University of Southern Queensland
Faculty of Engineering and Surveying

A Model to Establish a Global Navigation Satellite System (GNSS) Testing and Validation Center at the University of Southern Queensland

A Dissertation submitted by

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ABSTRACT

This project provides a research on the establishment of a Global Navigation Satellite System (GNSS) testing and validation facility at the University of Southern Queensland

Many successful surveying applications around the world today have been made possible because of the use of Global Navigation Satellite System (GNSS). It has been found by previous research that despite this efficiency, GNSS, just like conventional surveying techniques require that quality assurance processes must be utilized on a routine basis, as it is essential to ensure that satisfactory accuracy specifications can, and are, being met. A number of useful field methods have been used to properly estimate accuracy of GNSS positioning, but it also required to independently calibrate and test accuracy in realistic operating conditions such as on a test network

To determine the components comprising the testing and validation facility and how they may be structured, the desirable functionality of the facility is identified. This is achieved by considering two perspectives, that of the user and the administrator. Various elements of each of these components are designed to meet these perspectives.

The use of the facility is demonstrated by validating test results of an RTK GPS system. The validation process is based on comparisons and analyses carried out on the test results to indicate accuracies achieved and to what level of confidence are they limited to. Results of analyses recognize that while not being able to guarantee the results achieved in other survey areas, it at the very least checks that the entire GNSS system is being operated properly.

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Certification

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

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

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CHAPTER 1

INTRODUCTION

1.1 Background to the research

The use of Global Navigation Satellite System (GNSS) has proven success in many surveying applications ranging from high precision geodetic datum definitions to the near instantaneous positioning of moving objects. Despite this efficiency, GNSS, just like conventional surveying techniques, must utilize quality assurance processes on a routine basis as this is essential for managing risks and calibrating GNSS equipments before commencing contractual work.

Real-time kinematic (RTK) global positioning system (GPS) surveying is one of the surveying methods which offers efficient means of providing near-instantaneous positions. Despite its wide adoption as an engineering surveying tool, the short station occupation times it uses are influenced greatly by the effects of multipath and incorrect integer ambiguity resolution, resulting in less precise coordinates derived by this method.

Research has shown that users of GNSS systems such as RTK have tended to rely on the internal quality control indicators of coordinates precision provided by the proprietary software/firmware (Featherstone, 2001). The current status of these internal precision estimates however, cannot be used solely to validate the accuracy of GNSS-based positioning. Thus, the need for external, independent, objective testing and validation of GNSS systems in realistic operating conditions becomes obvious.

1.2 Research Aim and Objectives

Aim

The aim of this research is to investigate and report the establishment of a GNSS testing and validation facility at the University of Southern Queensland (USQ). The proposed testing facility will ensure independent quality control and quality assurance processes are applied in GPS positioning.

Objectives

To achieve this aim the following objectives will be achieved:

- Determine the significant factors impacting on the result of errors in GNSS positioning
- Investigate the need for quality control in GNSS positioning
- Determine what the components of the facility will be, and
- Use the facility to test the accuracy, integrity and reliability of a set of RTK-derived coordinates to demonstrate its benefits and requirements for future work.

1.3 Significance of the research

The USQ is currently moving towards developing a full GPS calibration and performance testing facility on its Toowoomba campus. Such a development will require in-depth study of the current status of GNSS systems of the university, the need for quality control and, most importantly, the most suitable methods for designing and implementing the facility. This project will facilitate this.

Additionally, quality checks to be performed on the existing GPS infrastructure and the network of monuments on-campus are required to take into consideration the uncertainty of these known coordinates. It will be highlighted in the later chapters of this dissertation to re-coordinate all monuments before full implementation of the facility.

Finally this research seeks to discover the possible potentials as well as limitations of a testing and validation facility in the attempt to utilize quality assurance measures in GNSS positioning. This is essential to ensure satisfactory accuracy and precision can, and are being met.

1.4 Scope of Research

This research activity seeks to design a model to establish a testing and validation facility on campus of the USQ for GNSS systems. Although the design aims to enable validation of various GNSS systems, the selection of appropriate methods to implement this design is limited to RTK GNSS for the purpose of this research, particularly in demonstrating how the facility can be used.

Discussions on determination of the components comprising the testing and validation facility are limited to features and functionality. One of the elements discussed in later chapters of this dissertation is web-based in nature. The requirements to construct this online facility, and how it may be structured is limited only to the purpose of this project. Future research is recommended to undertake the full implementation of this web-based component.

1.5 Summary

To achieve the aim of this research, which is to investigate the establishment of a GNSS testing and validation center at USQ, chapter two highlights past research work on this problem and the methods which have been employed in these attempts. Background information contained in this chapter identifies major problems with positions derived from GNSS systems and the obvious need for independent testing and calibration of their precisions and accuracies.

The research is expected to result in the identification of the components to form a GNSS testing and validation and how they may be structured and used. A review of literature in Chapter two will indicate relevant research approaches to be employed, and the stance on which these methods are to be developed.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

To develop a testing and validation facility at USQ, it is first necessary to establish the current state of research theory and practice in the areas of the use of GNSS technology, the need for quality control in GNSS positioning, and previous attempts to properly estimate the accuracy of GNSS-derived coordinates.

Therefore this chapter aims to provide background knowledge on what GNSS technology is, the concept of RTK GPS, the nature and source of errors in GNSS-derived positions, current quality measures being utilized, and will also identify and consider the currently accepted views on how to effectively design and implement the proposed testing facility.

The literature review will begin by giving a description of GNSS technology, specifically GPS and its current status in the use in the field of surveying. The nature and sources of most GNSS errors will be highlighted and a detailed assessment will be made on a number of quality assurance processes currently being used. A review, and critical analysis, of previous attempts by others regarding the same matter being investigated in this dissertation will be included to provide examples of methods they have employed. From this information knowledge will be obtained on what components and design structure might be most effective for the proposed establishment of the testing and validation centre at USQ.

2.2 GNSS described

2.2.1 What is GPS?

The GPS is a constellation of at least 24 satellites that provide accurate three-dimensional position, velocity and time to end users in all weather, 24 hour a day, seven days a week (Gibbings, 2002). GPS was originally designed by the United States as a navigation and timing system for its Department of Defense (DoD) who wanted to position their resources, such as nuclear submarines, very accurately anywhere in the world.

How GPS works

In short explanation GPS works by the operations of three segments: the space segment, the control segment and the user segment.

The space segment refers to the Navigation Satellite Timing and Ranging (NAVSTAR) constellation of satellites that transmit timing information, satellite location information and satellite health information. This implies that unlike previous navigation satellite systems using ground based transmitters, satellite based transmitters are used to cover earth with higher accuracy than that available from the land based systems. A minimum of four satellites are required to determine a point position fix.

The control segment consists of four ground control stations and one master control station that monitor and control the satellites for health and accuracy. Maintenance commands, orbital parameters and timing corrections are uploaded from the ground on a periodic basis.

The user segment refers to any GPS receiver capable of receiving the transmissions from the satellite. There is no limit to the number of users that can be using the system at any one time.

Real Kinematic Time (RTK) GPS

RTK positioning uses a static GPS receiver as a reference station located at a known point and another receiver as the rover which moves and surveys any points of interest. Both receivers make observations of the GPS signals at the same time, and data is sent via a radio data link from the reference to the rover, where calculation of coordinates is carried out. RTK GPS provides users with coordinates in real time with centimeter-level accuracy. Many applications take advantage of this technology and they include topographic surveying, engineering construction, geodetic control and others (University of New South Wales School of Geomatic Engineering, 2000).

2.2.2 What is GNSS?

GNSS is a generic name given to navigation systems which use satellite positioning. It includes the NAVSTAR Global Positioning System (GPS) of the United States of America, the similar Global Navigation Satellite System (GLONASS) of the Russian Federation, the European GALLIEO and several others. This technology implies fastest, easiest and most accurate means of achieving right timing and precise location in a number of different applications including surveying (United Nations Information Services, 2001).

There are currently two elements of GNSS in operation; they are the NAVSTAR and the similar GLONASS. Over the next few years, Europe will begin commissioning its GALILIEO service which will operate along with a second generation GPS available from 2007. Not only that, other geostationary systems such as the Japanese and Indian satellites will be launched in the future to compliment the GPS or GLONASS constellations being used today.

Originally, GLONASS and NAVSTAR GPS were developed as military navigation satellite systems, but the user community of these systems has grown exponentially in recent years and that growth is expected to continue (Gibbings, 2002). As identified in the third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE 3), a large number of remote sensing applications are increasingly demanding precise location information, some of which support strategic areas for development as disaster management, monitoring and protecting the environment, management of natural resources and food production (United Nations Information Services, 2001). Among these together with many other applications is the growing and successful use of GNSS for many surveying and navigation applications around the world ranging from high precision geodetic datum definition to the near-instantaneous positioning and navigation of moving objects (Featherstone et al, 2001).

2.2.3 How GNSS works

A GNSS uses satellite positioning techniques to provide users with accurate and timely navigation information. A GNSS must include real time navigation information, autonomous integrity and accuracy sufficient for safe navigation. Red Sword Corporation (n.d) reveals these elements which are explained respectively as follows:

- It must be possible to generate real-time navigation information fast enough for safe navigation.
- There must be some way for the user to determine the accuracy of the navigation solution in a timely fashion.
- There must be some external aids for a GNSS using NAVSTAR AND GLONASS to provide the accuracy sufficient for safe navigation (most significant as requirements for aircraft landing).

2.3 GNSS and Quality Assurance

2.3.1 GNSS errors

To emphasize the need for quality control measures in GNSS positioning, it is important to identify and discuss the major factors which act to degrade the accuracy of GNSS-derived coordinates in surveying applications. This is achieved by investigating the nature and source of most common GNSS errors.

Multipath and Electrical Interference

Multipath occurs when GPS signals are reflected from nearby objects before reaching the antenna. Electrical interference occurs when secondary sources or other transmitters and receivers distort the reception of the GPS signals or affect the receiver's circuitry. These problems are particularly common for RTK GPS because they act as a bias during the short occupations used, or can prevent satellite tracking completely. Tests concerning determination of frequency of initialization failures when working near high voltage power lines conducted by Gibbings and Manuel (2001) recognized that the presence of electromagnetic interference has been shown to significantly impair the process of ambiguity resolution. This concept of ambiguity resolution is described later in this section.

Featherstone and Stewart (2001) suggest the only solutions at present are to select sites well away from potentially reflective areas, use ground planes or choke rings attached to the antennas, and apply digital filtering techniques. The selection of survey sites becomes more difficult in the case of electrical interference for instance a 785 MHz television transmission source may affect a GPS receiver 15 km away.(Featherstone & Stewart, 2001).

Obstructions

Satellite visibility can be obstructed by tree canopy in the surrounding environment, resulting in loss of lock and the user having to reinitialize during a GNSS survey.

