB,OP13,BP12,AR0.0000,ZE84.4300,SD49.22225,HR1.505,--L
RD,FD 1:160.2720
RD,ZD 1:93.3550
MD,SD 1:77.375159
RF,OP13,FP19,AR160.2720,ZE93.3550,SD77.375159,HR1.488,--N
RD,BV 1:180.0010
RD,FV 1:340.2730
--RD,ZV 1:266.2400
--Not shooting reverse distances.

--Horizontal Angle Error: 0.0000

--Zenith Angle Error: 0.0000

--Horizontal Angle Error compares to the average: 0.0000

--Zenith Angle Error compares to the average: 0.0000

--Slope Distance Error compares to the average: 0.0

TR,OP13,FP19,AR160.2720,ZE93.3550,SD77.375159,--N

OC,OP19,N 4999.799163,E 5321.402666,EL93.325375,--N

BK,OP19,BP13,BS160.4738,BC0.0000

--HR at Backsight: 1.505

LS,HI1.546,HR1.488

OC,OP19,N 4999.799163,E 5321.402666,EL93.325375,--N

BK,OP19,BP13,BS160.4738,BC0.0000

--HR at Backsight: 1.425

--BS check 19 – 13:ZE86.2235,SD77.369063,HD err= -0.008328, VD err= 0.155181

--BS Circle check : angular err= 0.0000

OC,OP19,N 4999.799163,E 5321.402666,EL93.325375,--N

BK,OP19,BP13,BS160.4738,BC0.0000

--HR at Backsight: 1.425

--BS check 19 – 13:ZE86.2235,SD77.3679,HD err= -0.010387, VD err= 0.155051

--BS Circle check : angular err= 0.0000

LS,HI1.546,HR1.394

--RD,BD 1:0.0000
--BS zenith: 86.2230, slope dist: 77.367
--RB,OP19,BP13,AR0.0000,ZE86.2230,SD77.367,HR1.425,--M
--RD,FD 1:0.0000
--RD,ZD 1:
--MD,SD 1:
--RF,OP19,FP,AR0.0000,ZE,SD,HR1.394,--
--RD,BV 1:180.0000
--BS zenith: , slope dist:
--RB,OP19,BP13,AR180.0000,ZE,SD,HR1.425,--M
--RD,FV 1:180.0000
--RD,ZV 1:
--Not shooting reverse distances.
--Horizontal Angle Error: 0.0000
--Zenith Angle Error: 0.0000
RD,BD 1:0.0000
--BS zenith: 86.2225, slope dist: 77.366
RB,OP19,BP13,AR0.0000,ZE86.2225,SD77.366,HR1.425,--M
RD,FD 1:109.1350
RD,ZD 1:88.5320
MD,SD 1:321.425
RF,OP19,FP20,AR109.1350,ZE88.5320,SD321.425,HR1.394,--Old A
RD,BV 1:180.0000
RD,FV 1:289.1350

136
--RD,ZV 1:271.0625

--Not shooting reverse distances.

