University of Southern Queensland
Faculty of Engineering and Surveying

Effectiveness of Real Time Kinematic Global Navigation Satellite System Surveying (RTK GNSS)

A dissertation submitted by
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ABSTRACT

The use of Global Navigation Satellite Systems (GNSS) is becoming increasingly widespread, especially in the spatial science industry. The effect of additional GNSS systems such as the Russian GLONASS system in combination with the American Global Positioning System (GPS) is investigated in this research.

RTK surveying is an effective means of surveying for a range of applications, which delivers accurate coordinates to the user in real time. It is expected that in less than two years there will be over 70 satellites in operation from the major satellite systems, GPS, GLONASS, COMPASS and GALILIO.

The current operation of RTK GNSS relies largely on research and knowledge obtained from the use of RTK GPS over the last decade. An increase in the number of satellites available will theoretically lead to a higher accuracy and precision, and a more effective and efficient surveying tool.

Testing has been undertaken to determine how a variation in the number of GLONASS satellites affect the accuracy, precision and Time to First Fix (TTFF) of a RTK GNSS receiver. The results of this testing suggest that additional satellites do lead to a shorter TTFF, which is backed up by previous research conducted in this area. It also shows that RTK GNSS is at all times high in accuracy when the initialisation integrity is maintained. The precision of RTK GNSS is also quite high when initialisation integrity is maintained, however the results show that the addition of GLONASS satellites does not improve these figures. In fact, the addition of one or two GLONASS satellites often has an adverse effect, and results in a lesser accuracy and precision.

This research shows that RTK GNSS is an accurate and precise tool for surveying if the initialisation integrity is maintained. The addition and variation in the number of GLONASS satellites does not improve accuracy and precision, however results agree with past research that it will lead to a more robust and reliable solution.

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Limitations of Use

Candidates Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Signature

29/10/2008
Date

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NOMENCLATURE

DOP	Dilution of Precision
FOC	Full Operational Capacity
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
RTK	Real Time Kinematic
NMEA	National Marine Electronics Association
ppm	part per million
TTFF	Time to First Fix

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The use of Global Navigation Satellite Systems is becoming increasing widespread, especially as more satellite systems are expected to reach their full operational capacity (FOC). In only two years it is expected that there will be up to 70 satellites in operation (Rizos Et al. 2005) from the 4 major systems, GPS, GLONASS, COMPASS and GALILEO. The surveying industry commonly uses these satellites in Real Time Kinematic (RTK) Surveys, a process which delivers accurate and efficient coordinates to the user in real time.

Currently, the operation of RTK GNSS relies on the research and knowledge obtained from using RTK GPS in the last decade. There are some issues that are new to RTK GNSS that require further investigation. These issues include how the additional satellites from the various global navigation systems affect the accuracy, reliability, precision and effectiveness of RTK surveying. An investigation into previous research and testing has found that there are some questions and gaps in our knowledge of the effectiveness of RTK GNSS. This includes how a variation in the number of GLONASS satellites affects RTK surveying; this is detailed in chapter 2.

1.2 Research Aim

The aim of this research is to assess the effectiveness of RTK GNSS Surveying in terms of satellite availability and satellite geometry in relation to the GLONASS satellite system.

This effectiveness of RTK GNSS will be determined by examining the following factors, which are explained in detail in chapter 2:

- Accuracy

- Reliability
- Precision
- Time to First Fix (TTFF)

Tests will be conducted to investigate changes in the above elements as the number of GLONASS satellites vary. The results of testing will be analysed to determine how GLONASS or GPS satellite availability and geometry improves or impedes the effectiveness of RTK GNSS.

1.3 Justification

As to be demonstrated in Chapter 2, there is still a significant amount of research to be conducted into the use of GNSS systems. Many people in the surveying industry use GPS as the only satellite system when carrying out RTK or Post Processed surveys. As RTK GNSS use becomes more widespread, it is important that the implications of additional satellite systems are fully understood to ensure the surveyor can rely upon their equipment for practical purposes. This research will seek to explain and assess some of these with respect to the effectiveness of RTK GNSS in terms of satellite numbers and geometry.

In many everyday situations, the use of RTK GNSS has only minimal quality and field checks. In general, a check shot to an additional known control point is taken at the start of the session, at the end of the session, and occasionally during the session. However, between check shots, in a period of time that could be several hours, the availability and geometry of the satellites from all GNSS systems may change. This may or may not lead to additional errors or inaccuracies in the collected data, or it may lead to data that is higher in accuracy. This effect of this will be difficult to judge by the surveyor. Research into whether the accuracy and precision degrades with the additional satellites from GNSS, and other effects, such as TTFF will help in the understanding of this issue.

1.4 Summary: Chapter One

This research is expected to explain how additional satellites influence the effectiveness of RTK GNSS. A comprehensive review of literature and research has been conducted to form a background of knowledge to this topic. To complete this research, testing is required with a RTK GNSS system, and an analysis of results will be required. The conclusions drawn from this research will indicate how RTK GNSS performs in varying situations. This will be of use to surveyors in the future to allow increased confidence in their abilities to use RTK GNSS.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Over the past ten years there has been an increase into research on Global Navigation Satellite Systems (GNSS's). The increasingly common use of GLONASS satellites in addition to GPS satellites for surveying purposes, and the expected future use of GALILEO, has prompted investigations into their compatibility and effectiveness. Currently, for real time kinematic surveying purposes, there are a range of receivers that utilise signals from the American Global Positioning System and the Russian GLONASS system.

2.2 Global Navigation Satellite Systems

The Global Navigation Satellite System includes all global navigation satellite constellations, in particular GPS, GLONASS and GALILEO. A fourth system, COMPASS was launched by China in April 2007, and could reach full operation capacity (FOC) by 2010, around the same time that GALILEO reaches FOC (Chen et al 2007). For surveying applications in Australia, GPS and GLONASS are the primary systems used, and are effectively integrated into many surveying instruments.

2.2.1 Status of GLONASS, GPS, COMPASS and GALILEO

The United States GPS has been in operation since the launch of the first satellite in 1978 and this system is currently undergoing a modernisation process (Trimble 2006). This will see additional satellites launched, and additional carriers for military and civilian uses. New improvements in GPS will include a civilian L2C frequency and an L5 frequency to compliment the existing L1 and L2 frequencies.

The Russian GLONASS constellation is very similar to GPS (Rizos et al 2005). In the last 4 years the Russian government has launched a revitalisation of the constellation. The aim of this is to reach FOC in 2010 with the transmission of two civil signals, L1 and L2. By the year 2012, it is planned that the full constellation will be broadcasting three sets of civil signals. The main difference between GLONASS and GPS signals is that each GLONASS satellite transmits its own unique frequency, while all GPS satellites transmit on the same frequency and are distinguished by a unique code broadcasted by each satellite. It is important to note that all issues relating to the compatibility of the above systems have been resolved (Rizos et al 2005).

The Europeans Union GALILEO system is expected to reach FOC by 2010. This system will also be similar in structure to the GPS, with a full constellation of 24 satellites expected. These satellites will broadcast in a similar manner to GPS, being at similar frequencies. The Chinese COMPASS system is also due to reach FOC in the coming years, with a global coverage of 35 satellites.

2.3 Measurement of the Effectiveness of RTK GNSS

2.3.1 Accuracy and Precision

Accuracy and precision are measures of how well the integer ambiguities are solved. Rizos (2003) defines repeatable accuracy as ‘the accuracy at which a user can return to a position whose coordinate has been measured at a previous time’. Predictable accuracy is also explained as how close a position will be in comparison to a mapped point. The accuracy of RTK GNSS is how close the calculated position is to the true coordinates.

The precision of RTK GNSS is a measure of the ‘degree of confinement or consistency of a group of observations’ (Wolf and Ghilani 2002). High precision means that the resolved coordinates for a point will be similar for each measurement, however they are not necessarily accurate.

2.3.2 Time to First Fix (TTFF)

The Time to First Fix (TTFF) is the time required by the receiver to resolve the integer ambiguities and compute a position. The speed at which a position is calculated has a direct influence on how fast and efficient the task at hand is completed in real world surveying applications (Rizos et al. 2005).

2.4 Factors Contributing to Effectiveness of RTK GNSS

2.4.1 Satellite Availability

The availability of satellites at the time of survey can influence the effectiveness of RTK GNSS in several ways. The number of satellites can affect the speed at which the integer ambiguities are resolved, the quality of the computed position, and the robustness of the computed position (Lemmon and Gerdan 1999). With increased GNSS satellites available, there will be additional redundant measurements, which will ensure the computed position is more robust which will reduce errors.

2.4.2 Satellite Geometry

The geometry of the satellites relative to the receiver will influence the accuracy, precision and TTFF of the measurement. If the satellites are clustered, or your view of the sky is obstructed, you will have a large Dilution of Precision (DOP). This is a mathematical indicator of how good the satellite geometry is, and how the geometry of satellites will effect your accuracy (Mylne 2007). The best scenario for the improved effectiveness of RTK GNSS is that the satellites are spread across the sky in each of the four quadrants with an elevation of between 40° and 70° (Geodetic Surveying A, Study Book 2, 2005)

Other factors and possible errors can include:

- Troposphere and ionosphere delay

- Satellite clock bias
- Broadcast ephemeris errors

These effects can pose problems in GNSS navigation or positioning, however the effects of these are removed or significantly mitigated (Rizos 2003) through differential GPS surveying. This is due to the errors that are present at the base receiver are also present in a similar magnitude at the roving receiver, so therefore they cancel each other out.

2.5 Previous Research and Testing

In recent times there has been a considerable amount of research conducted into how factors such as satellite numbers affect the use of RTK GPS. Over the last ten years there has been a shift from the investigation of GPS only, to GNSS systems, as they become a more widespread technology. Interesting conclusions have been reached in testing done by Lemmon and Gerdan in 1999 and by Mylne in 2007, which is contradicted in some areas by simulation studies carried out by Rizos, Higgins and Hewitson in 2005, these will be described in the next section. The testing conducted by these three parties relate to how additional satellites, and in the case of Mylne and Rizos, how GLONASS satellites effect RTK effectiveness.

2.5.1 Effect of Satellite Numbers on RTK Surveying

The effect that the number of satellites has on RTK GNSS surveying was investigated by Lemmon and Gerdan in 1999 and by Rizos, Higgins and Hewitson in 2005. Below, the research conducted by these two is explained.

Lemmon and Gerdan 1999

The Influence of the Number of Satellites on the Accuracy of RTK GPS Positions

Research and testing was undertaken by Lemmon and Gerdan in 1999 which analysed the effect that the number of satellites has on the accuracy of RTK positions for the GPS constellation only. This research investigated the influence satellite numbers had on the positions calculated by a receiver over a 10 kilometre baseline. Over 3000 positions were collected over a four day period with changing satellite constellations. A computer program was written to control the operation of the roving GPS receiver, to extract RTK position information before forcing the receiver to stop tracking satellites temporarily and the reinitialize (Lemmon and Gerdan 1999).

The test was conducted with a Trimble 4000SSE receiver with a VHF radio real time communication link. Every 15 seconds the receiver was analysed for the best position, and if the ambiguities were resolved the position and point information (including the number of satellites and PDOP information) were recorded to a text file. The true position of the roving receiver was determined by a 24 hour static survey. Positions recorded that were more than 3 times the manufactures specifications from the static position were considered rouge and were omitted from the test.