Incorrect Integer Ambiguity

Computation of distance from a GPS ground receiver to a satellite requires the wavelength of the radio signal and the number of cycles. If the wavelength is known, the distance can be computed once the number of cycles is estimated. The uncertainty in the number of cycles the receiver is attempting to count is referred to as the ambiguity. When processing GPS data, the GPS software carries out statistical tests to determine whether the correct ambiguous integer number of cycles between the antenna and satellites has been estimated These tests can be incorrect due to the sometimes-invalid assumptions made about the stochastic nature of the ambiguity resolution process. For instance Featherstone and Stewart (2001) in their attempt to conduct a combined analysis of RTK GPS equipment and its user for height determination found that RTK GPS software may be statistically satisfied with the ambiguity set it has estimated, and inform the user so, but this may be incorrect.

Incorrect ambiguity resolution is more likely to occur in RTK GPS surveys because of the relatively short occupation times used, which prevents sufficient redundancy of GPS observations. Also importantly these short occupation periods make the integer ambiguity estimation process highly subject to localized and time-dependent biases, such as multipath as mentioned earlier.

Dilution of Precision (DOP) and Satellite Availability (SA)

DOP measures the geometry of satellites used for GNSS-positioning. As satellite orbit the earth, their geometry relative to a receiver varies and consequently the DOP errors will vary, causing time-related variation in the accuracy of GNSS positions. The geometry of GPS positioning is weaker in elevation because the satellites used are situated only above the antennas. In terms of RTK GPS the short data spans used can compromise positional accuracy in areas of poor sky visibility. A minimum of five satellites with a low position dilution of precision (PDOP) of less than six is required by most RTK GPS for each initialization. Even with clear sky visibility, GPS offers only a global coverage of four or more satellites in view with a PDOP of less than or equal to six at 99.9%. (Featherstone & Stewart, 2001) Hence even in perfect conditions, positioning with GPS cannot be expected to operate all the time, and in areas of restricted satellite availability due to tree canopy obstructions for instance, GPS observations can be delayed and y even have ceased to be continued.

GPS Baseline Length

The accuracy of Positioning with GPS, particularly RTK GPS, tends to degrade as the baseline length increases. This is due to atmospheric refraction effects, which become decorrelated and thus no longer cancel through differencing algorithms over longer distances. This poses a negative effect on the ability of GPS to resolve ambiguities. Also the increased noise decreases the reliability of the integer-fixed solution and thus may results in incorrect ambiguity resolution.

Blunders

Blunders are the result of bad survey practice or in other words human errors. These maybe incorrect geodetic datum selection, incorrect antenna height defined for base and roving antennas, roving antenna not held steadily or vertically above the ground mark, insufficient time allowed for ambiguity initialization or reinitialisation and the use of the singles station occupations by only one radiation.

2.3.2 The need for quality assurance and control

Section 2.3.1 developed an understanding of the main sources of errors contained in a GNSS measurement technique. Hence it can be seen that there is a need for quality assurance and control measures becomes obvious. This understanding is also important to ensure that the design and implementation of a model to establish a GNSS testing and validation facility can be carried out effectively.

Featherstone et al. (2001) identified GNSS techniques require the use of quality assurance processes on a routine basis to ensure that satisfactory accuracy specifications can be, and are being, met.

Featherstone et al. (2001) further indicated that there has been little independent testing of the precision, accuracy and reliability of GNSS systems and positioning procedures reported. It seems that the majority of commercial users of GNSS systems rely only on the internal precision estimates provided by the software/firmware while others seem to refer to manufacturer's brochures or specifications.

Unfortunately, there is no guarantee that these internal quality control indicators of coordinate precision can be used solely for validating GNSS-based positioning accuracy. These brochures do not necessarily inform users about the effects of multipath and incorrect integer ambiguity resolution resulting from short station occupation time used for RTK GPS positioning (Featherstone et al. 2001)

2.3.2 Evaluation of current quality assurance processes

To properly estimate the accuracy of the coordinates computed by a GNSS system, certain quality field methods have been regarded useful, as they attempt to apply redundancy in the form of additional independent observations. Despite this attempt, Featherstone et al. (2001) states that the burden of proof still remains with the user to ensure that the positions are accurate to the desired standards at all times and places in the GNSS survey.

An example identified by Featherstone et al. (2001) of a useful field practice is carrying out check measurements during each and every GNSS survey at multiple points interspersed throughout the area, given their known coordinates. The problem with this practice is that it doesn't guarantee that the same level of accuracy will be achieved for all other points in the survey. Additionally, with using only one independent check measurement at each point in the survey, it is impossible to distinguish between the correct and incorrect points at definite levels of accuracy, precision and significance.

Another rigorous approach also identified by Featherstone et al. (2001) is to independently estimate the uncertainty in GNSS-derived positions by making several separate observations at each and every point. This could use the GNSS data received from other or multiple base-stations, and/or observed at different times to ensure that the satellite geometry and multipath effects have changed sufficiently. Alternatively, *in situ* check measurements can be undertaken at each and every point using independent positioning technologies such as inertial navigation systems; this achieves better accuracy.

Furthermore, proper operational practice and procedures can be adopted such as the Inter-governmental Committee on Surveying and Mapping (ICSM) set of Standards and Practices (SP1), to tries to ensure that a GNSS survey has in fact been adequately carried out. For instance repeat baselines can be considered a proper practice where the same pairs of stations are occupied more than once. The amount by which the results deviate from each other and the proportion of multiple occupancies can be defined in these standards and practices (University of New South Wales School of Geomatic Engineering, 2000).

Importantly, Featherstone et al. (2001) went on to suggest that there is simply no guarantee that just because GNSS system delivers results of particular standard at a particular place and time that it will in others. This is due to the fact that accuracy of any GNSS-derived position is spatially and temporarily dependent.
Hence in the absence of such field practices as mentioned earlier, independent positioning as a check at all points, either post mission or *in situ,* one interim solution is to validate the GNSS system over a test facility that hosts conditions similar to those experienced in practice. This type of validation should be performed before and after the GNSS survey or at the very least when the software/firmware is updated and/or the hardware is serviced or repaired.

2.4 Review of Previous Work by Others

The establishment of the GNSS testing and validation facility in Perth, Western Australia comprised of a fixed-pillar component, a ground mark component and a software component (Featherstone, 2001). The installation of the test stations of this facility provided slightly different validation of GNSS systems. The part of the facility consisting of force-centering pillars has been used to provide some legal traceability to the GNSS systems validated on the facility. The other part includes some of these fixed-pillars, some standard survey marks of the Western Australian geodetic network, and ground monuments on and around the Bentley campus. This part has been used to set standards for RTK GPS surveys of roads Main Roads Western Australia (MRWA) (Featherstone, 2001).

The software component was a computer program which allows the users of the facility to perform verifications of their GNSS systems over the ground-mark component. This software is freely available for use, which means users don't have to engage others to perform analyses. Also, an element of independence is added by supplying the software as an executable file in which the coordinates of the control points cannot be accessed by users, who might be tempted to pre-analyze data and reject outliers so as to provide better than actually achieved results (Featherstone, 2001).

As the coordinates of these marks are known in three dimensions on the Geodetic Datum of Australia 1994 (GDA94) and on the Australia Height Datum (AHD), the user simply inputs their GNSS-derived three dimensional coordinates of the marks, then the software reports whether the results match and to what level of confidence to which they agree (Featherstone, 2001). This analysis takes into account the uncertainty in the known coordinates; hence it also enables accuracy of the existing control points to be determined.

2.5 Conclusion

This chapter explored the current status of GNSS technology and investigated its increase use in many applications including surveying. A brief outline of the concept of GPS is also documented. Research has shown that like most technologies, GPS surveying techniques are not infallible.

Information has been provided on the cause of most GNSS techniques to fail to provide accurate and reliable positioning. This information recognizes the need for quality assurance and control to be applied in GNSS measurements. A number of quality field methods have been discovered which are currently being used. These are mentioned in section 2.3.1.

However, research has shown that there must be some external, independent, objective testing and validation of GNSS systems in realistic operating conditions. In the absence of multiple in situ checks, the preferable interim solution is to validate the GNSS system and its operators on a well-controlled test network.

CHAPTER 3

RESEARCH METHOD

3.1 Introduction

Background information documented in Chapter Two has recognized the need to test and validate GNSS systems (software/firmware, the operator of these systems as well as their positioning procedures). This chapter will outline the methodology and choice of methods used in this research, to investigate the establishment of a GNSS testing and validation facility.

Knowledge gained in chapter two has defined the benefits and desired purpose of such a facility and how it has been put to use such as in the combined analysis of RTK GPS equipment and its users for determination of AHD heights by Featherstone and Stewart (2001). The aim of this chapter is then to identify the desirable functionality of this proposed facility, and explains how this provides a lead to how the facility will be structured and established.

To achieve this, the question to be asked is, from whose perspectives the establishment of the proposed facility will be seen from. This then forms the stance on which the model to establish a testing facility is designed, as well as validations carried out, and the recommendations to be followed.

In summary the approach will include:

- identify and discuss the desirable functionality
- establishment of the testing and validation facility
- validation, and
- discussions and Recommendations.

3.2 Desirable functionality

In order to establish a testing and validation facility, it is important to know its relevant components, the most suitable structure and approach to establishing it, and the results it intends to achieve. The identification of the desirable functionality of the facility is considered necessary to set these criteria. This is achieved by considering two perspectives, that of the user and administration.

It may be that a construction project dealer of whatever specific application wants to determine whether its surveys contractors can satisfy its specifications, such as tests of three RTK GPS equipment and users combined to determine whether they can meet vertical accuracy specifications for contract work with Main Roads Western Australia (Featherstone & Stewart 2001). It may also be that any random GNSS user wishes to validate their system for quality assurance purposes.

Firstly, the user expects to use the facility to validate GNSS systems in conditions replicating practical applications such as varying degrees of satellite visibility (e.g. trees) and site-dependent environmental factors (e.g. multipath). The user also requires ease of access to the facility when carrying out GNSS tests and results to be readily available for them to be informed of the validity of their systems.

This then draws attention to the creation of an element of the facility to allow for interactive use by its potential users, in other words a user-interface. The user-interface is designed to allow convenience, readiness of availability and ease of access to GNSS users who wish to validate their systems for quality assurance purposes. An online facility is considered to enhance this, simply by generating an access site to receive background information and instructions to the use of the facility, options to view locality maps and photos of the ground marks, tools for user data entry and reporting of results. Although a discussion of this is included, the full development and implementation of an online facility is beyond the scope of this research

Secondly, the facility will provide ideal forms of reporting and statistics summary for administration purposes, important to prepare analysis against certain sets of standards and specifications. The facility is required to process the data collected from GNSS tests and report these in order to conduct meaningful and effective analysis. These analyses are conducted to enable validation of an entire GNSS system (software/firmware, operator and field procedures they used), and the user can be emailed with a validation certificate of their equipment (although a design of this element is beyond the scope of this dissertation).

