University of Southern Queensland
Faculty of Engineering and Surveying

INVESTIGATION OF THE RIEGL TERRESTRIAL SCANNERS USES AND LIMITATIONS

A dissertation submitted by

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ABSTRACT

Terrestrial laser scanners are becoming more familiar in the surveying industry due to the significant technological advances in equipment over the past 10 – 20 years introducing many new types of equipment and methods for the capture of point data in a variety of environments.

The introduction of the terrestrial laser scanner in the surveying industry has been slowed by a lack of understanding in comparison with traditional surveying methods. This poses the question to the surveying industry of whether the relative accuracies and potential uses of terrestrial laser scanning systems can be of significant value to the surveying industry much like GPS has become over the last decade.

For this project I have conducted testing on various facets of terrestrial laser scanning operation, specifically confirmation of specifications and the ability to establish a method providing legal traceability of measurements obtained from these systems. This project utilised the RIEGL LMS-Z620 terrestrial laser scanner and a Trimble S8 total station.

The results from the various scan sessions were then analysed to compare the obtained data to the specified accuracies published by the manufacturer as well as extracting information that members of the surveying industry can use to evaluate the capabilities of this instrument for traditional and non-traditional scanning applications.

Terrestrial laser scanning is a relatively new concept for surveyors, with scanners capable of capturing large amounts of three-dimensional coordinated data quickly and very accurately without having to physically access objects and / or environments that may be hazardous or impractical to access. In Australia surveyors have not embraced the technology as quickly as other countries due to the unknown capabilities and questions about the accuracies that can be achieved, when compared to existing equipment.

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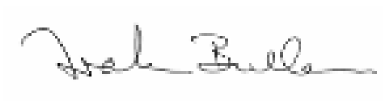

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CERTIFICATION

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.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

GLOSSARY OF TERMS AND ABBREVIATIONS

EDME	Electronic Distance Measuring Equipment.
Total Station	A surveying instrument where the theodolite and EDM are combined into one single instrument.
DERM	Queensland Department of Environment and Resource Management.
AHD	Australian Height Datum.
ppm	Parts Per Million
Point Cloud	A point cloud is a set of vertices in a three-dimensional coordinate system. These vertices are usually defined by X, Y and Z coordinates.
GPS	Global Positioning System is a space-based global navigation satellite system developed by the United States Department of Defense.
GNSS	Global Navigation Satellite Systems is the generic term for satellite navigation systems that provide autonomous geo-spatial positioning with global coverage.
Selective Availability	Selective Availability is a security measure built into the GPS network that adds intentional errors of up to 100 meters to the publicly available navigation signals of the system.
LASER	Light Amplification by Stimulated Emission of Radiation.
Albedo	The albedo of an object is the extent to which it diffusely reflects light from light sources. It is therefore a more specific form of the term reflectivity.
TPL (SOCS)	Tie Point Location (Scanner Oriented Control System)

1. INTRODUCTION

Terrestrial laser scanners are a recent addition to the tools available to surveying firms that has the potential to provide surveyors with another option by which to acquire three dimensional data quickly and easily. With more surveyors looking at the purchase and utilisation of this technology it is important to understand what some of the limitations are along with alternate uses that may maximise the usage of this expensive but exciting specialist equipment.

Recent developments regarding performance, range and accuracy have opened up new application areas for laser scanning with the latest range of terrestrial laser scanners starting to take into account the needs of spatial professionals by incorporating additional components providing the ability of levelling, centring, orienting and measurement / correction of errors like inclination.

Obviously there is a need for each piece of surveying instrument to be investigated and calibrated regarding instrumental errors and non-instrumental errors. It is worth noting that in his research Schulz (2007) mentions that he believes at the conception of GPS, the acceptance of the technique as well as the use of the instrument drew reservations from peers. Nowadays, GPS is well-accepted and state-of-the-art. He goes on to indicate that terrestrial laser scanning should be viewed in a similar manner. The performance is impressive regarding the data acquisition rate and the accuracy is in the range of centimetres or less (Schulz 2007).

Terrestrial laser scanners are able to record thousands of points a second and produce accurate 3D models of surfaces and structures in a short period of time. Most manufacturers have a variety of scanning systems available and they market these to suit individual applications. However it is generally accepted that the main applications of terrestrial laser scanners in the surveying industry are;

- Topography & Mining
- Architecture & Facade Measurement
- As-Built Surveying (Plant, Pipes, Road etc.)
- Archaeology & Cultural Heritage Documentation
- Monitoring & Civil Engineering
- City Modelling

Terrestrial laser scanners promise to revolutionise the field of surveying and alter the way the surveyors approach tasks that are today considered fairly complex much in the same manner that the introduction of GPS and GNSS systems have over the past 10 years. In a similar fashion to the introduction of GPS systems, the uptake of terrestrial laser systems will be gradual as the technology is still seen as young and unproven for many surveying tasks; there is no doubting the obvious advantages of using these systems for their intended purpose. Obviously with the technology only being fairly new and being recently introduced to the surveying market, the hardware is still extremely expensive and a large commitment to capital for any survey firm, large or small. This poses the question to many, what the scanner can be used for to maximise the time that it is spent earning a return on the investment, instead of the instrument only being used for certain tasks where it may have been more economical to just hire the equipment.

The introduction of total stations in the late 1980's and early 1990's saw a huge increase in the methodology and time savings across the surveying industry, however, there where critics of this technology which today is considered a minimum requirement for any survey team. Parallels of this introduction were also seen when GPS was introduced into the market in the mid 1990's and more noticeably in the first few years after selective availability was turned off by the United States government in May 2000; many survey firms were unable to access the hardware due to the extreme cost and the lack of suitable work as well as the lack of training and understanding about the technology. Since the introduction of the first GPS unit manufactured by Trimble Navigation, users and related professionals have gained an increased understanding of the uses and capabilities of the technology; this teamed with the progression of the electronic components and a dramatic decrease in price have seen most medium and large survey companies, civil construction, mining and general public utilise this technology in some way. In fact some survey companies specialise in this technology, with many survey tasks solely being undertaken by GPS.

Another advantage assisting with the integration of these instruments into the surveying market is the need to comply with specific occupational and site specific health and safety requirements. Some examples where this might be seen are for survey work of busy road networks where it is either not practical or economical to close the road for conventional surveying methodology or surveys where the risk posed from contact of the site whether it is from electrocution, contamination or machinery determines that traditional methods are unacceptable. In some cases, surveyors may be liable for damages if equipment or workers come in contact with machinery or live electrical apparatus when working around them.

To ensure that terrestrial laser scanning instruments can be used for more than just modelling applications in surveying, the same level of testing and requirements as any modern total station that is in use today should be undertaken. This testing is undertaken to ensure that the required accuracy for specific to the type of surveys can be achieved. A user of a specific instrument, be it total station, GPS, laser distance meter or terrestrial laser scanner would like to completely rely on the assurance of accuracies and techniques gained from product company representatives and documentation, independent testing must be undertaken to verify that measurements are being made correctly. This is done by a combination of regular servicing and calibrations to compare measured values against a set of known values.

For this project I plan to confirm the manufacturers stated accuracies of the terrestrial laser scanner through the use of some basic testing and whilst undertaking this testing try to establish how reliable the measurements obtained from the terrestrial laser scanner to determining if there are alternative uses for which this type of instrument can be used.

1.1. The Problem

The problem is that laser scanning technology is relatively new and surveyors are generally a conservative group of people, the equipment is currently very expensive which places it out of reach of many surveying firms. Obviously, having over $250,000 of survey equipment sitting around the office is not good business sense either, being able to utilise this equipment for other purposes may help maximise the amount of time that the instrument is providing a return to the survey company. It was noted that previous research was mostly focused on the technical specifics of these instruments; most surveyors are not interested in this, they want to know can it do the job efficiently and accurately. Hopefully my research can justify the use of this equipment on projects that are outside what is considered normal for laser scanning instruments.

It is understandable that surveyors in general are very cautious about new surveying technologies, with some surveying tasks like cadastral surveys being highly regulated and the reliance and expectations of end users that the product that they are being delivered is a true and accurate record of the information requested. It is understandable that most surveyors would want any new technology proven and tested before the majority would undertake the purchase of such an expensive item.

Previous research into the capabilities and performance of terrestrial laser scanning systems has traditionally been directed towards the more technical aspects of these instruments. As the uptake of these instruments by surveyors increases it is prudent that testing be undertaken to show surveyors the performance capabilities and reliability of these instruments without being overwhelmed by intricate details of operation.

1.1 Research Aims and Objectives

1.1.1 Research Aim

The aim of this research project is to investigate the limitations and alternate uses of terrestrial laser scanning systems. The research is focussed on data obtained utilising the RIEGL LMS-Z620 instrument.

1.1.2 Research Objectives

The main objectives of this research is to firstly investigate the current uses of terrestrial laser scanning systems and then to proceed to research and test the manufacturers published specifications and determine any limitations of this equipment from the testing undertaken with a specific terrestrial laser scanner.

Other objectives of the testing undertaken as part of this research project are to determine the effectiveness of laser scanning equipment, specifically the RIEGL LMS-Z620 for alternate surveying tasks and from both of these main objectives, attempt to establish best practice guidelines for the everyday use of laser scanning systems.

1.2. Scope of Research

A RIEGL LMS-Z620 terrestrial laser scanner will be tested under a variety of conditions to establish the effects that rain and water surfaces have on the quality of data and then the majority of testing will be focused on confirming some of the manufacturers specifications. This will be mostly done at an EDME calibration range due to the relatively easy accessibility, availability of quality meteorological data and the relative flatness of the overall site.

The testing will be limited to this single instrument due to time constraints; however it is expected that the resulting data from this research should be able to be applied to the majority of laser scanning systems on the market today.

1.3. Chapter Overview

1.3.1. Chapter 2 – Literature Review

In this chapter the previous research and technical documentation regarding terrestrial laser scanners have been researched and analysed to provide sufficient background knowledge of the subject matter and to ensure that this research is required. The literature review also will enable the reader to familiarise themselves with some of the background information needed to understand the reasoning behind some of the testing and provide some background leading to an increased understanding of the results.

1.3.2. Chapter 3 – Methodology

In this chapter the field work and office work will be explained in depth. It will provide additional information to how the field work and office work will be conducted. The aim of this chapter is to provide the reader with a better understanding of the testing methods that will be used in this project and why the testing methods were used to gain the best possible results.

1.3.3. Chapter 4 – Results and Data Analysis

In this chapter the data obtained from the testing will be presented along with the calculations of that data that provides the results for this research. Analysis of the raw observations, testing procedures, processing and the results will be undertaken at the same time to convey the need to form conclusions and recommendations on the performance of the terrestrial laser scanner.

1.3.4. Chapter 5 – Conclusions and Recommendations

This chapter concludes this report by providing a overall assessment of the project and the outcomes from the research, there is also recommendations for practical applications of the research and additional areas of research that may be related to this topic.

2. LITERATURE REVIEW

2.1 Introduction

Terrestrial laser scanners provide detailed and highly accurate 3D data rapidly and efficiently (RIEGL Laser Measurement Systems GmbH 2008a), they are a relatively new tool available to surveyors brought about by the rapid advancements in hardware and software. As the prevalence of this type of instrument increases, detailed testing is needed to determine the suitability of this equipment for various tasks in the surveying profession.

This chapter will review current available literature to establish the need for reliable and accurate measurements made using Terrestrial Laser Scanners. This review will describe how survey observations are made using laser scanning equipment and will identify what regulations in place to control distance measurement instruments used in the surveying field, as well as the accuracy requirements for cadastral survey measurements in Queensland.

To facilitate analysis of the results for surveys of this type, manufacturers technical notes on the instruments used will also be reviewed for completeness. But firstly, what is a laser Scanner?

2.2 Terrestrial Laser Scanner

Surveyors need not feel threatened by the onset of laser scanners - in fact, there are ways to transform threats into opportunity (Mitchell 2004).

2.2.1 What is Laser Scanning?

Terrestrial laser scanners are very capable measuring instruments. They could well be the cause of the next revolution in surveying (Mitchell 2004). 3D Scanning is a powerful technology that uses advanced laser measurement technology to obtain measurements at many thousands of points per second. Surveying professionals are eager to adopt this new technology due to the dramatic productivity benefits that can be obtained. However, the lack of versatility of scanners together with unfamiliar workflows has limited the widespread adoption of the technology.

3D Laser Scanning is a non-contact, non-destructive technology that digitally captures the shape of physical objects using a line of laser light. 3D laser scanners create “point clouds” of data from the surface of an object (Laser Design Inc n.d.). The only area that does not get scanned is the ground that the scanner is set up over. Several scanner locations may be needed in order to fully record the plant, room, building, structure or object that is being scanned without any details being hidden. The resulting data is reduced in specialised computer software to produce a complete 3d model of the site that is typically accurate to better than 5mm (Institution of Civil Engineering Surveyors 2007).

2.2.2 Background

In a similar way to early GPS technology, the first commercially available 3D scanners were generally used for specialized applications rather than typical survey tasks. As the technology has become more accessible and the benefits of such fast data acquisition have been realized, surveyors have started looking towards 3D scanners as a new tool for the future (Biddscombe & Lemmon 2005).

3D Laser scanning has many applications in surveying where precise three dimensional relationships are required. However, there are four criteria for gauging where its practicality and efficiency can be best applied and exploited required level of detail accessibility safety and traffic / business disruptions. With the technology becoming more accessible, the benefits of such fast data acquisition have been realized and surveyors have started looking towards 3D scanning and

Spatial Imaging as a new tool for the future and to widen their business opportunities (Satyaprakash 2007).

2.2.3 Classification of Laser Scanners

As the construction of each manufacturer's individual laser scanning hardware is configured differently, it is quite difficult to classify terrestrial laser scanners into defined groups. The only true commonality between these instruments is the range that they operate in and their method of measurement which provides this range.

There are three laser measurement methods that are used for laser scanning applications, however triangulation is a method that is primarily used for reverse engineering and industrial applications. For medium to long range scanning equipment that is used by surveying professionals typically only two measurement methods can be employed and this seems to be a logical starting point for any classification system.

The Institution of Civil Engineering Surveyors in England release regular information updates on developments in the surveying industry for the benefits of surveyors and interested parties, in one of these papers they describe that there are two types of scanner currently available and each uses a different measuring system. Time of Flight scanners are low noise, high accuracy and generally longer range scanners but are fairly slow and measure less than 5000 points per second.

Phase comparison scanners are higher noise and therefore slightly lower accuracy and have less range but will measure up to 625000 points per second. Time for a single scan can therefore vary between 3minutes and 3hours depending on the type of scanner and the point density setting (Institution of Civil Engineering Surveyors 2007).

2.3 Laser Measurement Principles

One of the most important features of a terrestrial laser scanner is measurement range because range determines to a large extent types of application. Maximum range does not depend only on the terrestrial laser scanner itself but also heavily on object reflectivity. Only time-of-flight systems, which make use of pulsed laser, are suited for long-range applications. Phase-shift systems are particularly suited for high-precision short-range and medium-range applications, for which high point densities are required (Lemmens 2007).

Laser Design Inc explain that laser scanners work by projecting a laser beam onto an angled rotating mirror that reflects the beam to the object being scanned, while the entire unit rotates around a vertical axis. The beam hits the object being measured and then the beam is reflected back to the scanner.
Generally the distance of the object being measured can be determined by either of two different methods. One way is to measure the time of flight of the laser beam and multiply it by the speed of light. The other method involves projecting constant waves of varying length and measuring the phase shift of the reflected beam in relation to a reference signal kept at the laser scanner.
Satyaprakash (2007) agrees with this statement by indicating in his article that the three most popular measurement techniques used in surveying are - laser triangulation, time of flight and phase shift. These laser scanning techniques are typically used independently but can also be used in combination to create a more versatile scanning system.

Laser scanning means the deflection of a laser beam by moving (sweeping or rotating) mirrors, the reflection of the laser beam on object surfaces, and the receiving of the reflected laser beam. In opposite to measurements on reflectors, the accuracy of distance measurements depends on the intensity of the reflected laser beam (Schulz & Ingensand 2004).

2.3.1 Triangulation

Satyaprakash (2007), describes laser triangulation as being accomplished by projecting a laser line or point onto an object and then capturing its reflection with a sensor located at a known distance from the laser's source. The resulting reflection angle can be interpreted to yield 3D measurements of the part.

In his research, Sinderberry (2007) outlined the principals of triangulation scanner measurement stating that these early scanners use an active laser light to explore the environment and that triangulation laser scanners typically have a very high resolution and accuracy (<1mm) making them ideal for accurately recording fine details on highly detailed objects. This type of scanner uses the time of flight principal for the transmission of the laser on an object, however, it uses a camera to look for the location of the laser dot. When the dot appears on the object, the camera locates its position and calculates the range. The laser dot will appear at different places on the camera's field of view and is dependent on how far away the laser strikes the objects surface (Sinderberry 2007).

This technique is called triangulation because a triangle is created between the laser dot, camera and laser emitter and the principal of operation of this type of scanning method is demonstrated in the figure below.

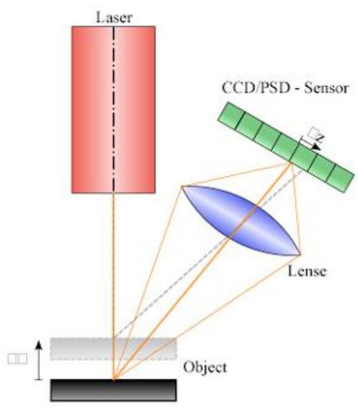


Figure 1 – Image illustrating the basic principles of the triangulation method employed by some laser scanning systems.

2.3.2 Phase Shift

Phased based scanners have the same technology as used in total stations, digital theodolites and interferometers. Phase shift laser scanners work by comparing the phase shift in the reflected laser light to a standard phase, which is also captured for comparison. This is similar to time of flight detection except that the phase of the reflected laser light further refines the distance detection (Satyaprakash 2007).

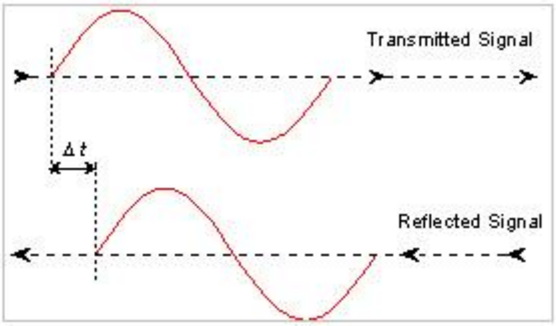


Figure 2 – Simplified diagram showing the principal of the phase shift method of measurement.

2.3.3 Time of Flight

Wikipedia describes the time of flight method of measurement is defined as the time taken for a light pulse to travel to the target and back. With the speed of light known, and an accurate measurement of the time taken, the distance can be calculated. Many pulses are fired sequentially and the average response is most commonly used. This technique requires very accurate sub-nanosecond timing circuitry (Wikipedia 2009a).

In their white paper for the Trimble GX scanner, Biddiscombe and Lemmon (2005), describe the principal of time of flight measurement in the following manner. Trimble 3D scanners use time of flight measurement technology that is based upon the principle of sending out a laser pulse and observing the time taken to reflect from an object and return to the instrument. Advanced electronics are used to compute the range to the target. The distance range is combined with angle encoder measurements to provide the three-dimensional location of a point (Biddscombe & Lemmon 2005).

Leica describe the measurement technique in their product specifications for the Scan Station 2 stating that pulsed or time of flight scanners are often considered highly versatile thanks to their excellent distance capabilities (Leica Geosystems AG 2007).
This technique allows measurements of distances up to several hundred of metres. Even ranges beyond one kilometre are achievable (Schulz & Ingensand 2004).

Among the different techniques available, time of flight is the most used measurement technique in laser scanners utilising this technology. It is based on the principle of sending out a laser pulse and observing the time taken to reflect from an object and return to the instrument. The resulting reflection is detected with a sensor and the time that elapses between emission and detection yields the distance to the object since the speed of the laser light is precisely known (Satyaprakash 2007). This is demonstrated basically in Figure 3.

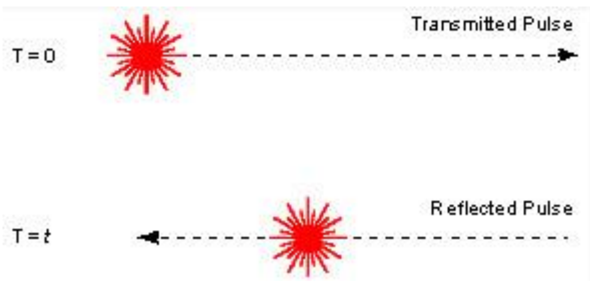


Figure 3 – Diagram illustrating the method of measurement utilised by the most familiar pulsed time of flight terrestrial laser scanners.

2.3.4 Multipath

The effect of multipath is well known amongst those who use GPS technology and is defined as the effect that occurs when signals are reflected by more objects than intended. For example, with GPS, the signals are reflected on nearby and high-reflective objects and do not travel directly from satellites to receivers. The same principal can affect distances that are measured with terrestrial laser scanners.

In laser scanning technology, multipath occurs when the laser signal is not received directly after hitting the first object, but instead is reflected by several objects and not travelling the shortest path. The probability of multipath is prevalent in scanning high reflective materials such as glass and water surfaces where this error results mostly in isolated pixels that are mirror-inverted. The detection of points affected by multipath becomes difficult if they are surrounded by other points and if they are not clearly detectable as isolated pixels, e.g. in corners and at nearby objects (Schulz 2007).