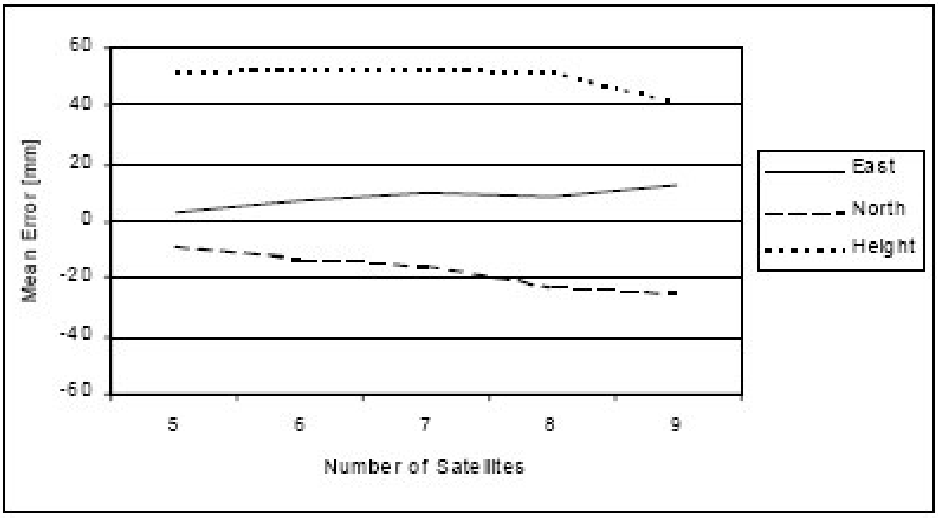


Figure 2.5.1 The mean error in relation to the number of GPS Satellites did not improve as the satellite numbers increased (Lemmon and Gerdan 1999)

The results from this test indicated that an increase in satellite numbers did not improve the accuracy of the RTK positions (Lemmon and Gerdan 1999).This is demonstrated in Figure 2.5.1 above. However, as satellite numbers increased the reliability and precision did improve, with the standard deviations decreasing as satellite numbers increased, in particular in the height component. Refer to figure 2.5.2.

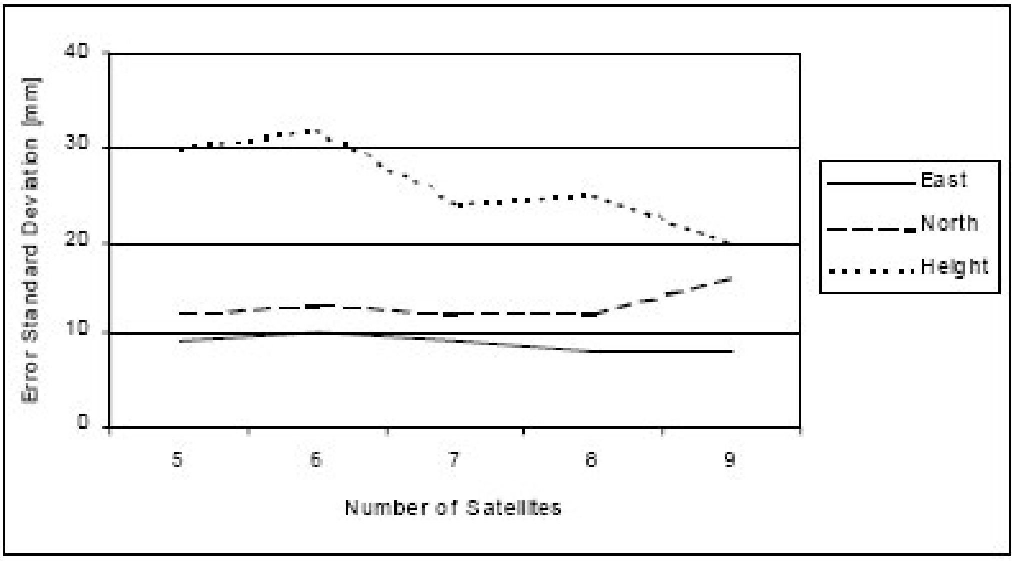


Figure 2.5.2 The Standard Deviation decreased as Satellite numbers increased (Lemmon and Gerdan 1999)

In analysing the PDOP values for the collected data, the precision and accuracy of positions collected with large PDOP's with only five satellites were similar to those collected with nine available satellites and low PDOP's. This suggests that the geometry of the satellites has no effect on the accuracy and precision of RTK GPS. The results from the test showed that when there were only five satellites and the average PDOP was 4.2, the average time to initialize was 166 seconds. In comparison when there were eight or nine satellites, with a PDOP of under 2.0, there were considerably less inaccurate initialisations and the average time to initialise for eight satellites was 78 seconds and for 9 satellites it was 91 seconds. This was a decrease in TTFF of over 75 seconds.

Rizos, Higgins, Hewitson 2005

New GNSS Developments and Their Impacts on Surveyors

This research investigates the background and theory of today's GNSS. From this knowledge, potential opportunities and issues are explored, and simulations of satellite locations are investigated for GPS, GLONASS and GALILEO.

Initially, the three main GNSS systems are described, before the expected advantages of a broader GNSS are examined. Simulation studies were carried out in order to determine the improvements to satellite visibilities and DOP's (Rizos Et Al 2005) for a combined GNSS. In this study, Japan's proposed 3 satellite Quasi Zenith Satellite System (QZSS) was also included.

The simulation had the following features:
- The GLONASS constellation contained 24 satellites in 3 orbital planes
- The GALILEO constellation contained 27 satellites with 3 spares in 3 orbital planes
- The GPS constellation was obtained from current ephemerides at the time of study

A scenario was assessed over Brunei for 24 hours starting at 1200h on the 27th May 2005 (Rizos Et Al 2005). From this simulation it was determined that for the 24 hour period there was a minimum of 17 satellites, with an average of 21. The corresponding Dilution of Precision values were found to be between 1.0 and 1.5, as compared to between 1.5 and 3.5 for just GPS only. This scenario had an elevation cut-off angle of 15°.

A similar scenario was also examined for the same time period with an elevation cut-off angle of 40° which could represent an urban environment. Similar results were found, in that the DOP values for the GNSS system were considerably better than just GPS, although on average only 8 satellites were available. A global snapshot of the visibility of GNSS satellites was generated for 1200h on the 27th May 2005. This shows that at that point in time, with a masking angle of 15°, most areas can see around 20 satellites or more.

The benefits of more satellites are expected to include improved continuity, accuracy, reliability, efficiency and availability (Rizos et al 2005).

- Improved continuity means that there is unlikely to be a major system disruption as GPS, GALILEO and GLONASS are independent systems.

- The improvements in accuracy are due to the additional satellites being available, more signal measurements and therefore more redundant observations to ensure ambiguities are resolved correctly, and the position will be less affected or influenced by satellite geometry.

- Improved efficiency as additional satellites will speed up the TTFF (Rizos et al 2005).

- Availability will improve particularly in urban canyons, open cut mines, steep terrain and other areas where the sky is obstructed.

- Reliability is improved as the extra redundant measurements due to increased satellite numbers ensures outlying results are identified and removed earlier.

Predictions for the future and some issues relating to GNSS are described, such as whether the signals will be fully compatible, whether you will need to subscribe to a system to access their signals, and possible implications to continuously operating reference stations (CORS). However, it is demonstrated by this research that additional satellites should improve the effectiveness of GNSS systems.

Summary: Effect of Satellite Numbers on RTK Surveying

The findings from these two investigations pose some interesting questions. Lemmon and Gerdan found that an increase in GPS satellites did not improve the accuracy of RTK GPS, but allowed greater reliability and a faster TTFF. Rizos et al concluded through simulation studies (no actual testing of receivers) that additional GNSS systems, i.e. GLONASS, will also lead to greater reliability, availability and TTFF and several other factors. This research also concluded that the additional satellites would lead to improvements in accuracy of RTK surveying, as there are more redundant observations.

2.5.2 GLONASS/GPS Testing

Mylne 2007

The Effectiveness of Multiple-Frequency Global Navigation Satellite Systems (GNSS) on Multipath Mitigation

Research was conducted into the effects that a difficult operating environment has on a RTK GNSS receiver in comparison to a RTK GPS only receiver. The test was conducted over a 24 hour period in a high and low multipath environment, for both a RTK GPS receiver and a RTK GNSS receiver. The aim was to analyse the effect the additional GLONASS satellites have on multipath mitigation. This was done by assessing the number of fixed solutions, TTFF, accuracy and precision (Mylne 2007) of the computed positions for the receivers.

The receiver involved in the testing process was the Trimble SPS880, capable of receiving GLONASS and GPS signals. The testing was done in four parts. The first two were observing solely GPS, and then GPS and GLONASS for 24 hour periods. The second two were the same as the first; however a multipath plane (a round metal disk under the receiver) was fixed to the receiver for the 24 hour periods (Mylne 2007). For all four periods the receiver was plumbed over a screw in concrete with known coordinates, less than 1 metre from a wall, and data was logged for 180 seconds before being reset after 30 seconds (this was done with the use of a USQ custom made program called RTK Collector which controlled the operation of the rover). The wall blocked around half of the sky, and introduced multipath into the testing in addition to the inclusion of the multipath plane.

The results were analysed in several different ways:

Number of initialisations: As expected the GNSS receivers outperformed the GPS receivers, with the GNSS receiver without the multipath plane having the highest number of initialisations.

TTFF: The Time to First Fix for the GNSS receiver was also better than the GPS receiver, with an improvement of around 17 seconds.

Accuracy and Precision: The accuracy and precision of the coordinates, in respect to easting, northing and ellipsoidal heights were examined. It was found, that due to a large number of outlying observations, that these results could be misleading and was statistically unbalanced. Therefore, the number of outlying observations was examined. The outlying observations were those that were three times the manufactures specifications from the true coordinates. It was found that the GNSS receivers had a lower percentage of outlying observations, which indicated that it was more reliable than the GPS in a high and low multipath environment.

Occupation time: The results were examined to determine if the outlying observations corrected themselves within the 180 second observation time. This test showed that a significant proportion of outlying observations did not correct themselves over the above timeframe.

Overall, Mylne found that the multipath mitigation capabilities of the GNSS receiver were greater than that of the GPS receiver, and it indicated that the GNSS receiver had an improved precision, and a greater reliability (Mylne 2007).

Summary: GLONASS/GPS Testing

This research and testing was conducted to determine if GNSS had better multipath mitigation capabilities compared to a GPS receiver. This was found to be correct, as the GNSS receiver had fewer outlying observations. In terms of accuracy, when the outlying observations were removed, it was found that RTK GPS was similar to RTK GNSS. The TTFF and reliability of GNSS was also found to be improved as compared to RTK GPS.

2.6 Summary: Chapter Two

This chapter has introduced the current status of the major Global navigation satellite systems. As shown, there is only limited research into the effectiveness of RTK GNSS in relation to satellite numbers.

Similar research with RTK GPS only found that additional satellites made no improvement to the accuracy and precision of RTK surveying (Lemmon and Gerdan 1999). It was also found, by Mylne in 2007, that additional satellites from the GLONASS satellites do not have a great effect on accuracy and precision under multi-path conditions. It is important to note, that for this data, all outlying positions were removed from the dataset. Simulation studies conducted by Rizos et al in 2005 show how the satellite constellation in coming years will change. It indicates that due to this, there will be an increased effectiveness of RTK GNSS; however no practical testing was undertaken.

There is obviously a research gap in that the effects of the additional satellites on RTK surveying are not fully known. Do GLONASS satellites improve the accuracy and effectiveness of RTK GNSS in normal conditions, and as the number of satellites increase, will accuracy improve even more? Simulation studies suggest it does, however previous testing in different situations suggest the accuracy may not improve significantly.

CHAPTER 3

METHOD

3.1 Introduction

Specific research objectives were identified by examining previous research into the performance of RTK GPS and RTK GNSS, and these objectives will be assessed based on a test methodology and analysis procedure developed in this chapter.

This chapter will present the test methodology and analysis procedure, and allow the testing to be undertaken in a controlled manner.

Due to technical and logistical difficulties, the testing procedure was required to be adjusted midway through the project. This resulted in two distinct tests being conducted, named Test One and Test Two.

3.2 Testing Objectives

The aim of the testing procedure is to determine the effectiveness of RTK GNSS in relation to the addition of GLONASS satellites. The effect of the GLONASS constellation, in addition to the GPS constellation was the only GNSS's investigated as these two systems are the only two in everyday use in Australia. The effect of an increase in GLONASS satellite numbers will be assessed by examining the following factors:

- Accuracy
- Reliability
- Precision
- Time to First Fix (TTFF)

To assess these factors, suitable test locations are required, as well as pre-test settings, data collection requirements, and a data analysis methodology. These will be explained for both Test One and Test Two.