--Horizontal Angle Error: 0.0000

--Zenith Angle Error: 0.0000

--Horizontal Angle Error compares to the average: 0.0000

--Zenith Angle Error compares to the average: 0.0000

--Slope Distance Error compares to the average: 0.0

--Traverse later to point: 20

TR,OP19,FP20,AR109.1350,ZE88.5320,SD321.425,--Old A

OC,OP20,N 4999.93549,E 5000.038132,EL99.710234,--Old A

BK,OP20,BP19,BS90.0128,BC0.0000

--HR at Backsight: 1.425

OC,OP19,N 4999.799163,E 5321.402666,EL93.325375,--N

BK,OP19,BP13,BS160.4738,BC0.0000

--HR at Backsight: 1.435

TR,OP19,FP21,AR215.4400,ZE93.2810,SD71.241,--nail

OC,OP21,N 5067.971693,E 5341.631346,EL89.166139,--nail

BK,OP21,BP19,BS196.3138,BC0.0000

--HR at Backsight: 1.435

LS,HI1.576,HR1.394

OC,OP21,N 5067.971693,E 5341.631346,EL89.166139,--nail

BK,OP21,BP19,BS196.3138,BC0.0000

--HR at Backsight: 1.435
--BS check 21 – 19:ZE86.4210,SD71.248666,HD err= 0.020291, VD err= 0.079675
--BS Circle check : angular err= 0.0000
LS,HI1.576,HR1.435
SS,OP21,FP22,AR0.0000,ZE86.4210,SD71.248666,--C
DP,PN22
TR,OP21,FP22,AR160.2305,ZE92.5420,SD219.581407,--Ottinger
OC,OP22,N 5286.952348,E 5329.81703,EL78.176606,--Ottinger
BK,OP22,BP21,BS176.5443,BC0.0000
--HR at Backsight: 1.435
SP,PN18,N 4896.968516,E 5047.621293,EL109.853514,--E
--Adjustment begin: Traverse Adjust
--Compass Rule
--Closed Traverse
--Original
  ■ Error Distance: 0.075
  ■ Error Azimuth: 329°24′46″
-- Precision: 1:18712
-- Length: 1,402.266
-- Perimeter: 1,402.341
--Adjusted
  ■ Error Distance: 0.000
  ■ Error Azimuth: ---
-- Precision: Perfect
-- Length: 1,402.266
-- Perimeter: 1,402.266

-- Traverse Point

-- The first point (1) is always fixed.

-- Traverse Point

AP, PN2, N 4963.36448, E 4836.658351, EL 101.735468, -- B

-- Sideshots

AP, PN15, N 4986.546575, E 4821.204388, EL 98.452588, -- Liews
AP, PN16, N 5097.49831, E 4819.79951, EL 87.808837, -- Andrews

-- Traverse Point

AP, PN3, N 4870.797489, E 4833.145672, EL 109.576374, -- nail

-- Sideshots

AP, PN17, N 4864.550733, E 4819.764121, EL 112.27455, -- C

-- Traverse Point

AP, PN4, N 4870.319057, E 4966.857115, EL 109.561409, -- D

-- Traverse Point

AP, PN18, N 4896.990543, E 5047.608273, EL 109.853514, -- E

-- Traverse Point

AP, PN6, N 4928.745425, E 5139.334917, EL 101.703916, -- F

-- Traverse Point

AP, PN7, N 4921.240324, E 5197.404639, EL 98.255518, -- G

-- Traverse Point

AP, PN8, N 4857.354093, E 5177.856353, EL 125.97404, -- H
-- Traverse Point
AP,PN9,N 4827.683971,E 5204.595472,EL127.711399,--I

-- Traverse Point
AP,PN10,N 4852.063206,E 5261.164968,EL105.397331,--J

-- Traverse Point
AP,PN11,N 4804.406738,E 5276.041888,EL107.660301,--K

-- Traverse Point
AP,PN12,N 4877.91043,E 5346.49136,EL102.762508,--L

-- Traverse Point
AP,PN13,N 4926.920796,E 5346.779306,EL98.181058,--M

-- Traverse Point
AP,PN14,N 5000.049728,E 5321.327139,EL93.21002,--N

-- Traverse Point
AP,PN20,N 5000.0,E 5000.0,EL99.710234,--Old A

-- Adjustment end
SP,PN100,N 224225.8018,E 926010.4843,EL529.843,--LEWIS
SP,PN101,N 224755.8206,E 926270.9375,EL509.338,--Ottinger