2.4 Laser Safety

LASER is an acronym which stands for Light Amplification by Stimulated Emission of Radiation. The laser produces an intense, highly directional beam of light (United States Department of Labor 2008). Laser safety can be defined as the avoidance of laser accidents, especially those involving eye injuries since even relatively small amounts of laser light can lead to permanent eye injuries. (Wikipedia 2009)

Most lasers that are used in surveying instruments, including terrestrial laser scanners can be considered dangerous and have the potential to cause damage to the skin or the eyes. Lasers are generally categorized into four classes according to the ability to cause damage to the eyes. Generally, most of the terrestrial laser scanners are classified as class 3 instruments with a select few, including the RIEGL, being categorized as class 1 (Schulz 2007).
Schulz (2007) goes on to explain that for all laser scanners, eye safety is frequently guaranteed since the operation of laser scanners in the scanning mode deflects the laser beam at a high speed. The laser beam does not hit the eyes long enough to cause damage due to the rotation.

Further to this, the relevant Australian Standard (Council of Standards Australia 2004) outlines the classification of laser products in their section titled *descriptions of laser classes*.

> *Class 1 Lasers are those that are safe under reasonably foreseeable conditions of operation, including the use of optical instruments for intra-beam viewing.*
>
> *Class 1M: Lasers emitting in the wavelength range from 302.5 nm to 4 000 nm which are safe under reasonably foreseeable conditions of operation, but may be hazardous if the user employs optics within the beam. Two conditions apply:*
>
> *a) for diverging beams if the user places optical components within 100 mm from the source to concentrate (collimate) the beam; or*
>
> *b) for a collimated beam with a diameter larger than the diameter specified in table 10 for the measurements of irradiance and radiant exposure.*
>
> *Class 2 Lasers are those that emit visible radiation in the wavelength range from 400 nm to 700 nm where eye protection is normally afforded by aversion responses, including the blink reflex.*
>
> *Class 2M Lasers are those that emit visible radiation in the wavelength range from 400 nm to 700 nm where eye protection is normally afforded by aversion responses including the blink reflex.*
>
> *However, viewing of the output may be more hazardous if the user employs optics within the beam. Two conditions apply:*
>
> *a) for diverging beams, if the user places optical components within 100 mm from the source to concentrate (collimate) the beam, or*
>
> *b) for a collimated beam with a diameter larger than the diameter specified in table 10 for the measurements of irradiance and radiant exposure.*

Class 3R Lasers are those that emit in the wavelength range from 302.5 nm to 106 nm where direct intra-beam viewing is potentially hazardous but the risk is lower than for Class 3B lasers, and fewer manufacturing requirements and control measures for the user apply than for Class 3B lasers. The accessible emission limit is within five times the AEL of Class 2 in the wavelength range from 400 nm to 700 nm and within five times the AEL of Class 1 for other wavelengths.

Class 3B Lasers are normally hazardous when direct intra-beam exposure occurs but the viewing of diffuse reflections is normally safe.

Class 4 Lasers are also capable of producing hazardous diffuse reflections. They may cause skin injuries and could also constitute a fire hazard. Their use requires extreme caution.

2.5 Scanner Accuracy

Latest technology introduced into the surveying / spatial science industry are potentially dangerous as they are generally easy to use; however, because of their complexity it is difficult for users to establish the accuracy and the precision of any resulting measurements. As with all survey equipment that is used, surveyors need to be able to ensure that the measurements and resulting co-ordinate information they generate during the scanning process is accurate and contain sufficient checks to facilitate any disputed information.

With terrestrial laser scanners, the accuracy of the vertical and horizontal angle measurements determines the accuracy of these instruments and the resolution of the instrument is determined by the minimum separation of points, and the diameter of the laser beam, which increases with range. As with all equipment, these specifications are improving all the time as further research and development is undertaken by instrument manufacturers (Aiken 2008).

Laser scanners are phenomenally accurate; they enhance productivity like no other instrument. But they do not diminish the responsibility of surveyors to be able to defend their results (Mitchell 2004).

2.6 Traceability of Surveyed Distances

"In relation to measurement, the professional Surveyor is intent not only on getting it right, but in proving that it is. To achieve this, Surveyors rely on their measuring equipment which must be systematically tested for errors and compared to the national standard." (Land Victoria 2007).

The Department of Lands in Victoria, through the publication of their EDM Handbook, advise that whilst legal action against spatial professionals has proven so far to be un-common, the validity of length measurement may at anytime be challenged in a court of law. The validity will be strengthened if traceability to the national standard can be proved (Land Victoria 2007).

The National Measurement Act 1960 establishes a national system of units and standards of measurement and provides for the uniform use of those units and standards throughout Australia to ensure traceability of measurement. The enforcement and duties enacted by this and related legislation is entrusted to the National Measurement Institute (NMI), a division of the Australian Governments Department of Innovation, Industry, Science and Research. The NMI website describes itself as the only 'one-stop shop' for all disciplines of measurement in Australia. NMI maintains a broad range of scientific and technical capabilities to fulfil its statutory responsibilities and to meet government and private sector requirements for traceability of measurements.

Obviously the NMI cannot itself carry out all the work of pattern approval testing, certifying and producing certified reference materials, certifying measuring instruments, verifying utility meters and verifying reference standards of measurement, the Regulations allow for the appointment of authorities to do this work (National Measurement Institute 2009).

In relation to surveying services and the certification of equipment used to undertake distance measurements, this authority is generally passed on to the relevant department in each state that deals with surveying. These are listed below and where taken from the National Measurement Institute website (National Measurement Institute 2009).

Verifying authorities for reference standards of measurement (sorted by state)

Australian Capital Territory

- ACT Planning and Land Authority
- National Mapping Division, Geosciences Australia

New South Wales

- Department of Lands

Northern Territory

- Department of Justice, Northern Territory Government

Queensland

- Department of Natural Resources and Water (now known as Department of Resource and Environment Management)

South Australia

- Department of Lands

Tasmania

- Consumer Affairs and Fair Trading

Victoria

- Division of Survey and Mapping

Western Australia

- Department of Land Administration

In the publication, Verification of Distance Measuring Equipment, The Surveyor General of New South Wales Government outlined that legal traceability of length measurement refers to the legal hierarchy of measurement standards traceable through an unbroken chain of verifications from the most precise standard (National Standard) down through the subsidiary standards to the working standard being the surveyor's steel band or EDM instrument. In particular the National Measurement Act requires "all measurements for legal purposes to be made in terms of the Australian standards of physical quantities."

Consequently, the requirements of the National Measurement Act which are relevant to Surveyors are incorporated in the current Surveying Regulation to ensure that length measurements, made using surveying equipment, have legal traceability. It should be noted that Legal Traceability of length measurement is not confined to cadastral surveys, as any length measurement stated by a surveyor could be subject to dispute and subsequent litigation (Surveyor General 2004).

2.7 Legislative Requirements

Legislative requirements for the calibration of survey equipment are very similar in each state and this can be attributed to the need to conform to national legislation in regards to legal traceability of distances measured by surveying equipment. For simplicity, Queensland requirements will be investigated.

Section 21 of the Survey and Mapping Infrastructure Regulation 2004 outlines the requirements for survey accuracy in Queensland.

> *A cadastral surveyor who carries out, or is responsible for carrying out, a cadastral survey must ensure any survey equipment used for the survey is—*
>
> *(a) calibrated and standardised; and*
>
> *(b) capable of achieving the accuracy stated in the relevant survey standard for cadastral surveys.*
>
> *Maximum penalty—6 penalty units.*

Furthermore, section 1.5 of the Cadastral Survey Requirements Version 4.0 for Queensland which relates to any Departure from Standards indicates that a surveyor may use any method and/or equipment in performing a survey where it can be demonstrated that such method and/or equipment is capable of achieving the survey standard.

Where a surveyor uses methods and/or equipment which involve a significant departure from conventional survey practice, the surveyor shall submit with the survey records sufficient information to identify the methods and/or equipment used (Department of Natural Resources and Mines 2005).

To satisfy the applicable legislative requirements for distance measuring equipment, a series of measurements on a baseline can also be used to check the performance and reliability of the instrument and to assess its precision against the manufacturer's claims and specified minimum standards. There are a number of sources of error inherent in surveying equipment. This procedure concentrates on those found in EDM equipment.

The three distinct systematic errors, which may occur in EDM instruments, are:

- zero constant or index error;
- scale error; and
- cyclic or short periodic error

(Western Australian Land Information Authority 2008)

However, in the case of terrestrial laser scanners we can assume that there is no source of cyclic distance error in the instrument because it times a pulse, rather than using phase measurement of a modulated wave (Mitchell 2004).

2.8 Equipment Specifications

2.8.1 RIEGL LMS620

2.8.1.1 Principal of Operation

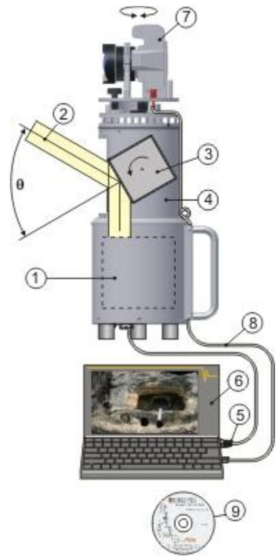


Figure 4 - RIEGL terrestrial laser scanner instrument configuration.

Figure 4 shows the standard instrument configuration for the RIGL LMS620 with the notes below outlining the principal of operation for this instrument as outlined on the RIEGL website. This information is particularly thorough and gives a good indication of the general method of operation for most terrestrial scanners on the market.

The range finder electronics (1) are optimized in order to meet the requirements of high speed scanning (high laser repetition rate, fast and highly accurate signal processing, and high speed data interface).

The vertical deflection ("line scan") of the laser beam (2) is realized by a polygon (3) with a number of reflective surfaces. For high scanning rates and/or a vertical scan angle of up to 80°, the polygonal mirror continuously rotates at an adjustable speed. For slow scanning rates and/or small scanning angles, it linearly oscillates up and down. The horizontal scan ("frame scan") is realized by rotating the complete optical head (4) up to 360°.

The RiSCAN PRO software (9) allows the operator to perform a large number of tasks including sensor configuration, data acquisition, data visualization, data manipulation, and data archiving. RiSCAN PRO runs on the platforms WINDOWS XP and 2000 SP2 (RIEGL Laser Measurement Systems GmbH 2008).

2.9 Conclusion

It is apparent that due to the short amount of time that terrestrial laser scanner has been available for use by surveyors for ground measurements a considerable amount of research has been undertaken into the finer details and analysis of instrument specifications. This report has the intention of undertaking research into simplified test methods to determine the limitations of this technology and to assess the likely hood of terrestrial laser scanners complimenting traditional survey methods in areas not currently assessed. It can be concluded that this review of the literature on terrestrial scanners has provided a technical basis of terrestrial laser scanners that shall provide an adequate platform on which to start to conduct the project.

3. RESEARCH METHODS

The methodology of this project has been defined by the findings of previous studies into the field of terrestrial laser scanning as outlined in the literature review found in Chapter 2 of this report. The limitations, current and envisaged uses of terrestrial laser scanning systems and other justifiable considerations have been used to come up with the best method of testing for this research topic.

Thus, the objectives of this project are:

a) To investigate the current uses of terrestrial laser scanning systems.
b) To research and test the specifications and limitations of a specific terrestrial laser scanner.
c) To determine the effectiveness of this equipment for alternate surveying tasks.
d) Establish best practice guidelines for the everyday use of laser scanning systems.

The literature review in Chapter 2 indicates that the surveying industry is relatively unaware of the possible results of these objectives and that revealing them will help surveyors to embrace this new technology.

To achieve these objectives, various testing needs to be undertaken under a variety of scenarios and conditions following conventional surveying instrument methodology. The data collected from these tests then needs to be analysed to provide tangible and valuable information to potential users of this emerging technology. Comparisons between known values and data obtained from conventional surveying also needs to be compared against to help determine information regarding instrument specifications, accuracy and also for determining advantages and disadvantages of use.

3.1. Test Sites

Test site 1 which was used for testing the effects that standing water has on the ability of the scanner to return useable data was a residential swimming pool in a townhouse complex. A photo showing the pool area and ledge being scanned are shown below Figure 5. This site was chosen due to its close proximity, ease of accessibility and the particular design of the steps that are under water allowing for an attempt at scanning a defined surface under water to be undertaken whilst allowing the relatively easy acquisition of the feature by conventional means.

Figure 5 – Residential pool site showing scanner location and under water ledges utilised for a portion of project testing.

The selection of test site 2 was based on the need to have a flat surface that was readily accessible and that could be located by conventional surveying equipment and the terrestrial laser scanner. There was also a need to have a relationship with the current owner of the property as there was a need to utilise a form of water supply to enable testing under simulated rain conditions, a local surveying firm was willing to allow the use of their property and tank water supply for the purpose of this research project. The site selected was a concrete tilt panel building and as stated previously, used for rain simulation. An image of the site with the terrestrial laser scanner in situ is shown in Figure 6.

Figure 6 – Image showing the selected building surface measured with the RIEGL LMS-Z620 shown set-up on the right of the image.

To meet the requirements of some of the testing objectives it was necessary to undergo testing at a suitably calibrated EDM baseline testing facility. There are a small number of these facilities located within the South-East Queensland area, being the Gold Coast, Caboolture and on the Sunshine Coast Airport baselines. All three calibration range facilities have current calibration certificates certified under regulations 71 and 73 of the National Measurement Regulations 1999 in accordance with the National Measurement Act 1960 and as such the closest and most easily accessible facility was chosen.

The majority of testing was undertaken at test site 3 which is situated on the Gold Coast at the EDM Calibration Range at Coombabah. This site is an Electronic Distance Measurement Baseline consisting of 7 concrete pillars within the Coombabah Sewerage Treatment Plant with a total range of approximately 1050m that is operated and maintained by the Gold Coast City Council. The range was verified on the 14th August 2008 to an accuracy of ± (0.5mm + 1.3ppm) utilising methods described in the Calibration of Electronic Distance Measuring Equipment 1986 and National Standards Commission's Verifying Authorities Handbook (Second Edition November 1988). The site is reasonably low lying which is not ideal for a baseline but it is close to a meteorological observation station operated by the Bureau of Meteorology which adds to the convenience of utilising this facility.

Figure 7 – Coombabah EDM range is shown as the cleared roadway at the centre of the image (http://www.whereis.com.au).

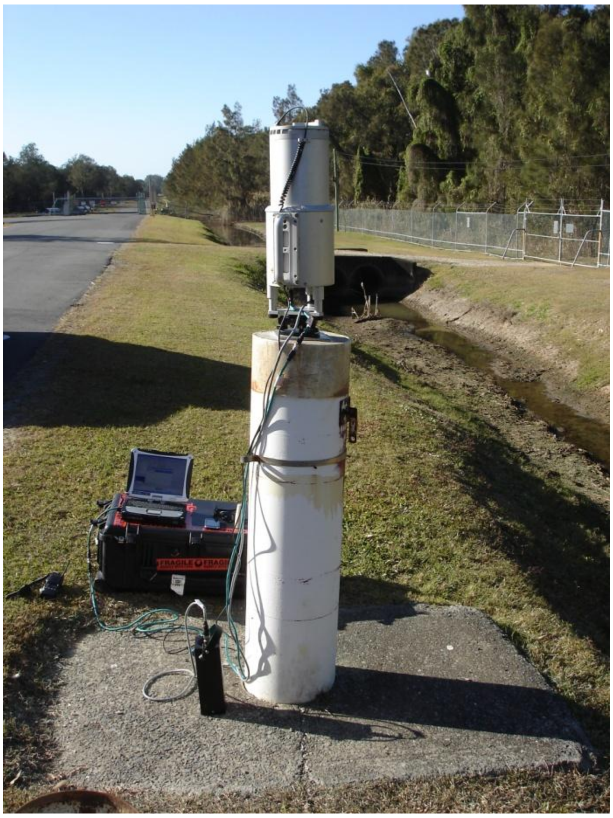


Figure 8 – Image showing the RIEGL instrument set-up over one of the concrete pillars at the Coombabah EDM range ready for testing.

Another one of the test sites was the basement at Conics (Brisbane) P/L and this was used for the portion of the testing related to the establishment of a basic testing facility used for checking the operational status of the instrument prior to undertaking precise work. The selection of the location of this facility was based on the need to have the testing be undertaken prior to the commencement of works and that this test site would be utilised by Conics (Brisbane) P/L as part of their utilisation of this piece of equipment.

Figure 9 – Image showing section of the basement of Conics (Brisbane) P/L office where simplified calibration testing was undertaken.

There was very little input into the selection of test site 5 as this site was being surveyed in conjunction with a project being undertaken by Conics (Brisbane) P/L on Samford Road adjacent to the Enoggera (Gallipoli) Army Barracks with the data being collected and supplied by Mr Nick McKelvey from Conics Mining and Infrastructure P/L. The site was however considered ideal as it provided valuable information in a real world application, the volume of traffic at this site also ensured that that testing procedures included a variety of variables that would be encountered upon acceptance of this research.

Figure 10 – Image showing a section of Samford Road, the location of the traversing testing undertaken as part of commissioned survey work by Conics (Brisbane) P/L.

3.2. Data Capture and Acquisition

3.2.1. Effects of Water

It has been noticed from practical experiences that when scanning objects that are close to water or have a portion submerged, a reflected image is produced by the scanner. This can be deceiving when scanning the likes of columns or symmetrical objects that penetrate the water, with some instances the data obtained from the scanner looking as though the portion of the column that is submerged has been scanned.

Long distance scanning of turbid or murky water often results in a reflected image being produced below the level of the water surface. This is just another set of data that needs to be removed as part of the manual processing involved in the reduction of the scan data.

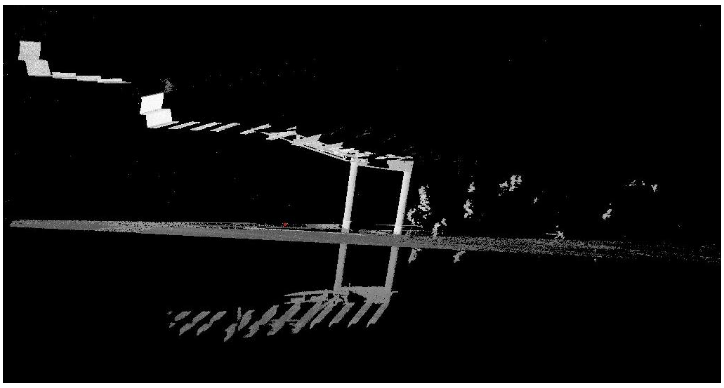


Figure 11 – An example of raw data from a scanned structure being reflected below the water surface. Image is of a bridge headstock and columns.

In testing the effects that water has on laser scanning, a test scan was undertaken to determine whether the angle of incidence of the laser beam when scanning objects in water is a contributing factor in the production of the mirrored images mentioned earlier. The scan involved positioning the scanner as close as possible to a water source, which in this case was a small swimming pool, the scanner was then tilted 90 degrees so that the laser would be striking the water surface at or near 90 degrees. The aim of the scan was to see if a ledge located at approximately 300mm below the water surface could be located. Almost immediately it was obvious that the aim of this testing would be unattainable; that the resulting data would indicate that scanning though a contained water body would not be possible with this particular scanner or a scanner with a similar laser wavelength.

Due to the possibility of an undesirable result from the above mentioned test of scanning objects contained within a body of water, it was determined that further testing into the effects that water has on scanning results was still warranted. A test was undertaken attempting to simulate reasonably heavy rain passing between the scanning instrument and the surface or objects being scanned. This was undertaken by directing the flow of a hose in the path of the laser beam of the scanner resulting in a mist of water.

3.2.2. Height versus Range

The stated maximum range provided by the manufacturers of these and in fact any surveying instrument state their specified maximum measurement range based on measurement to a card with a specified reflectance under ideal conditions i.e. Kodak grey 80% or percentage albedo are typical references given. However surveyors rarely operate their instruments under anything close to ideal conditions with most reflectorless measurements being made to surfaces that are far from ideal like road surfaces.

Given the pulsed laser technology used in these and many conventional surveying instruments, one could say that the single worst surfaces to measure to using reflectorless time of flight technology are to those surfaces that are black which has a reflectance of only around 3% based on the Kodak reference cards shown in Figure 12. Given that one of the most beneficial uses of the terrestrial laser scanner is the ability to undertake topographical surveys of road surfaces and coal workings whilst the roadways and mine sites are still under operation, it would be beneficial to see how well these instruments perform when scanning this type of surface.

Figure 12 – An example of one type of Kodak Grey card used as a benchmark measurement by instrument manufacturers (http://www.kodak.com).

The angle of incidence that the laser beam makes with the scanned surface of is also a major contributing factor to the maximum distance achievable when scanning to objects especially a surface that has very low reflectivity, like bitumen, dark painted surfaces or coal. This particular testing was undertaken in an attempt to establish the maximum useful range of terrestrial laser scanning instruments at varying heights and from these results and subsequent graph, formulate an equation that would let surveyors estimate the height required to collect a specified range of data from a single instrument set up or vice versa.

This testing could prove to be beneficial when firms are quoting for these types of projects, giving an indication of approximately how many instrument set ups will be required. The removal of only one instrument scanning position from a project equates to approximately 1 hour scan time at high resolution (depending on the point spacing and field of view) plus approximately 15 minutes for the actual instrument placement and initialisation. Testing was undertaken at the Gold Coast EDME Calibration range at Coombabah as the access road to the sewerage treatment plant is extremely flat and therefore ideally suited this type of testing.