3.3 Test One

3.3.1 Location and Facilities

Test One was conducted on the roof of the Engineering and Surveying building, Z block, at the University of Southern Queensland, Toowoomba shown in Figure 3.3.1 below. This is the same location as previous receiver testing conducted recently, by Mylne in 2007.

Figure 3.3.1 Test location on the roof of Z block, USQ, Toowoomba

The semi-permanent GNSS base station is positioned over a Permanent Survey Mark with MGA coordinates on the seventh level, and is controlled via software installed on a computer in the antenna hut on level five. This antenna hut is adjacent to an observation deck where the testing is to take place, refer to Figure 3.3.2 below.

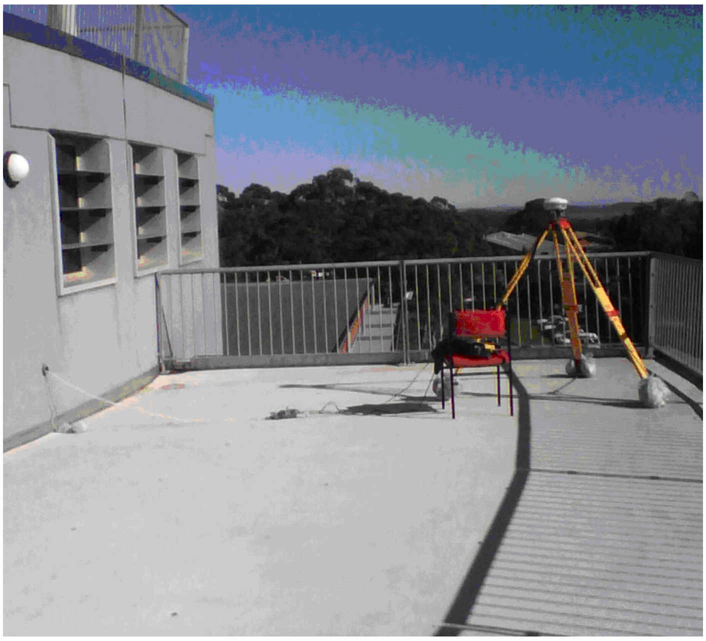


Figure 3.3.2 The receiver set up ready for testing

The Trimble SPS880 Receiver (v3.25, boot version 3.00) was set up on a tripod on the observation deck. This position was chosen as it had easy access to the antenna hut, which housed the GNSS base station controller, allows for a connection to mains power and a laptop to configure and record the data. The receiver was positioned as far as possible from the building to minimise obstruction, and to minimise the effect of multipath.

The SPS880 receiver was configured via the laptop in the computer hut. This was done with Trimble GPS Configurator (version 3.5.2.5), a program which allowed details such as output format, elevation cut-off angles, GPS and GLONASS tracking to be set. The settings for this were as follows:

- Multi channel GPS and GLONASS Tracking
- Elevation Cut-off angle of 10°
- PJK NMEA Output format as shown in Appendix A

To control the data collection, a program developed by USQ technicians called RTK Collector was used. This controlled the receiver and allowed the user to set recording constraints and to record the data into a text file. The settings for this were:

- 30 second power off/reset time

- 90 second observation time before shutting down again
- Recording of data every one second

3.3.2 Test Process

The testing was undertaken over a 24 hour period in July 2008 at the location mentioned in section 3.3.1. Testing commenced an around 1.00PM and was intended to conclude at 1.00PM the next day. Due to unforseen technical problems during the test, the test was shortened considerably. For this reason a second test was conducted, in a different location, and with a different procedure, which will be explained in section 3.4.

The laptop with the required programs was set up in the computer hut, and connected to the Trimble SPS880 receiver set on a tripod via a services duct. After an initial test run to ensure the system was correctly working, the test commenced. All indications were that the test was running as required. The 'RTK Collector' program was recording the data, and controlling the Receiver correctly. The receiver was tracking both GPS and GLONASS satellites, had a reliable radio link to the Base station, and a reliable power source.

During the tests conducted by Mylne in 2007, he reported issues where the GPS receiver reset its internal settings during the test. After ensuring the test was running correctly, it was left before another check and data backup was carried out prior to close of business that afternoon. It still appeared to be running correctly, so it was left for the night. Upon checking it first thing the next morning, it was found that at some stage during the night the process had stopped, and data was no longer being recorded. It appeared that the receiver had once again reset its internal settings, although when we ensured that they were reset, communication could not be regained between the receiver and RTK Collector. After a considerable amount of time, the test was aborted.

During the analysis phase of this test it was found that during the first couple of hours the receiver stopped tracking GLONASS Satellites, and further reduced the amount of data available. This however, was only found in the analysis process, at a later stage.

3.3.3 Overview of Test One

This test was designed to examine all of the factors identified in the research aims. The TTFF, accuracy, precision and reliability would be able to be determined as the process allowed the receiver to reinitialise over the same point, independent of the past observations. This data can be collected and statistically analysed to assess how the receiver responds to changes in satellite availability. Due to unfamiliarity with the Trimble GNSS equipment, and a range of unforseen technical problems, this test was aborted with only a small amount of data available for analysis.

3.4 Test Two

3.4.1 Location and Facilities

This test was conducted at a private premise on the Sunshine Coast, in South East QLD. The equipment used was a Leica 1200 GNSS system for this test. The setup involved one Base station and one rover set on a tripod over a temporary control mark, as per the photo shown in Figure 3.4.1.

Figure 3.4.1 Base and Rover set up for data collection

The receiver was positioned approximately 10 metres from the base, and both were controlled via a Bluetooth connection to their controllers inside the building. This allowed the radio, base controller, radio receiver, and rover controller to be kept secure. The Bluetooth connection was considered robust over the line of sight through a window of less than 15 metres, refer to figure 3.4.2 below

Figure 3.4.2 Controller setup with a Bluetooth connection

3.4.2 Test Process

The testing commenced at approximately 10:00am in August and continued for 24 hours with the rover being configured to record a position every two seconds to the internal storage. The data was stored in a DBX format, which contains information such as time, Horizontal DOP and Vertical DOP values and satellite numbers when imported into Leica Geo Office. The system is also configured to export the data directly to a text or .CSV file containing point ID's, and coordinates. The Base was configured to record observation data for later examination if required. As there were some minor obstructions, due to trees, the raw observation data recorded from the base and rover would show what satellites dropped out and when, to ensure accuracy of the analysis process.

The equipment was able to be left for around six hours at a time. After this time, a battery change was undertaken, which took around three minutes. The equipment used has several batteries. The rover has one in the antenna, which was the most critical, lasting around seven hours. There were also two batteries on the controller, with one of these powering the radio receiver. These had a slightly better life of 10 hours. The Base had one in the antenna and one in the controller; however the radio was powered by a 12 volt dry cell battery with a life of over 12 hours. All batteries, except for the 12 volt battery were changed every six hours to ensure no power failures were experienced.

3.4.3 Overview of Test Two

This test was unable to assess the effect of GLONASS satellites on the TTFF as data corresponding to the initialisation process was removed from the dataset. This is because the receiver was forced to initialise only five times when the batteries were changed. This test will allow the data to be examined for accuracy, precision and reliability in relation to changes in the GNSS constellation, and the number of GLONASS satellites.

3.5 Analysis of Test One Data

The analysis of the data was conducted in manner which would ensure the accuracy of the results. This analysis was done using Microsoft Excel, in a similar format to that used by Mylne, 2007. This will allow for a comparison of these results to Mylnes, and previous projects completed like this.

3.5.1 Reduction of NMEA Data to a Useable Format

The NMEA Output message was saved automatically to a text file by RTK Collector. An example of this data is shown below:

Message ID	UTC of position fix	Date	Northing, in metres	Direction, always North	Easting, in metres	Direction, always east
`$PTNL,PJK`	`031740.00`	`071608`	`+6946314.425`	`N`	`+394479.542`	`E`

GPS Quality indicator	Number of satellites in fix	DOP of fix	Ellipsoidal height	Checksum data
3	13	1.6	`EHT+726.183`	`M*44`

The GPS quality indicator is a value between 0 and 4, with a three meaning the solution is a RTK fixed solution.

The data was imported into Microsoft excel, which allowed the unnecessary information to be removed. All that was remaining after this was:

UTC of position fix	Northing, in metres	Easting, in metres	GPS Quality indicator	Number of satellites in fix	DOP of fix	Ellipsoidal height
031740.00	6946314.425	394479.542	3	13	1.6	726.183

For each initialisation, the data was edited to contain only two lines: One for the first observation when the receiver was first powered up and one for when a fixed solution was gained.

3.5.2 Calculation of 'True Coordinates'

The true coordinates were determined by using an arithmetic mean of the fixed solutions over a two hour period. This result excluded observations outside of a 95% confidence interval, and returned the values of:

Northing:	6946314.427
Easting:	394479.540
Ellipsoidal Height:	726.178

These results are relative, and cannot be considered the actual coordinates of the station. However, for the purpose of this research, it allows for a fixed point to compare coordinates against for analysis purposes.

3.5.3 Compilation of Data

The data was then compiled into a format ready for easy analysis. This contained the two lines of data explained before, but with the coordinates converted into distances from the mean. The UTC time was also converted into a useable format, wholly in seconds. The raw format is in hours, minutes, and seconds (*hhmmss*) which is difficult to process as it is not based on the decimal system.

The last requirement, and possibly the most important, was determining how many GLONASS satellites were in each recorded observation. This was done by taking into account the obstructions around the receiver, which were minimal, and the position of the satellites from the emperies. The numbers were then compared to what was recorded in the observation, and the total was split into GPS and GLONASS numbers. The data is now ready for a statistical analysis.

3.5.4 Statistical analysis: TTFF

Due to the abortion of the test, and lack of data, an analysis was only carried out on the TTFF. The data was compiled into groups based on the number of GLONASS satellites in the fix. The average TTFF of each group was then calculated, which then allowed for a comparison of how fast this process is when there are increased numbers of GLONASS satellites.

3.5.5 Overview of Test 1 Analysis Process

The results are based on a very small number of useable observations. For this reason, it was considered necessary to do a second test. The results of test one cannot be considered conclusive, and are an indication only.

3.6 Analysis of Test Two Data

The analysis of test two was done in a similar manner in Microsoft Excel. This test resulted in a large number of observations which was vital to ensure accuracy and confidence in the conclusions and results.

3.6.1 Reduction of Raw Data

At the completion of the test, the data was exported from the instrument in a CSV format. This contained a point ID, Easting, Northing, and Reduced Level. The Observation data was imported into Leica Geo Office, and from this further information was extracted, Refer to Appendix B This data contained similar information to the NMEA output file in Test One, including, HDOP, VDOP, point ID and the total number of satellites. The two datasets were then matched according to their unique point ID's which makes them ready for further analysis.

3.6.2 Calculation of True Coordinates

The true coordinates were determined by using an arithmetic mean of the fixed solutions over a six hour period. These results can be considered an accurate estimation of the mean, as the calculation involved around 10000 observations and had a standard deviation of around 0.002 metres.

3.6.3 Compilation of Data

To prepare the data for a statistical analysis, a similar process was used as in Test One. The coordinates were converted to distances from the mean, and the data was then grouped according to the number of GLONASS satellites, and then into subgroups based on the number of GPS satellites.

The process of splitting the observations into groups was done with the raw observation data in Leica Geo Office. Upon analysis of the occupied points, a timeline can be produced of what satellites were used in the observation, refer appendix C. The total number of satellites can then be divided into two groups, GLONASS and GPS, by counting how many of each are in the solution.

This task was a lengthy process, however the end results allowed for easy manipulation of the data.

3.6.4 Statistical Analysis

The first step of the statistical analysis process was to determine the descriptive statistics of each of the groups. This included the mean, standard deviation, range etc of the coordinates. It also included the mean, maximum and minimum DOP values for the set.