Not only that, the administration can be able to store this data for management purposes and to maintain archives. Importantly, from this perspective, the facility is able to give out warnings to alert administration when large residuals or coordinate differences are continually being recorded. This is useful to allow the administration of the system to re-coordinated marks before full implementation of the facility

3.3 Establishment of a GNSS testing and validation facility

As noted in section 3.2 above the approach to establish a GNSS testing and validation facility is designed to counter the perspectives of the potential user to form the proposed as the administration party. Consequently, the components required to form the proposed facility include selection of the ground component, an interactive face-to-face access mode, data processing and reporting, and finally means of carrying out meaningful analysis to enable validations to be performed.

The ground points are selected to meet the conditions as mentioned in section 3.2 above which replicate those experienced in real practice such as typical highway surveys. These marks are grouped under names, ‘Multipath, ‘Trees’, and ‘Clear’, to suggest that the tests will be conducted on stations affected by multipath, substantial obstruction of the sky by trees, as well as areas which are clear of any obstructions. To find these stations, a map (terramodel design) of the USQ campus is provided together with photos to view the marks and the existing environment prior to GNSS surveys. Each group is assigned different colours to easily locate them.

The implementation of a user-interface component of the facility requires that the web is the primary access to these locality maps and photos, such that the users are aware of the facility. This means background information as well as a clear set of instructions will be provided online for the user to follow. The user can then find these stations and be able to undertake GNSS measurements of the test stations as grouped and shown on maps. An element of the proposed online facility will allow users to directly input their GNSS-derived coordinates for later processing and reporting. Discussions on the relevant steps to forming this component are discussed, but the full development of the web facility is beyond limitations of this research.

To introduce an element of independence, the known coordinates of the test stations are not readily accessible by the user, thus avoiding pre-analysis of data and rejecting outliers so as to provide better than actually achieved results. These coordinates are compared with the GNSS-derived coordinates from the user. This requires a component of the facility to process the coordinate differences and report whether the control coordinates agree and to what level of confidence to which they agree. This report will demonstrate a listing of residuals and their graphical displays, as well as the necessary conditions to which these residuals are measured against. This is important to ensure that administration has undertaken analysis of the entire GNSS systems.

Finally, a component of the facility is required to critically analyze the accuracies achieved given a number of conditions such as number of satellites, etc; (these will be discovered in the next chapter). Basic statistics as well as consideration of these conditions against the residuals reported are necessary to ensure that results obtained agree to an acceptable level of confidence.

3.4 Validation

The key element of the proposed GNSS testing and validation facility is to determine whether GNSS systems and their operators have in fact been adequately and properly carried out to properly estimate their accuracies and reliabilities. Hence validation of the entire GNSS system (software/firmware, the system operator and their field procedures) is carried out. Based on assumptions being considered, results of this validation allow administrator to set standards and best practices for GNSS surveys undertaken under similar conditions, for instance typical highway GPS surveys.

Analyses which have been conducted on the user's GNSS-derived data will be used to estimate accuracies achieved at an acceptable confidence level, and are dependent on the given site factors, multipath, obstruction by trees and clear sky visibility. These accuracies will set proper operational procedures and best practices for GNSS-surveys carried out in areas with the same conditions as the site factors mentioned above. On completion of the validation process, the user will be emailed with a validation certificate, which can be used as a statement of adequacy in carrying out GNSS contractual work. However the certificate will have limited reliability and therefore will contain importance warning and explanatory clauses.

3.5 Recommendations

As a result of formulation of a structure for the establishment of a testing and the processes involved in validating RTK GPS tests results, several recommendations are made. These include:

- Ensuring to take into considerations the uncertainty of the known coordinates of the test stations
- Recoordination of these marks before full implantation of the facility
- Warning administrator when continual large residuals are being reported to alert them to recoordinate marks, and

- Implementing and an online component or a more sophisticated analysis software that is easier to use.

3.6 Summary of Research Methods

This chapter presented the methods chosen to tackle the problem in this research. The methods are chosen from the perspectives of the user and administrator. This consideration has determined the various desirable functionality of the testing and validation facility.

The components comprising the establishment of the proposed testing and validation facility include selection of suitable stations, development of a web access and processing and reporting of test results. The different elements and functions of these components have been pointed out to determine suitable approaches of how to carry on the implementation of these components into the establishment of the proposed facility.

Validation processes will then be carried out to demonstrate the use of the facility and to draw conclusions on benefits and limitations as well as recommendations for future research.

CHAPTER FOUR

ESTABLISHMENT OF A GNSS TESTING AND VALIDATION FACILITY

4.1 Introduction

Chapter three has identified the vital elements required to establish a GNSS testing and validation facility on campus at USQ. This chapter will explain how these elements are incorporated into the development of a facility to test and validate GNSS systems.

The desirable functionality of the proposed facility has revealed that the desired purpose to be fulfilled by the establishment of the facility is considered form two perspectives, that of the potential user and the administration. Therefore this chapter aims to provide an outline of how the development of a GNSS testing and validation facility may be designed to meet the principal objectives of these two parties.

Each component which forms the proposed facility together with how it is structured is discussed. The components include ground test stations, a web-based user-interface, and a software for data processing and reporting. Although a discussion of an online facility is included to demonstrate a user-interface component, it is reiterated that the full development of a web is beyond the purpose of this research.

Each component is interrelated and cannot be considered in isolation when implementing the facility. These are discussed separately and in detail as follows.

4.2 Test Station

4.2.1 Selection of Test Stations

The selection of ground test stations is based on the knowledge gained in background chapters that most GNSS-errors are site-and time-dependent, although this is mostly exaggerated in RTK GPS. Suitable stations are therefore considered to be at locations exposed to multipath effects, obstructed by trees, as well as clear sky visibility. This is to ensure that varying environmental factors and satellite visibility are accounted for in the coordinates derived from each of these stations.

Stations are grouped with respect to this selection method, such that each group is named according to its holding of these conditions as mentioned above, i.e. ‘Multipath’, ‘Trees’, and ‘Clear’.

4.2.2 Finding Test Stations

Users must be able to locate and find these test stations when they wish to carry out GNSS testing on the proposed facility. To find these stations, a map of the existing ground marks on the university campus is provided as follows:

Figure 4.1: Station Locations on University of Southern Queensland Campus

Photos are also included. Different colours are assigned to each group to better distinguish their representations on location maps and makes it easier for users to point them out rather than searching for where they are located on the maps.

These location maps and photos are web-based where users can access them. As mentioned and discussed in the following section, an online component of the facility is included to facilitate the user-interface component.

4.3 Web Access

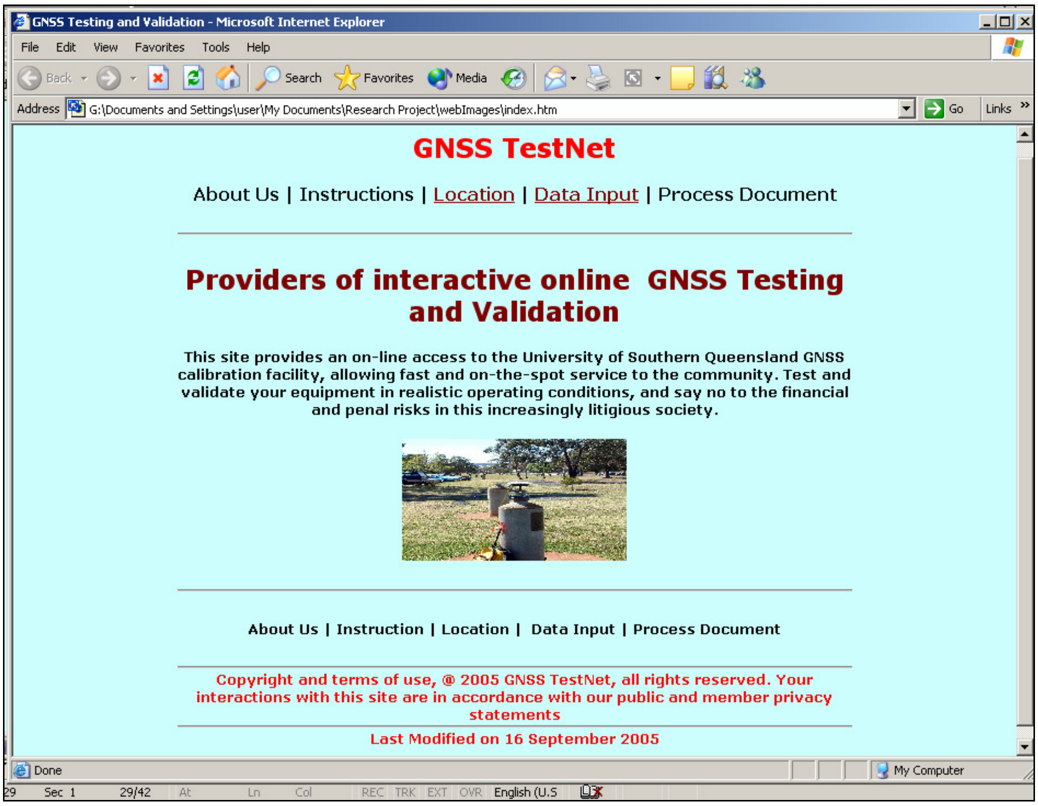
For users to find stations and to enter their test data for them to be processed, an online component is structured to enable interactive use and access to the facility. The requirements for this element to be constructed and how it may be structured is only discovered for the purpose of this dissertation. Future research is recommended to undertake the full implementation of this online component.

The web contains the following features and functions:

- Main entry to the site
- A title to relate the contents of the site (focussing on targeted audience and intended purpose of the site)
- Background information to explain the establishment of the site and its desired purpose
- A list of instructions to guide the use of the site and what they are required to input
- Map and photos to locate users to the groups of test stations
- An input screen for point entry
- Easy navigation paths between the pages that form the site
- Copyright information and disclaimers plus warning notes for liability limitation purposes, and

- Minimal graphics for background display and to make the site attractive to look while not causing too much viewing obstructions.

As mentioned above, instructions are provided to guide users when accessing the web site and what they are required to enter. These require them to enter a name and date of observations, the equipment and method of GNSS being tested, time when observations commenced and completed for each separate station groups, the coordinates which they measured of each test station in Eastings, Northings, and RLs, (E,N,&RLs) plus the number of satellites and PDOPs recorded at each test station. Also included in these instructions is the control coordinates definitions which guide users to what coordinate system, datum and units of measurement their entered data should use. The following figures, Figure 4.2 and 4.3 and 4.4 give an example of two web pages, the main entry and data input screen, which have been created to demonstrate these features and functions.