3.2.3. EDME range testing

Almost all surveyors in Australia should be aware that every one of their instruments and especially those that are used for high precision and cadastral surveys are required by specific legislation to undergo rigorous testing at least every twelve months over a suitably calibrated EDME calibration range. The calibration of surveying instruments over calibration ranges in undertaken to allow the comparison of EDM instruments to a standardised result. Each of the states operates a number of pillared ranges, each with slightly differing design, however the underlying principal behind these baselines are all the same. Whether there are 4 or 7 pillars at a particular range, these facilities allow surveying firms to verify their measurements and provide legal traceability of measurements made by their EDM instruments.

Leading into the testing at the Coombabah EDM baseline, a number of particular issues needed to be overcome. The biggest issue was the range of target acquisition, with the supplied cylindrical target only being visible at a maximum range of approximately 150m. Clearly on a baseline that is 1200m in length this would not be sufficient. Another issue is that the use of conventional corner cube survey reflectors for scanning operations, with warning statements provided by all terrestrial laser scanner manufacturers' alerting users that the scanning of traditional cubic reflectors is not permitted due to the possible damage that can occur to the sensitive internal electronics of these instruments.

Figure 13 – Example of a standard cylindrical target used by the RIEGL terrestrial laser scanning instruments.

Looking at these two issues it was clear that another form of target would need to be utilised and that this target would need to be somehow sourced for this testing. Taking notice of the construction of all of the targets utilised by this particular instrument, the use of retroreflective material is most likely to provide a suitable result. One of the issues with the smaller targets is that at a range of 1000m the beam divergence is 150mm for this particular instrument (0.15 mrad) and based on the maximum scanning resolution of 0.004° the distance between scanned points at 1000m is 69.8mm. This means that the size of the target is the major factor in selecting a target suitable for the task and from looking at previous scan data undertaken by surveyors on road pavement projects, street signs generally have a large reflective surface area and are easily definable at large distances. This combined with the allowable specifications for targets built into the terrestrial scanner software (RiScan Pro) it was determined that a circular target coated with a retroreflective material would be needed.

The need of knowing exactly where a point is generally means that in practice, targets will still need to be located utilising conventional surveying means at some point in time, i.e. a total station is used to determine local co-ordinates of the target and these co-ordinates are then utilised as part of the reduction or registration process to conform the scan data to a usable model. Upon discussions with other surveyors who utilise laser scanning technology and investigation of current retroreflective targets used with reflectorless total stations, it was resolved that a set of cross hairs should be located on the retroreflective surface so that the centre point of the designed scanner target could be located to the highest available accuracy as well as defining this target as a piece of survey equipment instead of simply a blank street sign.

The only other parameters required when deciding upon the final design for the custom target was the size of the reflective surface and the colour of the reflective material. The colour needed to have the highest reflectance available, which would be from a lighter colour like yellow or white, yellow was determined to be the best selection due the ability to visualise the target over a long distance where a white target poses the risk of being unable to be distinguished from other objects in the background. Size was simply selected from a range of standard sizes available and 450mm diameter was selected. An image of the scanner target is shown in Figure 14.

Figure 14 – Custom target positioned on one of the concrete pillars at the Coombabah EDME calibration range.

The processing software that controls the operation and data collection in the terrestrial laser scanner is called RiScan Pro. RiScan Pro allows the user to set specific target parameters much in the same way that modern total stations and data collectors allow for the addition of set prism constants to the measured distances. This is especially important outcome of this testing as once the distances obtained are reduced the output will provide an additive constant and scaling correction as currently occurs with the EDME calibrations for total stations.

The proposed method of testing is exactly the same as that of a total station EDME calibration with 5 measurements being taken from each pillar to all the forward pillars from that point. All of these distances should be taken with the relevant atmospheric corrections either applied directly to each set of measurements or recorded separately so that the relevant corrections can be applied at processing time, with the average of these distances used for the reduction process. It is worth noting that the method used to obtain each of the distances was the result of the instruments controlling software calculating the centre point of the scanner target from a large number of points.

To utilise the specifically designed targets at the calibration range there was a need to develop a method of mounting the target either directly to the pillars or to tribrachs that are already placed on the pillars. A prototype mounting was made from plastic with a 5/8th inch Whitworth thread tapped into the centre of the mount and a slot milled off centre to accommodate the thickness of the target. It was expected that with the mounting being milled off centre that the additive correction would be a in the order of a few millimetres.

Figure 15 – The design of the target mount used for testing.

3.2.4. Repetitive Scans

Another important test that was undertaken to confirm manufacturer's specifications was repetitive scanning of the cylindrical targets that come with the scanner, these are considered one of the standard targets used for short range scanning tasks that are under about 200 metres. Each of these retroreflective targets are 50mm high and 50mm in diameter and are coated in a white retroreflective tape; as with all targets used for the testing in this project and in all practical applications, these are scanned at the highest available resolution and then modelled within the controller / processing software to obtain co-ordinates for the centre point of the target.

This internal processing procedure is the same method employed for all targets used in scanning tasks for most terrestrial laser scanning systems. Flat surfaces are fairly simple to model, however cylinders and spheres are slightly more complex to model and the repeatability of this modelling was tested whilst at the EDME calibration range at Coombabah on the Gold Coast. A single cylindrical target was set up over one of the pillars at approximately 150m distance as indicated in Figure 16 and then twenty individual scans where taken to the target in an attempt to determine the ability of the processing software to produce a consistent result within the instrument specifications defined by the manufacturer.

Figure 16 – Image showing view from scanner location to reflector located on the top of the third pillar. Arrow shows third pillar location.

3.2.5. Traversing

Traversing is a very important role in any surveying task including detail surveys, whilst the use of terrestrial laser scanners for topographical surveys can be extremely efficient for data capture, there is generally a need to have an additional survey team preceded or follow the scanning crew to obtain accurate positions of the scanner and / or target locations. However, since the introduction of terrestrial laser scanning systems to the surveying market there has been ample feedback from surveyors who have been quick incorporate the technology to their capabilities to manufacturers requesting technology like compensators and tilt sensors which can provide surveyors with the ability to use the instrument to traverse in some form.

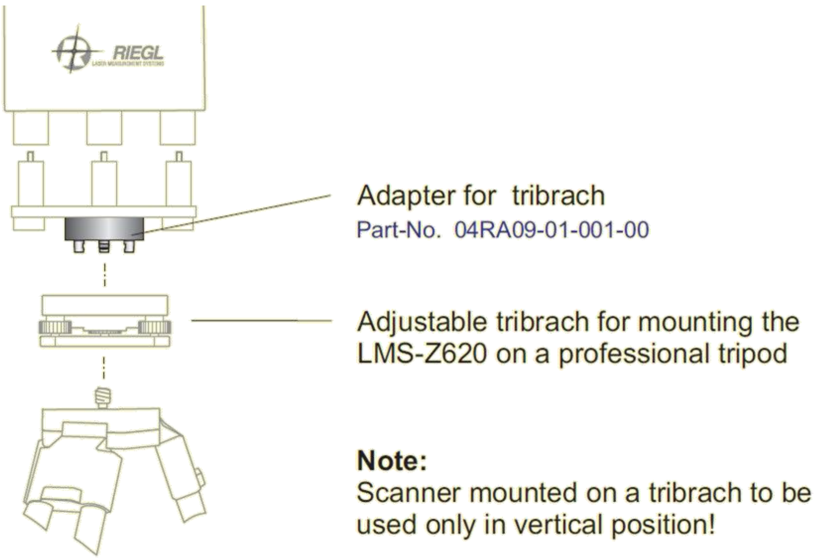


Figure 17 – Configuration of the laser scanner when operated using a tribrach (www.riegl.com).

The RIEGL and many other instruments can be set up over a survey mark with the use of a tribrach with an inbuilt optical plummet, the reduction software can then correct its position utilising the backsight orientation processing tool. Which for surveyors, is most similar to what is done when traversing with a traditional total station; from there further targets can be located forward of the scanner much in the same manner as rounds are read on a conventional traverse. Resection methodology or traditional traversing methods can then be utilised further until other known control marks are located and the residuals examined at the conclusion of processing.

Data was recorded using the laser scanners controlling software (RiScan Pro) with the horizontal and vertical angles along with the slope distance to the targets being booked manually in a field book for processing utilising least squares methods in a separate processing package. The package used for manual observations was StarNet, but any program capable of undertaking a least squared adjustment would be suitable for this task. There is a need for the data to be formatted so that it can be recognised and reduced by the chosen software with the instrument tolerances being set within the program to assist in determining whether the data will pass the adjustment.

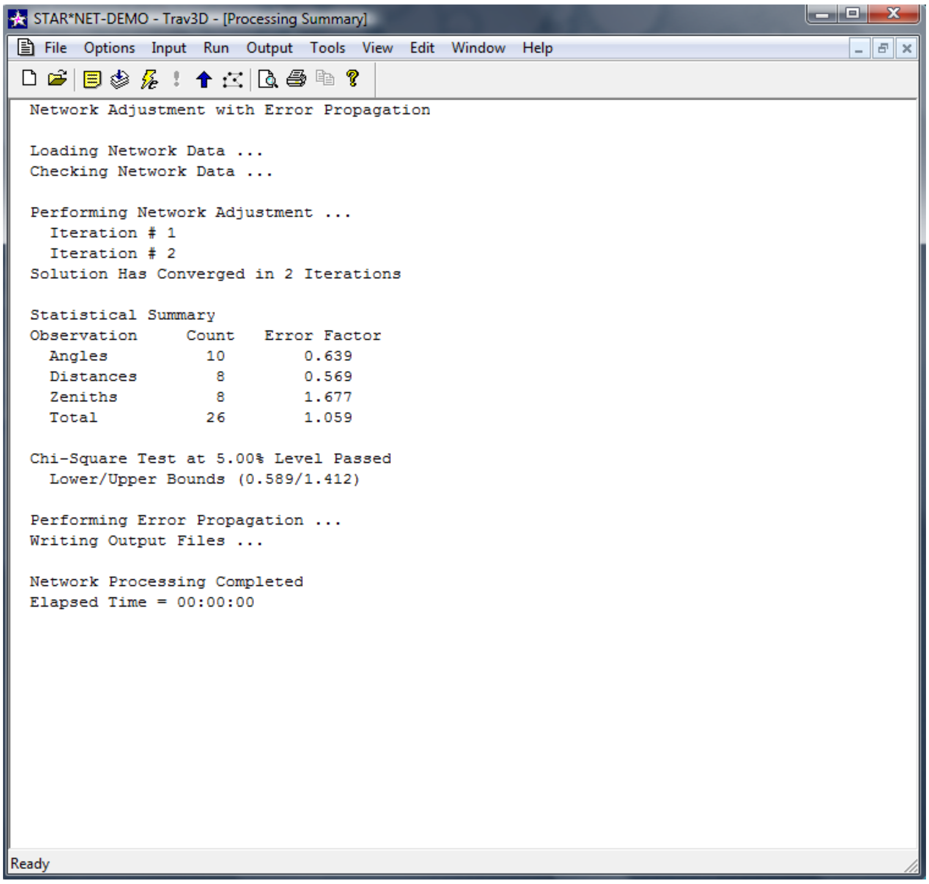


Figure 18 – An example of the processing result screen from the StarNet program.

3.3. Equipment for Data Collection

The following equipment is available for utilisation in this research and will be used in the field survey:

- 1 × RIEGL LMS Z620 Terrestrial Laser Scanner.
- 1 × Panasonic Tough Book Laptop Computer loaded with RiScan Pro for controlling and logging data from the scanner.
- 1 × Canon EOS 1Ds Mark II 16.6 Megapixel Digital Camera for automated digital image capture via laser scanner.
- 1 × Sony Cyber-Shot digital point and shoot camera for records.
- 1 × Trimble 1” Total Station for traditional survey requirements.
- 3 × Tripods.
- 7 × Tribrachs.
- 1 × Stocked survey vehicle.
- 1 × Custom retroreflective target.
- Various standard RIEGL retroreflective targets as needed.

3.4. Data Pre-processing and Analysis

Early inspection shows that the raw data for the testing appears to be consistent with the results that were expected and where some anomalies occurred, as seen in an initial attempt at the EDME calibration range, these have been analysed and the source of the problem has been determined prior to additional scanning being undertaken and the testing concluded. As with any surveying task it is important to continually monitor the status of the survey as it progresses to ensure that any issues are identified as early as possible and allowing for the capture of additional data where needed. Data for all of the scanning sessions was collected using RiScan Pro which is the software used to control the functions of the scanner as well as being used for the reduction of the scanned data. Very little data manipulation is needed due to the nature of the testing being undertaken, however to undertake comprehensive analysis of the results it was necessary to export the point data out of the RiScan Pro package and use Microsoft Excel.

Analysis of data from the EDM calibration range was undertaken using two separate processing methods; initially the data was imported and manipulated in Microsoft Excel to obtain a very simple set of results that will act as a confirmation on the second processing method. The second method involved utilising processing software similar to that used by the Department of Environment and Resource Management (DERM) use to reduce conventional total station calibration data. Generally data is sent directly to DERM to be processed and for the instrument to be certified against the manufacturers specifications, in this situation it was determined that this was not necessary for the project due to the unknown nature of the results, however it would be expected that any practice undertaking this form of testing would have their data processed by DERM.

Data that is to be used for testing of the terrestrial laser scanner traversing capabilities, needed to be either manually recorded in the field at time of data collection or exported at the processing stage and then manipulated into the required file format for StarNet. The data that was required was the horizontal angle, vertical angle, slope distance, instrument height and the target heights. This data is viewable in the tie point scan information within RiScan Pro and can be exported into Excel prior to creating the required file.

For the data obtained during the range versus height testing, it was necessary to select the required data manually from within the scanning software and record the distance for later use. The distances where then plotted against their corresponding instrument heights in Microsoft Excel for modelling and analysis, some manipulation of the data was required to account for the crude selection method of the data required. To account for the variable nature of scanning objects with low reflectivity, it was decided that a point would be selected from the last point cloud away from the scanner that is visible on the surface ignoring outliers and then taking 10% off this value.

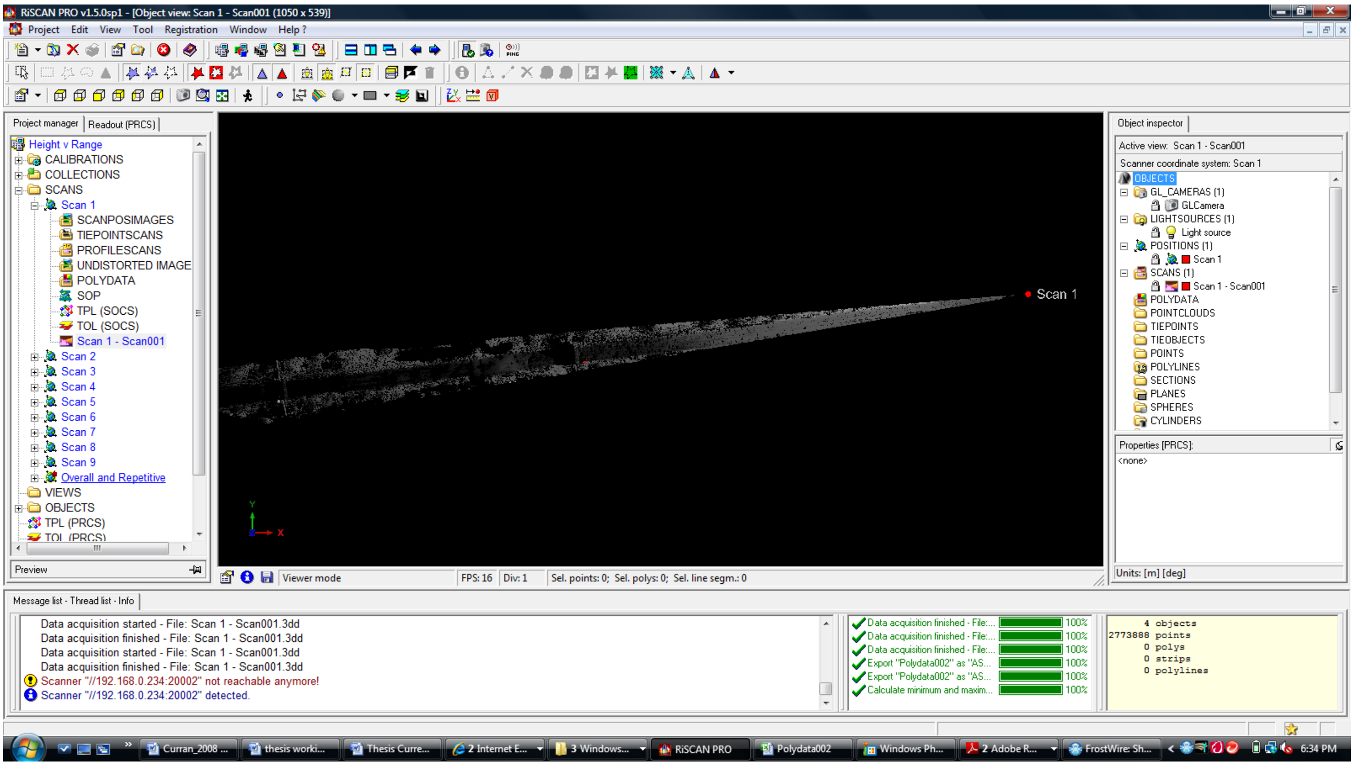


Figure 19 – Image showing scan data ready for analysis in RiScan Pro

3.5. Software

As mentioned previously a few different software packages have been used to collect, reduce and analyse the data for this project. These packages are explained briefly below.

3.5.1. RiScan Pro

RiScan Pro is the companion software that facilitates the control of the scanner and the collection of data in the field for the RIEGL's LMS-Z range of instruments. Where the scanner is equipped with the optional digital camera, camera image acquisition and processing are also managed by the software.

RiScan Pro is designed to minimise the time taken to collect data in the field whist also allowing users to visually inspect the completeness and coverage of data prior to moving the instrument. The software also offers the necessary functionality to post process data using a number of well developed tools and functions including the ability to generate meshes from surveyed data, attribute colour information to every laser measurement when using the digital camera, point cloud decimation, object construction and much more.

3.5.2. StarNet

StarNet is a least squares analysis program designed to adjust 2D and 3D survey networks with the ability to simultaneously adjust up to 10,000 stations under a variety of set parameters. The program is typically used for the adjustment of co-ordinated control networks with a high level of certainty.

This project will use the 3D adjustment capabilities using the obtained slope distances, horizontal angles and zenith angles to obtain a useable control network for processing. In addition to this the software has the capability of importing GPS vectors that can be input together with traditional surveying measurements.

The output consists of a file of adjusted station coordinates and a statistical analysis of the adjustment and graphical facilities are provided to allow the user to plot the network, including error ellipses of the adjusted points and relative error ellipses between stations.

3.5.3. Microsoft Excel

Microsoft Office Excel is a powerful tool that can be used to create and format spreadsheets; it has been used in this project to present data in a professional and organised manner and to make use of the calculation capabilities as part of the analysis of the presented results. Microsoft Excel has the ability to read all of the csv and ASCII data exported from the other software being used as part of this project.

3.5 Summary

This chapter has outlined the comprehensive testing regime that has been designed to investigate performance of the RIEGL LMS-Z620; a long range, high precision terrestrial laser scanning system. The test procedure has been developed and modified from previous testing procedures for both laser scanning instruments and traditional total station instruments and therefore can be trusted and relied upon by professionals within the spatial industry.

All of the research methods discussed have provided a thorough and efficient means of testing the terrestrial laser scanner as desired and processing of the raw data that is obtained. Chapter 4 will present the results of the testing completed in conjunction with the data calculations that were necessary and an analysis of this data.

The methodology for this project can be broken down into the following components as displayed graphically in Figure 20.

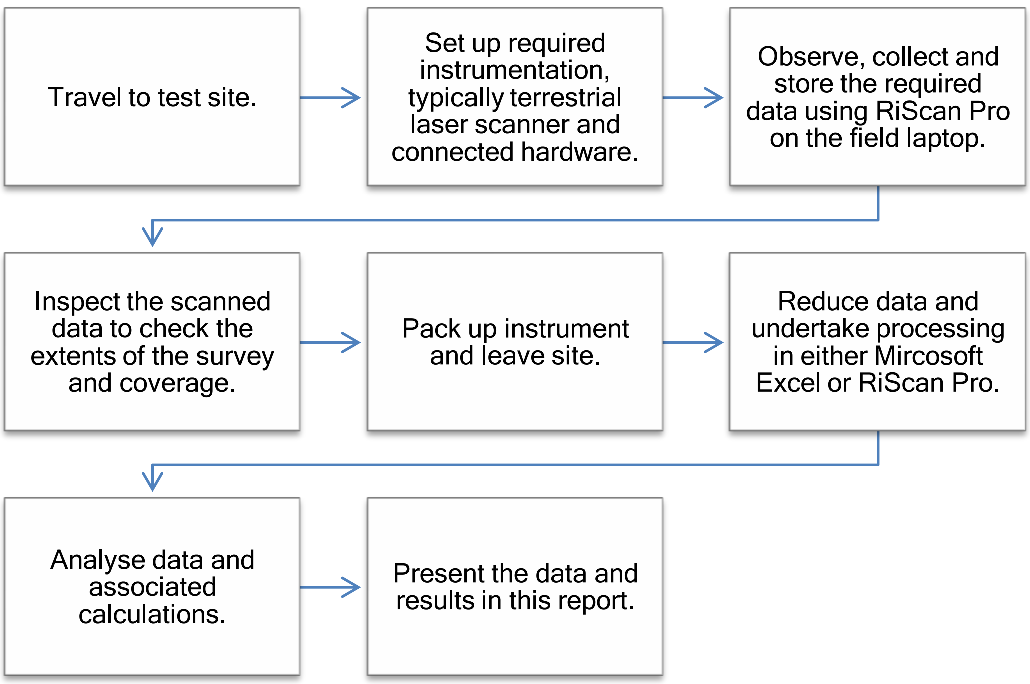


Figure 20 - Flow chart of the general testing procedure.