To examine the comparability of the datasets, the DOP values for the constellation of GPS satellites without the GLONASS satellites were estimated. This was done in Trimble Planning Utility and Leica Geo Office by assessing the mean DOP value for the observations in the dataset as recorded in the field and by comparing them to the planning programs over the same time periods. The data, if of a similar magnitude, confirms the accuracy of the program, and when the GLONASS satellites are deselected, a DOP value is returned for the GPS only constellation. This will allow a comparison between groups, i.e.
GROUP A with 7 GPS satellites and 2 GLONASS satellites, and;
GROUP B with 7 GPS satellites and 5 GLONASS satellites
(Refer to APPENDIX D for a full example)

If the calculated DOP values for the GPS only constellation are similar, then the change in GLONASS numbers is the major variable. Any effect on accuracy and precision between the two groups may be due to this.

3.6.5 Overview of Test Two Analysis Process

The process described above has allowed for a comparison of datasets where the major variable is the change in GLONASS satellite numbers. The results of this will allow conclusions to be drawn in relation to accuracy and precision. The effect of GLONASS satellites on RTK GNSS can be examined by the change in accuracy over time, and as the constellation of satellites changes. Graphs can be generated to show the change in the descriptive statistics as GLONASS numbers increase, and tests can be conducted to determine if there are any significant changes in these values. The results of this test are based on a spread of observations, with a total of 33,000 observations. The GLONASS satellite numbers range from zero to five, so it can be assumed that the data recorded is an accurate reflection of real circumstances.

3.7 Conclusions

The two tests will allow for an investigation into what effect additional GLONASS satellites have on RTK GNSS. These results will be presented in the next chapter, and will justify the conclusions that are drawn.

As explained earlier, Test One data can be used as an indication only, due to the small sample size, and unreliability of the testing procedure. However Test Two was completed with no difficulties and a large amount of data was collected for analysis. The process described above will present the data in a format which will allow conclusions to be easily understood.

CHAPTER 4

RESULTS

4.1 Introduction

The testing and analysis methods described in the preceding chapter, has produced a spread of results. These results were obtained from specifically designed tests to assess certain elements of RTK GNSS Surveying, which can be analysed to achieve the objectives of this research as defined in Chapter One.

This Chapter will present the results in a format suitable for comparison and analysis between variations in the GNSS constellation, which will allow detailed analysis and conclusions to be drawn in the next chapters.

The results obtained from Test One will be presented, followed by the results of Test Two. These will be presented in both a tabular and a graphical format for ease of analysis.

4.2 RESULTS OF TEST ONE

4.2.1 True Coordinates

For the purposes of comparison of the data that was collected in Test One, the 'true coordinates' of the test point need to be computed. This is done in the manner described in section 3.5.2

The true coordinates were based on the mean value in the Easting, Northing and Height components of the raw GPS observation data, with a 95% confidence interval to ensure outlying observations were removed from this calculation.

The 'true coordinates' for this test were calculated to be:

Northing: 6946314.427m

Easting: 394479.540m

Ellipsoidal Height: 726.178m

4.2.2 Number of Initialisations

The total number of initialisations was reduced considerably due to problems in the testing. During the test, there was only 31 initialisations recorded which included the GPS and the GLONASS constellation. The remainder of the initialisations had no GLONASS satellites in the solution, even though there were some available. These were discarded as they had no use in relation to accessing the benefits of GLONASS in RTK Surveying.

4.2.3 TTFF

This test was able to give an indication of the effect of GLONASS satellites on the TTFF. The data can be compiled to show the time in seconds that it took to gain initialisation, and the number of GPS and GLONASS satellites that were in the solution. Refer to Figure 4.2.3 below for this data;

Number of GLONASS satellites	TTFF (secs)	Number of Observations
0	81	18
1	76	7
2	72	5

4.2.4 Accuracy

The accuracy of RTK GNSS was not investigated in this test due to the lack of data; this would be assessed in test two.

4.2.5 Precision

The precision of RTK GNSS was not investigated in this test due to the lack of data, this would be assessed in test two.

4.2.6 Reliability

The reliability of RTK GNSS was not investigated in this test due to a lack of data. Test Two will allow some results to be produced, however due to the nature of the test; this element will not be able to be investigated fully.

4.2.7 Summary of Test One Results

The results of Test One will only form a small part of the analysis process, due to the minimal amount of data collected. This data can be considered as only a small sample; therefore these results cannot be used as an accurate indication of the effect of GLONASS satellites on RTK Surveying.

The results of Test Two will now be presented in detail, and these will form the majority of the data utilised in this research.

4.3 RESULTS OF TEST TWO

4.3.1 True Coordinates

The true coordinates of the receiver were determined in the same method as test one, in that the mean value of the observation data was calculated. This calculation utilised around 10,000 observations, collected over a six hour period.
The 'true coordinates' for this test were calculated to be:

Easting:	511865.729m
Northing:	7033855.545m
Height:	1.299m

4.3.2 Spread of Observations

During the 24 hour testing period 23,677 observations were recorded, ranging from zero to five GLONASS satellites and from seven to twelve GPS Satellites. The data was then grouped according to the number of satellites that were in each observation, these numbers are presented below.

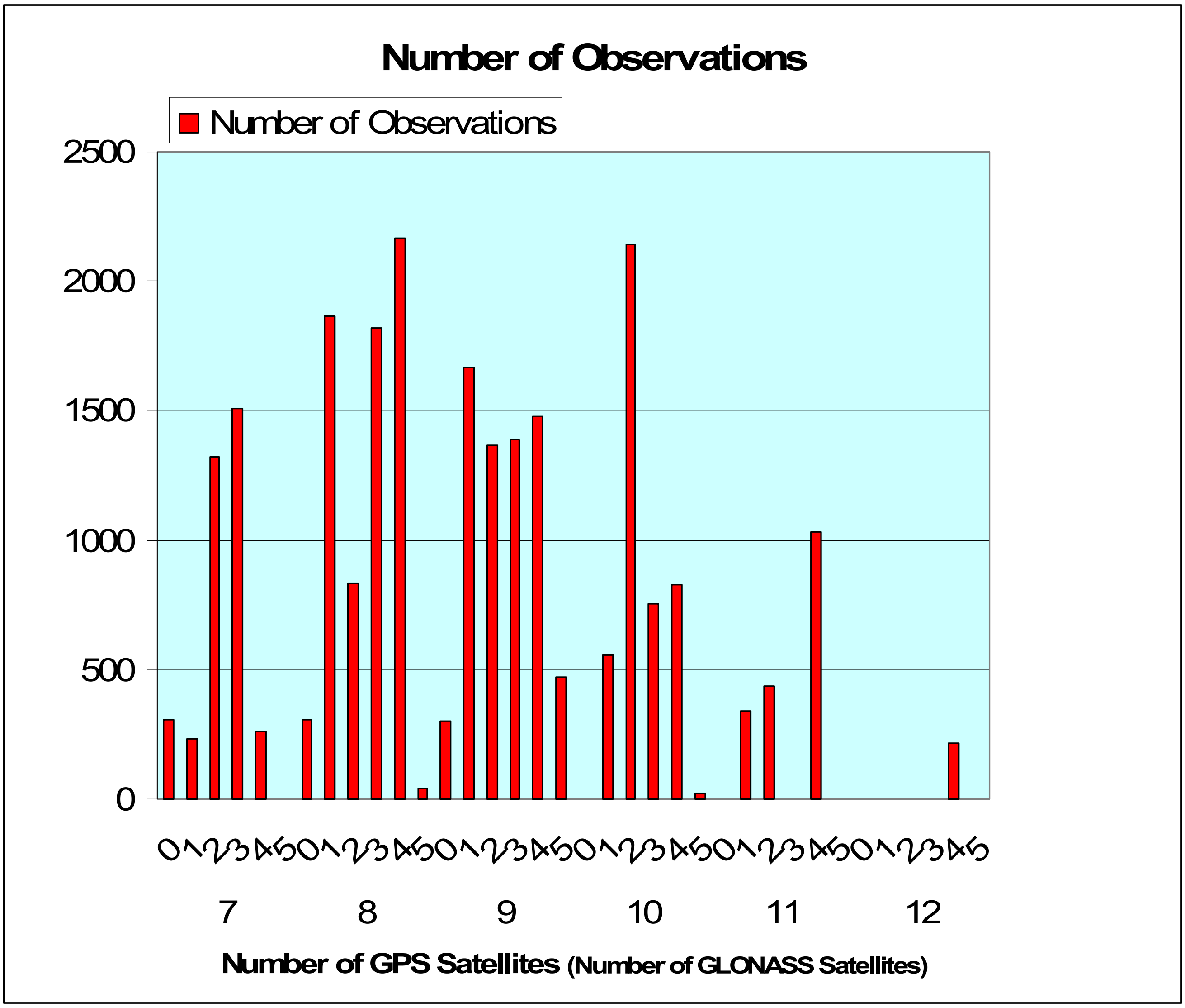


Figure 4.3.2 Total Number of Observations recorded

To ensure the data collected relevant, the data had to be assessed for comparability, based on the DOP values of the constellations.

To assess the objectives of the research, the above data groups need to be compared to determine the effect of a change in the number of GLONASS satellites. To do this, the strength of the GPS Constellation needs to be the same or similar as the number of GLONASS satellites vary.

4.3.3 Comparison of DOP Values

Using Leica Geo Office and Trimble Planning Utilities, the average DOP values for the datasets without the effect of the GLONASS satellites can be computed. This removes the effect of a change in GLONASS numbers from the DOP values, and allows a determination of how similar the GPS constellation is. This process will remove any data from the comparisons that is bias, or is influenced by strong or weak satellite geometry.

This test resulted in a series of the datasets being removed from the results, as they had significantly different DOP values for the GPS constellation. Therefore, a comparison of the effect of GLONASS involving these datasets is not reliable as the effect of the change in the GPS constellation is unknown.

The following results are considered comparable, as the data described above has been removed.

4.3.4 Accuracy

Initially the results were compared only amongst datasets with the same number of GPS satellites. However, due to the high accuracy which was found in all cases, it was more effective to combine all of the comparable results. This allowed for a clearer picture to be formed. The following figure shows the accuracy and how it changes as the number of GLONASS satellites increase.

	Component Accuracy (millimetres)		
No GLONASS Satellites	Easting	Northing	Height
0	-0.3	2.0	0.5
1	0.4	-0.6	2.7
2	0.3	0.4	-2.3
3	0.0	0.0	-0.7
4	0.5	0.1	-0.6

