University of Southern Queensland
Faculty of Engineering and Surveying

Evaluation of VRS-RTK GPS Latency in a Dynamic Environment

A dissertation submitted by

Mr. Rientz Inglis

In fulfilment of the requirements of

ENG4111/2, Research Project

towards the degree of

Bachelor of Spatial Science, Surveying

January, 2006

ABSTRACT

This research project investigates the effects of latency in dynamic GPS (Global Positioning System) measurements made within a Virtual Reference Station (VRS) – Real Time Kinematic (RTK) network.

The test method, which has been devised as an integral part of this research, allows for determination of the effects of latency in low speed dynamic VRS measurements. The method utilises a utility vehicle as a dynamic platform for testing, with a barcode reader attached to the vehicle to read barcodes which have been fixed to posts adjacent to the test path. Mounted in vertical alignment with the reader is the GPS antenna, providing the GPS signals to allow the GPS receiver(s) on board to determine the position of the vehicle as it passes the fixed barcodes and thereby providing a fixed frame of reference for the measurement of latency. Measuring lines in each direction and comparing the apparent position of the barcodes allows for the determination of latency. Conducting the testing procedure over a range of speeds will also facilitate the investigation of the relationship between platform speed and latency error.

The results of this research have implications for any machine guidance and precision agriculture applications intending to use the VRS network where data accuracy is a major consideration. If the latency present in the positioning system has been quantified, it becomes possible to correct for this position error in real time.

The research has only considered the effects of latency on the position solution, and this should be distinguished from accuracy. The accuracy of the VRS system in dynamic applications has not been investigated as part of this research project, but should also be considered in conjunction with latency when investigating the suitability of VRS to potential applications, dynamic or static.

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Faculty of Engineering and Surveying

CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, 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.

Rientz R. Inglis

Student Number: 0011221347

R Inglis
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(Signature)

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(Date)

ACKNOWLEDGEMENTS

The author wishes to acknowledge the support and guidance received from Mr. Peter Gibbings of the University of Southern Queensland, throughout the course of the research project.

Appreciation is also due to the following organisations and people, for the provision of equipment, facilities and guidance:

- Queensland Department of Natural Resources and Mines (DNRM), in particular Garry Cizlowski for his support and assistance.
- Herga / Ultimate Positioning Brisbane, in particular John Thompson for his assistance.
- Queensland Rail (QR), in particular Derek Stanmore for his assistance.
- Barry Rowan, USQ printing services.
- Dean Beliveau, Faculty of Engineering and Surveying, USQ.

TABLE OF CONTENTS

Contents **Page**

CHAPTER 1 - INTRODUCTION

CHAPTER 2 - LITERATURE REVIEW

2.3 The Latency Problem

CHAPTER 3 - RESEARCH DESIGN AND METHODOLOGY

CHAPTER 4 - DATA ANALYSIS

CHAPTER 5 – DISSCUSSION AND SUMMARY

CHAPTER 5 – Continued

APPENDICES

LIST OF FIGURES

Number Title **Page**

LIST OF Tables

Number Title **Page**

LIST OF APPENDICES

Number Title **Page**

ABBREVIATIONS

The following abbreviations have been used throughout the text and bibliography:-

CORS	Continually Operating Reference Stations
DLI	Department of Land Information (West Australian Government)
DNRM	Department of Natural Resources and Mines (Qld Government)
GPS	Global Positioning System
GNSS	Global Navigation Satellite System
GSM	Global System for Mobile communications
NZ	New Zealand
OSG	Office of the Surveyor General (New Zealand Government)
PC	Personal computer
Qld	Queensland
QR	Queensland Rail
RTK	Real Time Kinematic
USB	Universal Serial Bus
USQ	University of Southern Queensland (Toowoomba, Qld)
VHF	Very High Frequency
VRS	Virtual Reference Station
WA	Western Australia
WBS	Work Breakdown Structure

CHAPTER 1

INTRODUCTION

> *Future testing will need to more fully investigate the use of VRS in dynamic platforms such as rail and road surveys and in earth moving applications.*
>
> (Higgins, 2001)

1.1 The Problem

Conventional Real Time Kinematic (RTK) Global Positioning System (GPS) surveying is gradually being replaced in many applications, by wide area networks such as the Virtual Reference Station (VRS) for the supply of differential GPS corrections. The VRS network can deliver differential corrections via the mobile phone network; enabling users to be positioned anywhere inside the network in real time and with accuracy better than a few centimetres (Higgins, 2001).

At this time the difference between VRS-RTK and conventional RTK surveying should be noted. As opposed to conventional RTK where the user is required to establish their own base station over a known point, VRS uses a network of permanently running reference stations to compute atmospheric corrections for a 'virtual base station' at each users' approximate GPS position. The corrections are transmitted to an almost unlimited number of users in the field by way of the GSM (Global System for Mobile communications) cellular phone network. The method overcomes many of the limitations of conventional RTK, such as radio range, own base station set up, and a lack of redundant reference station data (Higgins, 2001). A more detailed description of the VRS technique is provided in section 4 of chapter 2.

VRS-RTK usage is increasing around the world; at the end of 2002 at least 28 VRS networks were in operation in several continents (Landau et al, 2002). An understanding of latency effects is critical in the application of VRS to dynamic applications, since it (latency) can be a source of positional error, if not allowed for (Raymond, 2005).

With the possibility of wider application of VRS technology, potential users such as Queensland Rail (primarily for track maintenance equipment) need to know how responsive the measurement system is for dynamic applications. Furthermore, the application of VRS technology to other endeavors such as the application of agricultural pesticides, automated field harvesting and civil machine guidance also requires an understanding of how responsive the guidance system is.

Some studies have been conducted to investigate latency in dynamic GPS systems in the past (see Smith et al, 2003). However, a lack of research specifically targeting VRS systems like the one maintained by the Queensland Department of Natural Resources and Mines (DNRM) with regard to latency in dynamic GPS observations has been identified. It would also appear that several state and federal governments around the world are at a 'cross-roads' with respect to GPS infrastructure (for example, see OSG, 2003, N.Z.). When considering a large capital outlay, such as the purchase of a state-wide GPS network, all factors and potential users must be considered.

A further recent example of this is witnessed in Western Australia (WA), where the Department of Land Information (DLI) (WA government) has recently issued a grant of $120,000 to Curtin University to conduct a feasibility study regarding the implementation of a CORS (Continually Operating Reference Stations) network across that state (DLI 2005).

Questions can be raised about the dynamic measurement quality of VRS, because the effect of latency (and therefore the restriction of VRS in dynamic applications) is a relatively unknown quantity, when compared to a more established system such as conventional RTK GPS. This research seeks to address this apparent gap through the development of a testing regime to quantify latency in dynamic VRS-RTK observations.

1.2 Research Aim and Objectives

Given the underlying requirement for research to determine the latency of the VRS system, the aim of this project is to develop and implement a method to quantify the latency in conventional RTK and VRS-RTK GPS measurements taken in a dynamic environment.

The data obtained from the testing will be processed and analysed, allowing conclusions to be made with respect to latency effects in dynamic VRS GPS observations, compared with conventional RTK methods.

1.3 Justification

Given that the operating distance restrictions such as those associated with conventional RTK GPS (radio range, on site obstructions such as hills etc) are less of a problem using GSM cellular network coverage, the VRS system may be particularly suited to large area dynamic platform applications such as machine guidance and precision agriculture.

Whilst some prior research has investigated latency in conventional dynamic RTK GPS (see for example the testing done by (Smith and Thomson, 2003) using an agricultural aircraft), there is a requirement to further this research to include VRS networks, given the large potential for an expansion of VRS applications in dynamic environments in the future.

This requirement has been brought about by increasing interest in multi-station GPS networks, and their integration into existing GPS infrastructure. Anyone planning to use such a system must have a clear understanding of any possible error sources, in order to apply quality controls to the spatial data obtained. This is a 'best practice' quality assurance requirement to ensure the end user receives reliable, quality data.

1.4 Methodology Outline

To determine the latency associated with VRS measurements being made in a dynamic sense, a major component of this research project was to develop a method to evaluate these effects. A detailed description of this method is given in chapter 3, although a brief introduction to the testing method is provided below.

The testing regime for this project requires a straight section of roadway using a utility vehicle on which the GPS antenna / receivers is mounted. The signal from the GPS antenna is corrected by whichever means is being used (either VRS or conventional RTK). Also mounted on the car is a barcode reader, directly under the GPS antenna. A plumb bob is used to verify this alignment. The barcode reader inserts an extra record into the data stream (originating from the GPS receiver and flowing to the data recording device (TSCe)), when the trolley travels past any of the known reference points (fixed standard barcodes) which are established on stakes adjacent to the road prior to testing.

These fixed points provided a static reference frame and position data is recorded for travel in each direction past the fixed points at a range of consistent speeds. By comparing the measured location of the barcodes for each run with the known fixed position, the latency of the system can be calculated (see section 2.4 of chapter 3 for a more detailed explanation). The testing is conducted over a range of speeds to better determine the relationship between dynamic platform speed and latency error.

1.5 Scope of Research

Although the VRS system is not the only means of correcting GPS observations, this project has specifically focused on the VRS network of differential GPS corrections. Further research is required to determine if similar results will be obtained with these other forms of wide area differential GPS corrections. Thus, the project aims to give a comparison with the conventional RTK method only. The research is intended to provide information for users considering the integration of VRS techniques into their dynamic surveying operations and also for both private sector and government agencies considering the further expansion of VRS networks.

It is also worth noting that this research only investigates latency using a GSM cellular phone network to obtain the correction data. The latency is directly related to the means by which the correction data is transmitted. Any user intending to utilise a different method of correction data supply (such as the internet etc.) would need to conduct similar testing using that correction facility and associated equipment configuration.

1.6 Summary: Chapter 1

This research provides a method for quantifying any latency present in low speed dynamic VRS-RTK systems, where correction data is provided by way of the GSM cellular phone network. It also provides for a direct comparison with the conventional RTK method. The findings will be useful to anyone using VRS networks (in conjunction with the GSM network) in dynamic environments.

Chapter two provides a complete review of existing literature relevant to this study and identifies the extent of prior research in this area. This includes a background study of the theory underpinning VRS, latency in conventional RTK-GPS and the general use of GPS in dynamic environments.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

Latency in GPS is not a new concept. To avoid duplication, there is a need to identify the extent and nature of existing research with respect to latency in dynamic VRS measurements. Also, a thorough background comprehension of the concepts involved in this project is also required, to assist in the design of an appropriate testing regime.

This chapter presents a review of literature relevant to the study of latency in VRS measurements in a dynamic environment. It introduces all relevant research to date, as well as highlighting the need for further research in the specific field of latency in VRS-RTK surveying in dynamic environments.

Chapter 2 also provides a definition of the concept of latency, followed by a review of conventional RTK GPS use in dynamic environments. This chapter also gives an overview of the VRS concept and summarises all existing literature regarding these subjects.

2.2 What is VRS?

The Virtual Reference Station concept was developed by Trimble Terrasat as a means of increasing the benefits gained by utilising networks of permanently running, fixed reference stations for centimeter-level accurate GNSS positioning (Vollath et al, 2000a).

In a paper presented to the 2001 International Federation of Surveyors conference titled 'An Australian Pilot Network for a Real Time Kinematic GPS Network Using the Virtual Reference Station Concept', (Higgins, 2001) comments that the virtual reference station concept is used as a means of utilising GPS correction data from a network of permanently operating base stations, allowing modeling of atmospheric and other effects for any point in and around the network. Although the concept is similar to conventional RTK, the move away from a single base station and towards a network based approach gives the user some increased redundancy in the correction data obtained.