4. RESULTS AND DATA ANALYSIS

4.1. Introduction

The aim of this chapter is to present the results from the testing undertaken in this research. The results from this chapter will be used when analysing and drawing conclusions on the performance of the terrestrial laser scanner in the following chapters.

The literature review in Chapter 2 outlined the theories, principals and previous research that are needed to understand the concepts and the rationale behind the testing undertaken as part of this research project. Leading on from this important background information, the methodology outlined in Chapter 3 describes in detail the research methods. This includes the proposed testing being undertaken and an outline of the data processing that would be needed to undertake thorough analysis of the data being collected from the terrestrial laser scanner at each of the testing sites.

There are two parts to this chapter: the presentation of the data obtained as well as the calculations and the results obtained from the individual testing. These will be analysed and discussed together for each of the individual tests that where completed as described in the methodology of this report. The data calculations cover the techniques used to turn point observations into useful and valuable information. The data analysis and calculations have provided results relating to the accuracy, precision, reliability and where possible the point collection time for the terrestrial laser scanner. The results from all of the testing completed have been presented through the use of graphs and tables.

Data from the RIEGL LMS-Z620 terrestrial laser scanner was collected during a number of field sessions at several test sites and then reduced utilising the software as outlined in Chapter 3. The observed and collected survey data and the calculations required to produce final results will be presented and analysed within the content of this chapter. It was possible to separate the presentation of results and the analysis of this data, however to facilitate understanding of the data presented it was decided to present the analysis with the data obtained.

After reading this chapter the reader should be able to have a good understanding of why the instrument has performed in the manner that it has and how the results obtained can confirm or reject the specified accuracies provided by the manufacturer. The reader should be able to see from the analysis of the test data how the terrestrial laser scanner can be tested to ensure that there is legal traceability to the measurements obtained in a similar manner to traditional surveying instruments.

4.2. Effects of Water

4.2.1. Contained Body of Water

Initial testing involved scanning the test site initially with the scanner in the vertical orientation to confirm that when scanning objects in or close to a water body that a reflected image of the topography above the water surface is obtained by the scanner and to attempt to define a ledge just below the water's surface. The initial high resolution scan was undertaken in favourable conditions at a resolution of 0.1 × 0.1 degrees taking 6 minutes to complete, the density of this scan is sufficient as the required scanned surface is at close range with the furthest point of the water body being just over 7m away the resolution represents 7mm between each surveyed position.

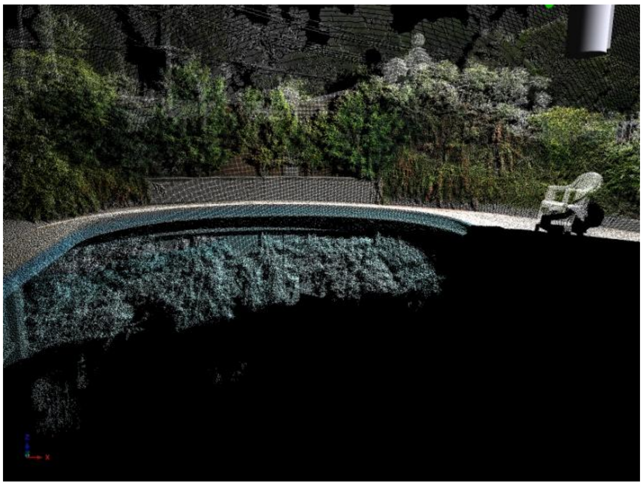


Figure 21 – Image showing reflected data below the water surface, scanner operated in vertical orientation.

The initial scan of the site with the scanner in the vertical orientation failed to show any sign of the defined ledges within the pool structure but did show that the topography above the water surface is reflected below the water surface and these points need to be removed during the processing of data as seen in Figure 21.

To confirm that the angle of incidence was not the reason that the ledge was unable to be determined from the vertical scan it was decided that a second scan was to be undertaken with the scanner in the horizontal orientation. This scan was undertaken in an attempt to have the angle of incidence of the laser as close to 90 degrees as possible. Figure 23 shows the scanner set up in position for the scan and Figure 22 shows the resulting data obtained from the scan.

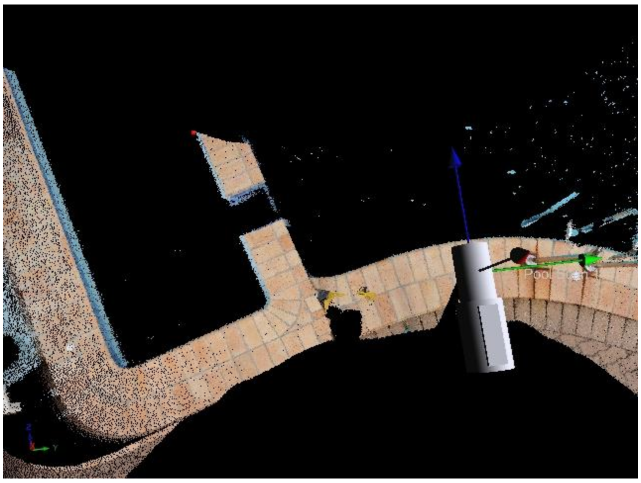


Figure 22 – Image from RiScan showing the captured data and scanner location / orientation.

Figure 23 – Photo showing the scanner mounted in the horizontal position ready for scanning.

It has been noted as part of the research for this project that quite often Class 1 infrared lasers devices, which include lasers with wavelengths of around 1.4 micrometres are often considered as being safe causing little to no damage to the human eye. The explanation of this is due to the intrinsic molecular vibrations of water molecules very strongly absorbing light in this part of the spectrum, and thus a laser beam at these wavelengths is attenuated completely with no signal returned to the instrument.

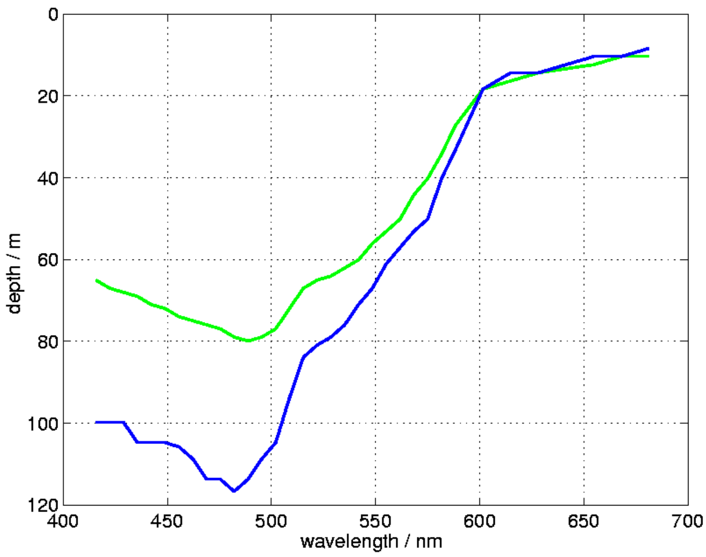


Figure 24 – Laser penetration of water bodies.
(http://www.laseroptronix.se/techinfo/Waterabsorption.pdf)

Assuming that another type of laser scanner was available for testing that utilises a laser with a shorter wavelength, one could assume that different results would be obtained. The ability to penetrate the water surface in an attempt to locate an object is dependent on the wavelength of the laser, Figure 24 shown above illustrates the ability of different laser wavelengths to penetrate water, the testing that provided this image was undertaken in the Atlantic Ocean with the green line indicating a turbid location close to the coastline and the blue line in the open ocean. It can be seen in that an instrument with a wavelength of around 480nm would provide the greatest penetration.

However this would warrant further testing to determine whether the testing in an ocean environment is comparable to other water bodies such as dams and rivers as well as to determine if the angle of incidence, level of turbidity, amount of suspended solids and chemical composition of the water body introduces other contributing factors that may affect the distance achievable and the accuracy of those measurements.

4.2.2. Passing Water Stream

Although testing of scans over a solid state of water produced unfavourable results due to the wavelength of the laser utilised by the RIEGL instrument, additional testing was undertaken to determine if the scanner suffered similar effects when a stream of water or rain was passed between the scanner and the surveyed surface. The initial scan for this test again only took 6 minutes to complete at a resolution of 0.1 × 0.1 degrees after the instrument had been set up as seen in Figure 25. The scan was undertaken at this resolution to ensure that the maximum amount of data was able to be obtained within a realistic time frame that represented the amount of time that one would expect to utilise in practice.

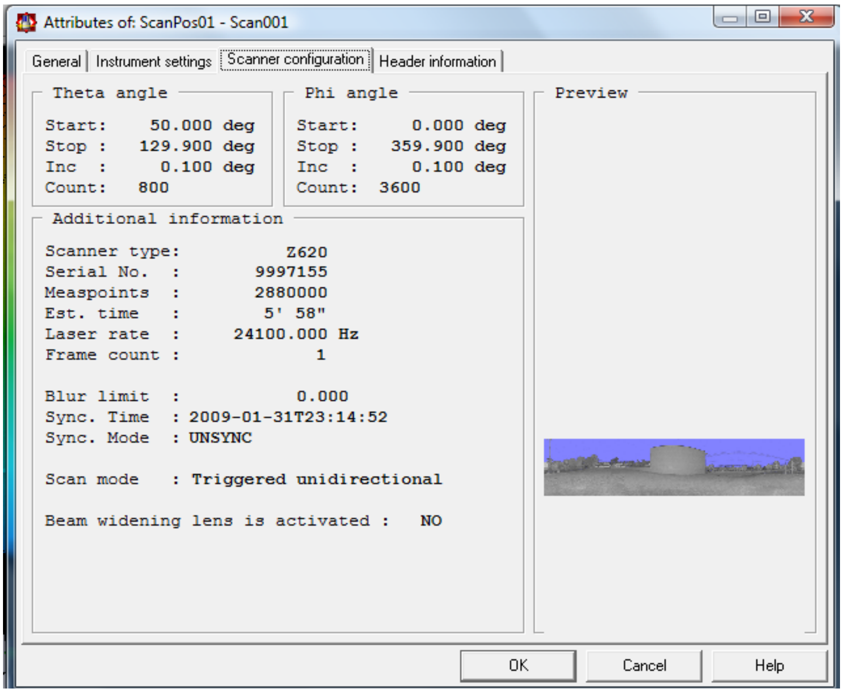


Figure 25 – Example of the attributes obtained from RiScan for each scan.

This scan involved the measurement of the building surface as defined in the methodology of this report to be used a comparison on the results obtained when the water stream was passed in front of the surveyed surface and resulted in 286724 points that provided good coverage over the subject area.

The scan of simulation of a stream or rain passing between an object surface and the scanner was undertaken to determine the effectiveness of this instrument under these conditions, a complete scan was undertaken and then the data was filtered by selecting points outside the area of interest to just show the building wall and any points determined to be in front or behind the structure. Undertaking this processing reduced the number of points being worked with from 1440800 scanned points down to 331394 individual points.

Investigating that data further it was noted that of these 331394 points, 94000 of these points where determined to be points between the scanner and the surveyed surface and 1100 points where located behind the wall and needed to be removed as part of the processing. After removing all of the erroneously located points, the wall still contains 236000 individual points and it can be seen in Figure 26 that while there are significant gaps in the surface of the wall due to the interference of the water passing through the path of the laser, it is expected that full modelling of the wall to a high degree of accuracy is still attainable due to the extremely high density of points.

As a comparison, the same section of wall scanned with no interference resulted in 286724 points as indicated earlier. This shows that the effect that the water spray had on the amount of data captured was only a decrease of around 8%, a possible solution to the reduction in quality is the use of functions contained within the controlling software that enables a user to take multiple scans at each set up instead of relying on a single scan.

The resulting data showed that whilst the mist of the water was received as noise between the scanned surface and the scanner that because of the method of measurement employed by the scanner that the surface being located was still produced although ultimately with less data in some sections. Obviously with equipment that is so expensive it would not be recommended to use this or any surveying equipment in heavy rain, the instrument can be operated in a dry area whilst the surveyed area is under the effects of rain the operator should understand the effects that this will have on the results. From the test it can be determined that whilst the required data will be obtained, there will be significant noise that will need to be manually removed and the amount of data will be significantly reduced.

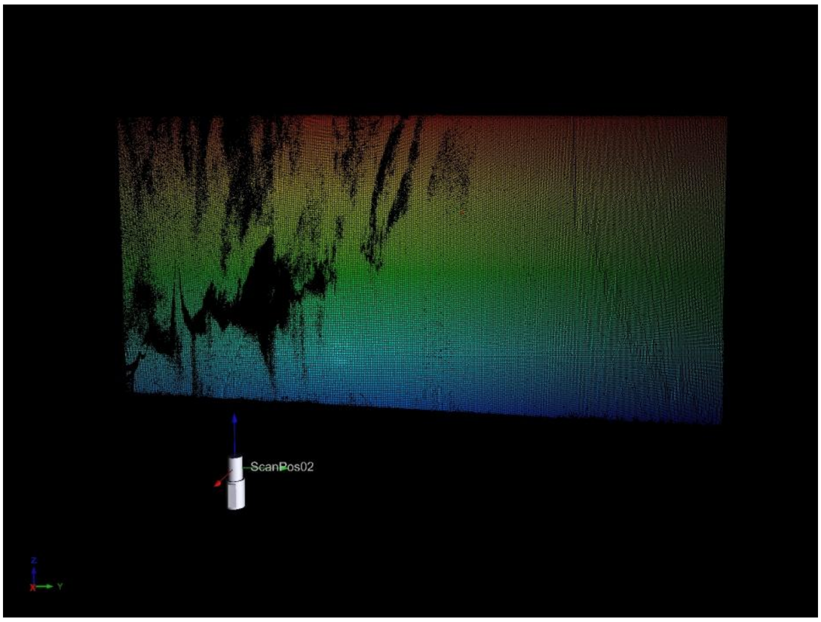


Figure 26 – Scanned surface after processing, noting the area to the left showing effects of passing water.

4.3. Height versus Range

In this series of testing a total of 8 scans where conducted, each at varying height increments. The height of the instrument started at the lowest level that it could be set at upon a tripod which was 1.375m and then subsequent scans where conducted increasing the instruments height by a few hundred millimetres at a time until the maximum height of 2.083m was reached. The scanning process took a total of approximately 3 hours to complete and providing an average of 2779815 points per scan with the analysis of those results being fairly interpretive.

The maximum scanned range was determined by examining the each of the individual scans data that was obtained along the road surface and manually selecting the point furthest away from the instrument within the last major cloud of data.

An example of this selection technique is illustrated in Figure 27 and Figure 28 with the first image illustrating an overall view of the data obtained and the second image showing the point that was selected to be used for further processing. It is worth noting that there were scattered points past this point, however selecting these points would defeat the purpose of the exercise as the number of these points was very low and considered outlying points; these points can be seen on the left hand side of Figure 28.

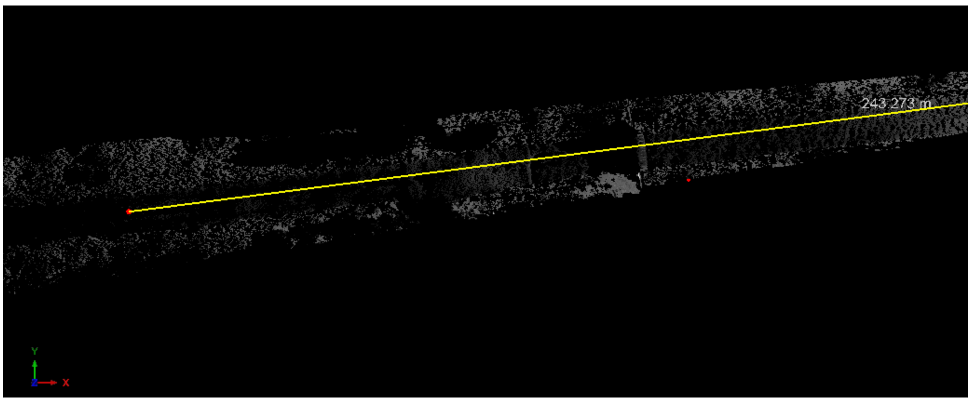


Figure 27 – Image showing the point selected for the first instrument set up.

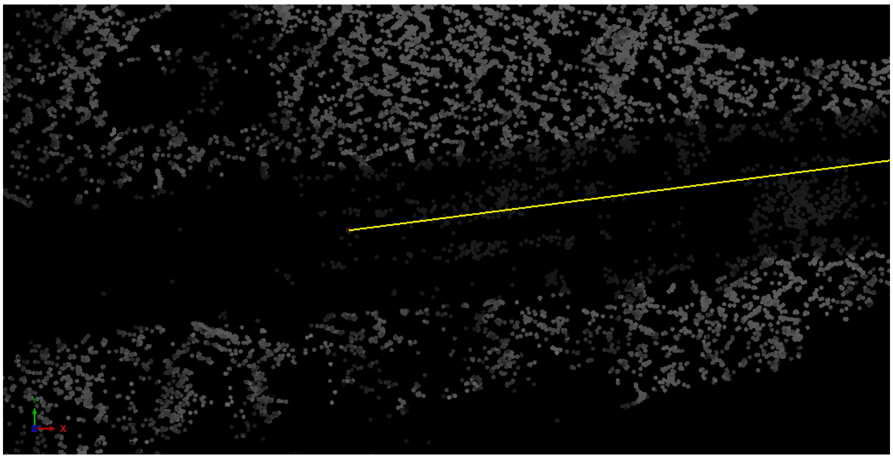


Figure 28 – Zoomed image showing the selected point, indicating the selection technique.

The test results indicate that a linear pattern is achievable within Microsoft Excel after graphing of the entered data is undertaken. Linear regression of the graphed data was undertaken using the built in tools within the software to provide a line of best fit, numerous regression types were tested to determine which solution provided the best results and this was determined to be by the use of linear regression. Microsoft Excel allows for the display of the equation of this line to be displayed within the graphic area, the given equation of this trend line is capable of allowing the extrapolation of an instrument height required to achieve a theoretical maximum range or the expected range from a specific instrument height and can be seen in the bottom right of Figure 29 on the next page.

With the manufacturer stating in the specifications for this particular instrument that the maximum range to a surface with 10% reflectance being 650m under ideal conditions and the fact that the bitumen surface scanned as part of this test has a reflectance of about 3% indicates that the range will be significantly less. This value was taken from the reflectance properties displayed within RiScan Pro and is not an absolute value measured using independent means. Obviously it would not be expected that the scanner would receive a return signal from a surface that has such a low reflectance such as bitumen at a long range even at an increased height.

It is worth noting that due to the interpretive nature of the selection of points, the equation shown in Figure 29 provides an approximation of the expected range or the required height and that for a more accurate result analysis and modelling of a data set utilising more scans would be required. A more useful outcome from the results would be that of assuming a certain height that the laser scanner can be set up at and finding the range that can be scanned.

As stated the raw data was picked manually from a point cloud and due to the range of possible effects that can influence the results obtained from the scanner, the range of these points was reduced by 10% and then rounded to the nearest tenth of a meter to represent the generalised nature of the selection. The values obtained for each of the instrument heights are listed in Table 1.

Instrument Height	***Last Point***	***90% Distance***	***Rounded Distance***
1.375	*243.605*	*219.2445*	*219.2*
1.515	*244.069*	*219.6621*	*219.7*
1.59	*244.6*	*220.14*	*220.1*
1.68	*244.991*	*220.4919*	*220.5*
1.77	*245.576*	*221.0184*	*221*
1.846	*246.094*	*221.4846*	*221.5*
1.926	*246.209*	*221.5881*	*221.6*
1.982	*248.885*	*223.9965*	*224*
2.083	*250.722*	*225.6498*	*225.6*

Table 1 - Data showing instrument height versus achievable range.

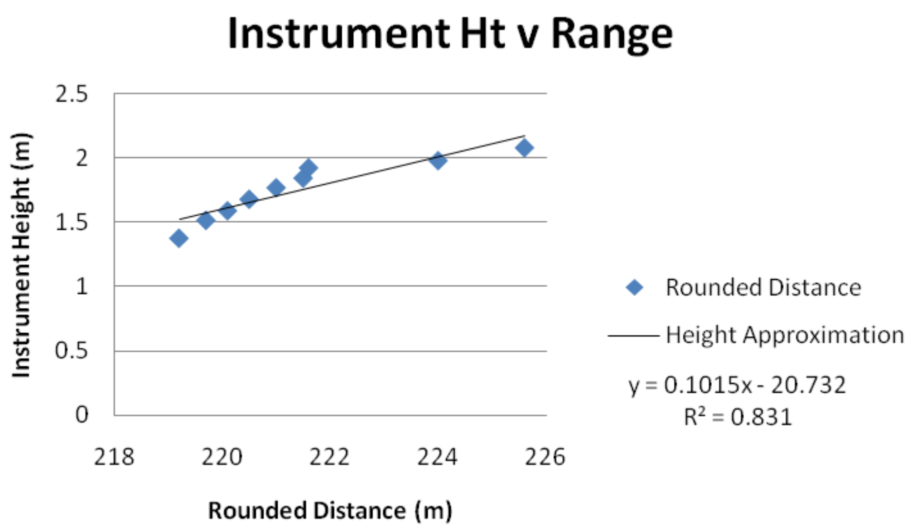


Figure 29 - Graph of height versus range data from Table 1

The R^2 value shown in Figure 29 is the co-efficient of determination which in the case of linear regression is simply the square of the sample correlation co-efficient between the outcomes and their predicted values typically being expressed as a value between 0 and 1. An R^2 value of 1.0 indicates that the regression line or line of best fit perfectly fits the data. Having a R^2 value of 0.831 indicates that the data has a reasonably good fit to the data, however it could be expected that with additional data and a more precise method of obtaining the distance would yield a slightly more accurate result. Based on this it is seen that the method of testing and analysis is sufficient for this project and may be a useful interpolative tool for a surveying practice but there is sufficient scope for further refinement of the method.