-- Adjustment begin: Rotation

-- Base Point: 15

-- Angle: 326.4415

-- Angle computed from (Old Az: 59.2556) to (New Az: 26.1011)
AP,PN1,N 5095.860921,E 4963.328416,EL100.0,--Start
AP,PN14,N 5272.142618,E 5231.984136,EL93.21002,--N
AP,PN2,N 4975.638605,E 4846.841289,EL101.735468,--B
AP,PN3,N 4896.310568,E 4894.674847,EL109.576374,--nail
AP,PN15,N 4986.546575,E 4821.204388,EL98.452588,--Liews
AP,PN16,N 5078.550159,E 4894.674847,EL109.576374,--Andrews
AP,PN4,N 4969.247992,E 5006.742286,EL109.561409,--D
AP,PN17,N 4883.747785,E 4886.911835,EL112.27455,--C
AP,PN18,N 5035.839841,E 5059.63504,EL109.853514,--E
AP,PN6,N 5112.702042,E 5118.917008,EL101.703916,--F
AP,PN7,N 5138.276357,E 5171.589331,EL98.255518,--G
AP,PN8,N 5074.135071,E 5190.283752,EL125.97404,--H
AP,PN9,N 5063.991664,E 5228.915448,EL127.711399,--I
AP,PN10,N 5115.403757,E 5262.845549,EL105.397331,--J
AP,PN11,N 5083.714643,E 5301.423544,EL107.660301,--K
AP,PN12,N 5183.81579,E 5320.016047,EL102.762508,--L
AP,PN13,N 5224.954548,E 5293.375826,EL98.181058,--M
AP,PN19,N 5271.974529,E 5232.184717,EL93.325375,--N
AP,PN20,N 5095.860921,E 4963.328416,EL99.710234,--Old A
AP,PN21,N 5340.073054,E 5211.708289,EL89.166139,--nail
AP,PN22,N 5516.697481,E 5081.723992,EL78.176606,--Ottinger

--Adjustment end

--Adjustment begin: Translate

--Azimuth: 90.0000

--Azimuth computed from (Point: 15) to (Point: 100)
--Horizontal Distance: 0.0
--Vertical Distance: 0.0

AP,PN1,N 224335.116146,E 926152.608327,EL531.390412,--Start
AP,PN14,N 224511.397844,E 926421.264047,EL524.600432,--N
AP,PN2,N 224214.893831,E 926036.121201,EL533.12588,--B
AP,PN3,N 224135.565793,E 926083.954758,EL540.966786,--nail
AP,PN15,N 224225.8018,E 926010.4843,EL529.843,--Liews
AP,PN16,N 224317.803585,E 925948.45526,EL519.199249,--Andrews
AP,PN4,N 224208.503217,E 926196.022198,EL540.951821,--D
AP,PN17,N 224123.00301,E 926076.191747,EL543.664962,--C
AP,PN18,N 224275.095066,E 926248.914952,EL541.243925,--E
AP,PN6,N 224351.957267,E 926308.19692,EL533.094328,--F
AP,PN7,N 224377.531583,E 926360.869243,EL529.64593,--G
AP,PN8,N 224313.390296,E 926379.563664,EL557.364452,--H
AP,PN9,N 224303.24689,E 926418.195359,EL559.101811,--I
AP,PN10,N 224354.658982,E 926452.12546,EL536.787743,--J
AP,PN11,N 224322.969868,E 926490.703456,EL539.050713,--K
AP,PN12,N 224423.071015,E 926509.295959,EL534.15292,--L
AP,PN13,N 224464.209773,E 926482.655737,EL529.57147,--M
AP,PN19,N 224511.229754,E 926421.464629,EL524.715787,--N
AP,PN20,N 224335.116146,E 926152.608327,EL531.100646,--Old A
AP,PN21,N 224579.32828,E 926400.988201,EL520.55655,--nail
AP,PN22,N 224755.952707,E 926271.003904,EL509.567017,--Ottinger
--Adjustment end

SP,PN1,N 224335.116146,E 926152.608327,EL531.390412,--A
VITA

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B.S. Surveying and Mapping, East Tennessee State University, Johnson City, Tennessee 2003
M.S. Technology, East Tennessee State University, Johnson City, Tennessee 2007

Professional Experience: Survey Party Chief, Grusenmeyer-Scott; Orlando, Florida, 1997-1999

Honors and Awards: Geomatics Student of the Year, East Tennessee State University
Resident of the Year, East Tennessee State University
Dedication to the University Department and Division for Housing and Residence Life, East Tennessee State University