The GPS data generated from the permanent base stations is sent to a central computer, which can then calculate the correction that would be required for any point in that network. The user in the field sends their approximate GPS position to the central computer by way of a mobile phone, and the central computer returns the correction data based on this approximate point. (Higgins, 2001). This effectively makes the approximate point a base or reference station, hence the name, **Virtual Reference Station (VRS).** The distinction should be noted between the virtual station and the permanent base stations of the network. While the virtual reference station is an 'imaginary point' based on the user's approximate position, the fixed physical base stations of the network provide the basis for the computation and supply of correction data, similar to that used in the conventional RTK technique. This distinction can be seen clearly in the following diagrammatic representation of the VRS network concept:

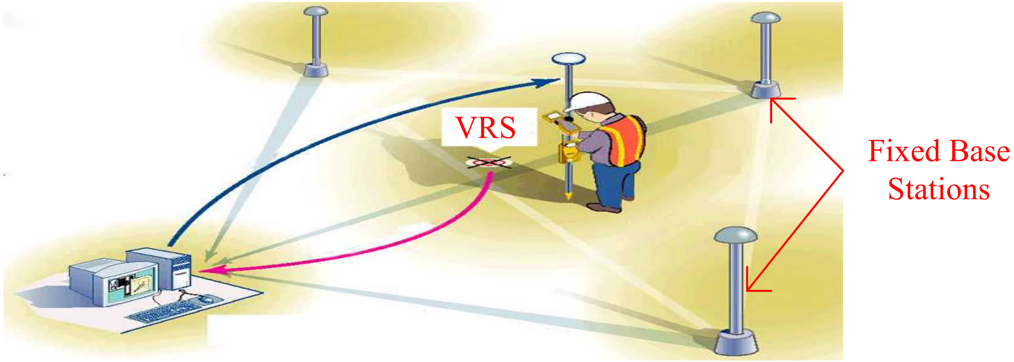

Figure 2.1 – VRS Network Operation (Source: Trimble 2005)

It is also worth realising that the central computer and associated software cannot maintain any number of virtual stations simultaneously (i.e. the maximum number of simultaneous users is limited by the capacity of the central server (Rizos and Han, 2002)). The infrastructure is also scalable, that is, the network may be expanded in the future to service a wider area.

The VRS network used for this research has been established over the South-East corner of the Australian State of Queensland by the Queensland Department of Natural Resources and Mines (DNRM). The network consists of 4 reference stations, with the spacing between fixed base stations varying from 29km to 76km. Figure 2.2 shows the location of the VRS network in South-East Queensland, which is utilised for this research project.

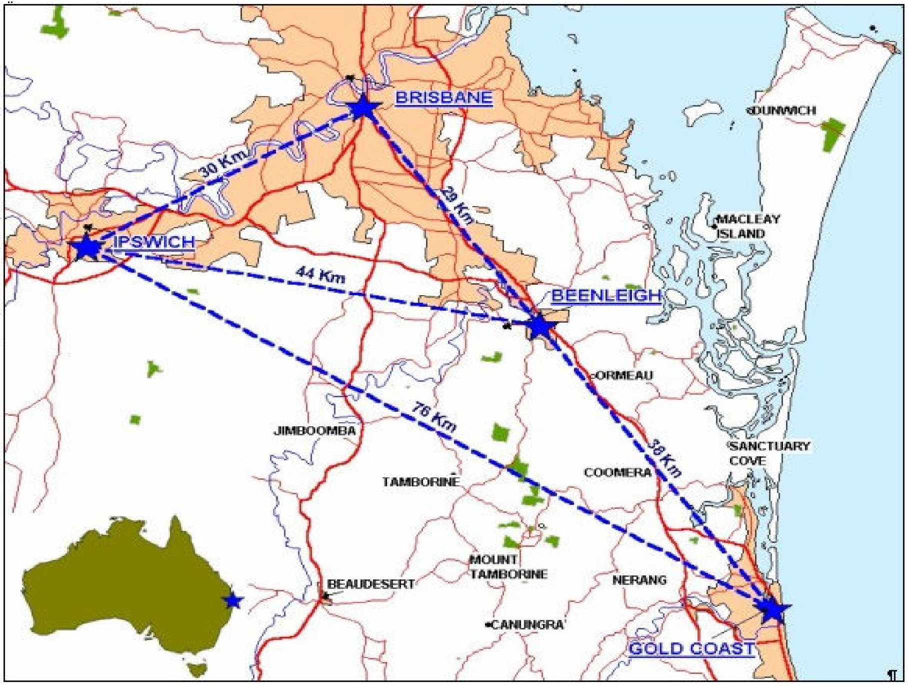

Figure 2.2 – South-Eastern Queensland Trial VRS Network Configuration. (Source: Higgins 2001)

VRS can improve the efficiency of data collection and increase confidence in that data. VRS is designed to provide real time differential GPS corrections to a large number of users operating within a wide area network. This eliminates the requirement for individual base stations for each job as is required with conventional-RTK. The corrections are delivered to the user by way of the GSM (or similar) cellular network, overcoming the shortfalls of the Very High Frequency (VHF) radio link between base stations and rovers (traditionally the weakest link in the conventional-RTK system). Finally, given that VRS in effect uses multiple base stations to compute corrections, there is an inherent increase in observation redundancy giving the user greater confidence in the position solution. (Higgins, 2001)

The wide area network used for the transfer of correction data from the individual base stations to the central computer is of great importance to the overall ‘smooth’ operation of the system. The network has to have a high data transfer rate in order to reduce the transmission latency introduced into the system (Hu et al, 2002). The system must also be stable and reliable.

The information technology and network design for the trial network utilised in this research is reproduced in Figure 2.3, showing the high speed local area network used to connect the various fixed components.

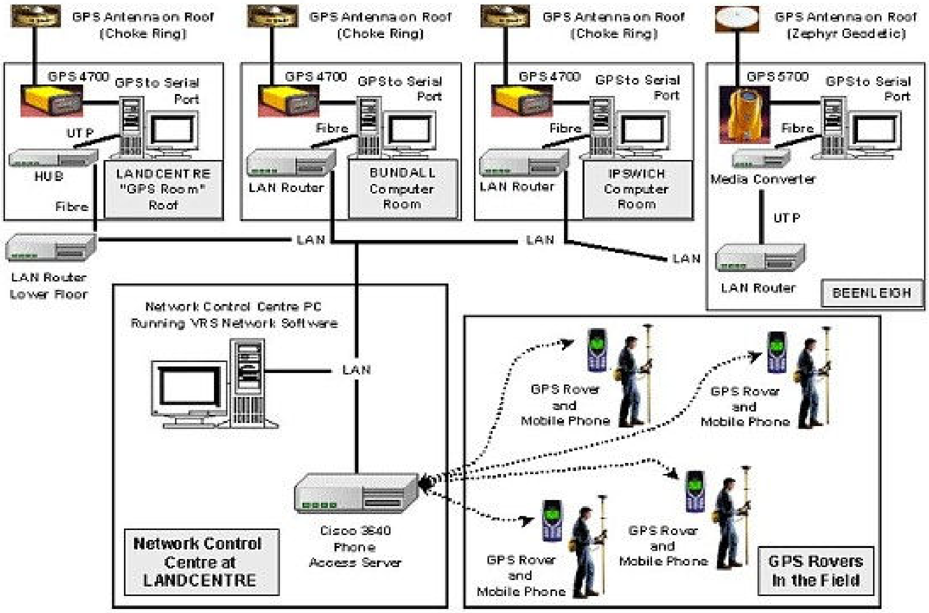

Figure 2.3 – Queensland Trial VRS Network, IT Infrastructure (Source: Higgins 2001)

2.3 The Latency Problem

2.3.1 What is Latency?

Although it may be better known for its effects on computer processor operations, latency is by no means a new concept with respect to dynamic GPS measurements. Latency, in general, may be defined simply as a measure of temporal delay (MM Internet, 1999). A further, more in-depth definition is given by (Interoute, 2005):

(Latency is the) "*Time taken to deliver a packet (of data) from the source to the receiver. Includes propagation delay (the time taken for the electrical or optical signals to travel the distance between the two points) and processing delay.*"

This is an example of latency in data transmission, but with specific reference to dynamic GPS observations, (Raymond, 2005) defines latency as the "*delay between the time of fix and when it is available to the user*". Hence if the GPS is in motion, the platform on which the measurements are being made will move some distance during the time when the measurement is made and the time when it is available to the user (refer to Figure 2.4 below). With respect to VRS, this latency is a relatively unknown quantity which needs to be identified and compared to some form of standard (in this case conventional RTK surveying), for the benefit of users and potential users. Below is a graphical representation of the latency effect:

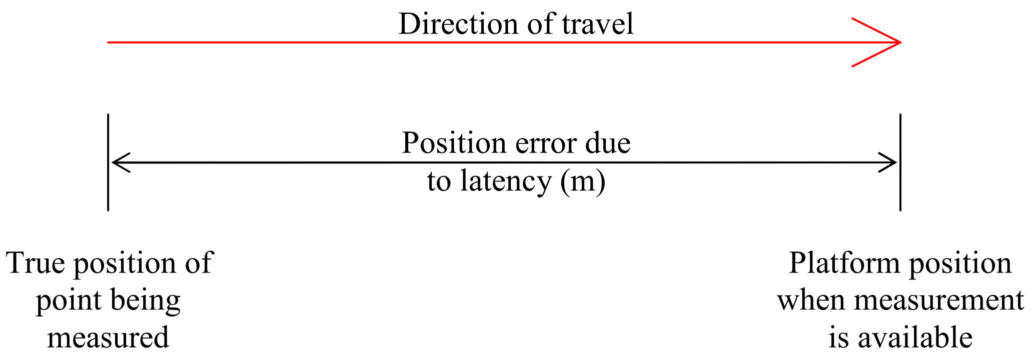

Figure 2.4 – The effect of Latency on the Position Solution.

Latency may be divided into separate components for analysis. For example, total latency, with respect to GPS measurements, is comprised of both internal processing latency and transmission latency. There are also other factors which may contribute to the total latency of the system, but a detailed investigation is not presented as this research has concentrated on the effects of the combined total latency of the system.

Internal latency is that quantity of time which the instrument takes to complete its internal processes and present the data ready for use or transmission. Transmission latency is the period of time taken to send the measurement data from the originating source to the user, in the field for example (Bouvet et al, 2000).

It should again be noted that this project has aimed to quantify total latency only, with respect to VRS measurements. The concept of total latency is best demonstrated by the following figure (2.5):

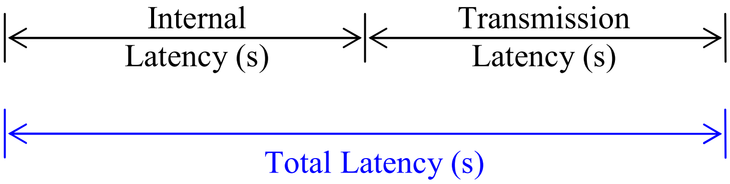

Figure 2.5 – The Concept of Total Latency.

Given that position error due to latency is a function of the update rate (total latency) and the velocity of the vehicle (Campbell, Carney and Kantowitz, 1998), then for any given latency period, the dynamic platform position error will increase in proportion with the platform's speed. This is an important fact to realise when designing the testing regime. Therefore this research hopes to assist in the determination of the relationship between platform velocity and position error due to latency for the VRS configuration under investigation, by completing the testing regime over a range of speeds. This would go some way toward facilitating a correction based on vehicle speed to be automatically applied directly to measurements which are made with this configuration. Of course, variations are possible for every different setup and individual latency calculations should be completed for the set-up in question before applying any correction to data.

A good definition of how latency affects GPS position is given by (Gibbings and O'Dempsey, 2005). The following quote relates to hydrographic measurements using GPS, but the principle remains the same:

"A time lag (latency) can be experienced between when a sensor record is measured and when it is recorded by the software. Similarly, a time lag (latency) may be experienced between when a GPS position is measured and when it is recorded.

Most importantly, these two time lags may not be the same, and consequently the GPS logged position may not be exactly the same location as the depth sensor when the hydrographic data is logged.” (Gibbings and O’Dempsey, 2005)

This is particularly relevant to the study of latency in VRS measurements being undertaken in this research. Although the authors of this work (Gibbings and O’Dempsey, 2005) were using hydrographic depth sounding equipment as an external sensor, the system latency is very similar in that they have measured latency of the RTK system using short transects in opposing directions to quantify the latency as a lateral shift in position. This concept is expanded in the following section.

2.3.2 Latency in VRS-RTK GPS Measurements

> *Whilst there has been testing and evaluation of VRS-RTK accuracy in static surveying situations, further research is required with respect to dynamic measurement environments. (Higgins, 2001)*

Given that there is very little information currently available regarding latency in the emerging field of VRS-RTK GPS, it becomes clear that it is an issue which must be addressed prior to the widespread implementation of such a system. (Raymond, 2005) asserts that latency may be a “significant source of error for a GPS in motion”.