GNSS TestNet

About Us | Instructions | Location | Data Input | Process Document

Providers of interactive online GNSS Testing and Validation

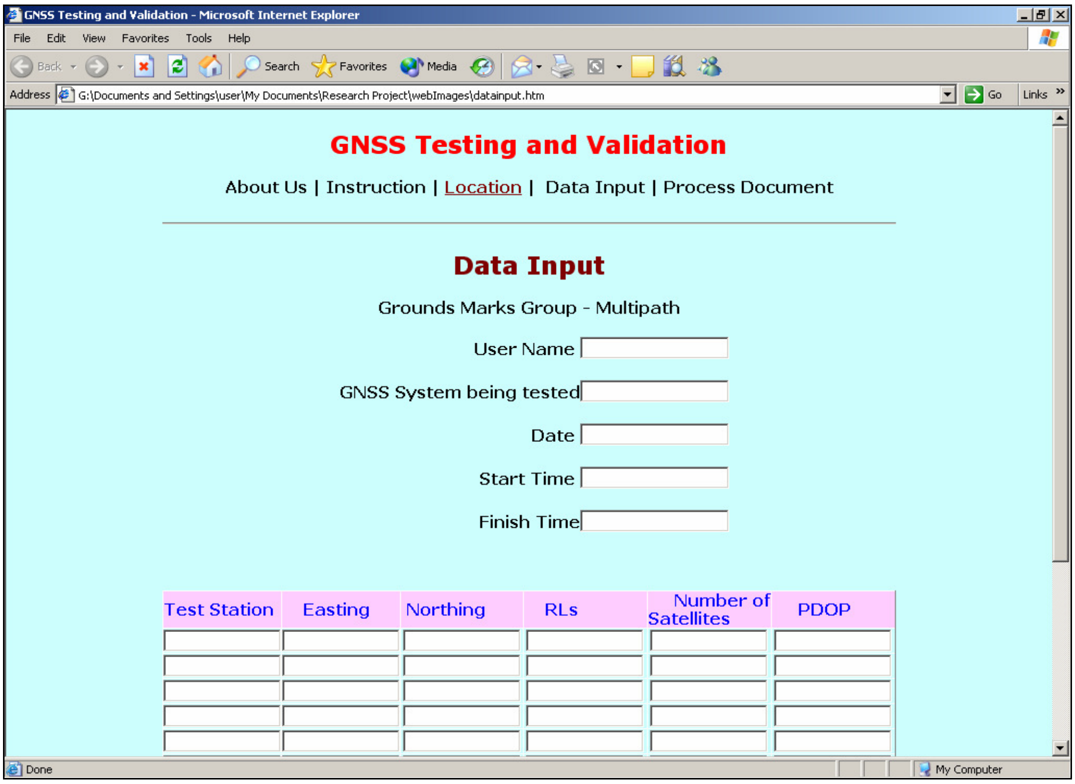
This site provides an on-line access to the University of Southern Queensland GNSS calibration facility, allowing fast and on-the-spot service to the community. Test and validate your equipment in realistic operating conditions, and say no to the financial and penal risks in this increasingly litigious society.

About Us | Instruction | Location | Data Input | Process Document

Copyright and terms of use, @ 2005 GNSS TestNet, all rights reserved. Your interactions with this site are in accordance with our public and member privacy statements

Last Modified on 16 September 2005

Figure 4.2: Web Main Page



GNSS Testing and Validation

About Us | Instruction | Location | Data Input | Process Document

Data Input

Grounds Marks Group - Multipath

User Name

GNSS System being tested

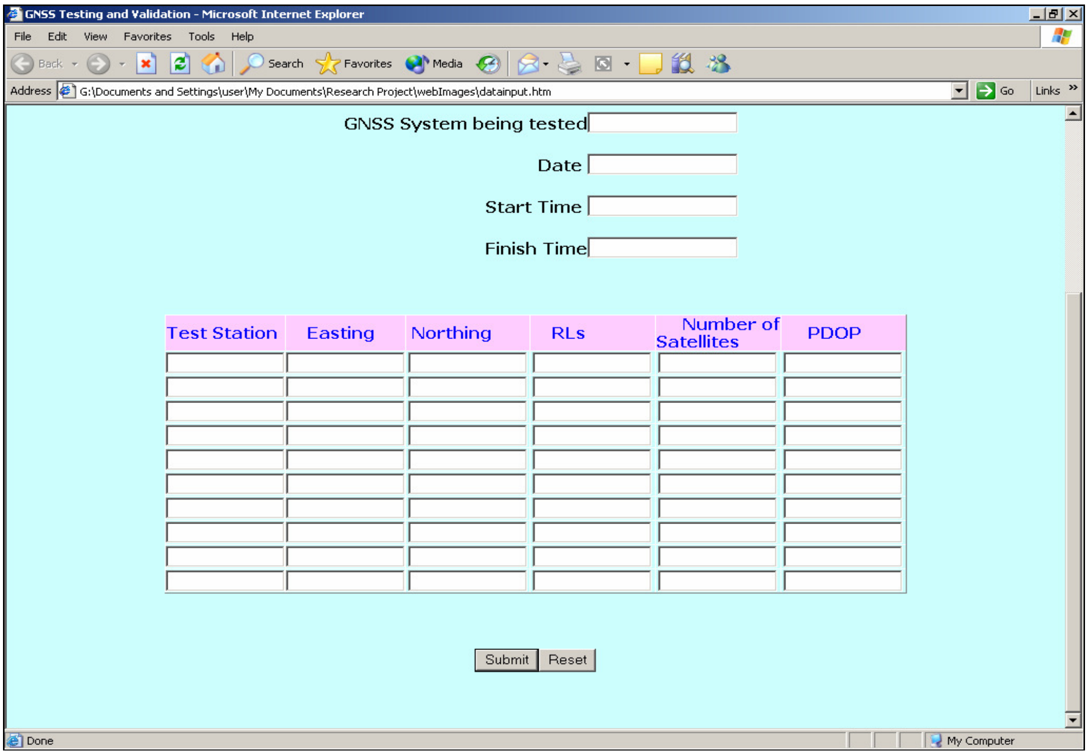
Date

Start Time

Finish Time

Test Station	Easting	Northing	RLs	Number of Satellites	PDOP

Figure 4.3: Data Input – top of page



GNSS System being tested

Date

Start Time

Finish Time

Test Station	Easting	Northing	RLs	Number of Satellites	PDOP

Figure 4.4: Data Input – bottom of page

4.4 Software Component

As mentioned in section 4.3 one of the elements of the web-based user-interface is to enable users to input their test data to process results and accuracies achieved. This element is the data input screen which directs a user to enter details as indicated. To process and report these data, a spreadsheet is developed using Microsoft Excel. An example of this spreadsheet is shown in Appendix B.

The various functions in Excel, which will be revealed in the following sections, allow computations to be carried out. Information is contained within cells which are referenced by the cell number. These references only need to be correctly entered in a function and an output of a calculation is resulted.

4.4.1 Data Processing and Reporting

In the attempt to process test data collected by GNSS users, the spreadsheet is formed to consist four worksheets, namely 1) Existing Coordinates Definition, 2) Separate Group Summary, 3) Combined Group Summary and 4) Report of Test Results.

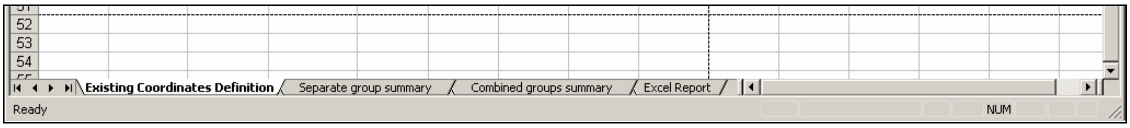


Figure 4.5: Worksheets comprising the Excel Spreadsheet

In the first worksheet, ‘Existing Coordinates Definition’, the known coordinates of the test stations for each group are listed. It also displays the coordinate system, geodetic datum and units of measurement which defines these known coordinates. Table 4.1 summarises this coordinates definition and a detailed example of this worksheet is found in Appendix B

Coordinate System	Map Grid of Australia (GDA) Zone 56
Project Datum	ITRF
Vertical Datum	Australia Height Datum (AHD)
Coordinate Units	Meters
Distance Units:	Meters
Height Units:	Meters

Table 4.1: Coordinates Definition of Test Stations

The second worksheet, ‘Separate Group Summary’, displays a summary of collected data for each group and the computations of residuals. These residuals include length of time taken to complete observations, the differences as well as the horizontal distances between known coordinates and GNSS-measured coordinates.

First a set of instructions is provided as a guide to indicate what information is contained in certain spreadsheet cells. For example, with reference to Appendix C it can be seen that the cells containing the time entered for when observations started and completed are within two columns, where one is the hour and other gives the minutes. This is saying that, if these instructions were not provided and the time is entered in 12 hour clock format, Microsoft Excel would have computed an incorrect figure for the length of time between start and completion of observations (e.g. 1:15pm entered as 1:15 instead of 13:15). On the other hand, Excel would have not been able to calculate the result at all if the time was entered as “12pm” for example, as it is non-numerical.

The worksheet then displays a summary of data collected by users, as entered via the web-access, and the residuals being calculated. For each group, the displayed information comprises the following:

- the name of GNSS operator
- date of observations
- times measurements commenced and completed

- number of satellites
- PDOPs and
- coordinates which they measured at each station

For each group, the total time taken to complete observations is represented by Δt. This is calculated by converting time into decimal degrees and subtracting the finishing time from the starting time. This result is multiplied by 60 to give the time length in minutes. In excel the function to return the absolute value (ABS) is used and is illustrated as follows, where the cell numbers refer to the cells containing the hours and minutes:

ABS((ABS(C21)+ABS(D21/60))-(ABS(C20)+ABS(D20/60)))*60

The differences between known and measured Eastings, Northings, and Heights (RLs) are represented as ΔE, ΔN and ΔRL respectively. These are calculated by directly subtracting GNSS-derived coordinated from the existing coordinates listed in the first worksheet. This saves time typing the coordinates repeatedly and avoids likely occurrences of mistyping errors. To do this, a certain cell in the Existing Coordinates Definition' worksheet is referenced and included in the subtraction function carried out in Excel (e.g. differences in Eastings) as follows:

=ABS('Existing Coordinates Definition'!C14-'Separate group summary'!C25)

ABS is used to return the absolute value of the resulting figure as negative values are not necessary.

The straight line distance between the measured coordinates and known coordinates is represented by Δ H Dist and calculated by using the Excel function, SUMSQ as follows:

SUMSQ(A,B)

The function returns the sum of the squares A and B where A and B are the cell numbers or reference for ΔE and ΔN respectively. This is based on the formula for horizontal line distance which is:

$$\Delta \text{ Horizontal Distance} = \text{SQRT}\ (\Delta E^2 + \Delta N^2)$$

For each group, the coordinate differences and horizontal distance computed at every station are represented on clustered column graphs to enable comparisons and interpretations to be made. Refer to Appendix C for illustrations.

In the third worksheet, 'All Groups Summary', statistical analyses are carried out on residual values, previously computed in the second worksheet. This is where the mean and standard deviation of ΔEs, ΔNs and ΔRLs of stations in each group, are determined. Again, retyping these values in this worksheet is not necessary as computations are carried out on values directly from the second worksheet by using their specific cell references in the mean and standard deviation functions such as the following:

```
=AVERAGE('Separate group summary'!H25:H34)
=STDEV('Separate group summary'!H25:H34)
```

For each group, the mean values of the coordinate differences are then multiplied by 1.96 to calculate the accuracies achieved at the 95% confidence level. These means and standard deviations are used to compute the range in which differences occur in Easting, Northing and RLs. The range is determined to fall within the 95% confidence limits.