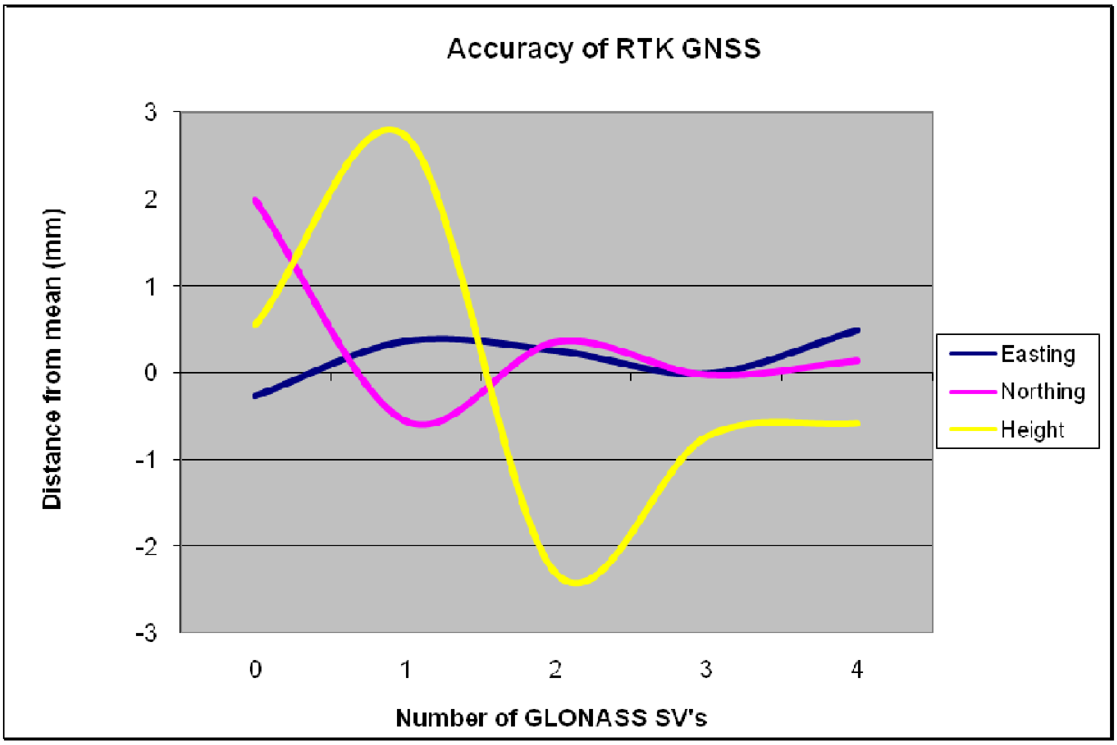


Figure 4.3.4 Distance from the mean of RTK GNSS in millimetres

4.3.5 Precision

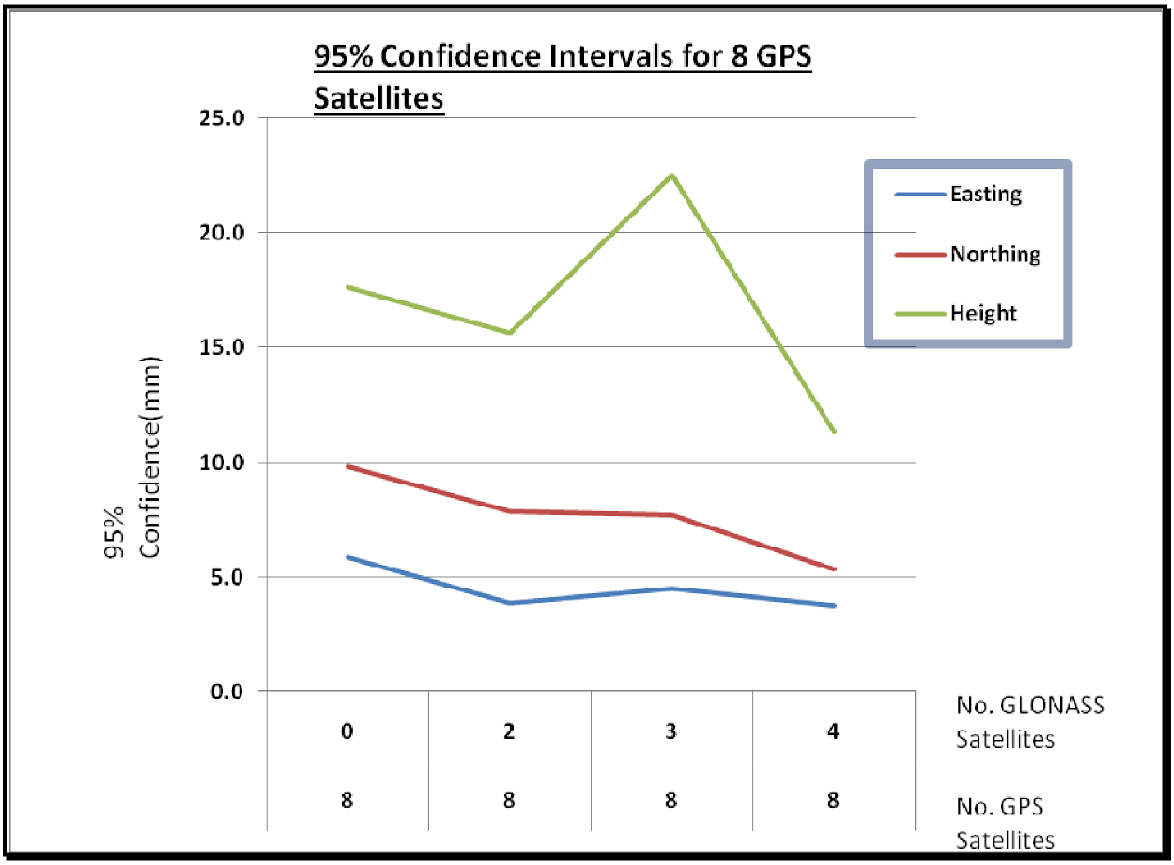
The precision is found by calculating the standard deviations and the 95% confidence intervals for the datasets. This was done for each sample, and these results are presented below.

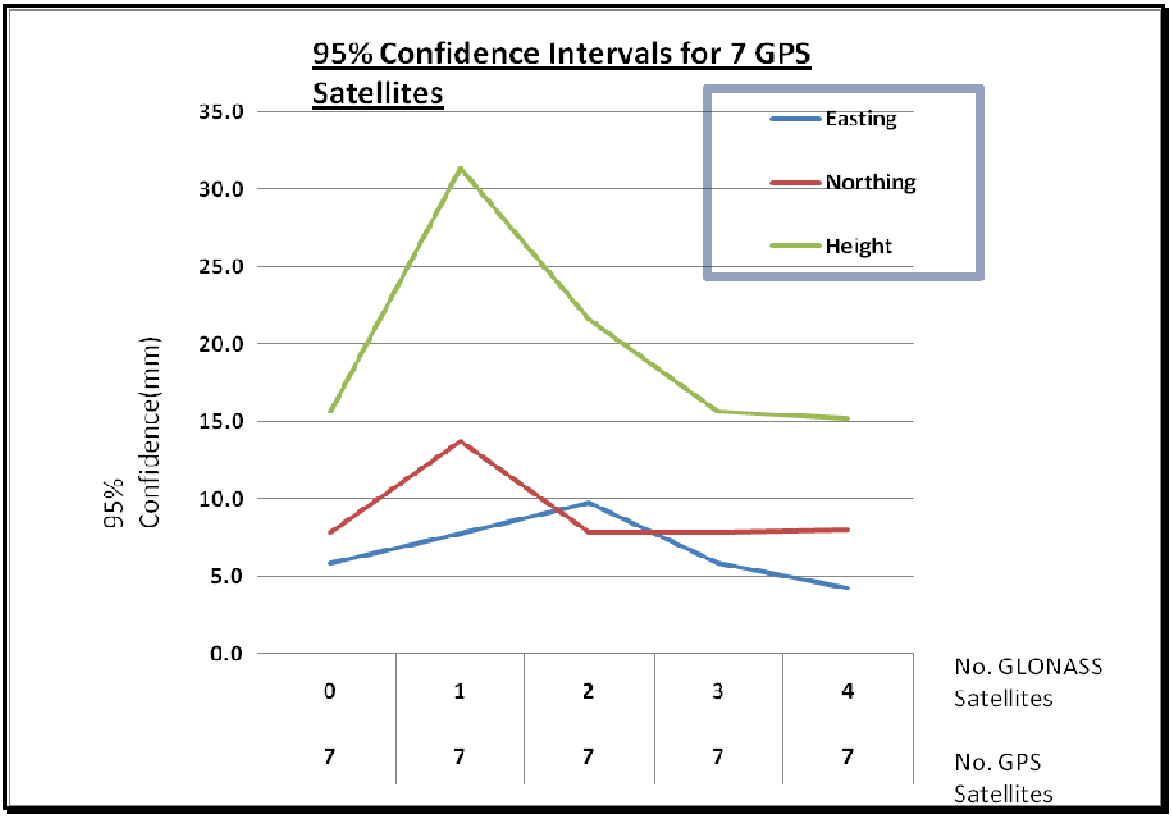
This table shows the standard deviations calculated from the data based on the number of GPS and GLONASS satellites in the solution:

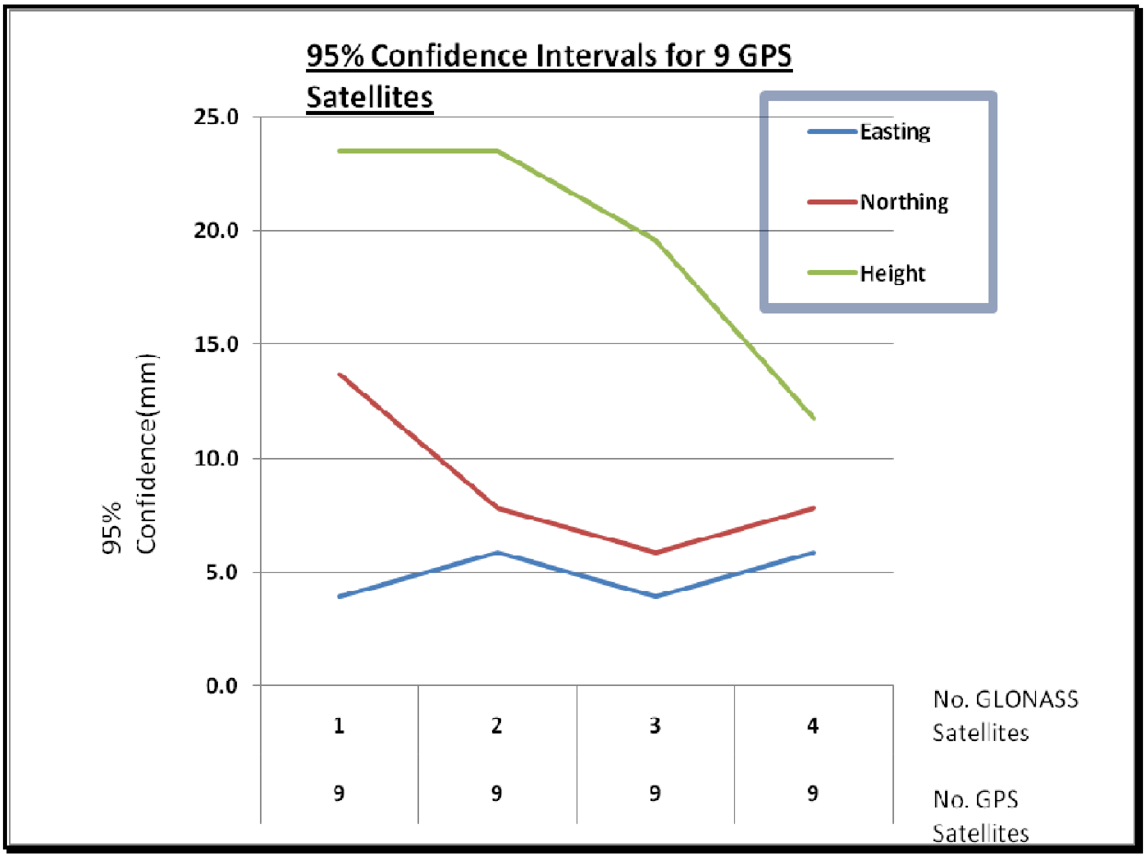
Standard Deviations (metres)				
Easting	Northing	Height	No. GPS	No. GLONASS
0.003	0.004	0.008	7	0
0.004	0.007	0.016	7	1
0.005	0.004	0.011	7	2
0.003	0.004	0.008	7	3
0.002	0.004	0.008	7	4
0.003	0.005	0.009	8	0
0.002	0.004	0.008	8	2
0.002	0.004	0.012	8	3
0.002	0.003	0.006	8	4
0.002	0.007	0.012	9	1
0.003	0.004	0.012	9	2
0.002	0.003	0.01	9	3
0.003	0.004	0.006	9	4
0.003	0.006	0.008	10	1
0.003	0.003	0.009	10	2
0.003	0.003	0.008	10	3
0.002	0.007	0.007	11	1
0.003	0.003	0.01	11	2
0.002	0.005	0.009	11	4