Further evidence of the effect of latency on dynamic GPS measurements may be found in the 2005 paper (Gibbings and O’Dempsey, 2005), published in the April edition of the Journal of the Spatial Sciences Institute (Queensland). The paper titled ‘Using GPS Asset Mapping Software for Hydrographic Measurements in Still Water’ (Gibbings and O’Dempsey, 2005) outlines the effects of latency on the position data obtained using mapping grade GPS equipment. The author’s report a latency of 0.58 seconds, which equates to 0.7 meters when traveling at 1.2 m/s. In the same paper, testing of latency was also conducted for RTK equipment (Trimble 5800 receiver) with similar results (0.53 seconds for the RTK system).

The positional error due to latency is a function of the time it takes for the system to calculate position and make it available to the user. Some of the early global positioning systems contain up to a few seconds worth of latency. (The Hydro graphic Society, 2002) and (Gallagher, 2002) state that common values for conventional RTK GPS latency (receiver latency) range from 300 to 500 milliseconds. It is also worth noting that some modern systems such as the Trimble MS750 receiver can reduce that figure to around 20 milliseconds (Trimble Navigation, 1999). Comparable data for VRS is not publicly available, but would be dependent on factors such as system configuration and the make and model of GPS receiver and ancillary equipment being used. This report intends to bridge the gap of research in this area, by quantifying latency with respect to a VRS user 'in motion' and comparing it to conventional RTK, for one particular equipment configuration.

In Technical Report 17 (OSG (N.Z.), 2003, p. 11), the New Zealand Office of the Surveyor-General states that for most applications 5 second latency is adequate however for applications such as fast moving platforms, less than 1 second of latency is required. That is to say that 5 seconds latency is not adequate for machine guidance and precision agriculture applications. This is reinforced by (Hu et al, 2002), who state that latency of up to one or two seconds is not critical for GPS RTK positioning, however this again this would not include high speed dynamic situations or those requiring the most precise dynamic measurements .

The problem we face is that measurement times (and therefore latency) for VRS observations may exceed this, and in a dynamic environment this may equate to significant position errors. Without an adequate knowledge of this error, users of these systems cannot have sufficient confidence in the position solution they are obtaining, and this will limit both the product's usefulness and in turn it's widespread application and acceptance.

2.4 GPS in Dynamic Environments

Other research has shown that static performance of GPS receivers is not necessarily indicative of dynamic performance and that few standards exist for testing GPS performance under dynamic conditions (Stombaugh et al. 2002).

Previous studies have been completed to investigate the effects of latency in GPS measurements. (Smith and Thomson, 2003) outlined a method to evaluate GPS position latency in the guidance system of an agricultural aircraft. The method involved reflecting a beam of sun light vertically from the ground using two mirrors (to the author's knowledge there is no explanation available regarding how the beam of light was checked to ensure it was vertical.). A photo-detector circuit under the wing triggered an extra data record to be inserted into the GPS data log. This position could then be compared with the known position of the light beam to determine position latency.

The authors report resulting latency determinations of less than 9 meters for all runs of the testing. This is a relatively small error given that the aircraft was travelling at 58 meters per second (around 208.8 km/h). The authors also report a high level of consistency in their findings, stating that the differences in consecutive runs were all less than 0.7 meters (7.77% of the error distance due to latency). The use of an optical sensor is seen as a very accurate means of referencing the dynamic measurements back to the fixed frame of reference and has therefore been adopted for this research project also.

Another particularly relevant research paper that has direct relevance to this project is that previously mentioned above, undertaken by (Gibbings and O'Dempsey, 2005). Although this research relates to the investigation of utilising mapping grade GPS equipment to still water hydro graphic measurements, the research has many similarities to this research project. The author's findings regarding latency in their GPS system have been outlined above (refer to section 3.2 of chapter 2, page 14).

The method used to determine latency is to measure a series of transects (over areas of rapidly changing surface height) in opposite directions and compute the lateral shift in position (for runs in opposite directions). An example of the output from the latency test conducted by (Gibbings and O'Dempsey, 2005) is reproduced below (see Figure 2.6), clearly showing the lateral shift observed due to latency. The authors present this as an effective means of determining latency (justified by their results) and therefore this method of measuring transects (runs) in opposite directions is to be adopted as the basis for latency measurement in this project.

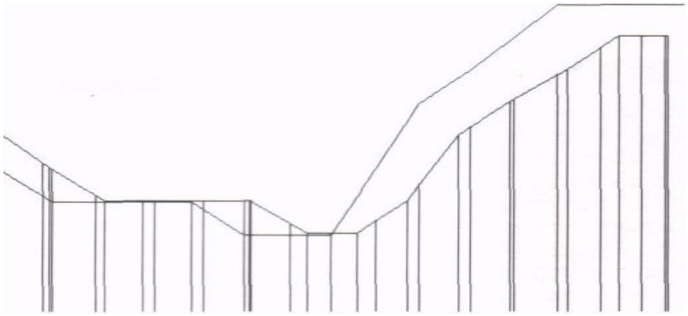

Figure 2.6 – Latency Test Results Showing Lateral Shift Observed by (Source: Gibbings and O'Dempsey, 2005)

This previous research also utilises an external sensor (depth sounder in their case) that is synchronised with an incoming stream of GPS data, similar to the bar code reading device decided upon for use in this research project. The primary difference being that in the case of the VRS research, the sensor information does not need to be extracted (as is the case in (Gibbings and O'Dempsey, 2005)), since it is only being used to relate the VRS measurements to the fixed reference frame.

Both of the previous testing methods outlined above are particularly relevant to this study, given the method that was devised for this research project has in effect evolved as a combination of both.

2.5 Machine Guidance – A Potential Application

The use of machine guidance systems has become increasingly popular over the past decade or so. Machine guidance systems are now becoming commonplace on large civil construction sites (see the image below of a bulldozer utilising machine guidance and note the GPS antenna mounted directly above one side of the blade) and also in precision agriculture applications. At the heart of the machine guidance system is a method for constantly and accurately locating the spatial position of the machine in question and then comparing that to the digital design for the work being undertaken.

Figure 2.7 – Bulldozer Utilising Machine Guidance – an Application (Source: Veit Companies 2005)

Given the requirement then for centimetre accurate positioning, the virtual reference station system does at first glance seem well suited to machine guidance applications. Latency is however, one of the primary factors presently affecting this suitability. The would-be user of the machine guidance system has to be sure that they actually are where the guidance system says they are at any given moment. Users have a requirement to know how responsive the guidance system is to changes in their spatial location on the work site.

It should also be noted that while latency does affect the position solution, other factors may also be affecting the quality of the spatial position solution given by the VRS RTK GPS. A distinction must be made between latency and accuracy. Future testing is also required to gain an understanding of the accuracy which is achievable using VRS in dynamic applications such as machine guidance.

2.6 Summary: Chapter 2

The main point that may be drawn from this chapter is the requirement for further research into the effects of latency in VRS-RTK GPS measurements made in a dynamic environment. It also demonstrates the fact that latency is not a ‘new’ problem, and provides a review of some of the methods used in previous research to quantify latency in other forms of dynamic GPS measurements. Finally an overview of the VRS concept was given, including the status of testing in the Queensland VRS network.

The following chapter will provide an outline of the methodology that has been developed for this research project to quantify latency in dynamic VRS measurements and at the same time provide a direct comparison with the conventional RTK technique.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction

The previous chapter established the need for a specific study into the effects of latency on VRS-RTK GPS measurements, where the measurements are made in dynamic situations.

The purpose of this chapter is to fully describe and document a method to quantify the latency present in GPS observations, made on a low speed moving platform. It is also intended that the following description of the methodology allow for full ‘traceability’ of the data gathered as a result of the testing and thereby allow the testing to be repeated or modified at any time in the future.

The method is designed to not only quantify VRS-RTK latency, but also to provide a direct comparison with the conventional RTK GPS technique, allowing potential users of the emerging VRS technology to assess its suitability for low speed dynamic positioning applications, when compared with conventional RTK.

Given that this initial testing focuses on relatively low speed machine guidance applications, the method devised herein considers test speeds of up to around 4 to 5 km/h. Future research may involve modifying the methodology developed in this paper to facilitate testing at a greater range of speeds (perhaps up to 20 km/h, which would be suitable agricultural applications).

3.2 Method

3.2.1 Reference Frame

To quantify any latency in the dynamic observations, the first step is to devise a method of referencing the measurements to fixed, stationary points. The previous chapter identifies a testing procedure where the fixed points are vertical beams of reflected light (Smith and Thomson, 2003) as outlined in section 4 of chapter 2. Given that the method used previously has demonstrated sound results measuring latency in a high speed dynamic environment, this methodology was originally based on the previous method, but has evolved to incorporate significant differences in determining a fixed reference frame and as such takes a varying approach to the problem. The main similarity that may still be identified is that the spatial position of the fixed marks must be accurately known and provides the basis for comparing the dynamic measurements to known stationary reference points.

The method developed in this testing regime uses an optical barcode reading device fixed to the moving platform, instead of a beam of light and a photo detector circuit as is used by Smith and Thomson (2003). The stationary points of reference used in this adaptation of the methodology are barcodes fixed to the face of stakes driven firmly into the ground, adjacent to the path of the moving platform. The fixed position of these stakes is measured by traditional static survey (either using GPS or a total station) both before and after the completion of the testing regime as a check to ensure the stakes do not move during testing.

3.2.2 A Dynamic Platform

To simulate the dynamic nature of potential applications of VRS technology, a moving platform is required to carry out the testing. The initial intention was to use a small rail trolley (similar to that used by (Taylor 2002)) provided by Queensland Rail (QR) to act as the dynamic platform for this testing, however due to time constraints and lack of availability, the methodology now assumes the use of utility vehicle as the dynamic platform (refer to Figure 3.1).

The GPS antenna is mounted on a purpose built frame, and the barcode reading device is also mounted on this frame, directly below the GPS antenna (checked using a plumb bob, see Figure 3.2 below). All other equipment as described below is mounted in the rear of the utility.

Figure 3.1 – Dynamic Platform, Utility with Frame Attached. (Author)

Figure 3.2 – Using a Plumb-bob to check the Antenna / Barcode Reader Alignment. (Author)

3.2.3 Setup Configuration

Design of the equipment configuration is a major component of this research project. Section 3.3 provides an in depth description of the problems encountered with this task, however a brief description of the major equipment is provided herein. A Trimble 5800 GPS unit was utilised for this testing. It features an antenna with built in GPS receiver and RTK radio. If the VRS signal is required, the cellular phone is usually plugged into the RS232 port on the bottom of the 5800, but this is discussed in greater detail in section 3.3. An RTK base station is also required near the test site to allow for the RTK correction information to be obtained.

One of the most complex components of the design process associated with this methodology is concerned with interfacing the barcode reader to the data recording device (laptop or TSCe). The only possible means for connecting the bar code reader to the data recorder / laptop in a simple fashion is by way of a RS 232 serial connection (see the discussion in section 3.3 of this chapter, page 29). All other means of interface require the development of dedicated electronic circuits, which are beyond the scope of feasibility for this research project.

Figure 3.3 – Microvision™ Flic™ Barcode Scanner Used for Testing. (Source: Expansys Australia)

The methodology designed in this research utilises Trimble GPS equipment and no testing is done using GPS receivers from other manufacturers. Further future testing is required using a similar method as that described in this chapter for each individual equipment configuration, before any generalised conclusions can be made regarding other makes of GPS receiver.

3.2.4 Measurement Sequence

The measurement sequence for this testing consists of driving the vehicle (dynamic platform) with all required equipment on board along a straight section of road, keeping the vehicle's tires against the kerb to maintain a consistent, repeatable path. The vehicle is driven in both directions past the fixed barcodes that are placed adjacent to the roadway (see Figure 3.4 below). This is done over the entire range of speeds for which the barcode reader will operate, as determined during initial testing.

In total, 4 barcodes are placed along the road section, at approximately 2 metre intervals, for a total run length of approximately 6 metres plus run-up and run-down distance to get the vehicle up to and down from the required speed. Note that for testing at higher speeds, the fixed reference marks may need to be spaced further apart to allow for greater latency errors in distance.