To compute this, the mean is represented as the 'close' value whereas the 'high' and 'low' values indicate the upper and lower limits defined within the 95% confidence. Appendix D gives an illustration of these in the spreadsheet. The formulae to calculate each of these values are based on the assumption that the errors are normally distributed . This is summarized in table 4.2 below

Range limits	Formulae
High	= mean + (2 * standard deviation)
Close	= mean
Low	= mean - (2 * standard deviation)

Table 4.2: Formulae to calculate ranges in which coordinate differences occur

The final worksheet contains the construct and contents of reports formed to illustrate GNSS test data and the residuals computed on these data. Information and results computed in the previous worksheets are again linked directly to this report by cell referencing. Hence records and processing in the previous worksheets affect information and values in the reports.

Reports for each group are provided as well as a report of all groups combined. These reports are structured to include the following features and functions:

- Identification information including a report title, the group report data belongs to, username for the operator of the GNSS-system being tested and date of observations
- Coordinate definitions to ensure the user's data is relevant to the appropriate coordinate system adopted by the facility
- Units of measurements to be consistent with computations undertaken by the facility
- The equipment and system of GNSS positioning tested (e.g. RTK GPS)
- Time observations started and when they were completed to take into account the time efficiency of the GNSS system given site- and time-dependent factors
- Number of satellites and PDOPs recorded at each station to take into account the existence of incorrect integer ambiguity resolution
- Coordinate residuals computed at each test point
- Mean, standard deviation and level of confidence of the residuals computed
- Graphical presentation of the residuals to compare distribution of errors recorded at test stations in the different groups

- Indication of when continual large residuals or outliers are recorded to alert administration to consider the ambiguity in terms of accuracy of the known coordinates
- Comparison with accuracies recorded for other users
- Warning notes and explanatory clauses.

An example of these reports are provided in Appendices E and F

4.5 Conclusion:

This chapter has detailed the various components which contain the establishment of a proposed GNSS testing and validation facility at USQ. Different elements of these components have been identified to meet the requirements set out for each component.

Test stations are located in areas which includes varying site-dependent factors and degrees of satellite visibility. Location maps and photos of these stations are web-based. An online facility has been structured to provide easy access to the facility and to input tests data for processing residuals.

Microsoft Excel is used to develop a spreadsheet to facilitate processing and reporting results of GNSS tests carried out on the test network. Simple arithmetic operations such as addition (+) and subtraction (-) are used with other Excel functions to make computations. Analyses are then performed on these accuracies being processed.

CHAPTER 5

VALIDATION

5.1 Introduction

The different methods and processes to establish a GNSS testing and validation facility have been detailed in chapter 4. The purpose of this chapter is then to validate results of an RTK GPS test as a result of analyses of the accuracies achieved.

The chapter aims to present and analyse results of an RTK GPS test to demonstrate whether the facility actually works and what limitations does it have. Data contained and used for this validation is made-up or assumed, as it is only required to be used to form a structure of the Excel spreadsheet and to carry out computations for reports and analyses. An actual field survey is limited to the scope of this research.

The chapter comprises of analyses of accuracies achieved for each group. These accuracies are presented as functions of coordinate differences, length of time to complete observations, as well as satellite visibility and PDOPs.

5.2 Coordinate Differences

For each group, the differences between the measured coordinates against the known coordinates of every test station are determined. The mean and standard deviation of these differences are then calculated and multiplied by 1.96 to get the values in the 95% confidence level. This is to show the level to which the coordinates agree. Refer to figure 5.1 for the mean coordinate differences for each group, where they can be compared.

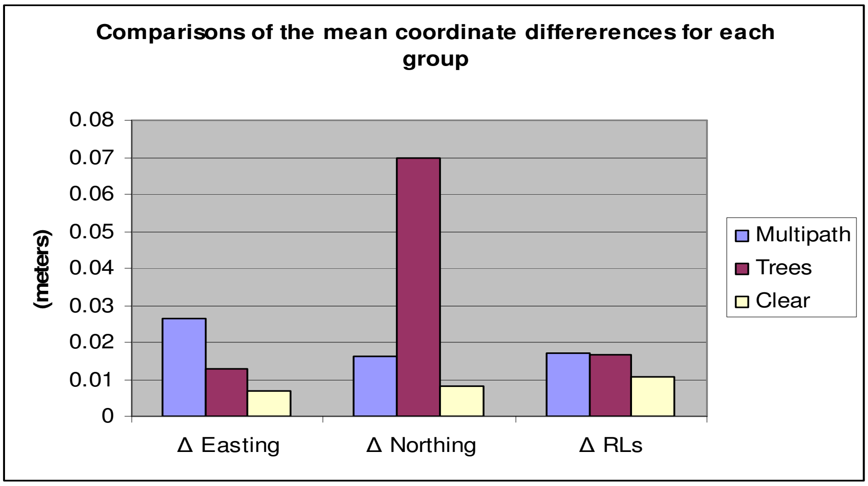


Figure 5.1: Mean of coordinate differences at 95% confidence for each group

This graphical representation enables comparisons made to determine if there were any significant differences between the amounts of residuals achieved for each group. A comparison of this sort pinpoints the relationship between the accuracies achieved and the effects of multipath, obstructions by trees as well as clear sky visibility or free reception of satellite signals.

The figures below, figure 5.2, 5.3 and 5.4 represent the range calculated within which the RTK GPS-derived coordinates agree with the known coordinates of test stations

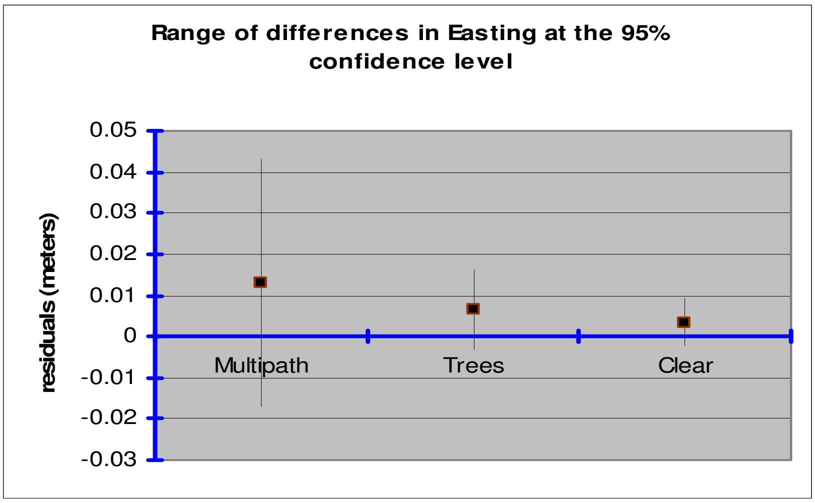


Figure 5.2: Graph of the range in which Easting differences fall within 95% confidence limits

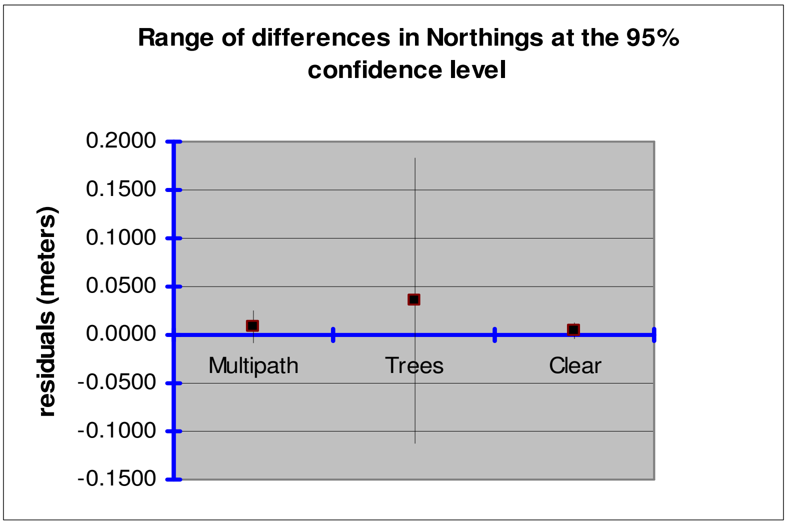


Figure 5.3: Graph of the range in which Northing differences fall within 95% confidence limits

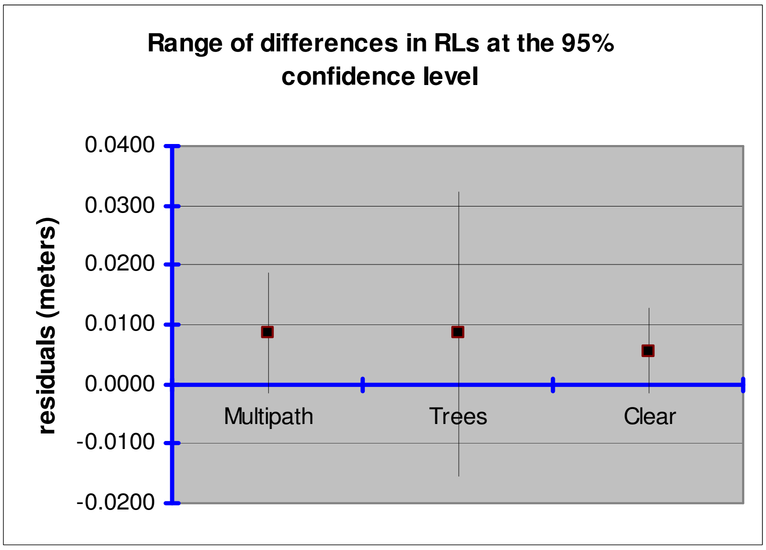


Figure 5.4: Graph of the range in which differences in RLs fall within 95% confidence limits

From this analysis, comparisons can be made to show any significant differences in the error margins or ranges which can be expected from measurements undertaken under these three groups.

5.3 Total Observation Times

The length of time taken to complete observations for each group is then compared and measured against the mean coordinate differences achieved. Refer to table 5.1 for the total times in minutes as recorded for each group. This is derived from the Excel spreadsheet which is given in Appendix C.

Table 5.1: Comparison of observation time lengths for each group

Group	Observation times (minutes)
Multipath	34
Trees	36
Clear	19

For each group, comparing the accuracies of coordinates measured against these times can be used to indicate the occurrence of loss of lock, assuming that it did happen given the varying degrees of satellite visibility. As this is only an assumption, the interpretations and conclusions drawn from them can be improved by comparing data produced by several other users. Although it doesn't guarantee a completely perfect result, it at least adds to the reliability of the analyses.

5.4 Number of Satellites and PDOPs

For each group, the Easting, Northing and RLs differences at each station are analysed as a function of varying number of satellites and PDOPs. This analysis is carried out to highlight how the facility is able to report if an incorrect ambiguity reinitialisation occurred. As the literature review indicates, RTK GPS solution with a PDOP greater than six or with less than five visible satellites is generally not accepted (Featherstone, 2001).