4.4. EDME Range

EDME range testing was one of the most critical components of the testing process for this project, with a variety of manufacturers stated accuracies being able to be confirmed or rejected based on the outcome of this testing because of the ranges involved. There was a need to have each scan made at the highest resolution available meaning that the amount of time taken to complete this test was around 5 hours for a single instrument which is about 3 times as long as a standard total station calibration.

With every scan being made at the highest resolution possible, anywhere up to 1700 individual points are obtained and need to be modelled by the scanning / processing software to obtain angles and distances to the centre of the targets being scanned. The output of this data and all other point data was given in ASCII format, conveniently providing access to all data relating to each individual scan point or modelled tie point including the horizontal (Phi) and vertical (Theta) angles in decimal degrees as well as the slope distance (range) to the target.

Custom retroreflective targets where manufactured as described in Chapter 3 of this report for use in this testing. These targets are 450mm in diameter and where mounted in tribrachs for the purpose of this testing procedure. Upon commencement of testing it was necessary for the first attempt at testing to be called off due to the effects that wind was having on the target. Due to the size and thickness of the target there was significant distortion of the target about the mounting point due to the windy conditions encountered on the day, with deviations of distances of up to 10mm at the centre point in some cases. Obviously there was no point in continuing the testing as there was an issue with the targets.

The results of the measurements made from the first pillar to the second pillar are listed below in Table 2, data in the range column shows that for these measurements there was a range of 6mm between measurements which would significantly affect the quality of any results obtained. Figure 30 below illustrates the amount of distortion introduced into the scan data from the effects of wind on the scan target when viewed from above.

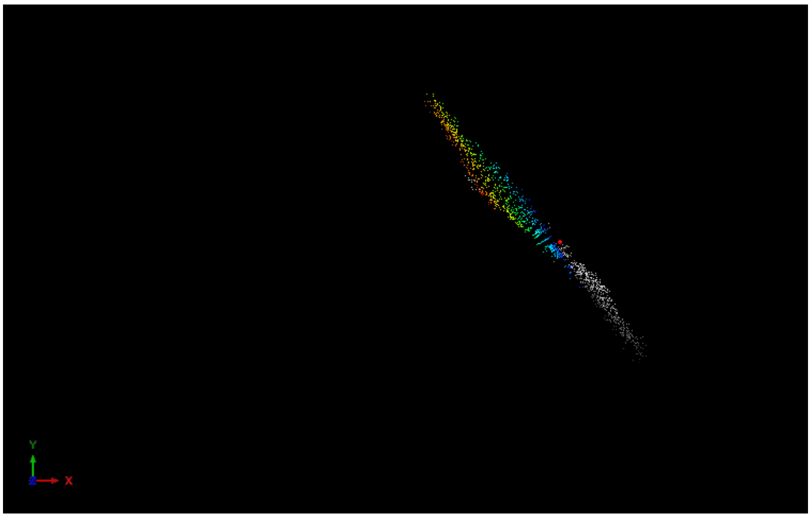


Figure 30 – Image showing the amount of distortion introduced into the scan data.

Measurement	***Reflector Type***	***Size(m)***	***Points***	***Horizontal Angle***	***Vertical Angle***	***Range(m)***
1	Flat 450	0.512	631	210° 6' 54"	90° 18' 32"	206.429
2	Flat 450	0.519	661	210° 7' 12"	90° 18' 25"	206.429
3	Flat 450	0.526	747	210° 7' 19"	90° 18' 25"	206.435
4	Flat 450	0.522	579	210° 7' 26"	90° 18' 00"	206.426
5	Flat 450	0.54	699	210° 7' 30"	90° 18' 25"	206.434

Table 2 – Data obtained from initial EDME range testing.

A second attempt at testing was made after altering the design of the signs slightly to provide a little more stability to the sign, this was achieved by placing a piece of 3mm masonite behind the scanned surface to offer some resistance against the effects of the wind. This small change enabled the completion of the testing on the EDME range with a reasonable amount of certainty; the average deviation of measurements from the first pillar was only 4mm with a standard deviation of 2mm indicating on average that each measurement will be ±2mm from the mean of 4mm. This is illustrated by the data shown in Table 3 below.

	Scan Number	Reflector Type	Scanned Size(m)	Number of Points	Amplitude (0..1)	Range(m)	theta(deg)	phi(deg)		Δ Range
Pillar 1-2	1	Flat 450	0.526	653	0.844	206.438	90.202	223.274		
	2	Flat 450	0.512	688	0.844	206.438	90.203	223.276		
	3	Flat 450	0.512	700	0.848	206.438	90.204	223.276		0.001
	4	Flat 450	0.522	661	0.848	206.438	90.203	223.275		
	5	Flat 450	0.512	701	0.848	206.439	90.203	223.275		
Pillar 1-3	1	Flat 450	0.456	94	0.813	543.926	89.967	223.434		
	2	Flat 450	0.475	79	0.813	543.925	89.967	223.434		
	3	Flat 450	0.451	79	0.813	543.925	89.969	223.433		0.003
	4	Flat 450	0.475	78	0.813	543.923	89.967	223.433		
	5	Flat 450	0.456	93	0.813	543.925	89.968	223.431		
Pillar 1-4	1	Flat 450	0.312	17	0.719	811.963	89.982	223.281		
	2	Flat 450	0.34	19	0.711	811.957	89.981	223.283		
	3	Flat 450	0.34	20	0.711	811.959	89.983	223.284		0.006
	4	Flat 450	0.312	15	0.711	811.957	89.984	223.281		
	5	Flat 450	0.248	14	0.695	811.961	89.984	223.281		
Pillar 1-5	1	Flat 450	0.369	18	0.699	960.848	89.981	223.371		
	2	Flat 450	0.436	27	0.664	960.847	89.98	223.37		
	3	Flat 450	0.47	27	0.699	960.849	89.98	223.371		0.004
	4	Flat 450	0.336	21	0.711	960.848	89.98	223.371		
	5	Flat 450	0.47	27	0.688	960.851	89.98	223.372		
Pillar 1-6	1	Flat 450	0.346	18	0.695	990.272	89.974	223.331		
	2	Flat 450	0.432	28	0.66	990.268	89.972	223.333		
	3	Flat 450	0.346	25	0.695	990.275	89.972	223.331		0.007
	4	Flat 450	0.346	18	0.684	990.273	89.971	223.332		
	5	Flat 450	0.38	22	0.68	990.273	89.975	223.332		
Pillar 1-7	1	Flat 450	0.404	17	0.66	1051.628	89.953	223.358		
	2	Flat 450	0.459	19	0.641	1051.629	89.953	223.358		
	3	Flat 450	0.367	14	0.656	1051.631	89.952	223.359		0.005
	4	Flat 450	0.33	16	0.66	1051.628	89.953	223.358		
	5	Flat 450	0.367	20	0.66	1051.626	89.953	223.359		

Average of all Differences 0.004333
Standard Deviation of all Ranges 0.00216

Table 3 – Data obtained from pillar 1 upon re-testing.

In total the testing took 5 hours to complete which is the same time that it takes to calibrate 3 standard total stations. The resulting measurements that were taken during the calibration where entered into the Microsoft Excel spreadsheet shown in Table 4 to determine the horizontal distance, corrected horizontal distance and residuals. The data has been plotted on a graph as shown Figure 31 in order to assist with determining the prism constant and the scalar corrections for the particular instrument. The absolute distances and offsets for each pillar as well as the reduced level of each pillar are required as part of the processing; the figures for reduced level and offset are used to reduce slope distances to horizontal distances and then to correct the horizontal distance for the effect that the baseline pillar eccentricity has on straight line distances. This combined with corrections for the meteorological effects of temperature and pressure provides a corrected distance that can be compared against the precisely measured absolute horizontal distance that is shown on the EDME baseline certificate. The calibration certificate for the Gold Coast EDME range is shown in Appendix D and these certificates are valid for two years from the date of certification.

EDM Calibration Range - GCCC Baseline

	RL	***Offset***	***Distance***
1	*3.125*	*0.000*	*0*
2	*2.311*	*0.192*	*206.447*
3	*3.098*	*-0.988*	*543.93*
4	*2.913*	*0.749*	*811.955*
5	*2.834*	*-0.703*	*960.844*
6	*2.967*	*0.000*	*990.27*
7	*3.368*	*-0.499*	*1051.627*

Intercept = Prism Constant		0.011274
Slope of Linear Trend Line		-0.000015
Scale Factor = 1 + Slope		0.999985
Check Prism Constant		
Distance 1-2 + 2-3	*Distance 1-3*	
543.9133	543.9238	
Three Peg Test Check		0.011

Line	***Slope Corr'n***	***Offset***	***Abs Dist (HD)***	***Slope Dist***	***Corrected HD (Meas)***	***Abs-Meas***	***Adjusted Distance measured x SF + PC***	***Absolute - Adjusted***
1-2	-0.00160	-0.00009	206.447	206.4381	206.4364	0.01063	206.44463	0.00237
1-3	0.00000	-0.00090	543.930	543.9247	543.9238	0.00615	543.92716	0.00284
1-4	-0.00003	-0.00035	811.955	811.9596	811.9593	-0.00426	811.95865	-0.00365
1-5	-0.00004	-0.00026	960.844	960.8487	960.8484	-0.00443	960.84564	-0.00164
1-6	-0.00001	0.00000	990.270	990.2720	990.2720	-0.00203	990.26881	0.00119
1-7	-0.00003	-0.00012	1051.627	1051.6282	1051.6280	-0.00104	1051.62392	0.00308
2-3	-0.00092	-0.00206	337.483	337.4799	337.4769	0.00607	337.48326	-0.00026
2-4	-0.00030	-0.00026	605.508	605.5088	605.5082	-0.00023	605.51064	-0.00264
2-5	-0.00018	-0.00053	754.397	754.4016	754.4009	-0.00389	754.40112	-0.00412
2-6	-0.00027	-0.00002	783.823	783.8259	783.8256	-0.00265	783.82545	-0.00245
2-7	-0.00066	-0.00028	845.180	845.1867	845.1857	-0.00573	845.18464	-0.00464
3-4	-0.00006	-0.00563	268.025	268.0145	268.0088	0.01615	268.01620	0.00880
3-5	-0.00008	-0.00010	416.914	416.9044	416.9043	0.00975	416.90943	0.00457
3-6	-0.00002	-0.00109	446.340	446.3304	446.3293	0.01066	446.33408	0.00592
3-7	-0.00007	-0.00024	507.697	507.6907	507.6904	0.00664	507.69420	0.00280

4-5	-0.00002	-0.00708	148.889	148.8870	148.8799	0.00911	148.88898	0.00002
4-6	-0.00001	-0.00157	178.315	178.3064	178.3049	0.01015	178.31352	0.00148
4-7	-0.00043	-0.00325	239.672	239.6642	239.6605	0.01149	239.66828	0.00372
5-6	-0.00030	-0.00840	29.426	29.4356	29.4269	-0.00094	29.43779	-0.01179
5-7	-0.00157	-0.00023	90.783	90.7776	90.7758	0.00724	90.78571	-0.00271
6-7	-0.00131	-0.00203	61.357	61.3529	61.3495	0.00746	61.35992	-0.00292

Table 4 - Basic method of calibration calculations using Microsoft Excel.

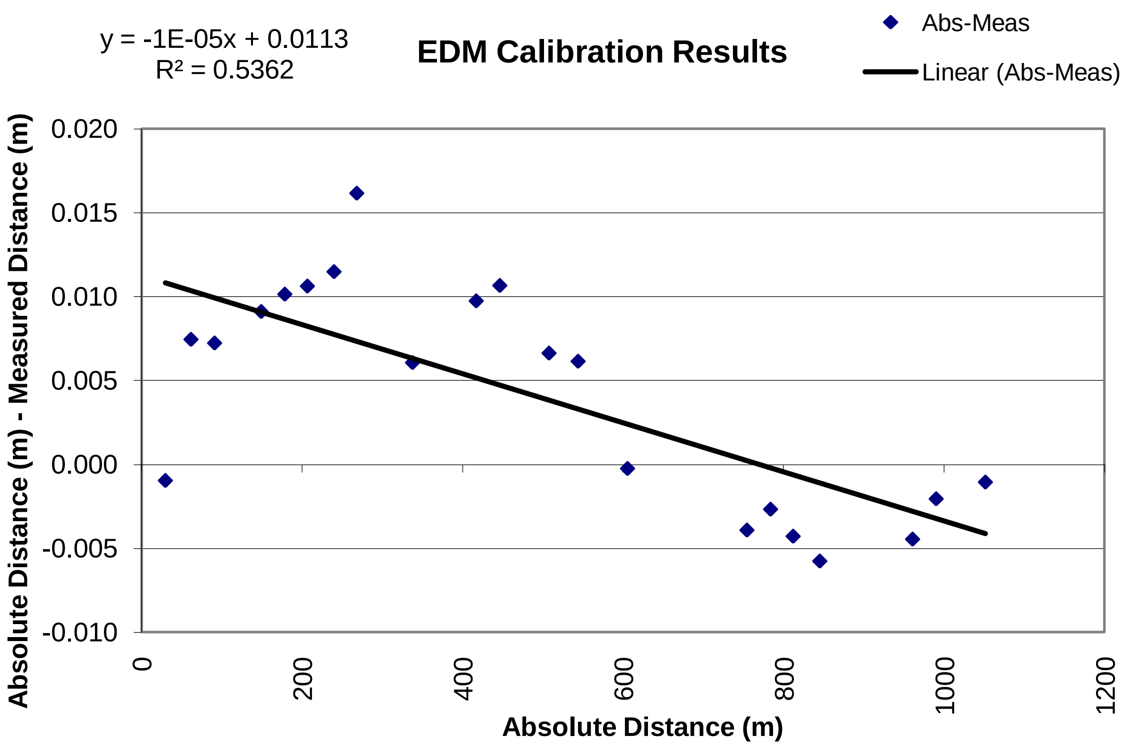


Figure 31 - Graph used for analysis of calibration data.

This method is fairly crude but is considered sufficient to obtain an approximate value for these results, however standard practice is the use of an EDM calibration reduction program such as that supplied by Moreton Bay Regional Council that uses least squares calculations to obtain the results and to determine if the results are statistically correct.

Statutory bodies such as the Department of Environment and Resource Management, other state land and surveying government departments and the National Measurement Institute use more rigorous software that provides a detailed statistical summary and automatically tests the data against set parameters to determine if the calibration meets the manufacturers stated measurement accuracies. It was deemed not necessary to take this step as part of this project, however to provide absolute traceability of measurements made this should be done in practice so that signed certification for the instrument can be obtained.

In the case of a traditional total station EDME calibration the user or the statutory body signing the certification then needs to determine if these values fall within the specified accuracies provided by the manufacturer, in most of the processing software, this is done automatically through a series of robust tests. However when using the Microsoft Excel spreadsheet as shown in Table 4, this will need to be done by comparing these specified accuracies manually. At this early stage in terrestrial laser scanner research and testing this will not be possible as at present the manufacturers of terrestrial laser scanners do not provide their measurement accuracies in terms of a distance and ppm as they currently do with conventional total station instruments.

The initial reduction of the data undertaken using the Microsoft Excel spreadsheet indicated that a prism constant correction of 11mm and a scalar correction of 0.999985 or -15ppm needs to be applied to all measurements for the distances to be standardised. It was decided that investigation into why the correction is so high, to do this the individual target scan was exported from RiScan Pro into Microsoft Excel, filtering of the data to only show points from the centre point up to the top of the target within a narrow band about the central axis of the target which reduced the number of points being analysed from 1650 to 20 points. Two outlying points where removed, with the filtered data being shown in Table 5.

Central VA (From TPL)	90.202
Central HA (From TPL)	223.274
Central SD (From TPL)	206.438

Pt ID	***X(m) SOCS***	***Y(m) SOCS***	***Z(m) SOCS***	***Range(m)***	***Theta(deg)***	***VA (DMS)***	***Phi(deg)***	***HA (DMS)***
786	-150.3	-141.513	-0.326	206.437	90.091	90° 5' 28"	223.275	223° 16' 30"
787	-150.299	-141.512	-0.355	206.436	90.099	90° 5' 56"	223.275	223° 16' 30"
788	-150.294	-141.508	-0.377	206.429	90.105	90° 6' 18"	223.275	223° 16' 30"
789	-150.295	-141.508	-0.398	206.43	90.111	90° 6' 40"	223.275	223° 16' 30"
790	-150.295	-141.508	-0.42	206.43	90.117	90° 7' 1"	223.275	223° 16' 30"
791	-150.3	-141.514	-0.441	206.438	90.123	90° 7' 23"	223.275	223° 16' 30"
793	-150.297	-141.51	-0.485	206.433	90.135	90° 8' 6"	223.275	223° 16' 30"

794	-150.304	-141.517	-0.506	206.443	90.141	90° 8' 28"	223.275	223° 16' 30"
795	-150.297	-141.51	-0.528	206.433	90.147	90° 8' 49"	223.275	223° 16' 30"
796	-150.302	-141.515	-0.55	206.44	90.153	90° 9' 11"	223.275	223° 16' 30"
798	-150.302	-141.515	-0.593	206.441	90.165	90° 9' 54"	223.275	223° 16' 30"
799	-150.292	-141.506	-0.614	206.427	90.171	90° 10' 16"	223.275	223° 16' 30"
800	-150.298	-141.511	-0.636	206.435	90.177	90° 10' 37"	223.275	223° 16' 30"
801	-150.302	-141.515	-0.658	206.441	90.183	90° 10' 59"	223.275	223° 16' 30"
802	-150.296	-141.509	-0.686	206.432	90.191	90° 11' 28"	223.275	223° 16' 30"
803	-150.299	-141.511	-0.708	206.436	90.197	90° 11' 49"	223.275	223° 16' 30"
804	-150.296	-141.509	-0.73	206.432	90.203	90° 12' 11"	223.275	223° 16' 30"

Maximum Distance	206.443		
Minimum Distance	206.427	Difference	0.016
Observed Mid Point Distance	206.437		
Observed Highest Point Distance	206.432	Difference	0.005

Table 5 – Filtered observations to target measurement 1 at Pillar 1 to Pillar 2.

It can be seen from this data that there were still some effects from the wind present given that the spread of the measurements was 16mm, however the difference in the distance from the observed centre point to the top of the target was found to be 5mm. This possibly indicates that the face of the target was not vertical or perpendicular for the observations and that the mounting of the target needs to be investigated as a possible source of error, if there is an error with the mounting of the scanner target to the manufactured bracket it is most likely the surface of the retroreflective target being angled towards or away from the instrument.

To check the results obtained from the processing of the observations as seen in Table 4, the same data has been entered into the EDM calibration software provided by the survey department of Moreton Bay Regional Council. Where the basic method using Microsoft Excel calculated the corrections through linear regression analysis, this second method of calculations as shown in Table 6 utilises least squares to obtain the required corrections.

```
Instrument: RIEGL LMS-Z620      Ser. No: 999715     Date: 30/08/2009
Operator: Damian Ling           Company: Conics (Brisbane)
```

Line	Measured	Corrected	Absolute	Residual.
0-1	206.4381	206.4359	206.44701	0.0111
0-2	543.9247	543.9213	543.92999	0.0087
0-3	811.9596	811.9510	811.95502	0.0040
0-4	960.8487	960.8399	960.84399	0.0041
0-5	990.2720	990.2610	990.27002	0.0090
0-6	1051.6281	1051.6151	1051.62695	0.0118
1-2	337.4799	337.4763	337.48297	0.0067
1-3	605.5088	605.4979	605.50800	0.0101
1-4	754.4016	754.3914	754.39697	0.0056
1-5	783.8259	783.8127	783.82300	0.0103
1-6	845.1867	845.1727	845.17993	0.0072
2-3	268.0145	268.0066	268.02502	0.0184
2-4	416.9044	416.8976	416.91400	0.0164
2-5	446.3304	446.3201	446.34003	0.0199
2-6	507.6907	507.6796	507.69696	0.0174
3-4	148.8870	148.8863	148.88898	0.0027
3-5	178.3064	178.3029	178.31500	0.0121
3-6	239.6642	239.6588	239.67194	0.0131
4-5	29.4356	29.4312	29.42603	-.0052
4-6	90.7776	90.7727	90.78296	0.0103
5-6	61.3529	61.3500	61.35693	0.0070

```
Calibration results using 10.07.2008 values as Absolute.

Zero Const: 0.0095    Scale Factor: 1.0000002 (  0ppm.)    Std Dev  5.9mm.

"                To correct a measured distance, multiply by"
                the Scale factor and add the zero constant.

Residuals after the scale factor has been applied to measured distances.
```

Line	Residual	Line	Residual	Line	Residual
0-1	0.002	1-3	0.001	2-6	0.008
0-2	-.001	1-4	-.004	3-4	-.007
0-3	-.006	1-5	0.001	3-5	0.003
0-4	-.006	1-6	-.002	3-6	0.004

Table 6 – Calibration results from provided EDM calibration processing software.