It is also worth noting that on some runs during the testing that has been carried out, the barcode reader would fail to read one or two of the four fixed barcodes. This is because the device itself has a 'timeout' function built in that turns of the reading light after 4 seconds. This means that if the button to take a reading is pressed too early, the light will be off before the reader reaches the fixed barcode. This is designed to increase battery life but should be removed to aid future testing endeavours. This issue results in some fixed points having more data than others, affecting to a small extent the quality of the average values for each fixed point. These points are noted in the data analysis presented in chapter 4.

Figure 3.4 Barcode Reader Moving Past the Fixed Reference Points. (Author)

For a run taken from left to right past the barcodes, it is expected that latency would cause the measurement of the fixed barcodes to be right of the true location (see Figure 3.5 below). For a right to left run at the same speed, it is expected that the barcodes are measured left of the true location (by the same distance, as long as the speed is the same). Therefore, halving the distance difference between opposite runs determines the distance value of the latency error. We can then compare the measured position with the known location of the fixed barcodes (as measured by traditional survey before and after testing), as a check to ensure that our position measured in a dynamic sense (after correcting for the latency distance) agrees with the known, fixed location of the barcodes mounted on the stakes.

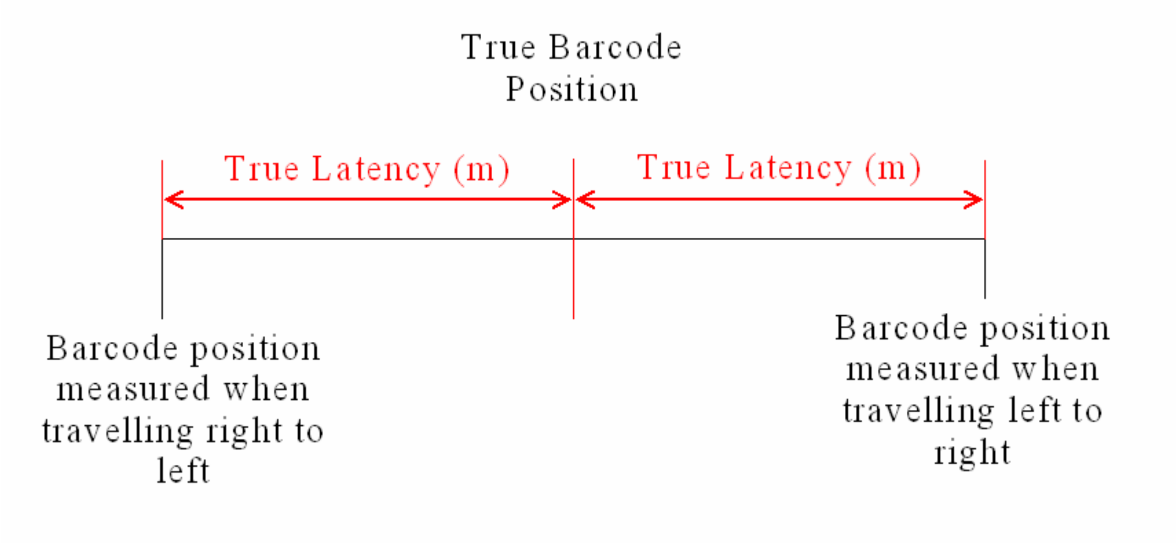

Figure 3.5 – Using the Measurement Sequence to Determine Latency. (Author)

The actual speed at which the testing is conducted is not a critical factor. The primary requirement relating to platform speed is that it remains constant for each run at a given speed, and in both directions. Therefore, low range four wheel drive is used to maintain a constant speed, with the driver concentrating on maintaining a consistent engine revolution value for a given gear ratio. This also creates a requirement that the section of road used for testing be relatively level, because travelling up a slope at a certain revolution value will be slower than travelling downhill at the same revolution value (for any given gearing ratio).

Prior to, and immediately after, completing the test regime, the position of the fixed barcodes is surveyed by conventional RTK, to provide the comparison discussed above, and to also ensure that none of the fixed stakes have moved during to course of the testing. Of course, the section of road used for the testing must be free from overhead obstructions to allow uninterrupted tracking of as many satellites as possible, and to reduce the chance of losing the fixed RTK solution, requiring the RTK system to be re-initialised.

The measurement data being logged by the data recorder is synchronised and combined with the barcode reader information using the external sensor function in TerraSync (Trimble Navigation, Christchurch, NZ) software. The synchronisation is done within the software by proportioning the time between consecutive GPS measurements and the input of external sensor information. For example, if the GPS is logging position data at 1 second intervals, the measurement timeline might be:

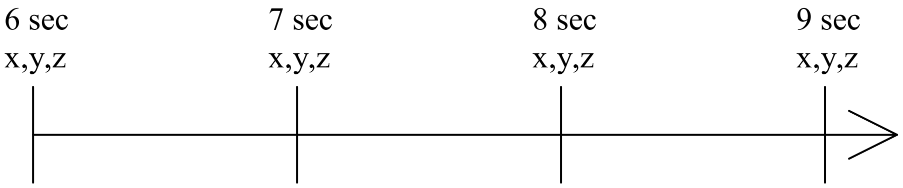

Figure 3.6 – GPS Measurement Timeline (fictitious example). (Author)

Once the input of external sensor information begins, the software will assign time and position data to the external sensor information based on when it occurs relative to the GPS measurements either side of this event. The resulting timeline might be:

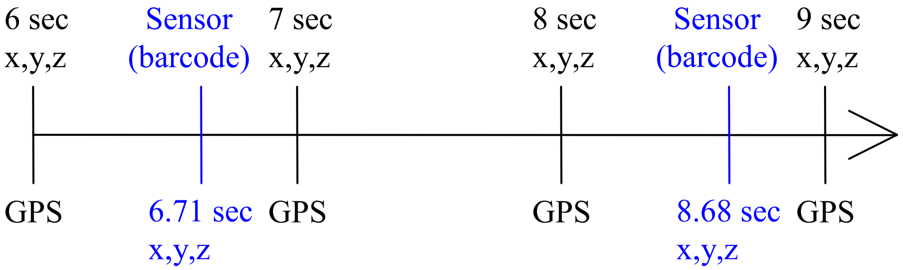

Figure 3.7 – GPS Measurement Timeline Example Showing External Data Record Synchronisation. (Author)

3.2.5 Validating the Method

Before the actual testing takes place, it is prudent to validate the methodology to ensure it works as planned, and to ensure that all necessary data is being obtained. The primary objective of this initial testing is to ensure that the barcode reader can read the barcodes properly in a dynamic situation and insert a record into the data file of the data logger (TSCe) as we require. The initial testing gives an indication of what speed ranges the barcode reader will operate over.

Once the barcode reader arrived, initial testing was conducted in Toowoomba at the USQ campus. Since the VRS signal is not available in Toowoomba, only the RTK correction could be applied in this initial testing. This is still sufficient to provide an understanding of the speed ranges over which the barcode reader will work. It also gives an understanding of how the testing regime works and also what format the output data is in.

Given that VRS is not to be used, a Trimble TSCe is used for data logging, with the barcode reader being plugged into the DB9 (com1) serial port. For this initial verification, the ANANGA semi-permanent base station at the USQ is used as the conventional RTK base station. An example of the raw data gathered during this initial testing is presented in Table 3.1 below and clearly shows the external sensor (barcode reader) information that has been recorded during this initial testing (displayed in the 'TEXT' column).

Table 3.1 – Sample raw data file generated during initial testing. Not that since only 2 bar codes were used at this initial stage, both were encoded as 1, and read as □1.

ID	EASTING	NORTHING	ELEVATION	TEXT	CHANNEL	GPS_DATE	GPS_TIME
97	394726.325	6945723.619	688.398	□1	1	13/01/2006	01:54:26.338pm
179	394725.901	6945724.646	688.446	□1	1	13/01/2006	01:55:47.149pm
181	394725.905	6945724.648	688.441	□1	1	13/01/2006	01:55:48.223pm
183	394725.906	6945724.645	688.446	□1	1	13/01/2006	01:55:49.847pm

3.3 Problems and Contingencies

There are two primary problems that were encountered in the course of this research project. The first problem concerns the investigation and subsequent supply of an appropriate barcode reading device. The second problem relates to the task of interfacing all the necessary hardware and software components to conduct the testing.

The majority of the barcode reading devices which are available utilise the Universal Serial Bus (USB) port or the PS2 port (usually reserved for keyboard / mouse) of the PC for connectivity. The initial barcode reader models investigated use either USB or PS2 ports, making them unsuitable (because the digital signal could not be sent to TerraSync). The models of barcode reader tested initially are:

- OPT6125 Scanner from Opticon (USB Connection)
- 1000 CCD Scanner from CipherLab (PS2 Connection)

Neither was suitable due to their method of connection to the Data logger. Both are capable of reading data into some word processing programs, but not into TerraSync. Therefore it becomes clear that RS232 serial (com port) connection is required. Many barcode readers available on the market feature RS232 connectivity. The next reader tested was the Datalogic Touch 90 CCD scanner with RS232 connection. Although the device would plug into the data recorder, no signal was achieved because the device requires its own power supply and cannot draw power from the host device (as is the case with USB or PS2 devices).

The other requirement which was found to be essential is the auto upload of data upon reading the barcode. Once a power pack was found for the Datalogic Touch 90 scanner, it was learned that the power pack also requires the output signal from the scanner to pass through it. The power unit would then store data onboard without automatically uploading the sensor data to the host computer.

This makes the Touch 90 scanner unusable, because any delay in the upload process introduces additional latency into the system and would therefore fail to provide a true measurement of the latency found in a ‘real world’ situation. This means that the 3 primary requirements to connect a barcode reader to the laptop and then import the signal data into TerraSync (as described above) are:

- Device must use a RS232 serial (com port) connection,
- Device must have it’s own power supply and
- Device must auto-upload data to the computer.

The only suitable device found on the market was the Microvision Flic barcode scanner (see figure 3.3). The technical specifications for this barcode reader are reproduced in appendix C of this dissertation (Expansys Australia).

This testing of barcode readers has taken a lot longer than the author had initially anticipated. Furthermore, unforseen extended delays (which have no explanation from the supplier) in the delivery of the barcode reader and associated equipment from the manufacturer have prevented the testing from being competed earlier in the course of this project. The author believes he has a much better understanding of how to both deal with suppliers and control logistics as a result of undertaking this exercise (as well as estimating task durations).

Given that initial testing in Toowoomba using RTK proceeded without incident once the barcode reader arrived (as discussed in the following chapter), full testing in Brisbane utilising both RTK and VRS corrections has been attempted. This was to reveal further problems which were not revealed by the initial testing due to the extra requirement of the VRS correction data.

The full implementation of the methodology developed in chapter 3 has been attempted using surveying / GPS equipment provided by the DNRM in Brisbane. Available equipment included a Trimble R8 GPS receiver / antenna / radio unit, a GSM cellular phone with serial cable and a Trimble TSCe data recorder running TerraSync. Each problem encountered in this last phase of the project will now be discussed in detail.

ISSUE 1. Mobile Phone Connectivity / TerraSync

The first problem encountered during testing in Brisbane involves utilising the VRS correction data at the same time as an external sensor. The standard software running on the TSCe is the Trimble Survey Controller package. When completing a survey using this software on the TSCe in conjunction with the R8 receiver, the mobile phone is plugged into the serial port on the bottom of the R8 and survey controller will dial the number for the correction data through the receiver.

However, the Survey Controller software does not allow for the input of external sensor information, making it unsuitable for reading in the barcode reader information. Trimble TerraSync does have an external sensor function and is capable of running on the TSCe (a Windows CE platform). TerraSync was installed on the TSCe and the setup was trialled again. The configuration now has the mobile phone plugged into the R8s' serial port, the receiver connected to the TSCe using the 0 shell lemo to 0 shell lemo cable, and the barcode reader plugged into the com 1 serial port of the TSCe. Using this configuration, the sensor information reads into TerraSync without a problem, but it was quickly discovered that TerraSync, unlike Survey Controller, cannot dial the mobile phone from the receiver, meaning that the VRS correction data could not be obtained.