5.5 Conclusion

This chapter has illustrated the results of tests of an RTK GPS system, and analysis carried out on these tests data. Analyses are drawn from the reports as processed and compiled in the Excel spreadsheet. For each group, accuracies achieved are represented as the mean coordinate differences, the length of time to complete observations and the number of satellites and PDOPs recorded at each station under different groups.

The mean coordinate differences of each group are compared and analysed to determine the expected error and range which this error occurs at the 95% confidence level. The observation times recorded for different groups are compared to indicate the occurrence of a loss of lock and time to first fix (TTF). The problem of an incorrect ambiguity reinitialisation is interpreted by comparing accuracies achieved as a function of the number of satellites and PDOPs recorded at every station within different groups.

CHAPTER 6

CONCLUSIONS

6.1 Introduction

Chapters four and five presented the various components and processes involved to establish a GNSS testing and validation facility at USQ and a demonstration of the use of the facility to validate RTK GPS system respectively. From this information, conclusions and recommendations are made. These are presented in this chapter.

The conclusions provide a summary of the relevance of different components comprising the proposed test network and the reliability of the processes involved. This will address the benefits of the facility as well as its limitations as a quality assurance measure.

The chapter also provides recommendations regarding requirements which need to be maintained on full implementation of the proposed test facility, as well as future research into a few areas identified during the conduct of this dissertation.

6.2 Conclusions

A model has been developed to establish a GNSS testing and validation center at USQ. Various components of comprising the proposed test network have been identified and structured to achieve its purpose. A number of considerations have been made to ensure that the facility contains elements necessary to carry out reliable validation of GNSS systems, and this project has successfully researched into the use of the facility to test RTK GPS systems.

The following conclusions are drawn from the structure of components and processes involved in the establishment of a GNSS testing and validation at USQ:

- All components are interrelated so they should not be considered in isolation during full implementation of the proposed facility

- Extra knowledge is considered relevant in the use and creation of functions contained in Microsoft Excel
- The development of an online facility recognizes a more sophisticated element to enhance access and ineteractive use of the test network.

From comparisons and analyses used in the validation process in this dissertation, it is concluded that

  - accuracies achieved really is only based on assumptions made. There are numerous other factors which are not considered but while not being able to achieve the results achieved in other survey areas, it at the very least checks that the GNSS system is being operated properly and quality assurance processes are achieved
  - the entire system is being validated and as completely accurate results are expected to be achieved, the facility at the very least indicates whether a GNSS survey has in fact been adequately done

This research has recognized the usefulness of the development of a proposed testing and validation facility. Its benefits include:

- Validating of GNSS in conditions replicating practical application. This is useful for users who are seeking to validate their GNSS systems as a requirement for contractual work
- For the administrator, the facility enables data to be stored for maintaining archives and they can be able to set standards and best practices.

6.3 Recommendations

The following recommendations are made for several requirements important to be achieved and future work required.

- During GNSS testing and validation processes, it is recommended to consider uncertainty of the known coordinates. Warnings should alert administration of the continual reportings of errors and to recoordinate these marks

- Marks used for tests should be re-coordinated before full implementation of the test network.
- Further research is required to complete the development of an online facility
- Warnings and explanatory notes should be provided to convey to users of the proposed GNSS test network what they expect of the operations and achievements of the facility so that the university is not held liable for any complaints or a matter in court.

6.4 Summary

This chapter has outlined the conclusions drawn from the design and structure of a model to establish a GNSS testing and validation center at USQ, as well as validation of RTK GPS systems in the attempt to demonstrate how the facility can be used. The chapter has identified what is expected of the structure and operations of the proposed facility when it is put to use.

A number of benefits have been identified which is mainly targeting the requirements of users such as contractors of surveying development projects or etc, as well as the administrators to be able to set standards and best practices.

Recommendations have been made to consider the uncertainty of the known coordinates and to recoordinate marks before full implantation of the facility. It is also recommended to include warnings and explanatory notes to protect the university from being held responsible for problems experienced by users during their GNSS tests. Future work is required to complete a development of an online component of the proposed facility.

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APPENDIX A

PROJECT SPECIFICATION

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **University of Southern Queensland**

TOPIC: A MODEL TO ESTABLISH A GNSS TESTING AND VALIDATION CENTER AT THE UNIVERSITY OF SOUTHERN QUEENSLAND

SUPERVISOR: Peter Gibbings

ENROLMENT: ENG4111 – S1, D, 2001;
ENG4112 – S2, D, 2001

PROJECT AIM: This project seeks to investigate the establishment of a facility at the University of Southern Queensland, for testing and validating Global Navigation Satellite Systems (GNSS) hardware, software/firmware and operators. The testing facility will ensure independent quality control and quality assurances processes are applied in GNSS positioning

SPONSORSHIP: Faculty of Engineering and Surveying

PROGRAMME: **Issue A, 21st March 2005**

1. Research background information relating to the need for quality control in GNSS positioning, its applications and accuracy of coordinates computed by this system.

2. Collect the existing coordinates for all the control points on campus and design a model to implement the facility with the use of these points.

3. Recoordinate all the marks before full implementation of the test facility

4. Familiarise with the associated computer software component of the test facility

5. Design field measurement programme using RTK equipment and procedures and using the facility, analyse the accuracy of the known control marks

6. Consider measurements by other methods and implement an in-built warning to indicate when these methods continually record large residuals against any of the known mark, in order to give an alert to recoordinate the known marks.

7. Analyse the field data and the factors affecting any resulting differences.

As time permits:

8. Research information on more sophisticated automated analysis software such as an establishment of an On-Line Testing and Validation Facility and development of on-line interface

AGREED: ___Levei Tanoi(student)_______Mr Peter Gibbings (Supervisor)
(dated) 24 / 3 / 2005___

APPENDIX B

EXCEL WORKSHEET – COORDINATES DEFINITION

Control Coordinates Definition	
Coordinate System:	Map Grid of Australia (GDA) Zone 56
Project Datum:	ITRF
Vertical Datum:	Australia Height Datum (AHD)
Coordinate Units:	Meters
Distance Units:	Meters
Height Units:	Meters

Known coordinates listing for the three stations groupings

Group - Multipath

Name	Easting	Northing	Elevation
B21	394813.360	6946260.485	686.040
B45	394675.437	6946290.721	690.480
B78	394642.475	6946486.187	692.300
B79	394671.183	6946412.256	691.870
PSM51778	394432.579	6946512.719	695.080
PSMX	394417.582	6946448.197	695.975
S502	394396.824	6946408.244	999.000
S508T	394605.604	6946388.307	693.713
S509T	394553.086	6946399.159	694.440
S510T	394538.639	6946325.023	694.069

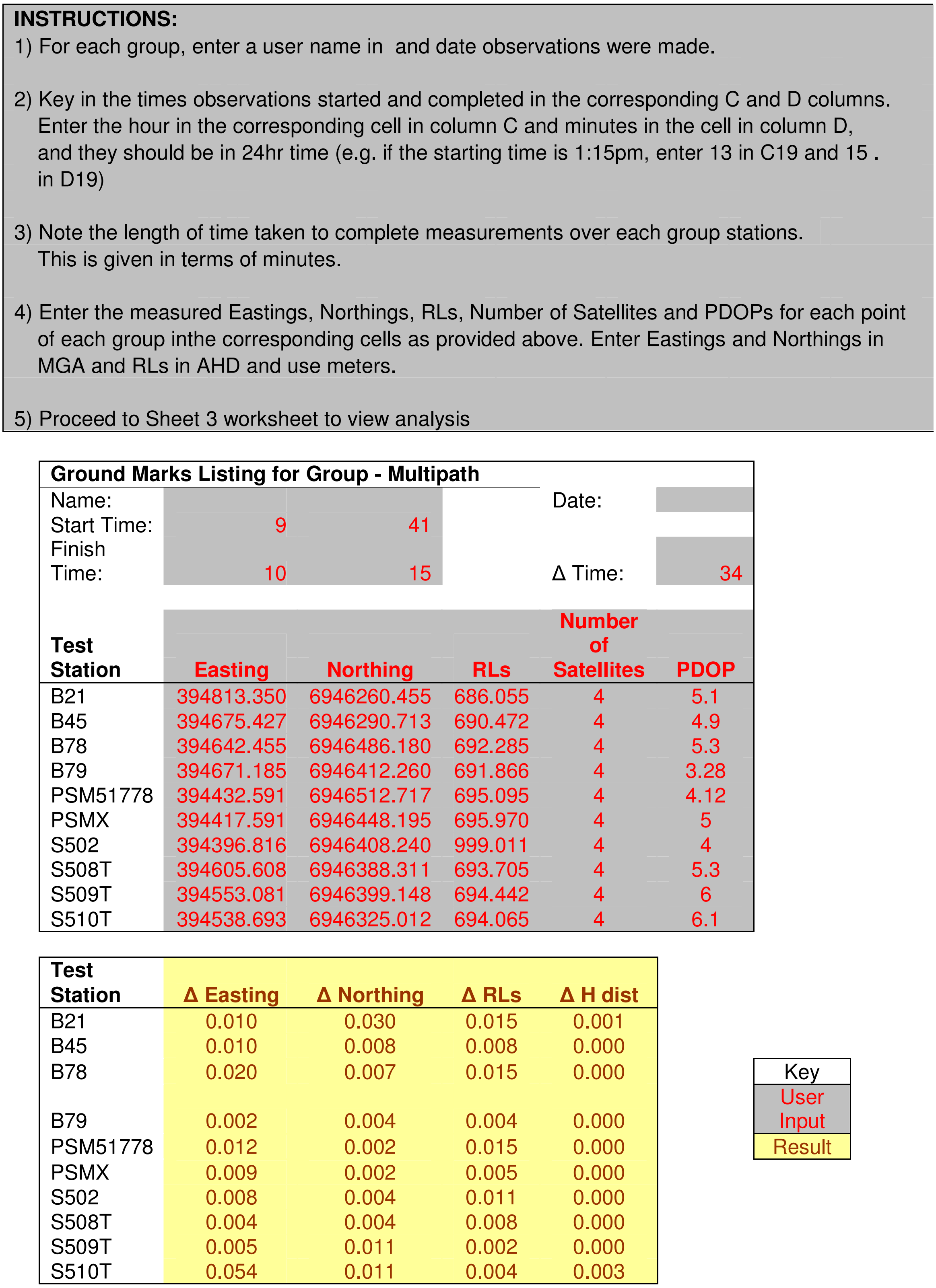
Group - Trees

Name	Easting	Northing	Elevation
B17	394688.612	6946273.443	689.680
B18	394787.684	6946260.465	686.790
B20	394649.708	6946135.238	689.500
B22	394931.818	6946198.829	682.950
B23	394813.323	6946049.729	687.165
B27	394944.369	6946267.733	682.360
B28	394938.311	6946258.501	682.575
B30	394914.267	6946101.464	684.130
B31	394906.754	6946096.607	684.350
B33	394788.546	6946195.063	686.585

Group - Clear

Name	Easting	Northing	Elevation
B29	394925.119	6946200.235	683.140
B32	394855.810	6946193.584	684.680
B38	394717.008	6946153.382	688.045
B50	394700.377	6946015.932	690.110
B51	394714.581	6946201.140	688.100
B52	394852.710	6946109.944	685.560
B55	394713.943	6946008.082	688.700
PSM40833	394200.968	6946401.077	693.915
PSM40834	394236.374	6946459.097	694.105
PSM40835	394256.524	6946492.479	694.080

APPENDIX C – WORKSHEET 2 – SEPARATE GROUP SUMMARY



INSTRUCTIONS:

1) For each group, enter a user name in and date observations were made.