Figure 4.3.5 Standard deviations of each dataset

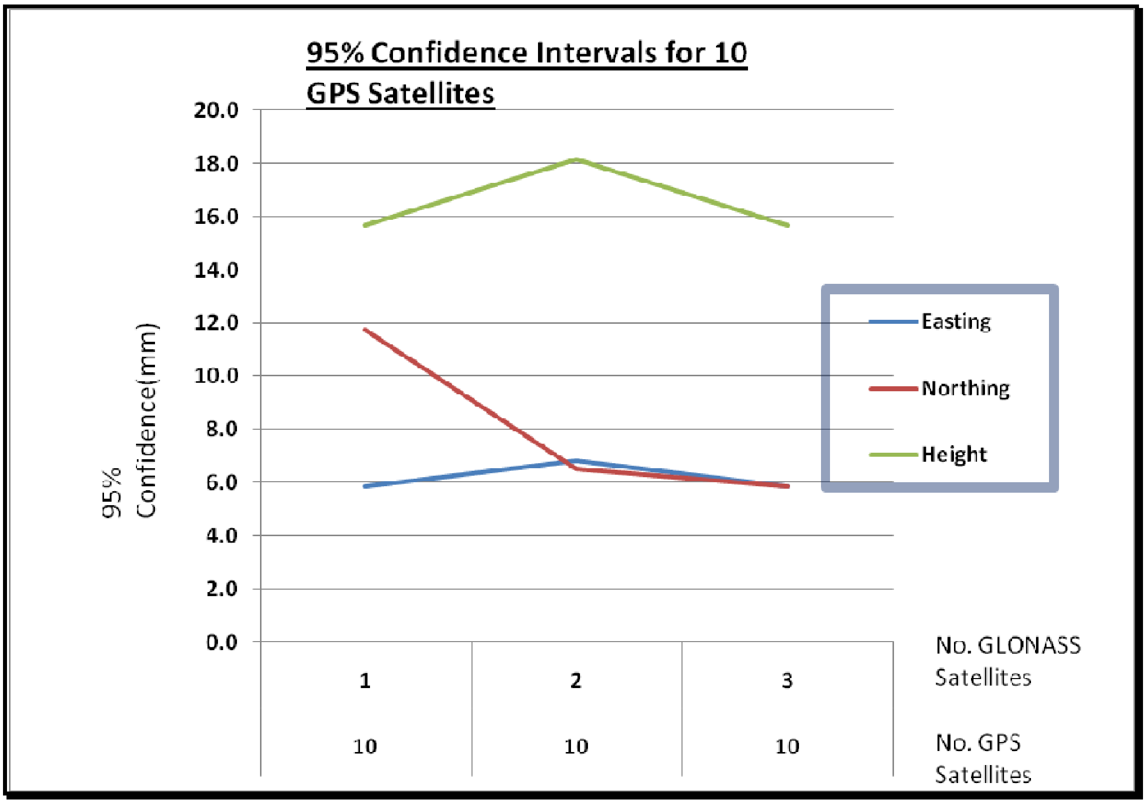
From these, the 95% confidence intervals can be calculated. This value represents a range from the mean that all bar 5% of observations will be within. These values are shown in the figures below for each group based on the same number of GPS satellites:


95% Confidence Intervals for 8 GPS Satellites
25.0
20.0
15.0
10.0
5.0
0.0
95% Confidence(mm)
Easting
Northing
Height
0
2
3
4
8
8
8
8
No. GLONASS Satellites
No. GPS Satellites


95% Confidence Intervals for 7 GPS Satellites
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
95% Confidence(mm)
Easting
Northing
Height
0
1
2
3
4
7
7
7
7
7
No. GLONASS Satellites
No. GPS Satellites



95% Confidence Intervals for 9 GPS Satellites
25.0
20.0
15.0
10.0
5.0
0.0
95% Confidence(mm)
Easting
Northing
Height
1
2
3
4
9
9
9
9
No. GLONASS Satellites
No. GPS Satellites



95% Confidence Intervals for 10 GPS Satellites
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
95% Confidence(mm)
Easting
Northing
Height
1
2
3
10
10
10
No. GLONASS Satellites
No. GPS Satellites

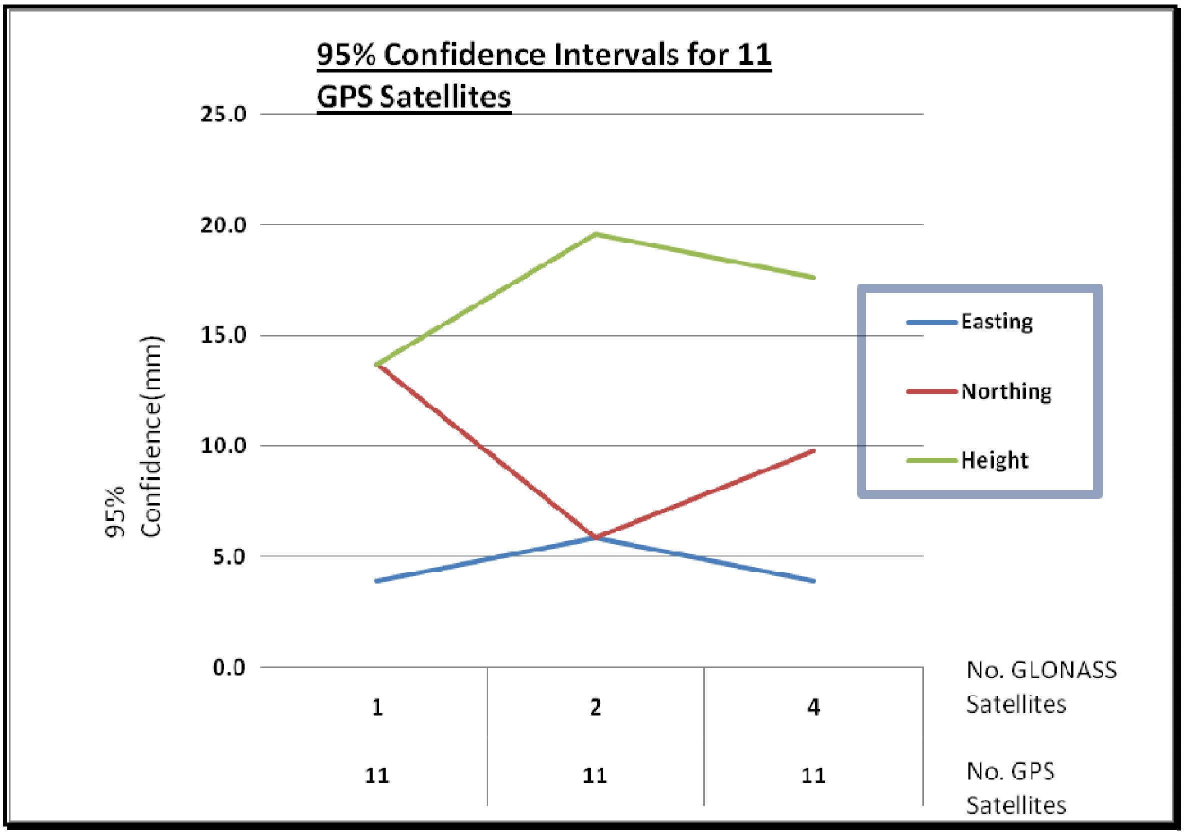


Figure 4.3.6 The 95% Confidence Intervals as the number of GLONASS satellites change

4.3.6 Reliability

The reliability cannot be accurately presented, due to a range of factors. The test involved a receiver continuously operating with a fixed solution, so at all times there was a fixed solution available. When one part of the equipment was switched off, and the receiver was forced to reinitialise, solutions were obtained that were significantly different. The test itself also didn't allow the results to show when the receiver had a fixed or a float solution, so to ensure the accuracy of the data, the first five minutes of data was removed to ensure these false solutions were not included. This resulted in a considerable amount of observation data that was continuously of a high quality. For this reason, an accurate analysis of the reliability will not be performed.

4.3.7 Summary of Test Two Results

The results of test two above will form the major part of the analysis in this research. This test will allow analysis of the accuracy and precision of RTK GNSS as the number of GLONASS satellites change.

In combination with the results of test one, these will provide data for analysis into how a change in the number of GLONASS satellites effect RTK GNSS. As explained, the results of test one were not complete, and can only provide an indication of the effect variations in the number of GLONASS satellites.

CHAPTER 5

ANALYSIS OF RESULTS

5.1 Introduction

The analysis of the results obtained in the previous chapter is a vital part of this research, and allows the formation of suitable conclusions.

This chapter will use the results presented in the previous chapter and will analyse them using statistics to allow conclusions to be drawn on the effectiveness of RTK GNSS in relation to the addition of the GLONASS constellation.

The remainder of this chapter will statistically analyse the elements, of accuracy, precision and TTFF, and describe the analysis process.

5.2 Results Analysis

5.2.1 Time to First Fix

The time a receiver takes to gain a fixed solution is an important measure of a receiver's ability. In many surveying situations the TTFF dictates the speed of a survey, and a superior receiver has many advantages to one which is slower.

The results of Test One do show an improvement in the TTFF as the number of GLONASS satellites increase. This trend can be shown more effectively in a line graph (Refer to Figure 5.2 below), but as explained in chapter four, this can only be considered as an indication of what would happen, as there is only a small amount of data available.

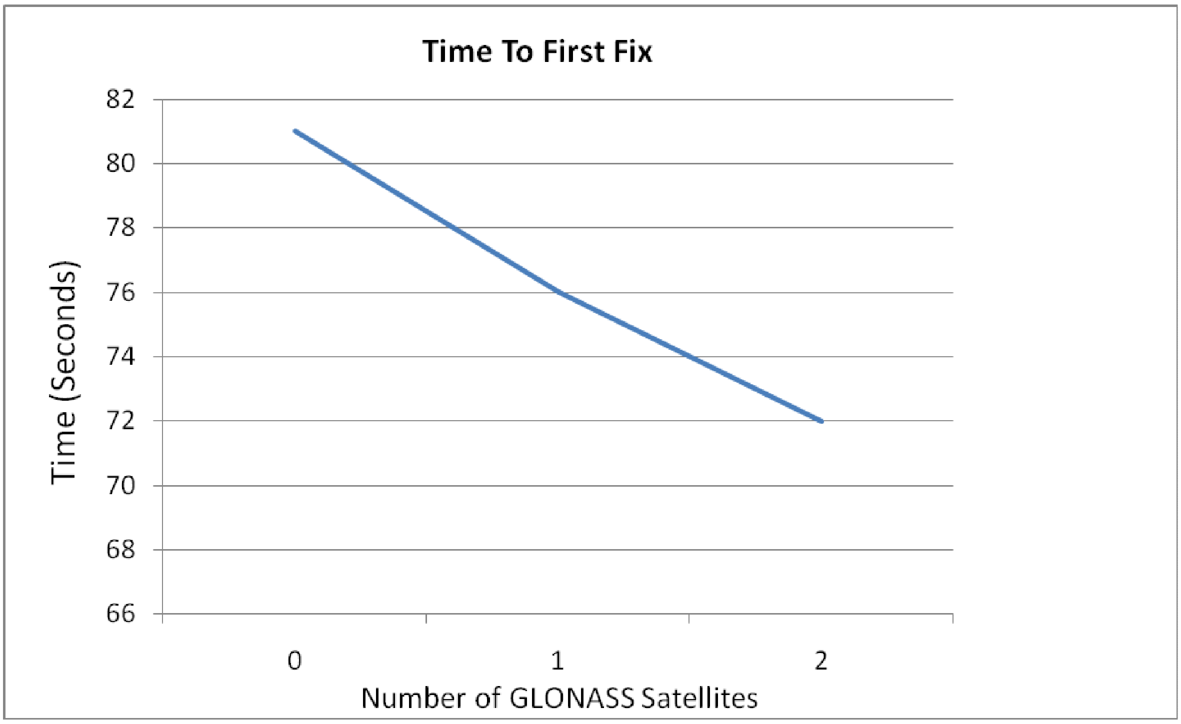


Figure 5.2 Trend of the TTFF as the number of GLONASS Satellites increase

As the graph shows, there is an improvement in the time to first fix of between four and five seconds for additional GLONASS satellites. Once again this data is not reliable, and this is also because the changes in the GPS constellation are not taken into account.

5.2.2 Accuracy

The accuracy was not assessed in Test One due to the small number of observations. The data collected in Test Two is not the best for assessing the accuracy of RTK GNSS. This is because the test process involved a receiver that was continuously receiving GNSS signals. For this reason, the results obtained were continuously of a high accuracy.

To truly assess RTK GNSS accuracy a test method similar to that of Test One would be required. This forces the receiver to reinitialise, and an investigation of the accuracy can be then undertaken. This would match real life situations, where RTK GNSS is moving in and out of lock repeatedly.