ISSUE 2. Laptop Computer for Data Recording

At this stage it was obvious that the primary issue was a lack of serial ports on the TSCe, so an attempt was made to do away with this device and a laptop computer was trialled as the data recording device. The laptop has TerraSync installed and utilises a USB to 4 serial port hub to provide sufficient serial ports. These ports automatically enumerate themselves as Com 7, 8, 9 and 10 when the device is connected. The barcode reader is plugged into com 7 and tested to ensure that this configuration would allow the import of external sensor data. This works fine. The receiver is connected to com 8 and a connection is established. The mobile phone is connected through com 9 and the driver software for the connection cable is installed.

The problem with this configuration arises when the phone settings are put into TerraSync. The correction source is set to VRS and the phone number is put into the software. The software then asks which modem to use to dial the number, and cannot find the modem of the mobile phone. The only options given are the built in 56k dial-up modem and the built in Bluetooth modem of the computer.

A method could not be found to get the software to recognise the mobile phone on com 9 as a modem capable of creating the VRS connection with the LANDCENTRE VRS server. This makes the laptop unsuitable as the data recording device (when using VRS) unless the corrections can be obtained by some other means (perhaps the internet for example).

ISSUE 3. TSCe I/O Ports

Given the problems arising using the laptop computer, the decision was made that the TSCe would have to be used for logging the data and running the survey. From the previous testing it was known that the mobile phones' serial cable must plug into the RS232 (DB9) com 1 port of the TSCe. The question then remains, how can the barcode reader information be brought into the TSCe?

The TSCe does have another multi-serial port usually reserved for the Bluetooth ‘Bluecap’ adaptor or the USB and phone line adaptor. The next configuration attempted was to use a USB to serial adaptor coming out of the Trimble USB and phone line adaptor to connect the barcode reader through this port. This was unsuccessful because software drivers for Windows CE are not available for the USB to serial adaptor.

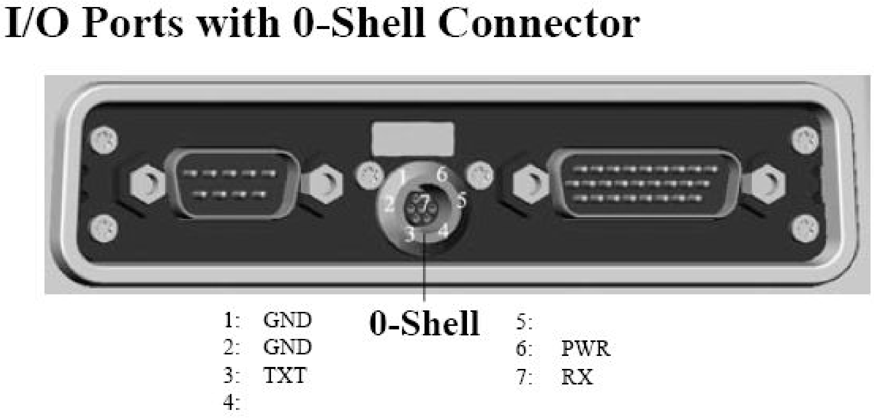

Figure 3.8 TSCe I/O Port Configuration. Note the DB9 (RS232 serial) port on the left and the 26 pin multi - port on the right, as well as the Infrared port directly above the 0 Shell port. (Trimble Navigation Ltd.)

The last attempt to interface these two devices without using com 1 (reserved for the mobile phone) is to fit a direct multi port to DB9 adaptor. Herga Ultimate Positioning in Brisbane supplied such a device, which was originally designed for use on the Trimble ACU controller (so there were no guarantees given!). Once the barcode reader was plugged in and the port settings configured, the sensor window in the status function of TerraSync showed that the software could recognise the reader, but when barcodes were read, the counter function did not count any of the observations, indicating that the information was not reaching the data file.

At this stage the technical experts at Herga were consulted regarding any other possible means of creating this connection but no solution could be found. If TerraSync could dial the mobile phone through the receiver (as Survey Controller can) then this would free up the com 1 port on the TSCe for the external sensor, and for this feature to be integrated into future versions of the software is therefore a major recommendation of this research.

Possible Future Solutions

Further research by the author has also given rise to another possible solution to this problem. It is understood that a new version of the TSCe will soon be commercially available, known as the TSC2. It is also understood that the DNRM in Brisbane has one of these new data recorders on order. The new TSC2 will feature an additional USB port, in addition to the RS2332 (com 1) serial port. A USB cable is also available for the barcode reader, possibly allowing connection by this means.

The TSC2 also features an integrated Bluetooth radio, and DNRM have also ordered a new mobile phone with Bluetooth capabilities. This may allow the phone to connect to the TSC2 by Bluetooth, also freeing up the com port. It is simply unfortunate that the TSC2 was not available in time for use in this initial stage of this research into VRS latency.

3.4 Summary: Chapter 3

This chapter describes and fully documents a method for quantifying latency in low speed dynamic GPS measurements, and through changing the correction data source and repeating testing, provides a comparison between different types of correction data facility. The method has been tested using conventional RTK corrections to ensure sufficient data is collected in the process. Although it has not been tested in the field due to the device not yet being available, the author can see no reason why the use of the soon to be released TSC2 data recorder (possibly in conjunction with a Bluetooth enabled mobile phone) would not allow future research efforts to complete this evaluation.

Chapter 4 presents an analysis of the data resulting from the implementation of the above testing regime, to gain useful information regarding GPS latency. This will allow conclusions to be drawn regarding the suitability of VRS to dynamic applications, where latency error is a primary consideration, and particularly where a comparison with conventional RTK GPS surveying is required.

CHAPTER 4

DATA ANALYSIS

4.1 Introduction

The previous chapter fully describes and documents a method for measuring what if any latency is present in dynamic VRS measurements. This method also provides a comparison with the conventional RTK technique, by simply changing the real time correction source from VRS to conventional RTK.

This section intends to present an analysis of the data analysis used to obtain useful information resulting from the implementation of the testing regime utilising only RTK corrections. Given that the VRS data was not able to be captured as a part of this research project for the reasons described in the previous chapter, the analysis of the RTK data will give a foundation for ongoing research in this area. It should however be noted that the data analysis process for VRS data is exactly the same as for the RTK data, since the output files would be in an identical format and the VRS / RTK corrections are automatically applied before the data is recorded.

4.2 Data Analysis

4.2.1 Raw Data Collection

The initial raw data from the GPS receiver is recorded in a Trimble TSCe data recorder using a RS232 - 0 Shell lemo cable. The RS232 (DB9) end plugs into the bottom of the 5800 receiver and the 0 shell lemo end plugs into the 0 Shell lemo port (com 2) of the TSCe. A similar configuration is also used to import the barcode scanner data into the TerraSync program, in real time. The barcode reader data is brought into the TSCe using the com 1 RS232 serial port (only possible since the VRS signal is not being used).

The TerraSync program includes a feature for combining the GPS data with the data being received from an 'external sensor' (located in the 'setup' menu), in this case, the barcode reader. The process of combing this data was discussed in section 3.2.4 (page 24) of the previous chapter.

Once the raw data has been brought into the TSCe, some cursory analysis using TerraSync can be performed, primarily as a check in the field that sufficient data has been captured to facilitate the later processing. This initial analysis includes reviewing the raw data files and basic on-screen plotting of the collected data within TerraSync, as a further check to make sure the captured data 'looks right'.

4.2.2 Data Transfer to Personal Computer

The raw data files must then be 'dumped' to a computer for analysis. The import of raw data is controlled from the personal computer (PC) within Trimbles' Pathfinder Office software package. The Trimble Data Transfer utility is initiated from within Pathfinder Office, once the TSCe is connected by USB adaptor to the PC. A connection is established between the two devices using Microsoft ActiveSync and the raw files are transferred to the computer. These raw files are in the .SSF format and can be opened using Pathfinder Office.

4.2.3 Outputting Data for Analysis

From within this program there is a function in the utilities menu to export the data. Using this function, the raw position, time and sensor information is output to a user defined location as two separate .DBF files which may be accessed through Microsoft Excel. One point worth noting is that since Pathfinder Office will allow the user to control a lot of settings relating to the output format. One default setting which should be changed is to increase the time decimal place setting from 0 to 3, allowing for greater accuracy in the analysis.

The first output file will contain all the points logged at the interval set by the user (every 1 second in this case). The second file will contain the sensor information, including the determined position of the sensor at the time of each sensor reading. In this case that will occur every time the barcode reader passes by the fixed barcodes. These two files may be combined as required by simply copying one into the other and performing a sort based on point ID numbers.

4.2.4 Analysing the Database Information

The majority of the analysis is performed using the Microsoft Excel spreadsheet program. Raw data relating to the measured position (corrected using conventional RTK in this case) of the fixed barcodes is extracted from the raw data files as described above (also see Table 4.1 below for an example).

Table 4.1 Sample Combined Output File. Table 4.1 shows combined output file of both positions every second as well as sensor data.

ID	Easting	Northing	Elevation	TEXT	GPS_Time	GPS_Second
90	394843.210	6946275.715	685.714		01:02:49.000pm	442983.000
91	394842.879	6946275.690	685.716		01:02:50.000pm	442984.000
92	394842.569	6946275.656	685.706		01:02:51.000pm	442985.000
				□5		
93	394842.542	6946275.654	685.707		01:02:51.083pm	442985.084
94	394842.246	6946275.638	685.717		01:02:52.000pm	442986.000
95	394841.891	6946275.604	685.739		01:02:53.000pm	442987.000
96	394841.447	6946275.560	685.743		01:02:54.000pm	442988.000
97	394840.963	6946275.534	685.780		01:02:55.000pm	442989.000
98	394840.599	6946275.500	685.772		01:02:56.000pm	442990.000
99	394840.212	6946275.477	685.795		01:02:57.000pm	442991.000
				□4		
100	394840.084	6946275.473	685.799		01:02:57.391pm	442991.392
101	394839.885	6946275.465	685.804		01:02:58.000pm	442992.000
102	394839.555	6946275.441	685.815		01:02:59.000pm	442993.000
103	394839.185	6946275.423	685.820		01:03:00.000pm	442994.000
104	394838.713	6946275.376	685.836		01:03:01.000pm	442995.000
105	394838.221	6946275.327	685.853		01:03:02.000pm	442996.000

For each run a separate file is logged in the field and subsequently output through Pathfinder Office. From these raw files the vehicle speed is calculated, utilising the time of measurement data (to 1/1000th of a second) and the distance between the barcodes (known from the static measurements of the bar code positions to the nearest millimetre), and applying the relationship:

$$\frac{\text{Distance}}{\text{Time}} = \text{Speed}$$

This calculation is performed for each run pair (i.e. up and back) to ensure that each of the run pairs at each speed share a constant speed. If the majority are the same speed but one run pair is significantly different, then that run should be omitted from the calculation of average latency for that speed range. If the outlying run pair is included, it will distort the average latency computed for that speed (higher speed observations will obviously show a larger distance error due to latency).

From the raw position data, the latency for each run pair can be calculated. Averages of the latency distance error can be computed for the run pairs which are made at the same speeds (i.e. rejecting any outliers as explained above). This results in average latency distance errors for each.

As mentioned previously, it should be kept in mind that during the testing on some runs, one or two of the barcodes were missed, reducing the data available for them. This may slightly affect the quality of the average latency measurements for the points which were missed. Fixed barcodes 2 and 5 in particular were not logged on several runs and as such have been omitted from the average calculations.

Table 4.2 – Sample Table Showing Raw Barcode Position (Sensor) Data. These positions have been corrected in the GPS receiver using a fixed RTK solution. The text column gives the encoded value of the barcode as read by the barcode reader. Note also the GPS time output to 1/1000th of a second.

ID	Easting	Northing	Elevation	Text	Channel	GPS_Date	GPS_Time
33	394839.970	6946275.457	685.787	□4	1	27/01/2006	02:24:45.532pm
88	394835.809	6946275.168	685.924	□1	1	27/01/2006	02:25:39.260pm
180	394835.776	6946275.148	685.947	□1	1	27/01/2006	02:27:10.263pm
191	394840.378	6946275.512	685.811	□4	1	27/01/2006	02:27:20.514pm
420	394835.704	6946275.147	685.947	□1	1	27/01/2006	02:31:08.424pm
428	394837.656	6946275.307	685.887	□4	1	27/01/2006	02:31:15.858pm
437	394840.371	6946275.520	685.781	□4	1	27/01/2006	02:31:23.282pm
502	394839.974	6946275.471	685.815	□4	1	27/01/2006	02:32:27.156pm
582	394835.781	6946275.127	685.945	□1	1	27/01/2006	02:33:46.908pm

4.2.5 Results

Finally, the results can be graphed in Excel to provide a graphical representation of the latency error for each run over the range of different speeds. Had the VRS signal been logged as well, these graphs would be output for both the conventional RTK and the VRS measurements, thereby presenting a graphical comparison of the latency for both these systems.