2) Key in the times observations started and completed in the corresponding C and D columns.
Enter the hour in the corresponding cell in column C and minutes in the cell in column D,
and they should be in 24hr time (e.g. if the starting time is 1:15pm, enter 13 in C19 and 15 .
in D19)

3) Note the length of time taken to complete measurements over each group stations.
This is given in terms of minutes.

4) Enter the measured Eastings, Northings, RLs, Number of Satellites and PDOPs for each point
of each group inthe corresponding cells as provided above. Enter Eastings and Northings in
MGA and RLs in AHD and use meters.

5) Proceed to Sheet 3 worksheet to view analysis

Ground Marks Listing for Group - Multipath

Name:				Date:	
Start Time:	9	41			
Finish Time:	10	15		Δ Time:	34

Test Station	**Easting**	**Northing**	**RLs**	**Number of Satellites**	**PDOP**
B21	394813.350	6946260.455	686.055	4	5.1
B45	394675.427	6946290.713	690.472	4	4.9
B78	394642.455	6946486.180	692.285	4	5.3
B79	394671.185	6946412.260	691.866	4	3.28
PSM51778	394432.591	6946512.717	695.095	4	4.12
PSMX	394417.591	6946448.195	695.970	4	5
S502	394396.816	6946408.240	999.011	4	4
S508T	394605.608	6946388.311	693.705	4	5.3
S509T	394553.081	6946399.148	694.442	4	6
S510T	394538.693	6946325.012	694.065	4	6.1

Test Station	**Δ Easting**	**Δ Northing**	**Δ RLs**	**Δ H dist**
B21	0.010	0.030	0.015	0.001
B45	0.010	0.008	0.008	0.000
B78	0.020	0.007	0.015	0.000
B79	0.002	0.004	0.004	0.000
PSM51778	0.012	0.002	0.015	0.000
PSMX	0.009	0.002	0.005	0.000
S502	0.008	0.004	0.011	0.000
S508T	0.004	0.004	0.008	0.000
S509T	0.005	0.011	0.002	0.000
S510T	0.054	0.011	0.004	0.003

Key
User Input
Result

Ground Marks Listing for Group - Trees

Date:				
Start Time:	10	20		
Finish Time:	10	56	Δ Time:	36

Test Station	Easting	Northing	RLs	Number of Satellites	PDOP
B17	394688.610	6946273.435	689.685		
B18	394787.691	6946260.411	686.791		
B20	394649.725	6946135.478	689.475		
B22	394931.822	6946198.822	682.952		
B23	394813.325	6946049.718	687.164		
B27	394944.359	6946267.712	682.362		
B28	394938.321	6946258.503	682.571		
B30	394914.265	6946101.460	684.135		
B31	394906.748	6946096.605	684.346		
B33	394788.541	6946195.057	686.549		

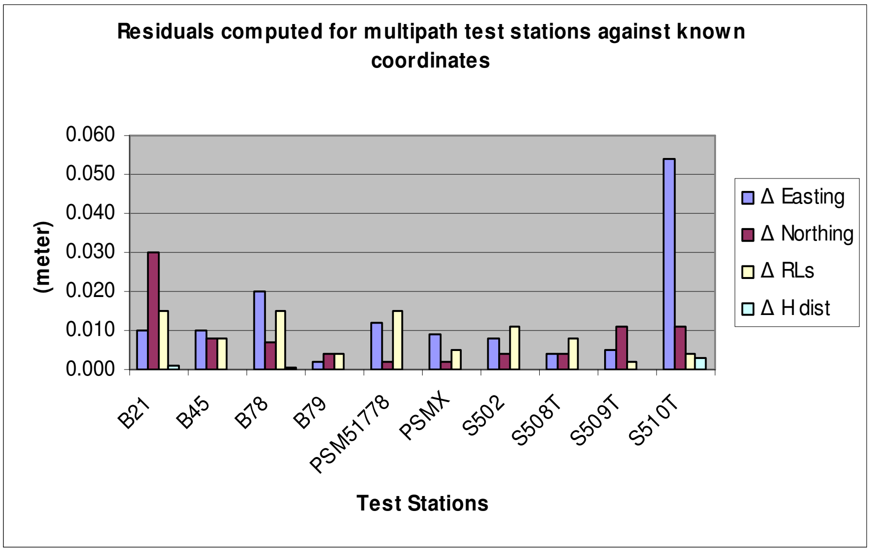
Test Station	Δ Easting	Δ Northing	Δ RLs	Δ H dist
B17	0.002	0.008	0.005	0.000
B18	0.007	0.054	0.001	0.003
B20	0.017	0.240	0.025	0.058
B22	0.004	0.007	0.002	0.000
B23	0.002	0.011	0.001	0.000
B27	0.010	0.021	0.002	0.001
B28	0.010	0.002	0.004	0.000
B30	0.002	0.004	0.005	0.000
B31	0.006	0.002	0.004	0.000
B33	0.005	0.006	0.036	0.000

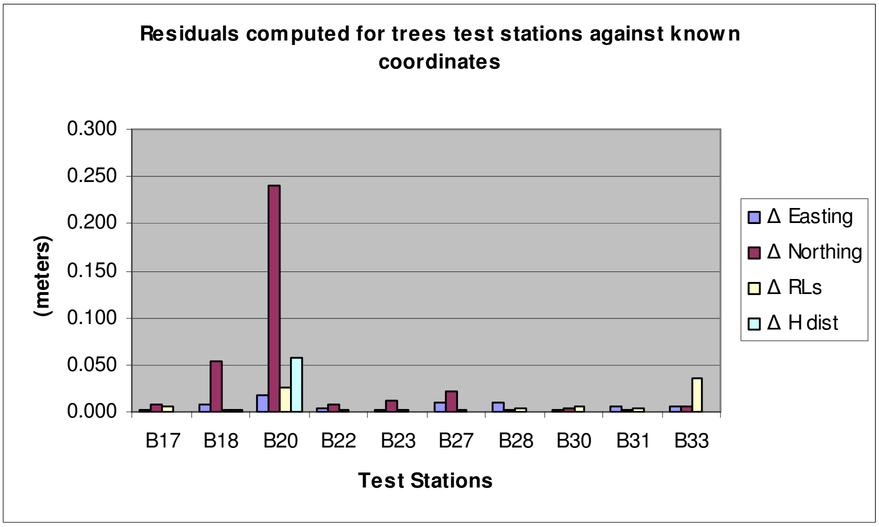
Ground Marks Listing for Group - Clear

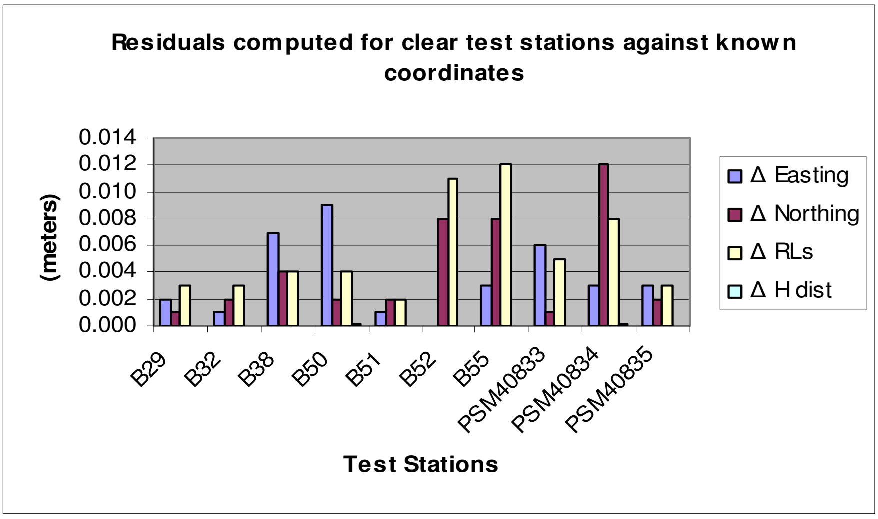
Date:				
Start Time:	12	56		
Finish Time:	13	15	Δ Time:	19

Test Station	Easting	Northing	RLs	Number of Satellites	PDOP
B29	394925.117	6946200.234	683.143		
B32	394855.811	6946193.582	684.683		
B38	394717.001	6946153.378	688.041		
B50	394700.368	6946015.930	690.114		
B51	394714.580	6946201.142	688.102		
B52	394852.710	6946109.952	685.549		
B55	394713.946	6946008.074	688.712		
PSM40833	394200.974	6946401.078	693.920		
PSM40834	394236.377	6946459.085	694.113		
PSM40835	394256.521	6946492.477	694.077		

Test Station	Δ Easting	Δ Northing	Δ RLs	Δ H dist
B29	0.002	0.001	0.003	0.000
B32	0.001	0.002	0.003	0.000
B38	0.007	0.004	0.004	0.000
B50	0.009	0.002	0.004	0.000
B51	0.001	0.002	0.002	0.000
B52	0.000	0.008	0.011	0.000
B55	0.003	0.008	0.012	0.000
PSM40833	0.006	0.001	0.005	0.000
PSM40834	0.003	0.012	0.008	0.000
PSM40835	0.003	0.002	0.003	0.000


Residuals computed for multipath test stations against known coordinates
(meter)
0.060
0.050
0.040
0.030
0.020
0.010
0.000
B21
B45
B78
B79
PSM51778
PSMX
S502
S508T
S509T
S510T
Test Stations
Δ Easting
Δ Northing
Δ RLs
Δ H dist


Residuals computed for trees test stations against known coordinates
(meters)
0.300
0.250
0.200
0.150
0.100
0.050
0.000
B17
B18
B20
B22
B23
B27
B28
B30
B31
B33
Test Stations
Δ Easting
Δ Northing
Δ RLs
Δ H dist


Residuals computed for clear test stations against known coordinates
(meters)
0.014
0.012
0.010
0.008
0.006
0.004
0.002
0.000
B29
B32
B38
B50
B51
B52
B55
PSM40833
PSM40834
PSM40835
Test Stations
Δ Easting
Δ Northing
Δ RLs
Δ H dist

APPENDIX D

EXCEL WORKSHET - COMBINED GROUPS SUMMARY

Mean and Standard Deviation of coordinate differences for each group

Station Group	Mean Δ Easting	Std Dev Δ Easting	Mean Δ Northing	Std Dev Δ Northing	Mean Δ RLs	Std Dev Δ RLs
Multipath	0.0134	0.015108497	0.0083	0.008313978	0.0087	0.00503433
Trees	0.0065	0.004766783	0.0355	0.07352135	0.0085	0.01197451
Clear	0.0035	0.002915476	0.0042	0.003794733	0.0055	0.00356682