Comparing the results obtained from the second method of processing it can be seen that from the results a zero constant of 10mm and a scale factor of 1.00000 or 0ppm need to be applied to any measured distances to standardise the measurements, which in the case of the zero constant is confirmation of the Microsoft Excel data that indicated corrections of 11mm and 15ppm respectively. The difference in the ppm figure is likely to be due to the different methods of processing as both calculation methods utilised the same data, with both using the observed slope distances as the starting point for the calculations.

It would be possible to further analyse the data in an attempt to remove any outlying observations from the data prior to re-processing. However without access to the high end processing software used by statutory departments this would be a very time consuming process. Another important procedural aspect to note is that only 5 measurements were made to each of the targets from each pillar, following total station methodology. Inclusion of additional data from further scans at each set of observations or see if using the median value instead of the mean could provide a more accurate result.

Looking at the instrument specifications for the RIEGL LMS-Z620 instrument, the stated measurement accuracy is 10mm @ 100m and this testing would indicate that after target errors are removed, this value is attainable and can be tested utilising this method.

4.5. Repetitive Scans

Repetitive testing of the laser scanner was undertaken to determine the ability of the scanners processing software to consistently determine the calculated centre position of the laser scanning targets, this was undertaken to determine if the manufacturer's specified accuracy can be tested and achieved as well as aiding users by providing a method of verification for these instruments.

In this set of field observations, testing took approximately 30 minutes to complete once the instrument had been set up with 1 overall scan being completed initially enabling the single target, which was located about 140m away to be selected 20 times ensuring that 20 individual high resolution scans of the retroreflective target could be made. Each of these scans compromised of between 800 and 1300 points and from this observed data RiScan Pro was able to model the scanned object to obtain the centre point of each of the scans, using approximately 170 of these individual points to achieve this calculation.

Name	Reflector Type	Range (m)	theta (deg)	phi (deg)	Variance	Variance Squared	±3σ from Mean	Binomial 'x' Value	Binomial 'y' Value
tp001	RIEGL Cylinder 5cm	137.861	90.694	190.213	-0.00015	2.25E-08	137.85871	15.44618	5.45305
tp002	RIEGL Cylinder 5cm	137.862	90.692	190.215	0.00085	7.225E-07	137.85897	15.44621	13.37895
tp003	RIEGL Cylinder 5cm	137.862	90.694	190.214	0.00085	7.225E-07	137.85923	15.44624	29.70950
tp004	RIEGL Cylinder 5cm	137.861	90.692	190.213	-0.00015	2.25E-08	137.85948	15.44627	59.71168
tp005	RIEGL Cylinder 5cm	137.862	90.692	190.214	0.00085	7.225E-07	137.85974	15.44630	108.62110
tp006	RIEGL Cylinder 5cm	137.861	90.693	190.214	-0.00015	2.25E-08	137.86000	15.44633	178.83804
tp007	RIEGL Cylinder 5cm	137.862	90.698	190.214	0.00085	7.225E-07	137.86025	15.44636	266.49956
tp008	RIEGL Cylinder 5cm	137.861	90.696	190.215	-0.00015	2.25E-08	137.86051	15.44638	359.43795
tp009	RIEGL Cylinder 5cm	137.859	90.696	190.213	-0.00215	4.6225E-06	137.86077	15.44641	438.77534
tp010	RIEGL Cylinder 5cm	137.861	90.691	190.214	-0.00015	2.25E-08	137.86102	15.44644	484.78744
tp011	RIEGL Cylinder 5cm	137.861	90.695	190.213	-0.00015	2.25E-08	137.86128	15.44647	484.78744
tp012	RIEGL Cylinder 5cm	137.862	90.69	190.214	0.00085	7.225E-07	137.86153	15.44650	438.77534
tp013	RIEGL Cylinder 5cm	137.861	90.695	190.213	-0.00015	2.25E-08	137.86179	15.44653	359.43795
tp014	RIEGL Cylinder 5cm	137.86	90.696	190.212	-0.00115	1.3225E-06	137.86205	15.44656	266.49956
tp015	RIEGL Cylinder 5cm	137.862	90.69	190.214	0.00085	7.225E-07	137.86230	15.44659	178.83804
tp016	RIEGL Cylinder 5cm	137.861	90.69	190.214	-0.00015	2.25E-08	137.86256	15.44661	108.62110
tp017	RIEGL Cylinder 5cm	137.86	90.696	190.211	-0.00115	1.3225E-06	137.86282	15.44664	59.71168
tp018	RIEGL Cylinder 5cm	137.862	90.691	190.213	0.00085	7.225E-07	137.86307	15.44667	29.70950
tp019	RIEGL Cylinder 5cm	137.861	90.696	190.212	-0.00015	2.25E-08	137.86333	15.44670	13.37895
tp020	RIEGL Cylinder 5cm	137.861	90.695	190.213	-0.00015	2.25E-08	137.86359	15.44673	5.45305

Table 7 – Observed data and analysis for repetitive target scanning.

The instrument manufacturer states in their product specifications and data sheets (Appendix B) that the repeatability of measurements of this instrument is 10mm for any single point location and 5mm for an averaged location at a distance of 100m away from the instrument under ideal conditions. As described in previous results analysis the location of the targets is undertaken by the processing software modelling each of the target scans to determine the most likely position of the target centre, this would definitely fall under the averaged observations category listed in the specifications. This then requires the results of the test to show that at a minimum range of 100m the spread of calculated distances to the target should be no greater that 5mm.

Table 7 shows the results of each of the 20 scans, providing information on the type of target being modelled, the calculated range, vertical and horizontal angles; the data to the right of the table was used for further statistical analysis of the results and will be discussed later in this section. However, upon reviewing the basic data shown in reference to the range to the target it can be seen that this collection of data clearly exceeds the manufacturer's specifications on this occasion with a spread of only 3mm over the course of 20 individual scans with the shortest recorded distance of the test data being

137.859m to tp009 and the furthest distance being 137.862m taken to a total of 7 out of the 20 targets. As there was one single distance recorded to the shortest distance it could be considered that this point may be an outlier and could possibly be removed from the data but as the results indicate that the test confirmed the stated accuracy, there is no need to take this action on this occasion.

Further statistical analysis shows that the standard deviation or average deviation expected from the average of the measurements is 0.8mm. Graphing the binomial distribution indicates that the data is well spread about the mean with all observations being contained within 3 standard deviations of this point, this graph is shown below as Figure 32. From this graph and the built in functions within Microsoft Excel it was possible to determine the 90%, 95% and 99% confidence intervals of the observed data. These where 0.3, 0.4 and 0.5mm respectively, indicating that for any measurement taken to the target it can be expected that the range to the target will be no more than 0.5mm of the mean of the measurements with 99% confidence when using a sample size of 20 measurements. Obviously these figures are likely to change as the number of measurements are reduced or increased.

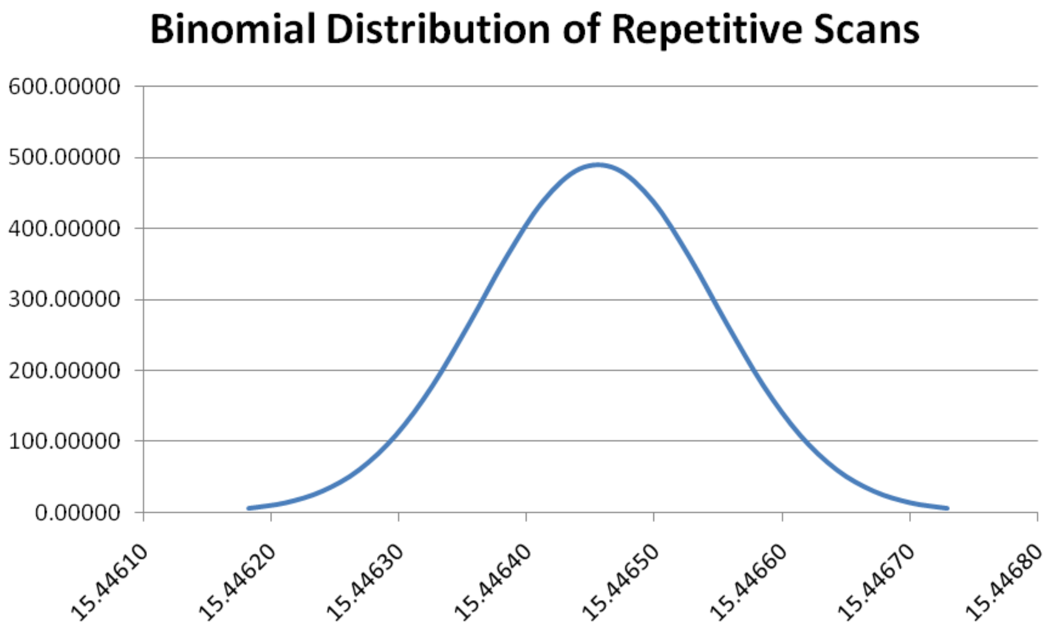


Figure 32 – Graph showing binomial distribution of measured points.

4.6. Traversing

The data for this test was collected as part of a topographical detail survey undertaken by Conics (Brisbane) P/L; Mr Nick McKelvey was the operator of the instrument for this task and has provided the information for use on this project. The scanning and associated traverse data recording where undertaken on Stafford Road, Enoggera in Queensland and was undertaken in much the same manner as a conventional detail survey / traverse is completed with a total station instrument. An image showing the initial instrument set up location along with the backsight point and the foresight point can be seen in Figure 33.

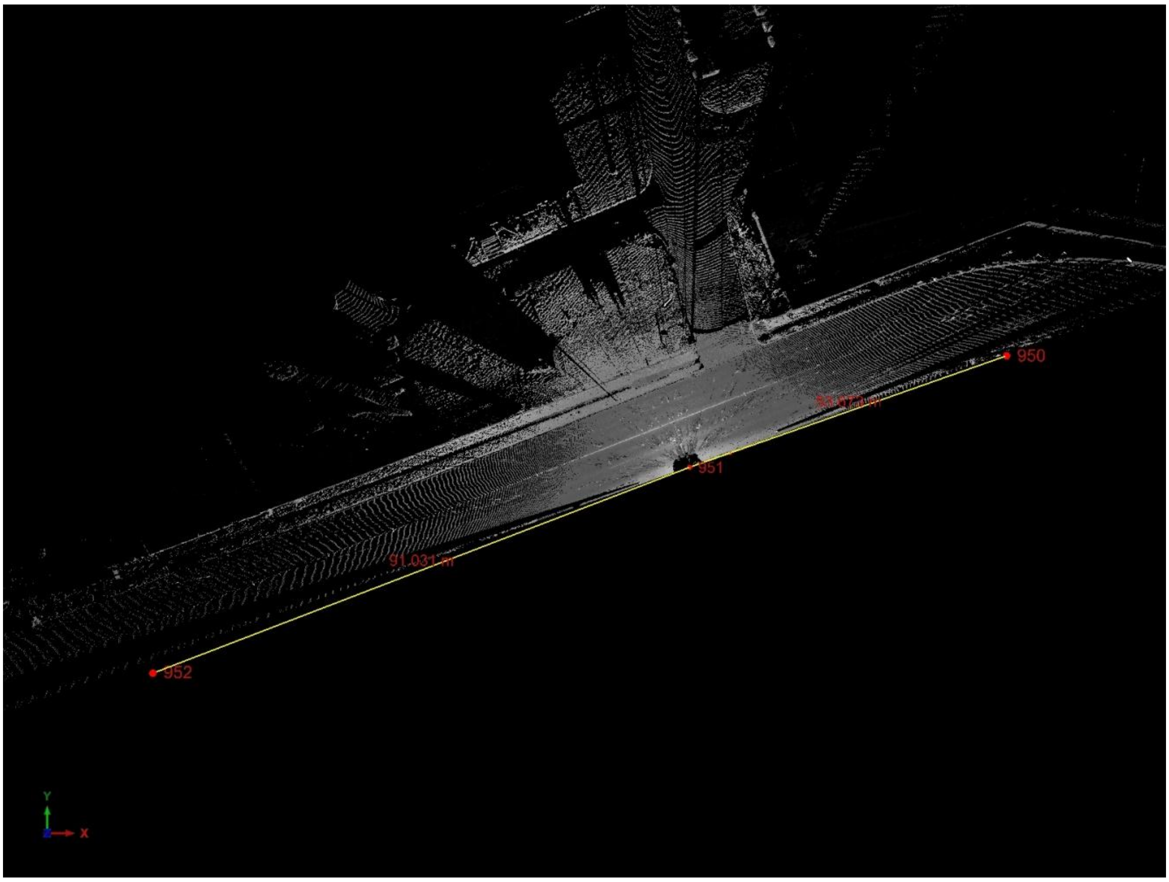
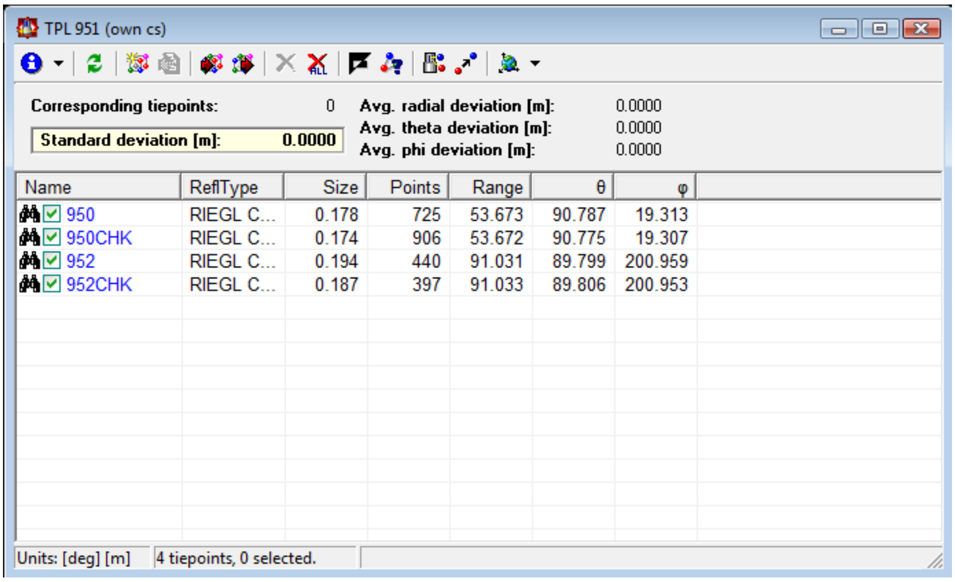


Figure 33 – Initial traverse setup showing scanner position, backsight and foresight points.

Each of the targets where scanned in the same way as any survey undertaken with the terrestrial laser scanner, the data for each target location was viewed within the TPL (SOCS) window within RiScan Pro which shows the angle and distance information. Figure 34 shows the data that was recorded from the initial scan location, this along with the data from all of the other scan locations where exported into Microsoft Excel where the horizontal and vertical angles where converted from radian measure to degrees minutes seconds format for entry into the required format for the StarNet least squares adjustment program. An example of the formatting for StarNet of a 3D traverse undertaken with a conventional total station can be found in Appendix E, this is the required data format that the scan data needed to be arranged in. For this project the control used for the scanner location and target location was located using a traditional total station with the scanner and target heights recorded manually in a field book for later comparison of these results.


TPL 951 (own cs)

Corresponding tiepoints: 0
Standard deviation [m]: 0.0000
Avg. radial deviation [m]: 0.0000
Avg. theta deviation [m]: 0.0000
Avg. phi deviation [m]: 0.0000

Name	ReflType	Size	Points	Range	θ	φ
950	RIEGL C...	0.178	725	53.673	90.787	19.313
950CHK	RIEGL C...	0.174	906	53.672	90.775	19.307
952	RIEGL C...	0.194	440	91.031	89.799	200.959
952CHK	RIEGL C...	0.187	397	91.033	89.806	200.953

Units: [deg] [m] 4 tiepoints, 0 selected.

Figure 34 – Screen capture of the target data obtained during the traverse process.

The data was reduced in preparation for adjustment in 3D with the required program parameters like units, instrument settings and co-ordinate order set correctly. However at the completion of the reduction process the program indicated that the reduction of the traverse data had failed the statistical analysis of the results as seen on the screen image of the reduction analysis as shown in Figure 35. This figure shows the horizontal data is consistent with the expected outcome however the vertical component of the data is erroneous, investigation into the target and instrument heights was inconclusive as the data entered into the program was identical to the field notes. There is a possibility that the wrong reference point was selected when measuring the height of the scanner or the wrong height written down (transcription error) and thus the wrong correction made to the height.

```
Network Adjustment with Error Propagation

Loading Network Data ...
Checking Network Data ...

Performing Network Adjustment ...
  Iteration # 1
  Iteration # 2
  Iteration # 3
Solution Has Converged in 3 Iterations

Statistical Summary
Observation     Count   Error Factor
  Angles          10        0.334
  Distances       19        0.947
  Az/Bearings      1        0.001
  Zeniths         19       31.552
  Total           49       19.657

Warning: Chi-Square Exceeded Upper Bound
  Lower/Upper Bounds (0.707/1.293)

Performing Error Propagation ...
Writing Output Files ...

Network Processing Completed
Elapsed Time = 00:00:00
```

Figure 35 – Statistical analysis of 3D reduction.

Detailed inspection of the reduction report was undertaken to try and determine which measurement contained the height error by inspection of the adjusted zenith observations along with their residual and standardised residual provided in the adjustment process. It was not possible to determine where the error in height occurred and therefore it was decided to undertake the least squares adjustment of the survey data in 2D only, which would ignore the obviously erroneous heights. The aim of undertaking this additional analysis is to see if it is possible to complete accurate traversing with a terrestrial laser scanner without needing the assistance of an additional survey crew using a total station, if a 2D adjustment is possible it will also give credit to the assumption made earlier that the error in the testing of traversing process in this project belongs solely to the measurement of the instrument and target heights in the course of the survey. This adjustment was undertaken in StarNet, once again with the required parameters set and the adjustment type set to 2D. At the completion of the reduction and viewing of the statistical output of the reduction it was seen that the process was successful as seen in Figure 36.

```
Network Adjustment with Error Propagation

Loading Network Data ...
Checking Network Data ...

Performing Network Adjustment ...
  Iteration # 1
  Iteration # 2
Solution Has Converged in 2 Iterations

Statistical Summary
Observation     Count   Error Factor
  Angles          10        0.202
  Distances       19        0.906
  Az/Bearings      1        0.001
  Total           30        0.731

Chi-Square Test at 5.00% Level Passed
  Lower/Upper Bounds (0.606/1.395)

Performing Error Propagation ...
Writing Output Files ...

Network Processing Completed
Elapsed Time = 00:00:00
```

Figure 36 – Statistical analysis of 2D reduction.

It is not common practice to just assume that because the data passes the adjustment that it is correct. On this occasion a suitable method of checking the quality of the adjustment is to compare the co-ordinates obtained from the laser scanner traverse against the co-ordinates obtained as part of the conventional total station traverse, which has also been adjusted as part of a larger control network that includes additional bracing and redundant observations. Table 8 shows the co-ordinates of the control points and the co-ordinates obtained from the scanner adjustment, comparison of the two sets of co-ordinates are also shown along with the total difference between the points in bearing and distance. Upon analysis of the differences it can be seen that the worst difference is 46mm at station 957 which was expected due to location of the point and its relationship to other points in the control network. The average difference is 15mm with a standard deviation of 13mm, undertaking further statistical modelling indicates that at the 95% confidence level one could expect that any measured value would fall within 8mm of the value obtained from a conventional traverse undertaken with a total station.

	Control by Total Station Traverse			By Scanner		Total Station v Scanner Traverse			
Stn	***Easting***	***Northing***	***RL***	***Easting***	***Northing***	***Δ East***	***Δ North***	***Error BRG***	***Error Dist***
950	498654.544	6966920.097	35.833	498654.543	6966920.095	0.000	0.002	0° 14' 42"	0.002
951	498705.040	6966901.921	36.289	498705.040	6966901.921	Fixed Control Station			
952	498791.538	6966873.569	37.324	498791.549	6966873.565	-0.011	0.004	358° 46' 30"	0.012
953	498747.333	6966872.050	36.985	498747.345	6966872.049	-0.012	0.001	358° 30' 57"	0.012
954	498646.968	6966907.281	36.567	498646.978	6966907.275	-0.010	0.006	358° 58' 27"	0.012
955	498600.573	6966954.498	35.493	498600.569	6966954.490	0.004	0.008	0° 25' 60"	0.009
956	498547.676	6967016.562	36.483	498547.658	6967016.552	0.018	0.010	1° 3' 15"	0.020
957	498524.124	6967066.069	38.621	498524.083	6967066.089	0.041	-0.020	358° 52' 49"	0.046
958	498579.842	6967001.572	35.700	498579.836	6967001.557	0.006	0.015	0° 21' 47"	0.016
959	498631.967	6966940.924	35.539	498631.964	6966940.916	0.002	0.008	0° 17' 29"	0.008

Table 8 – Total station and scanner co-ordinate comparison.

Some of the possible reasons for the difference in the two sets of data include the ability to reliably centre the scanning instrument and respective targets over ground control marks as accurately as conventional equipment. As well as this, the lower quality of compensator contained within terrestrial laser scanners at the moment could be another possible reason as these provide corrections for slight errors in levelling of the instrument. One other possible cause links this test to the EDME testing undertaken; with a conventional total station it is possible to apply corrections obtained from calibrations, meteorological observations and any prism constant corrections directly to the measured distances. Whereas with a laser scanner it is generally only possible to apply the meteorological observations and prism constant to observations depending on the operator's knowledge of the instrument and operating software. These may be overlooked and introduce additional errors into the observations.