The following table (Table 4.2) provides the results of this analysis for the data collected using the conventional RTK correction facility at the USQ campus in Toowoomba. The table clearly shows that the errors in position due to latency increases with speed. This has then been represented graphically in figures 4.1, 4.2 and 4.3 following the table.

Table 4.3 – Relationship Between Platform Speed and Position Error (Distance Difference). Not that the direction of travel for this testing was in an almost due east / west direction.

Barcode Value / No.	Speed Km/h	Measured Easting	True Easting	Difference	Measured Northing	True Northing	Difference	Distance Difference
□4	1.16	394840.298	394840.201	0.097	6946275.511	6946275.471	0.040	0.104924
	1.18	394840.084	394840.201	-0.117	6946275.473	6946275.471	0.002	0.117017
	1.75	394840.378	394840.201	0.177	6946275.512	6946275.471	0.041	0.181687
	2.1	394840.001	394840.201	-0.200	6946275.482	6946275.471	0.011	0.200302
	2.16	394839.995	394840.201	-0.206	6946275.468	6946275.471	-0.003	0.206022
	2.190	394839.952	394840.201	-0.249	6946275.462	6946275.471	-0.009	0.249163
	2.21	394839.970	394840.201	-0.231	6946275.457	6946275.471	-0.014	0.231424
	2.38	394839.937	394840.201	-0.264	6946275.447	6946275.471	-0.024	0.265089
	2.540	394839.974	394840.201	-0.227	6946275.471	6946275.471	0.000	0.227000
□1	0.560	394835.704	394835.687	0.017	6946275.147	6946275.120	0.027	0.031906
	0.91	394835.749	394835.687	0.062	6946275.150	6946275.120	0.030	0.068877
	1.190	394835.776	394835.687	0.089	6946275.148	6946275.120	0.028	0.093301
	1.430	394835.809	394835.687	0.122	6946275.168	6946275.120	0.048	0.131103
	1.52	394835.557	394835.687	-0.130	6946275.136	6946275.120	0.016	0.130981
	1.750	394835.515	394835.687	-0.172	6946275.125	6946275.120	0.005	0.172073
	1.8	394835.485	394835.687	-0.202	6946275.128	6946275.120	0.008	0.202158
	1.99	394835.448	394835.687	-0.239	6946275.123	6946275.120	0.003	0.239019
	2.57	394835.455	394835.687	-0.232	6946275.095	6946275.120	-0.025	0.233343

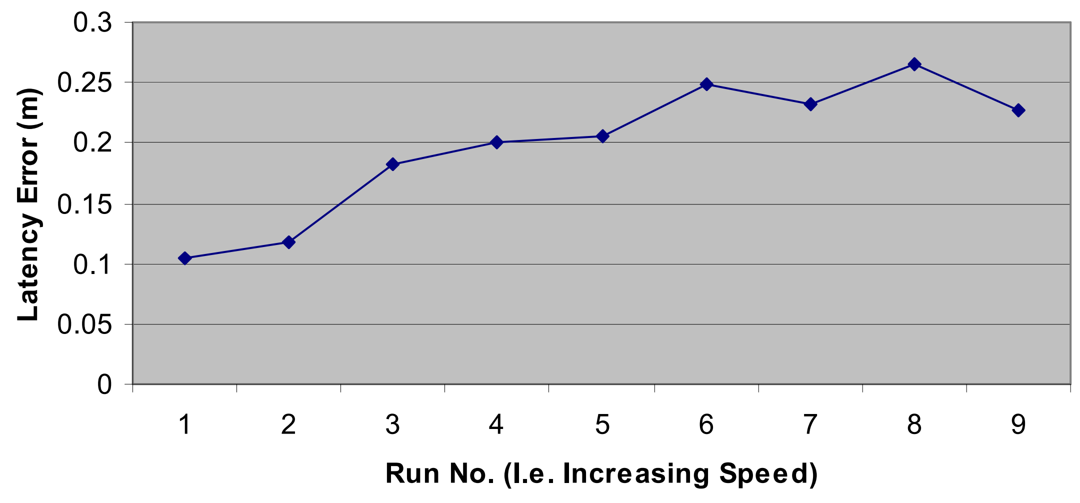

Figure 4.1 - Barcode 4 Latency

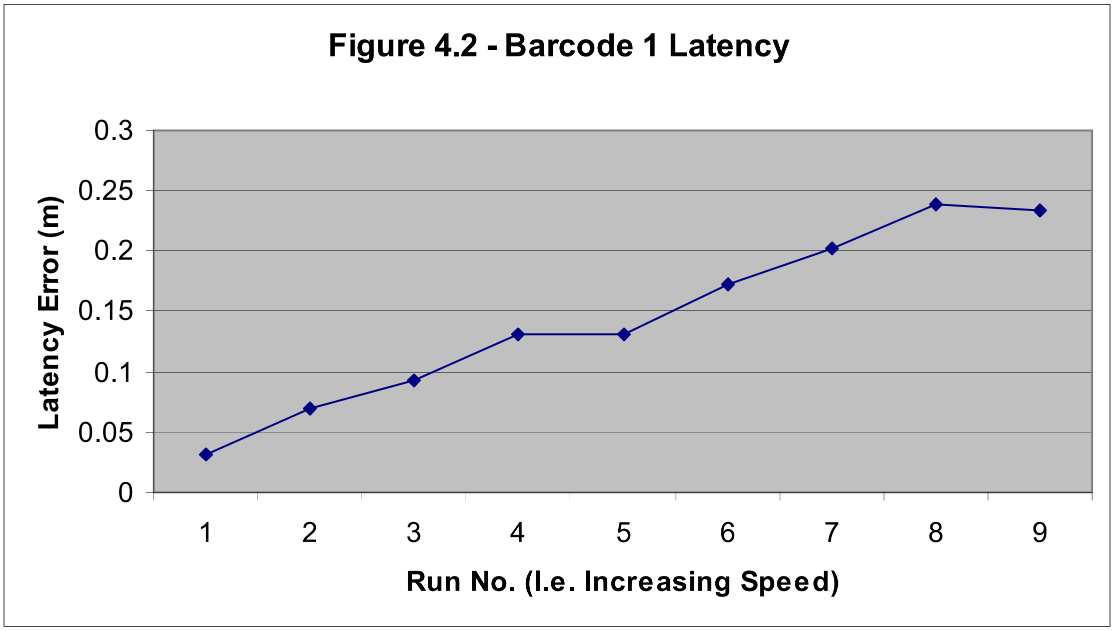
Figure 4.2 - Barcode 1 Latency
Latency Error (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
Run No. (I.e. Increasing Speed)

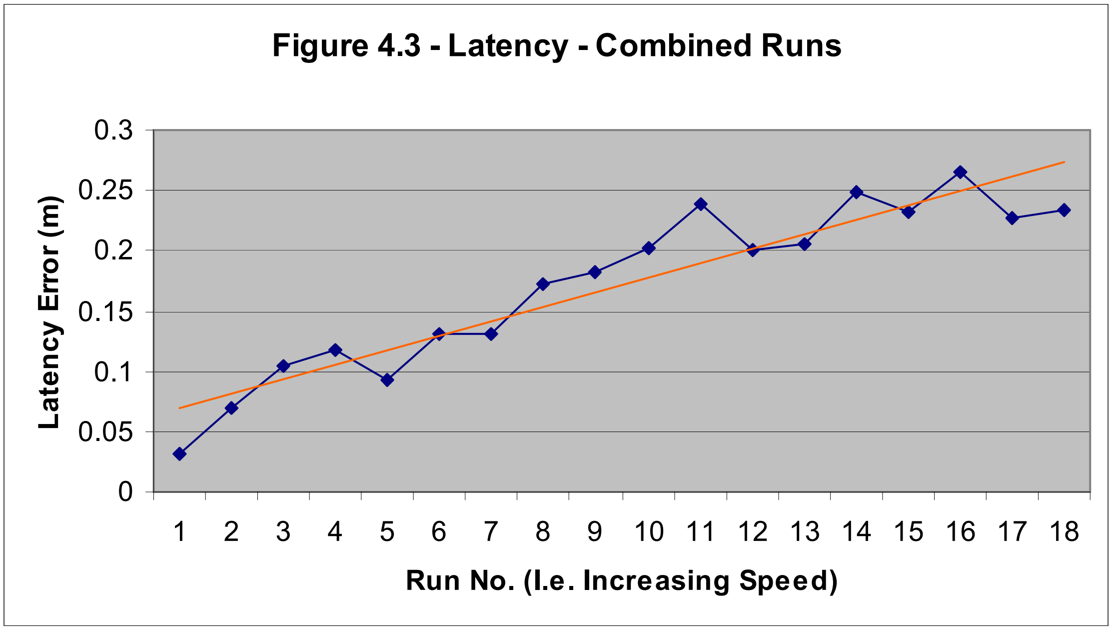
Figure 4.3 - Latency - Combined Runs
Latency Error (m)
0.3
0.25
0.2
0.15
0.1
0.05
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
Run No. (I.e. Increasing Speed)

It is clear to see from the graphic representations of the results provided above that a significant latency error is affecting the position solution of these dynamic RTK measurements, especially when the low platform speed is considered (from around 0.5 to 2.6 km/h). These results raise two important questions which should become the immediate focus of ongoing research efforts:

1. How much of this latency error is attributable to the GPS measurement component and how much is accounted for within the barcode reading device?

2. To what extent does the size of the barcode which is fixed to the stake in the ground affect the position at which the barcode is being measured?

The first point is difficult to determine and may be the source of its' own complete investigation / research project. The second point is a little easier to determine. The width of the barcodes used in this testing is 50mm because it was found during the initial trials that barcodes of less than 50mm almost doubles the occurrence of the reader failing to detect the fixed barcode. Therefore, it would not be unreasonable to expect that because we are comparing travel in both directions, up to 100mm (0.1m) of the error **could** be attributable to the inaccuracy caused by using a 50mm wide barcode. This would however also require further investigation and has not been completed as part of this research due to time constraints.

Given that results using this method are only available up to around 3 km/h, it also becomes clear as a result of this testing that the barcode reading device does not really provide a satisfactory means of relating the dynamic measurements to a fixed reference frame. Future testing at higher speeds will require a better method of providing this fixed reference.

The final point worth noting is that the relationship between platform speed and latency error appears to be linear. This is demonstrated in the combined graph (Figure 4.3) by the addition of the linear trend line in orange. This is to be expected because if the speed is doubled and the time (latency) remains fixed, the relationship of speed x time = distance shows that the distance value should double (i.e. 2 x 1 = 2 and 4 x 1 = 4, where the 4 would demonstrate a doubling of the platform speed).

4.3 Summary: Chapter 4

Chapter 4 has presented the method of data analysis that is applied to the data captured as a result of the implementation of the methodology outlined in chapter 3. This is a complete description of the methods of analysis required to extract useful information regarding latency in dynamic VRS RTK measurements from the raw data files attained in the implementation of the research methodology.

Chapter 4 has also demonstrated that latency is affecting the results that have been obtained from the testing carried out as an integral component of this research. As such, it becomes all the more important that further investigation of these effects is undertaken, over a greater range of speeds to allow potential users of dynamic VRS data to correct for the effects of latency in real time.

Chapter 5 summarises the current status of this research and makes recommendations regarding the continuation of this research, and also the adaptation of the methodology described in chapter 3 to higher speed applications.

CHAPTER 5

DISCUSSION AND SUMMARY

5.1 Introduction

Chapter 4 has outlined the data analysis processes required to extract useful information from the data that is collected upon implementation of the testing regime developed in this research project, to quantify latency in low speed dynamic VRS RTK GPS measurements. Chapter 4 also demonstrated that there is some latency error present in the gathered data.

During the course of this research, several issues have arisen which need to be addressed in the future. Chapter 5 provides an outline of the current status of the research, and also makes recommendations regarding the continued research and investigation of latency in dynamic VRS measurements.