Mean and standadard deviation at 95% confidence

Station Group	Mean Δ Easting	Std Dev Δ Easting	Mean Δ Northing	Std Dev Δ Northing	Mean Δ RLs	Std Dev Δ RLs
Multipath	0.026264	0.029612653	0.016268	0.016295396	0.017052	0.00986728
Trees	0.01274	0.009342895	0.06958	0.144101846	0.01666	0.02347004
Clear	0.00686	0.005714333	0.008232	0.007437677	0.01078	0.00699097

Multiplier	1.96

Range in which Easting Differences fall in 95% confidence limits

Group	High	Low	Close
20/10/2005	0.0855	-0.0330	0.0263
21/10/2006	0.0314	-0.0059	0.0127
20/12/2007	0.0183	-0.0046	0.0069

Range in which Northing Differences fall in 95% confidence limits

Group	High	Low	Close
Multipath	0.048804	-0.016322793	0.016268
Trees	0.20874	-0.218623692	0.06958
Clear	0.024696	-0.006643354	0.008232

Range in which Northing Differences fall in 95% confidence limits

Group	High	Low	Close
Multipath	0.036787	-0.00268256	0.017052
Trees	0.0636	-0.030280079	0.01666
Clear	0.024762	-0.003201944	0.01078

APPENDIX E

GROUP REPORT OF GNSS TEST RESULTS

MULTIPATH STATIONS
REPORT OF RESULT OF GNSS TESTING
SEPTEMBER 12 2005

Username: A
RTK
GNSS system tested: GPS
Time taken to complete observations:

Coordinate definition:

Coordinate system: Map Grid of Australia (GDA) Zone 56
Project Datum: ITRF
Vertical Datum: Australia Height Datum (AHD)

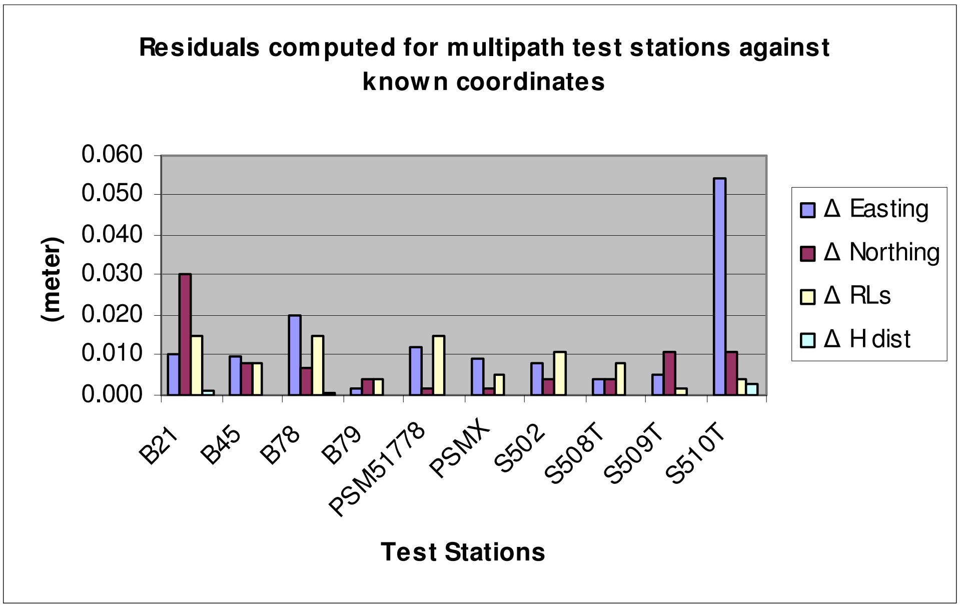
Units:

Coordinate Units: Meters
Distance Units: Meters
Height Units: Meters

Coordinate differences at the ten test stations

Test Station	Resid.E	Resid.N	Resid.RL	Resid. Horiz Dist	
B21	0.010	0.030	0.015	0.001	**0.4110**
B45	0.010	0.008	0.008	0.000	**0.2691**
B78	0.020	0.007	0.015	0.000	**0.9203**
B79	0.002	0.004	0.004	0.000	**0.2340**
PSM51778	0.012	0.002	0.015	0.000	**0.7439**
PSMX	0.009	0.002	0.005	0.000	**0.3854**
S502	0.008	0.004	0.011	0.000	**0.1959**
S508T	0.004	0.004	0.008	0.000	**0.3025**
S509T	0.005	0.011	0.002	0.000	**0.3516**
S510T	0.054	0.011	0.004	0.003	**1.0000**

		95% confidence	-
Mean Resid.E	0.013	0.0263	
Std Dev Resid.E	0.015	0.0296	
Mean Resid.N	0.008	0.0163	
Std Dev Resid.N	0.008	0.0163	
Mean Resid.RL	0.009	0.0171	
Std Dev Resid.RL	0.005	0.0099	


Residuals computed for multipath test stations against known coordinates

Residuals against No of Satellites and PDOPs at the ten test stations

Test Station	Resid.E	Resid.N	Resid.RL	Resid. Horiz Dist	No of Satellites	PDOPs
B21	0.010	0.030	0.015	0.001	4	5.1
B45	0.010	0.008	0.008	0.000	4	5.1
B78	0.020	0.007	0.015	0.000	4	5.1
B79	0.002	0.004	0.004	0.000	4	5.1
PSM51778	0.012	0.002	0.015	0.000	4	5.1
PSMX	0.009	0.002	0.005	0.000	4	5.1
S502	0.008	0.004	0.011	0.000	4	5.1
S508T	0.004	0.004	0.008	0.000	4	5.1
S509T	0.005	0.011	0.002	0.000	4	5.1
S510T	0.054	0.011	0.004	0.003	4	5.1

APPENDIX F

REPORT OF COMBINED GNSS TEST RESULTS FOR ALL GROUPS

ALL STATIONS
REPORT OF RESULT OF GNSS TESTING
SEPTEMBER 12 2005

Username: A
RTK
GNSS system tested: GPS
Time taken to complete observations:

- **Coordinate definition:**

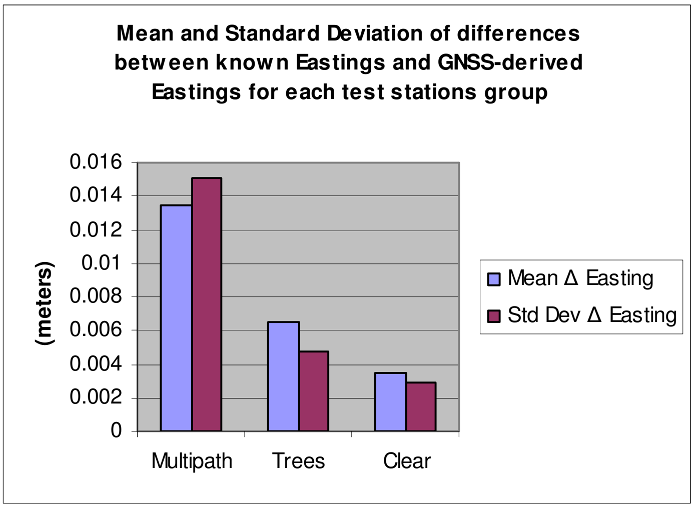
Coordinate system: Map Grid of Australia (GDA) Zone 56
Project Datum: ITRF
Vertical Datum: Geoid Model AUSGEOID98 (Australia)

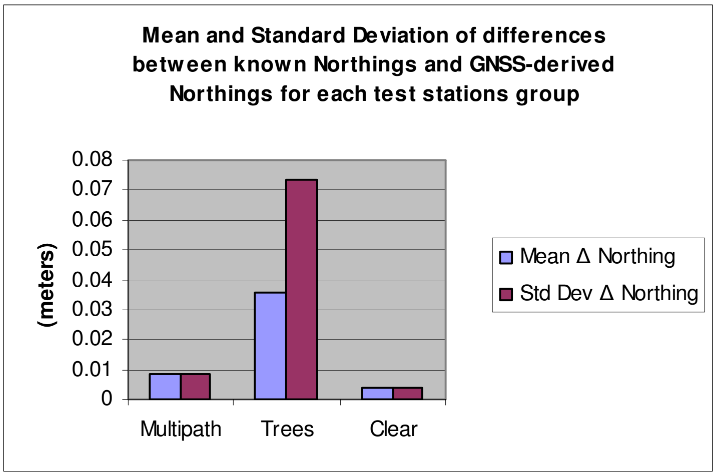
Units:

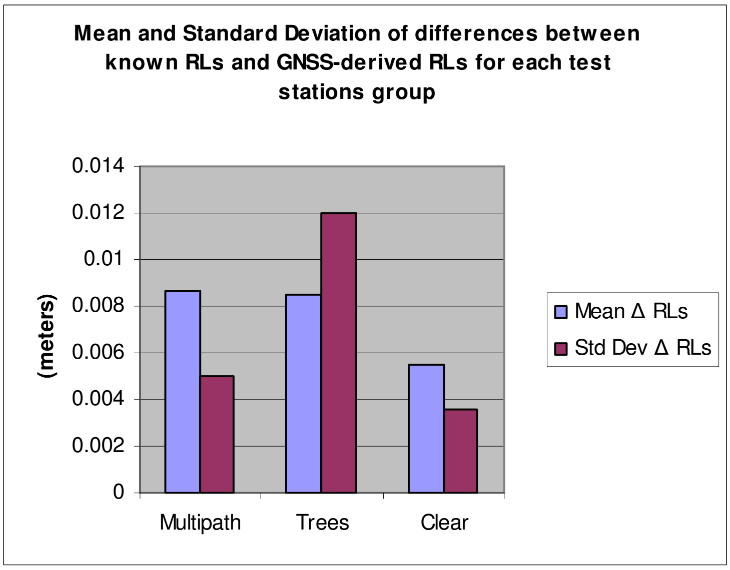
-

Coordinate Units: Meters
Distance Units: Meters
Height Units: Meters

Station Group	Mean Resid.E	Std Dev Resid.E	Mean Resid.N	Std Dev Resid.N	Mean Resid.RL	Std Dev Resid.RL
Multipath	0.0134	0.0151	0.0083	0.0083	0.0087	0.0050
Trees	0.0065	0.0048	0.0355	0.0735	0.0085	0.0120
Clear	0.0035	0.0029	0.0042	0.0038	0.0055	0.0036




Mean and Standard Deviation of differences between known Northings and GNSS-derived Northings for each test stations group
(meters)
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
Multipath
Trees
Clear
Mean Δ Northing
Std Dev Δ Northing


Mean and Standard Deviation of differences between known RLs and GNSS-derived RLs for each test stations group
(meters)
0.014
0.012
0.01
0.008
0.006
0.004
0.002
0
Multipath
Trees
Clear
Mean Δ RLs
Std Dev Δ RLs