Another possible reason for the difference in the results obtained is the method in which the traverse data is obtained; with a total station the horizontal angles, vertical angles and slope distance are all measured and recorded directly. With a terrestrial laser scanner these measured values are a best fit model of anywhere up to a few thousand individual point locations. Whilst these small inaccuracies may not be evident when undertaking conventional scanning tasks, their effects are more noticeable when undertaking testing or surveying tasks of this nature.

4.7. Basic Testing Facility

This testing was undertaken in an attempt to refine a procedure for the intermediate testing of the equipment prior to using it for precision projects and at pre determined intervals. This facility would not be a replacement for EDME baseline testing on a yearly basis but would provide the means to ensure that the equipment is measuring correctly and within the specifications prior to heading to the job site or when otherwise needed.

The testing involved the placement of 6 × 50mm flat, self adhesive retroreflective targets at strategic locations within the test site at varying heights and angles from the proposed instrument location. This placement of targets was undertaken as outlined in the manufacturer's manual with assistance from Mr François Dubois of CR Kennedy who undertakes sales and training of terrestrial laser scanning equipment. Once the targets were in place a calibrated high precision Trimble S6 total station was used to measure a face left and face right observation to each of the placed targets, this provided the point co-ordinates used for the testing of the terrestrial laser scanner. The observed co-ordinates for all of the targets can be seen in Table 9, these where exported from the Trimble TSC2 data controller in csv format and viewed in Microsoft Excel.

Target	***Easting***	***Northing***	***RL***
T1	994.978	4990.530	14.279
T2	1021.235	4988.983	12.831
T3	1022.122	5002.872	10.321
T4	1004.596	5001.380	13.012
T5	1001.723	5017.949	10.021
T6	999.999	5054.859	13.247
BM	1000.000	5000.000	10.000

Table 9 – Testing facility co-ordinates.

The co-ordinates assigned to a benchmark screw placed in the concrete floor for the test location of the instruments was assigned the arbitrary co-ordinates of 1000.000, 5000.000 and an arbitrary reduced level of 10.000m. To commence the testing on the terrestrial laser scanner, the instrument was placed over the control point using the tribrach mounting option and then the levelness of the scanner was viewed using the scanner control tools that are available in RiScan and adjusted as necessary. Figure 37 shows a typical screen capture of the scanner orientation, this is the equivalent of a pill bubble on a normal total station or level instrument.

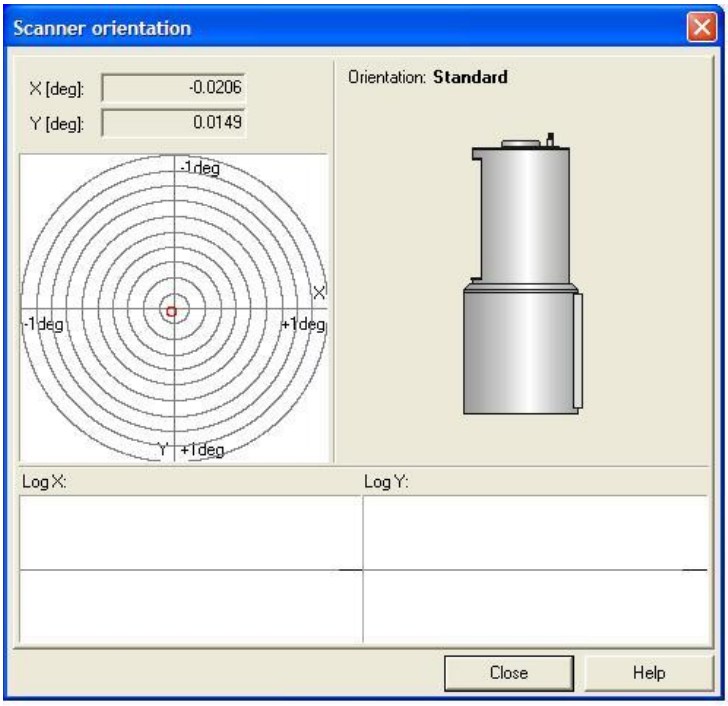


Figure 37 – RiScan scanner orientation screen.

Once the scanner was in place a full scan of the basement area was undertaken to enable the location of each of the targets, this scan took about 4 minutes to complete with the capture of just fewer than 2 million individual data points. From this collection of data, each individual target was selected as a reference target from within the scan window and scanned individually as part of the target acquisition process. These individual scans took approximately one minute each and involved the collection of an average of 5000 additional points for computations.

Comparison of the results obtained from the scanner to those established with the total station was fairly simple and involved the importing of the established co-ordinates into the scanner processing software and linking the two set of data together. RiScan Pro then completed an adjustment to suit these co-ordinates much in the same manner as a typical resection is undertaken within the software of a modern total station controller and provided a listing of the residuals to each of the individual scanned targets, this can be seen below in Table 10.

Name	***Reflector Type***	***Range (m)***	***theta (deg)***	***phi (deg)***	***delta X (m)***	***delta Y (m)***	***delta Z (m)***	***delta R (m)***	***delta theta (m)***	***delta phi (m)***
T1	RIEGL Flat 5cm	10.989	77.870	65.701	0.001	0.002	0.001	0.002	0.000	0.000
T2	RIEGL Flat 5cm	23.890	87.981	156.405	0.001	0.000	0.001	-0.001	-0.001	-0.001
T3	RIEGL Flat 5cm	22.318	94.217	191.313	0.000	0.000	-0.001	0.000	0.001	0.000
T4	RIEGL Flat 5cm	4.870	77.476	200.811	-0.002	-0.002	-0.002	0.002	0.002	0.001
T5	RIEGL Flat 5cm	18.136	96.004	268.553	-0.001	0.000	0.000	0.000	0.000	-0.001
T6	RIEGL Flat 5cm	54.881	88.531	273.927	0.000	0.000	0.000	0.000	0.000	0.000

Table 10 – Test facility comparison table.

It can be seen in the table above that the residuals of the targets are all within the ± 5mm averaged point accuracy stated by the manufacturer, this is a good result and shows that this is a valid method of checking that the instrument is in good working order prior to being used for survey work. A second test was undertaken 6 months after the initial set up of the testing facility to check the operation of the instrument and the results of this instrument test are shown below in Table 11.

Name	***Reflector Type***	***Range (m)***	***theta (deg)***	***phi (deg)***	***delta X (m)***	***delta Y (m)***	***delta Z (m)***	***delta R (m)***	***delta theta (m)***	***delta phi (m)***
T1	RIEGL Flat 5cm	10.942	78.141	44.438	-0.003	-0.001	0.001	-0.003	-0.002	0.001
T4	RIEGL Flat 5cm	4.891	79.039	179.040	0.003	-0.001	-0.003	-0.004	0.002	0.001
T3	RIEGL Flat 5cm	22.377	94.632	169.723	0.002	-0.002	0.001	-0.002	-0.001	0.001
T5	RIEGL Flat 5cm	18.143	96.598	246.847	-0.001	0.004	0.001	-0.003	-0.001	-0.003

Table 11 – Subsequent test facility comparison table.

It can be seen from the table above that there were only 4 of the 6 targets scanned on this occasion; this was primarily due to having visibility to the two missing targets restricted during the course of the testing. Obviously if there was a problem with the result obtained from the test, then there would be a need to scan the remaining 2 targets in an attempt to determine where the issue may have occurred. Once again good results were obtained with this check of the operational status of the terrestrial laser scanner with all of the residual values again falling within the ± 5mm value. On this occasion the height of the instrument was measured and a conscientious effort made to ensure that the terrestrial laser scanner was centred over the benchmark screw as accurately as possible, with the instrument being brought as close to level as possible through the use of the inclination sensor in the scanner controls. Registering the data using the known target locations and measured angles and distances to these points, the scanner was able to compute the co-ordinates at the centre of laser beam output as being 999.996, 5000.001 with a reduced level of 12.064. This shows that the deltas for easting and northing are very low with the scanner being able to determine a position within 5mm of the actual value, as stated earlier the determined height is to the centre of the laser beam output as shown in Figure 38 and hence the instrument height (corrected for the measurement location) will need to be subtracted from this value to obtain the comparative level at the benchmark.

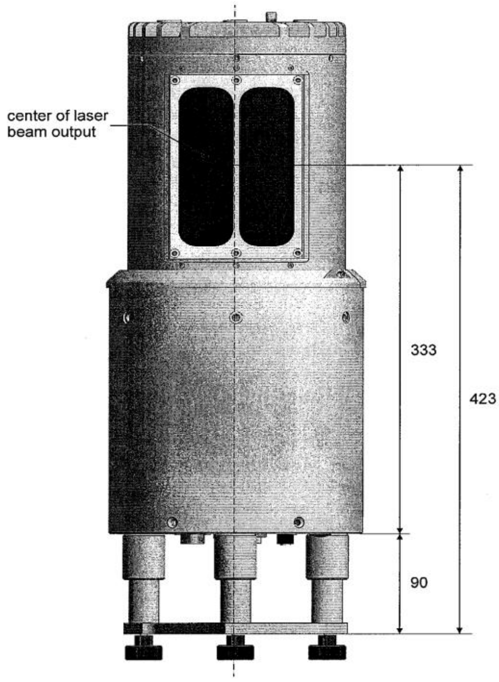


Figure 38 – Instrument reference heights when mounted on the vertical adapter in mm.

The value given from the scanners processing software was 12.064m as described earlier and the height of the instrument was measured to be 1.734m at the base of the scanner, as seen in Figure 38 it will be necessary to add an additional 0.333m to this figure to get the corrected height of the instrument on this occasion. This gives a result of 2.067m which when taken from the value of 12.064m gives a value for the reduced level at the benchmark of 9.997m, this is another good result indicating the calculation capabilities of the instrument as this value is only 3mm lower than the actual value of the benchmark at 10.000m.

4.8. Summary

Reviewing the testing that was undertaken as part of this research project it can be seen that in general the testing undertaken within the context of this study has provided consistently good results with significant amounts of valuable data to analyse. The results proved to be close to what was expected at the commencement of this research and again prior to the testing phase of this project. The results also indicate that the terrestrial laser scanner can be more than just a piece of equipment used solely for topographic surveys and modelling, there is justification for this equipment to be used more comprehensively in the surveying industry by firms who have undertaken the purchase of such instruments.

There was some difficulty in accessing the additional processing licences required to undertake some of the planned analysis of the data but this has not affected the reliability of the data presented in this report. The additional data would have served as supplementary data only and therefore has not affected the overall results presented. The additional analysis mostly involved the modelling of scanned surfaces within the processing software and then inspecting the residuals of the individual scan points to determine the relative accuracy of the modelling, this is more of a investigation of the capabilities of the processing software but may have shown additional irregularities not noticed in the preceding results and analysis.

Further conclusions and recommendations based on the whole body of this report will be presented in the subsequent section of this report.

5. CONCLUSIONS & RECOMMENDATIONS

5.1. Introduction

The main purpose of this chapter is to provide some conclusions and recommendations on the research and testing undertaken within this project based on the data collected and the results obtained from this significant amount of data.

The main aims and objectives of this project primarily arose from the requirement to prove to surveyors that terrestrial laser scanners do provide accurate and reliable measurements when operated proficiently and that there may be alternate uses for these instruments, outside what is considered normal operations. There have been many methods of data capture developed over the years and most methods have been embraced by the surveying industry, with these instruments being used in conjunction with traditional methods to produce a more cost effective and more accurate result.

The aims and objectives outlined in the first section of this report have been investigated thoroughly, with the required testing and analysis completed against the manufacturers published specifications. As well as this testing has been undertaken to determine the effectiveness of laser scanning equipment for alternate surveying tasks, with some best practice guidelines being outlined throughout the analysis and in the body of this conclusion.

5.2. Conclusions

Terrestrial laser scanning instruments have been applied in various fields of surveying, however this is still a relatively new technology to the surveying industry and as such the uses and limitations are relatively unknown to most professional surveyors. For the laser scanner to be accepted more widely as a practical surveying tool, the relative accuracies against more traditional methods needs to be examined. In addition to this the benefits of using the laser scanner need to be made known to the professional, providing the surveyor with an additional piece of equipment with which to achieve high quality results which may have been otherwise unattainable or extremely time consuming.

It has been seen that like all other surveying equipment, the terrestrial laser scanner is capable of being standardised, with this lending itself to the traceability of any measurements made by the instrument. This is especially important in an industry such as surveying where small mistakes in measurement can often lead to large financial settlements for those involved. Independent verification of measurement accuracies is important to ensure that equipment being used meets manufacturers stated specifications as a minimum. The testing within this project has been successful in showing that the distance measurement accuracies of this particular scanner are certainly achievable and with further testing it is expected that these favourable results will be continually evident in the analysis of any angular accuracy testing.

Testing and quality assurance is an important part of any surveying practice with considerable time and resources being spent on ensuring that the equipment being used from day to day is performing the required task within the manufacturer's specified tolerances. The same should be evident with terrestrial laser scanners, standard procedures for the verification of specified accuracies and the traceability of measurements need to be established much in the same manner as total stations and GPS instruments. The results of the testing undertaken in this report provides the basis for these procedures by adapting testing methods in use for total stations to terrestrial laser scanning operation.

5.3. Recommendations for Practical Applications

One of the factors in selecting the methods of testing undertaken was that although these instruments may be able to be used in conjunction with traditional instruments and surveying methodology for some type of cadastral and titling projects. It is expected that the specific area where this technology may be of most assistance is for complex cases of volumetric and lease surveys as well as encroachments, where there are significant irregularities in the defining surfaces or where there may be a cost saving by having access to the additional amount of data that a terrestrial laser scanner provides. A specific example of this type of survey work would be the creation of volumetric lots for any number of the many tunnel projects being undertaken.

Section 10.10.4 on page 53 in the Registrar of Titles Directions for the Preparation of Plans outlines the requirements needed for the provision of rectangular co-ordinates being used to define a volumetric parcel and states *The use of rectangular co-ordinates as part of the definition of a volumetric parcel is suggested when the volumetric parcel is of a complex nature* (Department of Natural Resources, Mines and Water 2006).

When undertaking projects with the additional level of accuracy required for cadastral surveys, it would be expected that survey companies would ensure that a minimum level of checking has been undertaken. Surveyors should expect that the minimum testing required would be that the scanner has completed a round of observations over a suitably calibrated EDME baseline within the past 12 months and that the operation of the instrument passes using the methodology used in this report for the basic testing facility, this would help firms to meet their quality assurance requirements. In addition to this, suitable redundant observations would need to be made whilst undertaking the survey by the location of additional common points between scans.

Another important result of the testing undertaken is the ability to estimate the range of measurements for road and highway applications, the ability to model the test data has allowed for an estimation of the density of scan locations that will be needed on these projects. The reduction of one scan location will result in approximately 30 minutes less field time and has the possibility of reducing man hours significantly over the course of a large scale project without affecting the integrity of the overall site survey. The testing of traversing capabilities also has the possibility of reducing the need of a secondary survey crew to place and located control marks used for the topographical survey. Provided that surveyors maintain good records of target and instrument heights as well as the instrument reference point being measured to, the problems found in the testing phase of this function should not be encountered.

As a minimum surveying firms who have undertaken the purchase or hire of terrestrial laser scanning instruments should be aware of the manufacturers stated specifications, these should be reviewed regularly to ensure that the capabilities that the scanner can provide will meet the required accuracies of the ask being undertaken. Further to this laser scanning instruments should be calibrated through the use of a suitably certified EDME baseline as indicated earlier in this report, this is to ensure that the scanner is measuring within the distance specifications outlined by the manufacturer and will provide traceability of the observed measurements. The frequency of these calibrations shall be as directed in relevant state legislation for total station instruments with the maximum time between calibrations being 12 months. In an attempt to reduce the issues encountered in the testing due to wind effects, it is recommended that a minimum of 10 measurements be made to each pillar. As an additional check to the operational status of the terrestrial laser scanner between calibrations, it is recommended that the instrument be tested in a suitably basic test facility as outline earlier. This will ensure that the instrument is measuring correctly, with these checks being undertaken at pre determined intervals or when required for high precision projects. Records of these tests will provide the surveying company with confidence in their measurements and data output especially when queried by a client or other third party, this is especially important when utilising hire equipment where a user may not be familiar with the manner in which the instrument has been handled in the past.

5.4. Recommendations for Future Research

There is still sufficient scope for further research into the testing of terrestrial laser scanners that can provide valuable data for both surveyors and the instrument manufacturers. Of most value would be to conduct the same testing on a variety of different instruments, as many of the instrument manufacturers have their laser scanners operating within different laser wavelengths. This will be especially evident conducting additional testing on ability to scan objects in water and the interference of water, where as the wavelength of the laser gets shorter the penetration into water bodies should increase as outlined in the research.

Testing into the performance characteristics of other terrestrial laser scanning systems under the same conditions, this would provide a good measure of how the different instrument configurations affect the end result and will also provide additional data to confirm whether the methods of testing undertaken within this project are suitable across a broad range of instruments. The additional testing may indicate that some slight changes may need to be considered and made to the established testing procedures.

Whilst the testing within this report has confirmed that the measurement accuracies of this terrestrial laser scanner scan can be confirmed and verified allowing traceability of the measurements made, it is important to progress the findings of this research further by conducting testing on the proposed additional uses of the laser scanning system. Initial testing would be undertaken in conjunction with traditional methods to establish the suitability of using this technology and determining the differences between the number of points, quality of points and the time taken for location and processing.

5.5. Summation

Finally it should be noted that terrestrial laser scanning instruments are powerful surveying tools which have both accuracy and economic benefits, when used correctly. This includes the use of QA procedures for the clear and concise arrangement of survey evidence, which can be achieved by following the procedures developed in this dissertation.

The RIEGL LMS-Z620 terrestrial laser scanning system has been shown to perform as claimed by the manufacturer and is suitable not only for its current marketed surveying tasks but also for applications in cadastral surveying. This research has therefore achieved it aim of evaluating the performance of the RIEGL LMS-Z620 instrument.

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7. APPENDICIES

7.1. Appendix A

Project Specification

Appendix A

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project
PROJECT SPECIFICATION

FOR: **Damian James LING**

TOPIC: INVESTIGATION OF THE USES AND LIMITATIONS OF RIEGL TERRESTRIAL SCANNERS

SUPERVISOR: Assoc Prof Armando Apan
Mr Glenn Campbell
Mr Nick McKelvey

PROJECT AIM: This project seeks to investigate the limitations and examine alternate uses of terrestrial laser scanning systems for surveying companies, specifically the REIGL LMS instrument.

SPONSORSHIP: Conics (Brisbane) Pty Ltd

PROGRAMME: (Issue B – Monday, 16 March 2009)

1. Research existing literature with respect to the use and limitations of terrestrial scanners.
2. Research the background information relating to the REIGL instrument and terrestrial laser scanning technology, current and possible applications.
3. Design a field measurement programme and collect sufficient data to confirm the stated accuracies and limitations specified by instrument manufacturer.
4. Design a field measurement programme to investigate the possible uses of terrestrial laser scanners whilst ensuring that these methods meet legislative and quality assurance requirements required for many types of survey work.
5. Analyse gathered data and evaluate the limitations and potential for using terrestrial scanning technology to assist in cadastral projects.
6. Submit an academic dissertation on the research.

AGREED:

Damian Ling — Student 23/3/ 2009

Armando Apan — Supervisor _/_/ 2009

Examiner / Co-Examiner: __________ _/_/ 2009

7.2. Appendix B

RIEGL LMS-Z620 Datasheet and Specifications

EXTRA LONG RANGE & HIGH ACCURACY 3D TERRESTRIAL LASER SCANNER SYSTEM

LMS-Z620

The terrestrial laser scanner system *RIEGL* LMS-Z620 consists of a high performance long-range 3D scanner, the accompanying operating and processing software RiSCAN PRO, and a calibrated and accurately orientated and mounted high-resolution digital camera.

The system provides data which lends itself to automatic or semi-automatic processing of scan- and image data to generate products such as textured triangulated surfaces and high resolution panorama images as a basis for e.g. geotechnical analysis and mining assessment.

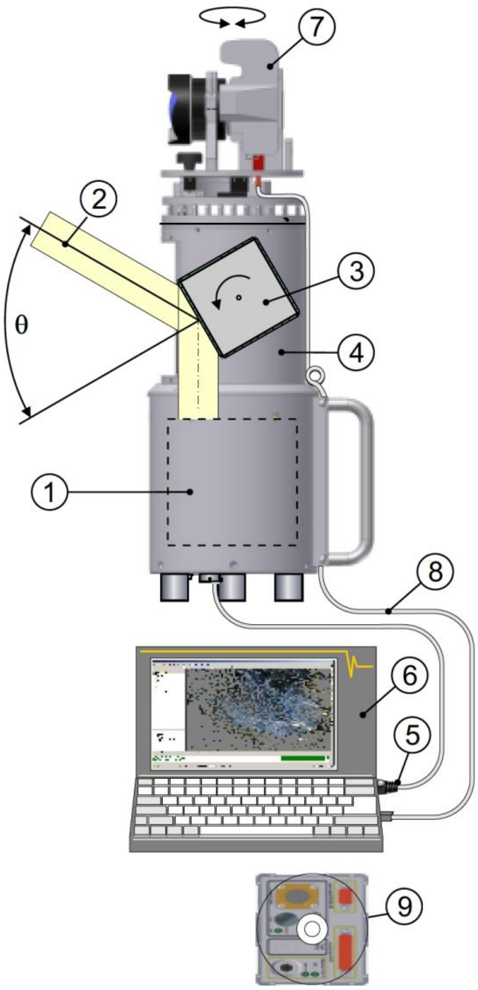
The *RIEGL* LMS-Z620 is a rugged and fully portable sensor especially designed for the rapid acquisition of high-quality three dimensional images even under highly demanding environmental conditions, providing a unique and unrivalled combination of a wide field-of-view, high maximum range, and fast data acquisition.
A standard Windows notebook and the bundled software package RiSCAN PRO enable the user to instantly acquire high-quality 3D data in the field and provide a variety of registration, post processing and export functions.