5.2 Further Research and Recommendations

5.2.1 VRS Testing

Due to the extended delays in delivery of the barcode reading equipment, and the subsequent issues outlined in chapter 3, the implementation of the methodology described in this dissertation has only been possible utilising the conventional RTK correction facility. Further research efforts are required in this specific field of VRS latency measurement, to implement this testing in a similar fashion and analyse the resulting data (in accordance with the practices described herein) to give potential VRS users and understanding of the effects of latency in low speed dynamic environments. These effects should then be compared to the results obtained in this research to provide the basis for a comparative measure of latency in the two systems.

It is expected that this will initially involve the testing of the TSC2 once it becomes available, in an attempt to gather external sensor position information in conjunction with the VRS correction facility.

5.2.2 Additional TerraSync Requirements

As previously mentioned, this research has also led to the discovery that it is not possible to utilise the external sensor function in TerraSync on a TSCe data recorder and VRS correction data simultaneously. It is therefore a primary recommendation stemming from this research project that future versions of TerraSync should be able to dial the cellular mobile phone from the receiver, in the same way that the Survey Controller software package can (this information has been passed on to the manufacturer).

5.2.3 Testing at Higher Speeds

Future testing is also required to investigate latency and its' effects on higher speed applications to gain a more thorough understanding of the relationship between platform speed and latency, in dynamic VRS measurements. It is the authors' opinion that testing is required up to around 25 kilometres per hour in order to be of use to the precision agriculture community.

The methodology used for this future testing may be based on the techniques and processes described in this dissertation, but it is recognised that modification of the equipment configuration and testing regime is required to facilitate this. This research has also demonstrated that the use of a barcode reader is probably an inadequate method of providing a fixed reference frame, given that this device will have difficulty reading barcodes at speeds in excess of 3 km/h.

One possible method to allow higher speed testing may be the design of a dedicated electronic circuit to facilitate input of ‘through beam’ optical sensor data into a Trimble data recorder (this was briefly considered in this project however time constraints proved prohibitive). For the same reasons given in this dissertation (i.e. there is insufficient com ports on the TSCe), the Trimble TSC2 running TerraSync will probably be the required data logging device (but this would need to be determined during the investigation mentioned above). The only other possibility would be to find a means of expanding the port capabilities of the TSCe, but this would probably require a dedicated device with Windows CE driver software, which to the best of the authors’ knowledge is not currently available (after a brief search).

5.2.4 Testing Involving Different Manufacturers

Future testing of the VRS network should also include experimentation with different equipment configurations. All the testing put forward in this research project utilises Trimble GPS equipment. Future testing should also be conducted to fully investigate the effects of latency in dynamic VRS networks, where trials are conducted using different makes of GPS equipment, and different models of equipment from the various manufacturers. This would provide a more generalised view of how latency affects dynamic measurements within VRS networks.

5.2.5 Accuracy Testing

Again, it is also worth noting that this research has only considered the effects of latency on the position solution, which should be distinguished from accuracy. The accuracy of the VRS system in dynamic applications has not been investigated, but would also be a major consideration for potential users. A correction for latency is of little value if the accuracy of the VRS system under dynamic conditions is insufficient. Therefore, it is a further recommendation of this research that future testing be conducted to investigate the accuracy of the VRS system in dynamic environments, possibly through data collection in conjunction with the ongoing latency testing.

5.3 Summary

Chapter 5 presents various recommendations regarding possible future direction for ongoing research into the effects of latency on dynamic VRS measurements. The continuation of the research presented in this dissertation is required; in particular, the methodology developed herein needs to be carried through to completion, possibly through ongoing research efforts at the USQ once the required equipment becomes available. The TSC2 should be trialled to investigate whether or not this hardware can provide a solution to the current problem of a lack of serial ports on the data recording device. This research has also highlighted the need for a function to be incorporated into TerraSync to allow for the simultaneous use of VRS and an external sensor, namely enabling TerraSync to dial the VRS mobile phone from the receiver, not the TSCe com port 1.

Furthermore, the methodology described in this dissertation may be adapted in the future to investigate the effects of latency on higher speed applications of VRS. This testing will probably require the development of a specialised electronic circuit to interface some type of ‘through beam’ optical sensor with the data recording device. A thorough investigation into the accuracy of dynamic VRS measurements is also required, and may possibly be conducted in conjunction with future latency testing at higher speeds.

BIBLIOGRAPHY

Bar-sever, Y. E., 2000, Marine Benefits from NASA's Global Differential System: Sub Meter Positioning, Anywhere, Anytime, Dynamic Positioning Committee, Marine Technology Society, Dynamic Positioning Conference (Sensors).

Bouvet, D., Garcia, G., Improving the Accuracy of Dynamic Localisation Systems using RTK GPS by Identifying the GPS Latency, Institut de Recherche en Communications et Cybernétique de Nantes, France.

Campbell, J., Carney, C., Kantowitz, B., 1998, Human Factors Design Guidelines For Advanced Traveler Information Systems (Atis) And Commercial Vehicle Operations (Cvo) , Chapter 5, Vehicle Location Accuracy, Battelle Human Factors Transportation Center 4000 NE 41st Street Seattle, WA. [online], Available from:

http://www.fhwa.dot.gov/tfhrc/safety/pubs/atis/ch05/ch05_10.html

[Viewed April 8th, 2005]

DLI, 2005, Landmarks – 'Curtin Uni to Get $120,000 for Cutting Edge CORS Study', Department of Land Information, Western Australian Government, p14, available from:

http://www.dli.wa.gov.au/docvault.nsf/web/LM_DLI_landmarks45_200509/$FILE/LM_DLI_landmarks45_200509.pdf

[Viewed November 20th, 2005]

Gibbings P., O'Dempsey A., 2005, Using GPS Asset Mapping Software for Hydrographic Measurements in Still Water, Journal of the Spatial Sciences Institute (Qld)

Higgins, M., 2001, An Australian Pilot Network for a Real Time Kinematic GPS Network Using the Virtual Reference Station Concept, [online], Available from:
http://www.fig.net/pub/proceedings/korea/full-papers/session11/higgins.htm
[Viewed April 3rd, 2005]
Hu, G., Khoo, V., Goh, P., Law, C., 2002, Internet-based GPS VRS RTK Positioning with a Multiple Reference Station Network, Journal of Global Positioning Systems (2002), Vol. 1, No. 2: 113-120 [online], Available from:
http://www.gmat.unsw.edu.au/wang/jgps/v1n2/v1n2pE.pdf
[Viewed April 6th, 2005]

Interoute Communications Limited, 2005, Glossary of Terms [online], Available from:
http://www.interoute.com/glossary.html
[Viewed April 1st, 2005]

K. Mike, Patch Test Uncertainty II, Available from:
http://www.hypack.com/newsletter/5_00/Mike_K.htm
[Viewed June 4th, 2005]

Kashani I., Wielgosz P., Ionospheric Correction Latency Analysis in Long-Range RTK, IAG Working Group 4.5.1: Network-RTK, Available from:
http://www.network-rtk.info/kashani2/kashani2.html
[Viewed June 3rd, 2005]

Office of the Surveyor-General (OSG), 2003, Options for Automated Processing of GPS Continuous Tracking Data, Technical Report 17, Office of the Surveyor-General, Land Information New Zealand, [online], Available from:
http://www.linz.govt.nz/docs/surveysystem/survey_publication/OptionsforAutoProcessingTechReport17.pdf
[Viewed April 8th, 2005]

P.I. Coyne, S.J. Casey, and G.A. Milliken, 2003, Comparison of Differentially corrected GPS Sources for Support of Site-Specific Management in Agriculture, Department of Communications, K-State Research and Extension, Kansas State University, [online], Available at:
http://www.wkarc.org/Research/ARCH/PrecisionAg/DGPS_web.pdf
[Viewed April 4th, 2005]

Raymond, E., 2005, Where's the Latency? Performance analysis of GPSes and GPSD [online], Available from:
http://gpsd.berlios.de/performance
[Viewed April 1st, 2005]

Rizos C., Han H., 2002, Reference Station Network Based RTK Systems - Concepts and Progress, the University of New South Wales, Sydney NSW 2052 AUSTRALIA, Available from:
http://www.gmat.unsw.edu.au/snap/publications/rizos_etal2002a.pdf
[Viewed May 1st, 2005]

Scarfe, B., 2002, Measuring Water Level Corrections Using RTK GPS, Issue 104 of 'The Hydrographic Journal'.

Smith, L. and Thomson, S., 2003, GPS Position Latency Determination and Ground Speed Calibration for the Satloc Airstar M3. National Agricultural Aviation Association Meeting. Paper No. AA03-009, 11 pg, [online], Available from:
http://www.ars.usda.gov/research/publications/publications.htm?seq_no_115=157208
[Viewed April 3rd, 2005]

Stombaugh, T., Shearer, S., Fulton, J., 2002, Standards for comparison of GPS receiver performance, Proceedings of the 6th International Conference on Precision Agriculture, ASA Misc. Publishing, ASA, CSSA, and SSSA, Madison, WI

Taylor, R., 2002, Dynamic GPS Testing, Kansas State University, [online], Available from:
http://www.oznet.ksu.edu/pr_prcag/Projects/Current/DynamicGPS.shtml
[Viewed April 5th, 2005]

The Hydrographic Society, 2002, Online Forum Answer Ref No. THS2001-007 (Gallagher K.), Available from:
http://www.hydrographicsociety.org/Forum/questions/GPS&dGPS.htm
[Viewed June 4th, 2005]

Trimble Navigation, 1999, MS750 Operation Manual. Revision B, (Manual for the Trimble MS750 RTK GPS unit).

Trimble Navigation, 2005, Trimble Virtual Reference Station (VRS) System (data sheet), Available from:
http://trl.trimble.com/docushare/dsweb/Get/Document-11465/VRS_Spec_Sheet.pdf
[Viewed June 3rd, 2005]

Vollath, U., Buecherl, A., Landau, H., Pagels, C., Wagner, B., 2000a, Multi-Base RTK Positioning Using Virtual Reference Stations, Proceedings of ION GPS 2000, 13th International Technical Meeting of the Satellite Division of the Institute of Navigation, September 2000, Salt Lake City, Utah.

Vollath, U., Buecherl, A., Landau, H., Pagels, C., Wagner, B., 2000b, Long-Range RTK Positioning Using Virtual Reference Stations, Proceedings of ION GPS 2000, 13th International Technical Meeting of the Satellite Division of the Institute of Navigation, September 2000, Salt Lake City, Utah.

APPEDICES

Appendix A – Project Specification

University of Southern Queensland
Faculty of Engineering and Surveying

ENG4111 / 4112 Research Project
Project Specification

FOR:	Rientz INGLIS
TOPIC:	Evaluation of VRS-RTK GPS Latency in a dynamic environment.
SUPERVISOR:	Peter Gibbings
SPONSORSHIP:	Faculty of Engineering and Surveying, USQ, Department of Natural Resources and Mines
PROJECT AIM:	This project aims to quantify the latency in VRS-RTK GPS measurements made in a dynamic environment.