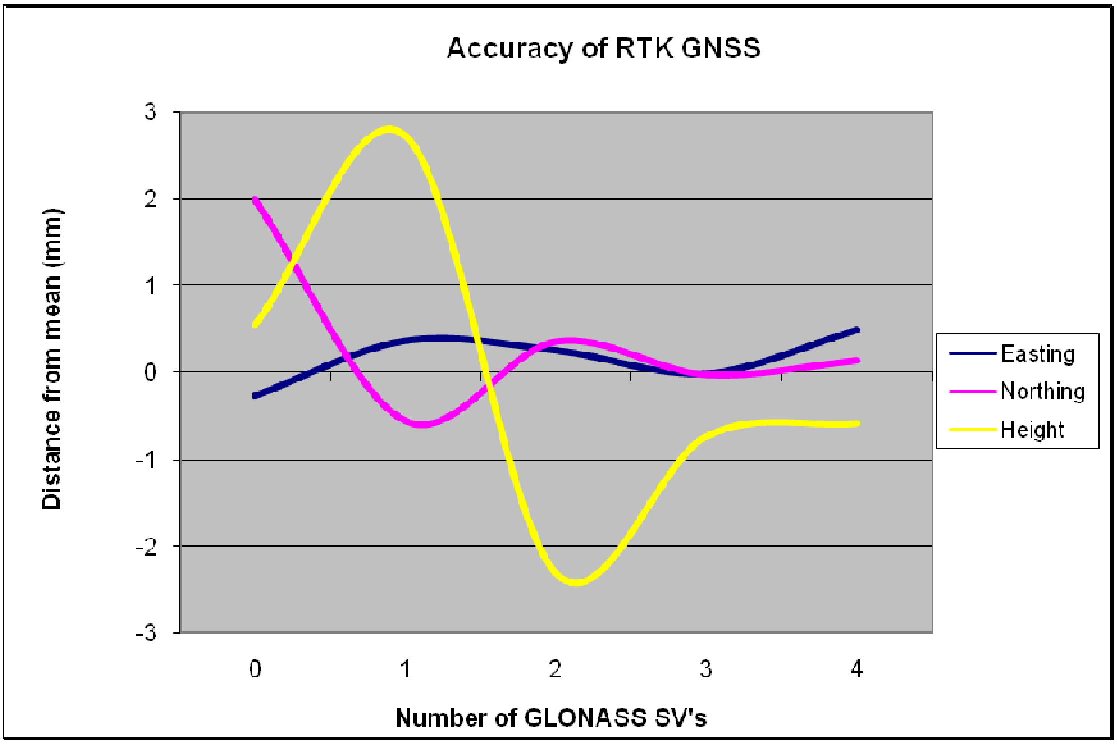


Figure 5.3 Distance from the mean of RTK GNSS in millimetres

The results presented in chapter four are recreated in figure 5.3 above. These show that there is perhaps a slight improvement in accuracy as the GLONASS numbers increase, however realistically, this is minimal.

The levels of accuracy in the above graph are all within three millimetres of the mean. For most RTK receivers the horizontal accuracy is given as ±10mm + 1ppm, and the vertical accuracy as ±20mm + 1ppm (Leica Smartstation Manual, 2008). This shows that the sheer number of observations is evenly centred around the true coordinates and an analysis of the standard deviations will give us an idea of the spread of observations.

The levels of accuracy shown above are extremely high, and for most current field applications would be insignificant and undetectable.

5.2.3 Precision

An analysis of the effect on precision due to a variation in the number of GLONASS satellites can be done using the results presented in chapter four. Five graphs were presented in section 4.3.5 showing the variation in the 95% confidence intervals for each group of observations. These 95% confidence interval results had the following characteristics as the number of GLONASS satellites increased:

Satellites Available	7 GPS 0,1,2,3 & 4 GLONASS
Easting	Increase of 4mm at 2 GLONASS SV's, before decreasing by 6mm
Northing	Similar levels bar peak at 1 GLONASS, which is 6mm higher
Height	Increase of 16mm at 1 GLONASS, before decreasing constantly over 17mm

Satellites Available	8 GPS 0,2,3 & 4 GLONASS
Easting	Steady decrease over 2mm
Northing	Steady decrease over 4mm
Height	Steady decrease over 8mm, bar abnormal peak at 3 GLONASS SV's of over 5mm

Satellites Available	9 GPS 1,2,3 & 4 GLONASS
Easting	Steady, variations only between 2mm
Northing	decrease over 6mm
Height	decrease over 11mm

Satellites Available	10 GPS 1,2, & 3 GLONASS
Easting	Steady, variations only between 1mm
Northing	decrease over 6mm
Height	Peak at 2 GLONASS, only 2mm higher

Satellites Available	11 GPS 1,2, & 4 GLONASS
Easting	Peak at 2 GLONASS, only 2mm higher
Northing	decrease over 7mm at 2 GLONASS, before increasing 4mm
Height	Increases a minimum of 4mm

As you can see, there is a wide variation in the results. A general trend that was found was that the Easting is more precise than the northing, which in turn is more precise than the height component.

These observations indicate that the precision does improve as the number of GLONASS satellites increase, bar some abnormal spikes in the data. To provide a clearer picture, it was decided that these graphs could be combined into one line graph, for each of the three components; easting, northing and height. This would provide a broader collection of data which will minimise any irregularities.

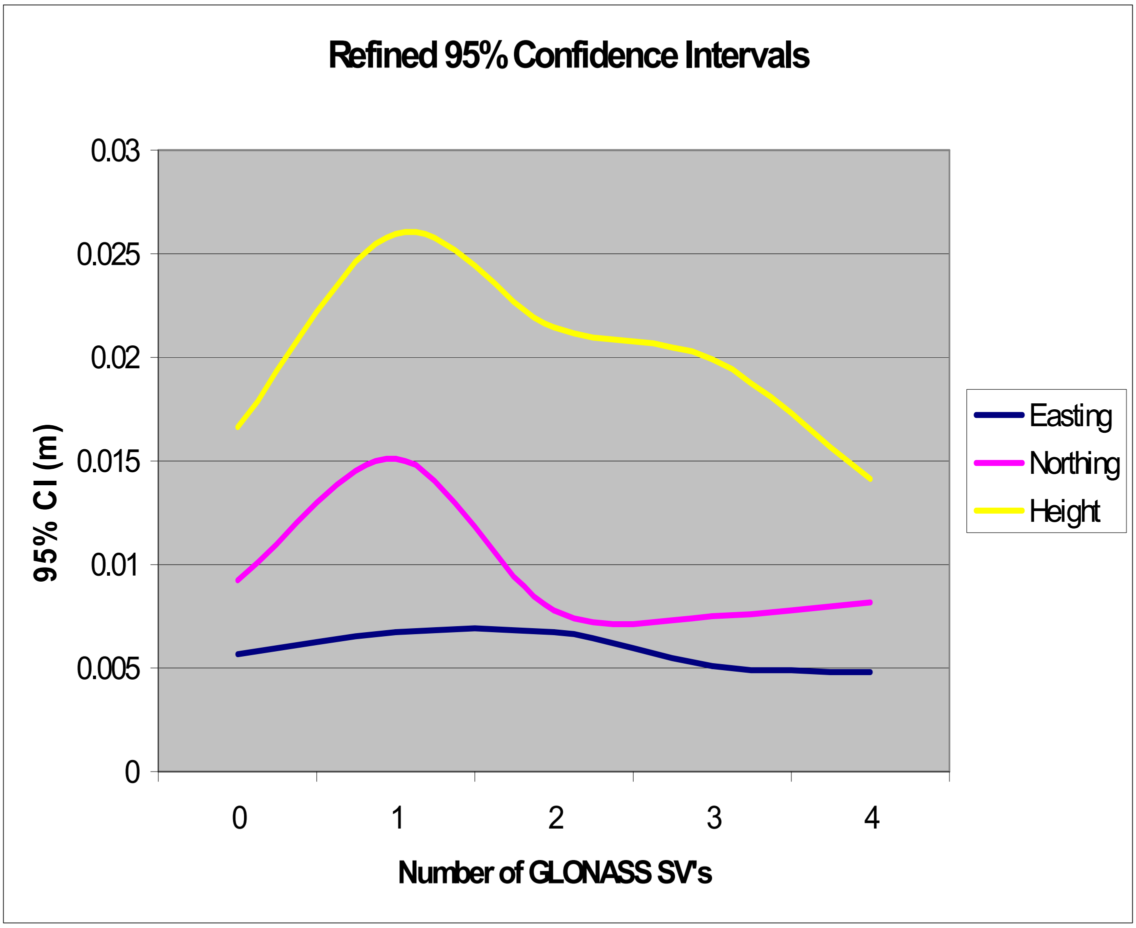


Figure 5.4 Combined 95% confidence intervals

The combined 95% CI's shown in the above graph display the overall trend of the data. Once again, the height component is two to three times worse than the easting and northing component.

Easting Component:

The easting component is the most precise, and varies between seven millimetres and four millimetres. It is only minor variation; however the peak in this data is once again at one GLONASS satellite.

Northing Component:

The northing component has a peak at one GLONASS satellite also, but this is considerably more, being over five millimetres different from any other value. In general all of the data bar that for one GLONASS satellite is still very precise, being under 10 millimetres. The variation in this data is no more than three millimetres.

Height Component:

The height component is the least precise of the three. There is again a peak at one GLONASS satellite, which is 10 millimetres higher than zero GLONASS satellites. From then there is an improvement of 12 millimetres over two, three and four GLONASS satellites.

5.3 Summary

The results have not shown a clear trend of improvement or otherwise as the number of GLONASS satellites increase. The three main features analysed, accuracy, precision and TTFF have all provided different results.

Due to the testing method used in test two, and the failure of test one, the reliability of RTK GNSS surveying could not be accurately analysed. Further testing in a manner similar to that of test one would be required to assess this, as test two was comprised of a receiver with a continuous fix. There was no challenge to the integrity of the receiver in test two, therefore at all times the receiver was able to give reliable and accurate coordinate results.

The results of test one, as shown in figure 5.2, suggest that the addition and an increase in GLONASS satellite numbers does improve the TTFF. This result is as expected, as more satellites allow the receiver to solve the signal ambiguities faster (Mylne, 2007).

The accuracy and precision of RTK GNSS is quite high at all times in test two. The height component is the worst in terms of accuracy and precision, and the easting is generally the best, as shown in figures 5.3 and 5.4. There is at no time a definite improvement in accuracy or precision as the number of GLONASS satellites increase in the easting, northing or height.

The remaining chapter will discuss the final conclusions based on this data, and it will highlight future research that may be done to build upon these results.

CHAPTER SIX

CONCLUSIONS

6.1 Introduction

The results of testing and data collection have been presented and analysed in the preceding chapter in order to analyse the effect a change in the number of GLONASS satellites has on accuracy, precision and the TTFF of a receiver.

Conclusions can now be drawn on the overall effectiveness of RTK GNSS now that all of the data is analysed and presented.

This chapter will provide these conclusions and determine the effectiveness of RTK GNSS.

6.2 Conclusions

The specific aims have been identified of which are used to assess the effectiveness of a RTK GNSS receiver. The three main elements, accuracy, precision and TTFF have been tested and analysed in the testing and analysis process. These results provided trends and patterns which have allowed conclusions to be drawn.

6.2.1 Accuracy

The accuracy of RTK GNSS in relation to a variation in GLONASS satellites was assessed in test two. The results of this test showed that the use of RTK GNSS for surveying can be a very accurate process if the correct measures are taken. This includes maintaining the initialisation integrity of the receiver.

The results have shown that RTK GNSS is highly accurate for all numbers of GLONASS satellites in a clear sky environment, with minimal multipath present. This is assuming that at all times there are a minimum of seven GPS satellites, which is the lowest number recorded during the testing process. These results produced mean errors of less than three millimetres; and, when there were three or more GLONASS in addition to this, the mean error was plus or minus one millimetre.

These differences will be undetectable for most, if not all field surveying applications. It is concluded from the data that the accuracy of RTK GNSS has possibly peaked (at a very high level of accuracy), and no increase in satellite numbers will improve this.