PROGRAMME: Issue A, March 18th 2005

1. Define the problem of latency in dynamic VRS-RTK measurements and the associated implications to users of such systems.
2. Critically analyse any relevant prior research and literature regarding latency in RTK GPS, use of GPS in dynamic environments and VRS networks.
3. Develop and validate a method for testing the effects of latency in a dynamic VRS-RTK GPS environment
4. Collect data to allow measurement of latency and, as time permits, collect extra data for a comparison against conventional RTK GPS.
5. Analyse the collected data to quantify any latency evident in the measurements and draw suitable conclusions / make recommendations about the impacts of the results.
6. Present project work and results by way of a formal academic dissertation

Agreed: _________________ (Student) _________________ (Supervisor)

___ / ___ / ___ ___ / ___ / ___

Appendix B – Trimble Virtual Reference Station (VRS) Specifications

(courtesy of Trimble Navigation)

General
- High-accuracy real-time kinematic GPS positioning
- Fixed virtual reference station network available at any time without setting up a base station
- Common control network for large areas
- Real-time atomospheric error correction
- Built-in integrity monitoring by VRS server
- Seamless package of GPS hardware, modeling and networking software, and communications interface

5700 CORS Receiver
- Tough, lightweight magnesium alloy casing
- Compact flash data storage expandable up to 128 MB
- Low power consumption
- Up to 10 hours backup receiver operation on 2 internal miniature camcorder batteries
- Dual rate logging up to rates of 10 Hz *Zephyr $_{TM}$ Geodetic Antenna*
- 4-point antenna feed for sub-mm phase centre repeatability
- Trimble Stealth$_{TM}$ ground plane for reduced multipath
- Superior phase center repeatability

GPSNet Software
- Communications control of remote receivers (no PC required at site)
- RINEX file creation and archiving
- Statistical analysis and integrity monitoring of reference stations
- Single base RTCM generation

DGPSNet Software
- Network modeled RTCM messages optimized for networks with reference station spacing of 70–300 km, and L1 C/A roving receivers

RTKNet Software
- Full network modeling of ionospheric, tropospheric and ephemeris errors
- VRProcessor provides network modeled RTK messages to roving receivers

5700 CORS Receiver

GPS measurements Advanced Maxwell 4 custom survey GPS chip High precision multiple correlator L1 and L2 pseudorange measurements Unfiltered, unsmoothed pseudorange measurements data for low noise, low multipath error, low time domain correlation and high dynamic response Very low noise L1 and L2 carrier phase measurements with <1mm precision in a 1 Hz bandwidth L1 and L2 Signal-to-Noise ratios reported in dB-Hz Proven Trimble low elevation tracking technology 24 Channels L1 C/A code, L1/L2 full cycle carrier WAAS/EGNOS tracking

Casing Tough, lightweight fully sealed magnesium alloy

Waterproof IPX7 for submersion to depth of 1 m

Shock Will survive a 1 m drop onto concrete; shock and vibration tested to 40 G random

Weight With internal batteries, battery charger 2.9 lbs (1.3 kg)

Power DC input 10.5 to 28 V with over voltage protection

Power consumption 2.5 Watts

Power output 10.5 V–20 V (Port 1), 10.0 V–27.5 V (Port 3)

Certification Class B Part 15 FCC certification and CE Mark approved

Operating temperature –40$_{o}$C to +65$_{o}$C (–40$_{o}$F to +149$_{o}$F)

Storage temperature –40$_{o}$C to +80$_{o}$C (–40$_{o}$F to +176$_{o}$F)

Humidity 100%, condensing, passes testing per MIL-STD-810F, FIG. 514.5C-17

Communications and data storage
CompactFlash—advanced lightweight and compact removable data storage. Options of 64 MB and 128 MB from Trimble
Dual position and data logging at rates of 1, 2, 5, and 10 Hz
Continuous logging support
Update firmware remotely over a modem line
Support for modem initialization
Logging and streaming of meterological data

Zephyr Geodetic Antenna

Tracking characteristics 4-point antenna feed for sub-mm phase center repeatability
Integral Low Noise Amplifier
50 dB antenna gain
Superior low elevation tracking performance
Trimble Stealth ground plane for reduced multipath
Phase center repeatability <0.5 mm horizontal

Dimensions 34.3 cm (13.5") diameter x 7.6 cm (3") max depth

Weight 1.0 kg (2.2 lbs)

Operating temperature –40$_{o}$C to +70$_{o}$C (–40$_{o}$F to +158$_{o}$F)

Humidity 100% humidity proof, fully sealed

Shock MIL-810-F Figure 514 5c-17 vibration levels on each axis Shock tested to MIL-810-F Table 516.5-I to survive a 2 m (6.56 ft) drop. Shock tested for a drop of 2 m (6.56 ft) onto concrete

GPSNet Software

Sensor compatibility Interfaces to Trimble's 5700, 4700, MS750, and 4000 receivers. Interfaces to most third party receivers

Data integrity monitoring Gross error detection Provides detection and correction of cycle slips RAIM monitoring Watchdog timer for reliable operation User definable alarms via e-mail / SMS

Logging capability Capacity to log multiple RINEX files at different rates to local or LAN drives

FTP capability FTP mirror functionality for ease of publishing data

IGS compatibility Ability to use IGS Ultra Rapid Orbits

Single base positioning Single point RTCM or CMR RTK messages from the nearest base station

Reporting capability XML reports for easy web publishing

Appendix C – Bar Code Reader Specifications

(courtesy of Expansys Australia)

Connect the Flic scanner to your host for real-time scanning or unplug it and scan up to 500 bar codes. The Flicware wedge software is included (download) for use with Windows PC's to add bar code scanning to any application in only minutes.

Features & Benefits:

- Versatile - Operates in either a real-time tethered mode or a batch data storage mode. Suits a variety of applications in small business, route sales, healthcare, inventory management, asset tracking and mobile workforce. A wide variety of connectivity solutions makes the Flic scanner a versatile tool. The 500 barcode memory makes the Flic scanner an efficient batch data collector.

- Practical - Uses AAA batteries for convenience and low cost of ownership. Draws no power from the host computer. The Flic Tethered/Batch scanner delivers 24,000+ scans in 12 months from a fresh set of alkaline batteries.

- Easy - one button "point and Flic" operation. Little or no training required.

- Ergonomic - pocket-sized, central scanning button and tapered design works in either hand.

- Smart - instantly reads UPC/EAN/JAN from 2.5 to 7 inches... and small codes down to 10 mil.

- Flexible - enables direct connection to a Windows desktop, notebook, laptop, and Tablet PCs.

- Manageable - Eliminate repairs, spare parts, and battery chargers. Keep a few spare scanners on-hand to reduce down-time and have them replaced at your convenience.

Additional Technical Details:

- Bar Codes Supported: UPC/EAN/JAN, Code 39, Code 128, Interleaved 2 of 5
- Minimum X Dimension: 7.5 mil (0.19mm)
- Depth of Field: 2.5 to 3.5 in for 7.5 mil; 2.5 in to 5.5 in for 10 mil; 2.5 in to 6 in for 13 mil; 3 in to 7 in for 17 mil
- Memory Capacity: 500 UPC-A bar codes
- Interface: RS-232 compatible; Batch or Real-time Tethered
- Software: Flicware Wedge Software for Windows PCs included (download)
- Auto-upload: Automatically uploads data when connected to host computer
- Dimensions: Length: 4.5 inches; Width: 2 inches; Height: 1 inch; Weight: 2.5 oz (3.7 oz with batteries)
- Power: 3 AAA alkaline batteries (fresh) deliver 24,000+ scans in 12 months
- Warranty: 1 year

APPENDIX D – Trimble 5800 GPS Receiver Specifications

(Courtesy of Trimble Navigation)

Specifications

General

- Front panel for on/off, one-button-push data logging, CompactFlash card formatting,
ephemeris and application file deletion, and restoring default controls
- LED indicators for satellite tracking, data logging, and power monitoring
- Tripod clip

Performance specifications

Measurements

- Advanced Trimble Maxwell technology
- High-precision multiple correlator L1 pseudorange measurements
- Unfiltered, unsmoothed pseudorange measurement data for low noise, low multipath error, low time domain correlation, and high dynamic response
- Very low noise L1 measurements with <1 mm precision in a 1 Hz bandwidth
- L1 Signal-to-Noise ratios reported in dB-Hz
- Proven Trimble low-elevation tracking technology
- 12 Channels L1 C/A Code, L1 Full Cycle Carrier, WAAS/EGNOS[1]

Code differential GPS positioning[2]
Horizontal . . . . ±(0.25 m + 1 ppm) RMS
Vertical . . . . ±(0.5 m + 1 ppm) RMS
WAAS differential positioning accuracy typically <5 m 3DRMS[3]
Static and FastStatic GPS surveying[2]
Horizontal . . . . ±5 mm + 0.5 ppm RMS
Vertical . . . . ±5 mm + 1 ppm (× baseline length) RMS

Kinematic surveying[2]
Real-time and postprocessed kinematic surveys
Horizontal . . . .±(10 mm + 1 ppm) (× baseline length) RMS
Vertical . . . . ±(20 mm + 1 ppm) RMS

Hardware

5800 GPS receiver

Physical:

Casing . . . . .Tough, lightweight, fully sealed magnesium alloy
Waterproof . . . . Tested to IPX7 standards
Shock and vibration . . . . . .Tested and meets the following environmental standards:
Shock . . . . MIL-STD-810F to survive a 1 m (3.28 ft) drop onto concrete
Vibration . . . . MIL-STD-810-F on each axis
Weight . . . . .With internal batteries, internal battery charger: 1.4 kg (3 lb)
Dimensions (W×H×L) . . . . . . .13.5 cm × 8.5 cm × 24 cm (5.3 in × 3.4 in × 9.5 in)

Electrical:
Power . . . . DC input 11 to 28 V DC with over voltage protection
Power consumption . . . . 2.5 W receiver only
Battery . . . . Greater than 10 hours data logging
Battery weight . . . . 0.1 kg (3.5 oz)
Battery charger . . . . Internal with external AC power adapter; no requirement for external charger
Power output . . . . 11.5 to 20 V DC (Port 1), 11.5 to 27.5 V DC (Port 3)
on external power input
Certification . . . . Class B Part 15 FCC certification, CE Mark approved,
C-Tick approved, Canadian FCC

Environmental:

Operating temperature[4] . . . . –40 °C to 65 °C (–40 °F to 149 °F)
Storage temperature . . . . –40 °C to 80 °C (–40 °F to 176 °F)
Humidity . . . . 100%, condensing
Communications and data storage:
- 2 external power ports, 2 internal battery ports, 3 RS232 serial ports
- Integrated USB for data download speeds in excess of 1 Mb/s
- External GPS antenna connector
- CompactFlash advanced lightweight and compact removable data storage, 64 MB
- More than 1,700 hours continuous L1 logging at 15 seconds with 6 satellites
typical with 64 MB card
- 1 Hz, 2 Hz, 5 Hz, and 10 Hz positioning and data logging

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[1] Upgradable to 24 channels L1 C/A code, L1/L2 full cycle carrier, WAAS/EGNOS
[2] Accuracy may be subject to conditions such as multipath, obstructions, satellite geometry, and atmospheric
parameters. Always follow recommended survey practices.
[3] Depends on WAAS/EGNOS system performance.
[4] Receiver operates normally to –40 °C (–40 °F) but some office-based functions such as USB download or internal battery charging are not recommended at temperatures below freezing.

APPENDIX E – Trimble TSCe Datasheet

(Courtesy of Trimble Navigation)

Specifications

Power . . . . Internal 3800 mAh NiMH rechargeable battery pack
Battery life of 30 hours under normal operating conditions
Complete recharge in under three hours
Size . . . . 25.8 cm (10.2 in) × 13 cm (5.1 in) × 5.2 cm (2.1 in)
7.4 cm (2.9 in) at handgrip
Weight. . . . . 990 gm (2.2 lb) including battery
Certification. . . . . FCC class B, CE Mark, CSA, and C-tick approval
Serial Port I/O. . . . . 9-pin serial port—RS232 (115 kB/s),
COM1 with 5 V (250 mA) on pin 9
MultiPort I/O . . . . 26-pin MultiPort—RS232, COM2, Ethernet 10BaseT,
USB client, power in/out and audio in/out
0-Shell Lemo
RS-232 (115 kB/s)
Processor . . . . Intel StrongARM SA-1110 @ 206 MHz
Memory . . . . 512 MB non-volatile flash disk; 64 MB SDRAM
Display . . . . 320 × 240 pixels (1⁄4 VGA) reflective color TFT,
frontlight lluminated display
Touch Screen. . . . . Passive touch screen, works with stylus or finger
Keyboard. 57-key tactile action with separate navigation,
alpha and numeric keypads
Audio . . . . Integrated speaker and microphone

Environmental

Temperature:
Operating . . . . –25 °C to 60 °C (–13 °F to 140 °F)
Storage . . . . –30 °C to 60 °C (–22 °F to 140 °F)
Water . . . . ICE 529, IP 67, sealed against temporary immersion
Drop . . . . 1.22 m (4 ft) to concrete on all faces, edges and corners
Sand and Dust . . . . ICE 529, IP 6X and MIL-STD-810E, Method 510.3
Vibration . . . . MIL-STD-810E, I-3.4.9 category 10, Fig 16 and 17
Altitude . . . . MIL-STD-810E, Method 500.3