6.2.2 Precision

The precision of RTK GNSS was tested in test two as data was collected for varying numbers of GPS and GLONASS satellites. These results showed mixed levels of precision for each individual GPS analysis group; however there was a slight trend in some of the data for an improvement as the number of GLONASS satellites increased.

To allow an analysis to be done and for the trends to be clearer, the data was combined into one sample, (Refer to Figure 5.4). This showed that there is a definite improvement in precision from one GLONASS satellite, as the GLONASS numbers increase. However, the precision of the data is much higher at zero GLONASS satellites than it is for one, and in the easting and height component, two GLONASS satellites.

This would suggest that there is perhaps an issue when there are only one or two GLONASS satellites which affect the precision of the coordinate fix. Further research is required to determine exactly why these results were obtained, and perhaps if there is a compatibility issue with some receivers and minimal numbers of GLONASS.

Otherwise, the 95% confidence level intervals appear to remain quite high in the easting and northing components as the number of GLONASS satellites increase. The height component does show improvement however, and this is the worst component, generally two to three times higher than the horizontal components.

It is concluded from these results that an increase in the number of GLONASS satellite numbers will not affect the precision of the horizontal precision, if you have three or more of these. The height component will improve considerably for three GLONASS satellites and higher, as there is still room for improvement.

6.2.3 TTFF

The effect an increase in the number of GLONASS satellites had on the TTFF was assessed in test one. This data consisted of only a small sample, and therefore it can be considered an indication only.

The results indicate that as the number of GLONASS satellites increase, there will be an improvement in the TTFF, and this was demonstrated in the small amount of data that was collected.

6.3 Future research

There is possibly a need for future research into the true effect that one or two additional GNSS satellites have on the GPS constellation. This will particularly come into effect as COMPASS and GALILEO grow and become common use in the Australian spatial science industry.

As RTK surveying becomes more widespread in its use, and as it is being used for more and more applications and for higher accuracy applications, issues such as this may need to be resolved.

This research and testing should also be conducted again, or in a similar manner when GALILEO and COMPASS reach a capacity similar to GLONASS.

6.4 Close

The testing and research conducted in this project have allowed for the evaluation of RTK GNSS and the effect of a variation in the number of GLONASS satellites on RTK GNSS.

The results have shown that there are improvements with the additional satellites, mainly expected in an improved TTFF, and improvements in the height precision. The accuracy of RTK GNSS can be considered high when you have seven or more satellites in your solution, as with the horizontal precision. The results have shown that the addition of one or two GLONASS satellites may have a negative impact on the precision of RTK GNSS.

This testing has shown that RTK surveying is indeed an effective surveying tool, and its use in a wide range of surveying applications has been justified by the high levels of accuracy and precision. The main area in which users can find improvement is now in the speed of the first fix, as this factor can considerably lengthen a survey time, and can still be quite high at times. The importance of maintaining initialisation integrity is also highlighted in this research, as the results show that by keeping lock your data maintains accuracy and precision.

The aim of the research was to assess the effectiveness of RTK GNSS is relation to a number of factors. This was not done to the full extent, in particular for the TTFF and the reliability, however conclusion were made on the accuracy and precision of RTK GNSS.

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APPENDICES

APPENDIX A

NMEA Output format example

```
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```

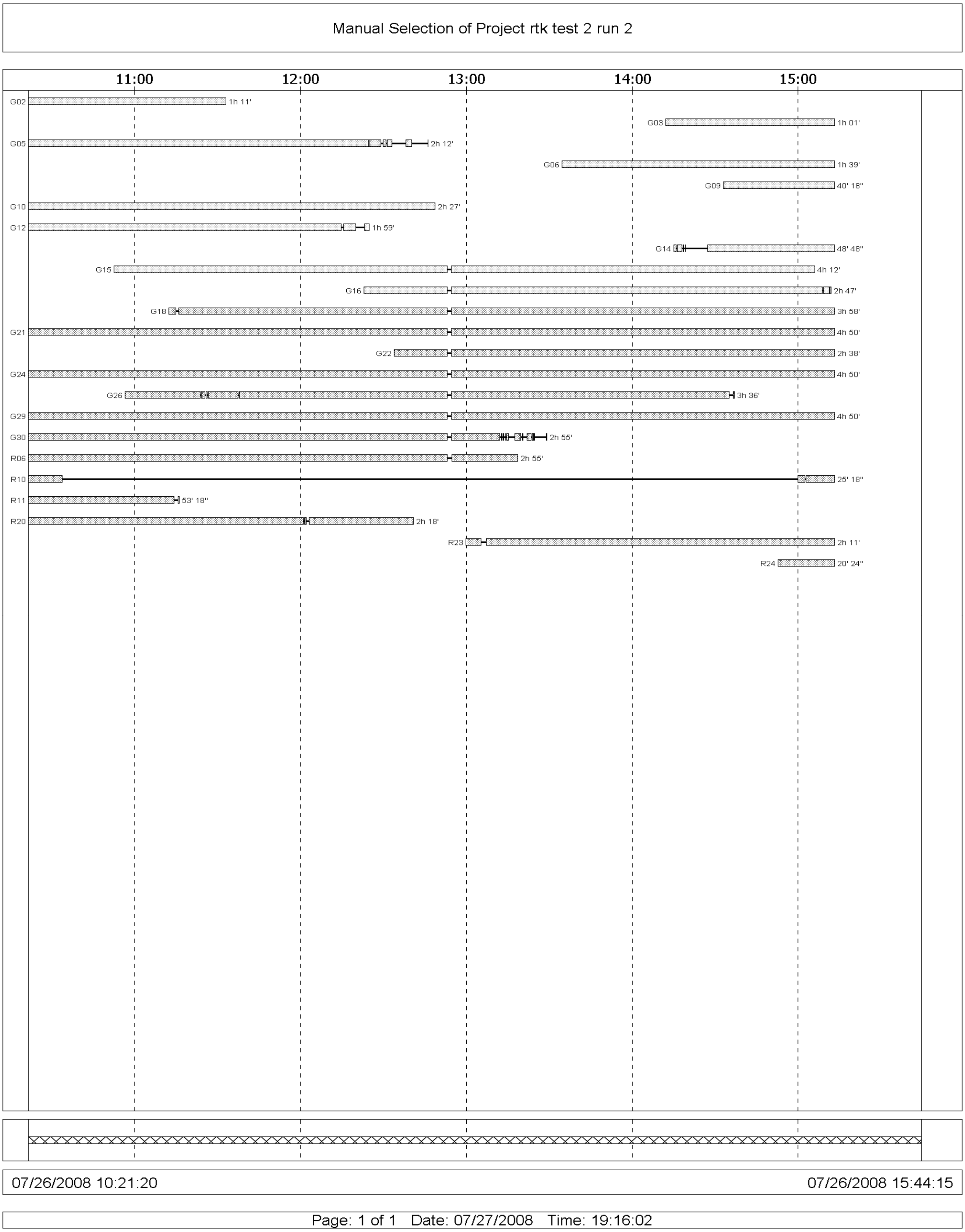
APPENDIX B

Leica Geo Office Output example

Date/ Time	Latitude	Longitude	Ortho Ht	HDOP	VDOP	Number of SV's
07/26/2008 10:17:00	26° 49' 00.29999" S	153° 07' 09.85051" E	44.7924	1	2.1	11
07/26/2008 10:17:02	26° 49' 00.29997" S	153° 07' 09.85053" E	44.794	1	2.1	11
07/26/2008 10:17:04	26° 49' 00.29978" S	153° 07' 09.85054" E	44.7925	1	2.1	11
07/26/2008 10:17:06	26° 49' 00.30020" S	153° 07' 09.85049" E	44.7904	1	2.1	11
07/26/2008 10:17:08	26° 49' 00.30100" S	153° 07' 09.85024" E	44.7876	1	2.1	11
07/26/2008 10:17:10	26° 49' 00.30195" S	153° 07' 09.84983" E	44.7592	1	2.1	11
07/26/2008 10:17:12	26° 49' 00.30315" S	153° 07' 09.84923" E	44.7471	1	2.1	11
07/26/2008 10:17:14	26° 49' 00.30011" S	153° 07' 09.85050" E	44.7926	1	2.1	11
07/26/2008 10:17:16	26° 49' 00.30007" S	153° 07' 09.85056" E	44.7952	1	2.1	11
07/26/2008 10:17:18	26° 49' 00.30014" S	153° 07' 09.85065" E	44.8042	1	2.1	11
07/26/2008 10:17:20	26° 49' 00.30011" S	153° 07' 09.85080" E	44.8104	1	2.1	11
07/26/2008 10:17:24	26° 49' 00.30018" S	153° 07' 09.85049" E	44.7953	1	2.1	11
07/26/2008 10:17:26	26° 49' 00.30004" S	153° 07' 09.85055" E	44.7879	1	2.1	11
07/26/2008 10:17:28	26° 49' 00.30002" S	153° 07' 09.85055" E	44.7819	1	2.1	11
07/26/2008 10:17:30	26° 49' 00.30021" S	153° 07' 09.85051" E	44.7993	1	2.1	11
07/26/2008 10:17:32	26° 49' 00.30014" S	153° 07' 09.85055" E	44.7893	1	2.1	11
07/26/2008 10:17:34	26° 49' 00.30003" S	153° 07' 09.85054" E	44.7864	1	2.1	11
07/26/2008 10:17:36	26° 49' 00.30005" S	153° 07' 09.85054" E	44.7886	1	2.1	11
07/26/2008 10:17:38	26° 49' 00.30005" S	153° 07' 09.85061" E	44.7866	1	2.1	11
07/26/2008 10:17:40	26° 49' 00.29987" S	153° 07' 09.85073" E	44.784	1	2.1	11
07/26/2008 10:17:42	26° 49' 00.30036" S	153° 07' 09.85043" E	44.8004	1	2.1	11

APPENDIX C

Leica Geo Office Satellite timeline



Manual Selection of Project rtk test 2 run 2

07/26/2008 10:21:20 07/26/2008 15:44:15

Page: 1 of 1 Date: 07/27/2008 Time: 19:16:02

APPENDIX D

DOP value comparison example

For 9 GPS satellites

B = 1 GLONASS SV'S

C= 2 GLONASS SV'S

D = 3 GLONASS SV'S

E = 4 GLONASS SV's

	field data		trimble planning software		difference		GLONASS removed in software	
SAMPLE	HDOP	VDOP	HDOP	VDOP	HDOP	VDOP	HDOP	VDOP
B	0.94	1.54	0.88	1.55	0.06	-0.01	0.88	1.55
C	0.91	1.62	0.93	1.47	-0.02	0.15	0.97	1.58
D	0.89	1.37	0.82	1.43	0.07	-0.06	0.93	1.5
E	0.83	1.52	0.87	1.45	-0.04	0.07	0.91	1.5

APPENDIX E

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Christopher Hetherington**

TOPIC: EFFECTIVENESS OF RTK GNSS

SUPERVISOR: Mr Peter Gibbings/ Mr Glen Cambell

PROJECT AIM: to analyse ane evaluate the effectiveness of RTK GNSS in relation to the addition of GLONASS satellites

PROGRAMME: **(Issue A, 17 March 2008)**

1) Research the background of RTK Surveys and measurement principles and GLONASS and GPS systems in general

2) Define accuracy, reliability, precision, TTFF, etc in relation to RTK GNSS and factors which may influence them

3) Investigate satellite availability, satellite geometry, effects of obstructions and elevation masks etc of GPS and GLONASS satellites and test how these effect the reliability and effectiveness of GNSS measurements in comparison to GPS measurements

4) Determine suitable test methodology and procedures, possibly:
   - collect RTK GPS data for a period
   - collect RTK GNSS data for a same period

5) Collect and Analyse data to determine results/conclusions concerning:
   - GPS and GLONASS satellite availability at time of collection
   - Compare TTFF, accuracy and precision of datasets
   - Analyse variations in results based on satellite availability and geometry

6) Compile an academic dissertation to report on research and results

AGREED:
……………………..(Student)……………………., ………………………(Supervisor)

…../…./….   …../…./….   …../…./….

Examiner/Co-examiner: ……………………………….