- ***Topography & Mining***
- ***Monitoring & Civil Engineering***
- ***Archaeology & Cultural Heritage Documentation***
- ***Architecture & Facade Measurement***

visit our webpage
www.riegl.com

RIEGL
LASER MEASUREMENT SYSTEMS

Principle of Scanner Operation



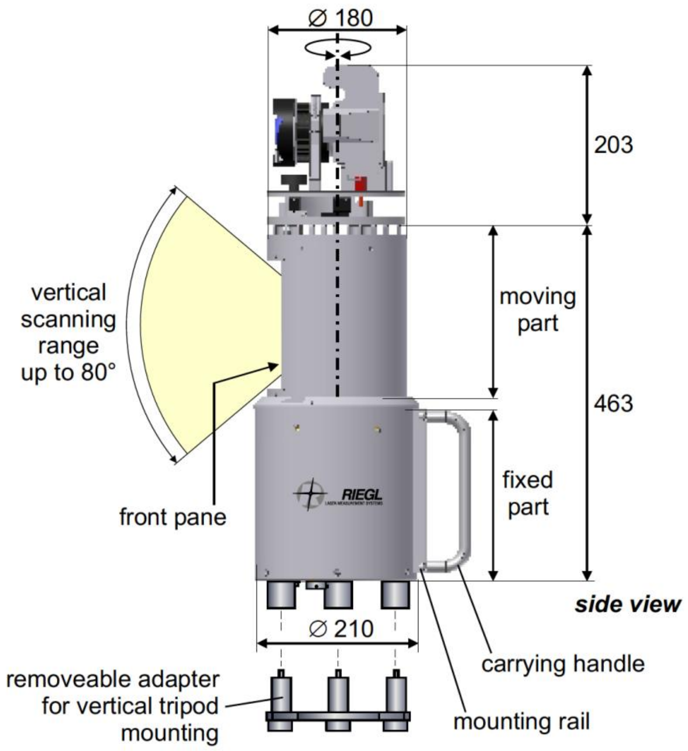
The **range finder electronics (1)** of the 3D scanner *RIEGL* LMS-620 are optimized in order to meet the requirements of high speed scanning (high laser repetition rate, fast signal processing, and high speed data interface).

The *vertical deflection* ("line scan") of the **laser beam (2)** is realized by a **polygon (3)** with a number of reflective surfaces. For high scanning rates and/or a vertical scan angle of θ up to 80°, the polygonal mirror continuously rotates at an adjustable speed. For slow scanning rates and/or small scanning angles, it linearly oscillates up and down. The *horizontal scan* ("frame scan") is realized by rotating the complete **optical head (4)** up to 360°.

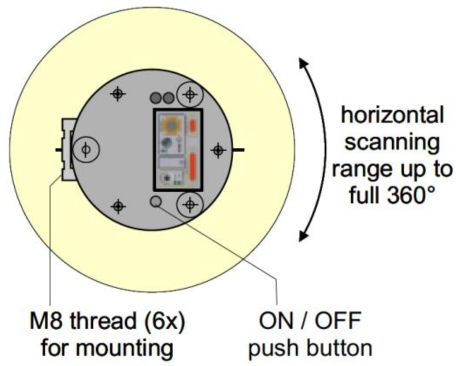
Scandata: RANGE, ANGLE, SIGNAL AMPLITUDE, and optional TIMESTAMP are transmitted to a **laptop (6)** via **TCP/IP Ethernet Interface (5)**. **Camera (7)** data is fed into the same laptop via **USB/firewire interface (8)**.

The RiSCAN PRO software (9) allows the operator to perform a large number of tasks including sensor configuration, data acquisition, data visualization, data manipulation, and data archiving. RiSCAN PRO runs on the platforms WINDOWS XP or 2000 SP2.

Dimensional Drawings



side view



bottom view

Technical Data 3D Scanner Hardware *RIEGL* LMS-Z620

Rangefinder performance [1]

Eye safety class	CLASS 1 LASER PRODUCT according to IEC60825-1:1993+A1:1997+A2:2001. The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated July 26, 2001.
Max. Measurement range [2]	
for natural targets, $\rho \geq 80$ %	up to 2000 m
for natural targets, $\rho \geq 10$ %	up to 650 m
Minimum range	2 m
Accuracy [3) 5)]	10 mm
Repeatability [4) 5)]	10 mm (single shot), 5 mm (averaged)
Measurement rate	up to 11000 pts/sec @ low scanning rate (oscillating mirror) up to 8000 pts/sec @ high scanning rate (rotating mirror)
Laser wavelength	near infrared
Beam divergence [6]	0.15 mrad

1) First, Last, or Alternating Target Mode selectable.

2) Typical values under average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter and near perpendicular incidence of the laser beam and atmospheric visibility in excess of 23 km. In bright sunlight, the operational range is considerably shorter than under an overcast sky.

3) Accurcy is the degree of conformity of a measured quantity to its actual (true) value.

4) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.

5) One sigma @ 100 m range under *RIEGL* test conditions.

6) 0.15 mrad correspond to 15 mm increase of beamwidth per 100 m of range.

Scanner performance

Vertical (line) scan	
Scanning range	0° to 80°
Scanning mechanism	rotating / oscillating mirror
Scanning rate	1 scan/sec to 20 scans/sec @ 80° scanning range
Angle stepwidth $\Delta\vartheta$ [7] between consecutive laser shots	$0.004° \leq \Delta\vartheta \leq 0.2°$
Angular resolution	0.002°
Horizontal (frame) scan	
Scanning range	0° to 360°
Scanning mechanism	rotating optical head
Scanning rate [8]	0.01 °/sec to 15 °/sec
Angle stepwidth $\Delta\varphi$ [7] between consecutive scan lines	$0.004° \leq \Delta\varphi \leq 0.75°$
Angular resolution	0.0025°
Inclination Sensors	integrated, for vertical scanner setup position (specifications to be found in separate datasheet)
Internal Sync Timer	Option for GPS-synchronized time stamping of scan data (specifications to be found in separate datasheet)

7) Selectable via Ethernet Interface or RS232.

8) Horizontal scan can be disabled, providing 2D-scanner operation.

General technical data

Interface: for configuration & data output	TCP/IP Ethernet, 10/100 MBit/sec
for configuration	RS 232, 19.2 kBd
for data output	ECP standard (enhanced capability port) parallel
Power supply input voltage	12 - 28 V DC
Power consumption	typ. 75 W, max 85 W
Current consumption	typ. 6.25 A, max 7.1 A @ 12 V DC; typ. 3.13 A, max 3.54 A @ 24 V DC
Main dimensions	463 mm x 210 mm (length x diameter)
Weight	16 kg
Temperature range	0°C to +40°C (operation), -10°C to +50°C (storage)
Protection class	IP64, dust and splash-water proof

Data sheet, LMS-Z620, 13/08/2008

RIEGL LASER MEASUREMENT SYSTEMS
www.riegl.com

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RIEGL USA Inc., Orlando, Florida 32819, USA
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RIEGL Japan Ltd., Tokyo 1640013, Japan
Tel.: +81-3-3382-7340, Fax: +81-3-3382-5843, E-mail: info@riegl-japan.co.jp

7.3. Appendix C

Leica ScanStation C10 Instrument Specifications

Leica ScanStation C10
Product Specifications

General	
Instrument type	Compact, pulsed, dual-axis compensated, very high speed laser scanner, with survey-grade accuracy, range, and field-of-view; integrated camera and laser plummet
User interface	Onboard control, notebook or tablet PC
Data storage	Integrated hard drive or external PC
Camera	Auto-adjusting, integrated high-resolution digital camera with zoom video

System Performance	
Accuracy of single measurement	
Position*	6 mm
Distance*	4 mm
Angle (horizontal/vertical)	60 µrad / 60 µrad (12" / 12")
Modeled surface precision/noise**	2 mm
Target acquisition***	2 mm std. deviation
Dual-axis compensator	Selectable on/off, resolution 1", dynamic range +/- 5', accuracy 1.5"

Laser Scanning System	
Type	Pulsed; proprietary microchip
Color	Green, wavelength = 532 nm
Laser Class	3R (IEC 60825-1)
Range	300 m @ 90%; 134 m @ 18% albedo (minimum range 0.1 m)
Scan rate	Up to 50,000 points/sec, maximum instantaneous rate
Scan resolution	
Spot size	From 0 – 50 m: 4.5 mm (FWHH-based); 7 mm (Gaussian-based)
Point spacing	Fully selectable horizontal and vertical; < 1 mm minimum spacing, through full range; single point dwell capacity
Field-of-View	
Horizontal	360° (maximum)
Vertical	270° (maximum)
Aiming/Sighting	Parallax-free, integrated zoom video
Scanning Optics	Vertically rotating mirror on horizontally rotating base; Smart X-Mirror™ automatically spins or oscillates for minimum scan time
Data storage capacity	80 GB (onboard hard disk)
Communications	Dynamic Internet Protocol (IP) Address, Ethernet
Intergrated color digital camera with zoom video	Single 17° x 17° image: 1920 x 1920 pixels (4 megapixels) Full 360° x 270° dome: 230 images; streaming video with zoom; auto-adjusts to ambient lighting
Onboard display	Touchscreen control with stylus, full colour graphic display, QVGA (320 x 240 pixels)
Level indicator	External bubble, electronic bubble in onboard control and Cyclone software
Data transfer	Ethernet or USB 2.0 device
Laser plummet	Laser class: 2 (IEC 60825-1) Centering accuracy: 1.5 mm @ 1.5 m Laser dot diameter: 2.5 mm @ 1.5 m Selectable ON/OFF

Electrical	
Power supply	15 V DC, 90 – 260 V AC
Power Consumption	< 50 W avg.
Battery Type	Internal: Li-Ion; External: Li-Ion
Power Ports	Internal: 2, External: 1 (simultaneous use, hot swappable)
Duration	Internal: >3.5 h (2 batteries), External: >6 h (room temp)

Environmental	
Operating temp.	0° C to 40° C / 32° F to 104° F
Storage temp.	-25° C to +65° C / -13° F to 149° F
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing
Dust/humidity	IP54 (IEC 60529)

Physical	
Scanner	
Dimensions (D x W x H)	238 mm x 358 mm x 395 mm / 9.4" x 14.1" x 15.6"
Weight	13 kg / 28.7 lbs, nominal (w/o batteries)
Battery (internal)	
Dimensions (D x W x H)	40 mm x 72 mm x 77 mm / 1.6" x 2.8" x 3.0"
Weight	0.4 kg / 0.9 lbs
Battery (external)	
Dimensions (D x W x H)	95 mm x 248 mm x 60 mm / 3.7" x 9.8" x 2.4"
Weight	1.9 kg / 4.2 lbs
AC Power Supply	
Dimensions (D x W x H)	85 mm x 170 mm x 41 mm / 3.4" x 6.7" x 1.6"
Weight	0.9 kg / 1.9 lbs

Standard Accessories Included
Scanner transport case
Tribrach (Leica Professional Series)
4x Internal batteries
Battery charger/AC power cable, Car adapter, Daisy chain cable
Data cable
Height meter and distance holder for height meter
Cleaning kit
Cyclone™ SCAN software
1year CCP Basic support agreement

Additional Accessories
HDS scan targets and target accessories
Service agreement for Leica ScanStation C10
Extended warranty for Leica ScanStation C10
External battery with charging station, AC power supply and power cable
Professional charger for internal batteries
AC power supply for scanner
Tripod, tripod star, rolling base

Notebook PC for scanning with Cyclone software	
Component	**required (minimum)**
Processor	1.7 GHz Pentium M or higher
RAM	1 GB (2 GB for Windows Vista)
Network card	Ethernet
Display	SVGA or OpenGL accelerated graphics card (with latest drivers)
Operating system	Windows XP Professional (SP2 or higher) (32 or 64) Windows Vista (32 or 64)

Control Options
Full colour touch screen for onboard scan control
Leica Cyclone SCAN software for laptop PC
(see Leica Cyclone SCAN data sheet for full list of features)

Ordering Information
Contact Leica Geosystems or authorized representatives

All specifications are subject to change without notice.
All ± accuracy specifications are one sigma unless otherwise noted.
* At 1 m – 50 m range, one sigma
** Subject to modeling methodology for modeled surface
*** Algorithmic fit to planar HDS targets
Δ Minimum requirements for modeling operations are different. Refer to Cyclone data sheet specifications

Laser class 3R in accordance with IEC 60825-1 resp. EN 60825-1
Laser class 2 in accordance with IEC 60825-1 resp. EN 60825-1

Windows is a registered trademark of Microsoft Corporation. Other trademarks and trade names are those of their respective owners.

776241en – IX.09 – RDV

Leica Geosystems AG
Heerbrugg, Switzerland

www.leica-geosystems.com/hds

- when it has to be **right**

Leica Geosystems

7.4. Appendix D

Coombabah EDME Baseline Certificate

Queensland Government

BASE NAME : **GOLD COAST** (QldBase.005.2008)

Department of Natural Resources and Water, Locked Bag 40, Coorparoo Delivery Centre, Queensland 4151.
Telephone: (07) 3896 3037 Email: alan.spence@nrw.qld.gov.au

Certificate of Verification of a Reference Standard of Measurement in Accordance with Regulation 13 of the National Measurement Regulations 1999 in Accordance with the *National Measurement Act 1960*

Description of standard of measurement: Electronic Distance Measurement Baseline consisting of six concrete pillars within the Coombabah Sewerage Treatment Plant.

Permanent distinguishing marks: Numerals 1 to 7 marked on pillars.

Date of verification: 10 July 2008

Date of expiry of certificate: 10 July 2010, on the condition that the monumentation remains undisturbed.

Values of standard of measurement: The base linear distances herein have been established by point to point measurement, corrected for slope, offset and datum plane. The base alignment is from Station 1 to Station 7. Negative offsets are to the left of the line viewed from Station 1. Datum Plane is based on Reduced Level (RL): 0.0 metres.

Station No.	RL (metres)	Offsets (metres)	Distance (metres)
1	3.125	0.000	0.000
2	2.311	0.192	206.447
3	3.098	-0.988	543.930
4	2.913	0.749	811.955
5	2.834	-0.703	960.844
6	2.967	0.000	990.270
7	3.368	-0.499	1051.627

Method of verification: *Calibration of Electronic Distance Measuring Equipment* 1986 and National Standards Commission's Verifying Authorities Handbook (Second Edition November 1988).

Uncertainty of value: ± (0.5 mm + 1.3 ppm)

This uncertainty is calculated in accordance with the principles of the *ISO Guide to the Expression of Uncertainty in Measurement* (1995), with an interval estimated to have a confidence level of 95% at the time of verification and a coverage factor (k) of 2.

Signature: A L Spence

Date of issue: 14 August 2008

Name of signatory: Alan Spence

Position: Queensland EDM Calibration Officer

Being a person, or a person representing a body, appointed as a verifying authority under Regulations 71 and 73 of the National Measurement Regulations 1999 in accordance with the *National Measurement Act 1960*, I hereby certify that the above standard is verified as a reference standard of measurement in accordance with the Regulations by the above named authority.

NATA

The tests, calibrations or measurements covered by this document have been performed in accordance with NATA requirements which include the requirements of ISO/IEC 17025 and are traceable to Australian national standards of measurement. This document shall not be reproduced, except in full.
NATA Accredited Laboratory Number: 15032

7.5. Appendix E

Example 3D StarNet Input File

```
# Starnet File:  S:\Projects\22000\22300\22321\StarNet\22321control_djl.dat created by
PmmSurvey.
# Date Created:  Wednesday 29 April, 2009
# Time        :  7:41:02 AM
# These obs are 3 Dimensional.

# __ Begin Observations in SDR file:
S:\Projects\22000\22300\22321\Downloads\22321so210409.sdr __
# ____________ Control from SDR ____________
#C Stn        East           North          RL
C  9999       1280.775       4830.295       26.872        * * * # Description
C  9999       1280.775       4830.295       26.872        * * * # Description
C  332        1393.293       4847.635       20.641        ! ! * # Description
C  9997       1376.073       4955.125       22.601        * * * # Description
C  9995       1305.827       4864.606       25.398        * * * # Description
C  9993       1262.182       4894.441       26.797        * * * # Units of pressure fields
within file
C  9989       1150.346       4855.898       29.997        * * * # Units of pressure fields
within file
C  9981       1041.033       4736.882       34.509        * * * # Units of pressure fields
within file

.2d
B  332-9002   300.2202   !
D  332-9002   100.483    *

B  9004-9003  116.1749   !
D  9004-9003  97.089     *
.3d

C  9002       1306.597       4898.431       25.437        * * !
C  9003       1123.456       4684.163       30.486        ! ! *
C  9004       1036.415       4727.176       34.756        * * !
C  358        1159.343       4890.365       30.355        ! ! *

# ____________ Station 332 ____________
#M AT-FROM-TO                Angle          Slope Dist     Zen Angle      HI/HT
DV 332-9002    100.6073430342                87.1259       1.706/1.805
M  332-9002-9997              50.3154       108.873         89.0359       1.706/1.52     ' simh
M  332-9002-9998              295.3313      83.886          86.5          1.706/1.58     ' nik
DV 332-9002    100.607268033825              87.1258       1.706/1.805
M  332-9002-9997              50.3154       108.872         89.0359       1.706/1.52     ' simh
M  332-9002-9998              295.3312      83.886          86.4955       1.706/1.58     ' nik
DV 332-9002    100.60727303385               87.1259       1.706/1.805
M  332-9002-9996              356.3833      37.043          85.4543       1.706/1.53     ' sigt
DV 332-9002    100.60707303285               87.1258       1.706/1.805
M  332-9002-9996              356.3833      37.044          85.4544       1.706/1.53     ' sigt

# ____________ Station 9997 ____________
#M AT-FROM-TO                Angle          Slope Dist     Zen Angle      HI/HT
DV 9997-332    108.873749366025              90.561        1.52/1.705
M  9997-332-9996              18.55         92.062          89.2412       1.52/1.53      ' sigt
DV 9997-332    108.874259368575              90.561        1.52/1.705
M  9997-332-9996              18.5501       92.061          89.2414       1.52/1.53      ' sigt
DV 9997-332    108.8746643706                90.5609       1.52/1.705
M  9997-332-9995              46.5451       114.613         88.3126       1.52/1.676     ' sik
DV 9997-332    108.87469437075               90.5609       1.52/1.705
M  9997-332-9995              46.5451       114.613         88.3127       1.52/1.676     ' sik

# ____________ Station 9995 ____________
#M AT-FROM-TO                Angle          Slope Dist     Zen Angle      HI/HT
DV 9995-9997   114.61228305855               91.2843       1.676/1.52
M  9995-9997-332              63.1005       89.222          93.0226       1.676/1.705    ' sic
M  9995-9997-9996             52.2321       54.587          92.0542       1.676/1.53     ' sigt
DV 9995-9997   114.612598060125              91.2841       1.676/1.52
M  9995-9997-332              63.1005       89.222          93.0227       1.676/1.705    ' sic
M  9995-9997-9996             52.2322       54.588          92.0542       1.676/1.53     ' sigt
DV 9995-9997   114.612373059                 91.2843       1.676/1.52
```

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DV 9995-9997   114.61248305955        91.2844     1.676/1.52
M  9995-9997-9993             266.3219   52.881      88.2649     1.676/1.719   ' sik
M  9995-9997-9002             323.2835   33.833      90.0021     1.676/1.644   ' pin
DV 9995-9997   114.612318058725       91.2844     1.676/1.52
M  9995-9997-9993             266.3218   52.882      88.2649     1.676/1.719   ' sik
M  9995-9997-9002             323.2832   33.834      90.0021     1.676/1.644   ' pin

# _____________  Station 9993  _____________
#M AT-FROM-TO                 Angle      Slope Dist  Zen Angle   HI/HT
DV 9993-9995   52.88411653562         91.353      1.727/1.648
M  9993-9995-9002             320.3022   44.605      91.4411     1.727/1.738   ' pin
M  9993-9995-9992             177.5121   67.138      89.4424     1.727/1.645   ' sik
DV 9993-9995   52.88464653774         91.3531     1.727/1.648
M  9993-9995-9002             320.3022   44.605      91.4411     1.727/1.738   ' pin
M  9993-9995-9992             177.5122   67.137      89.4423     1.727/1.645   ' sik
DV 9993-9995   52.88382653446         91.3532     1.727/1.648
M  9993-9995-9994             318.5208   42.208      91.4016     1.727/1.635   ' osimh
DV 9993-9995   52.88420153596         91.3532     1.727/1.648
M  9993-9995-9994             318.5208   42.207      91.4016     1.727/1.635   ' osimh
DV 9993-9995   52.88421653602         91.3532     1.727/1.648
M  9993-9995-9999             39.2908    66.779      89.5858     1.727/1.679   ' nik
DV 9993-9995   52.88388153468         91.3531     1.727/1.648
M  9993-9995-9999             39.2908    66.780      89.5859     1.727/1.679   ' nik
DV 9993-9995   52.88354153332         91.3531     1.727/1.648
M  9993-9995-9991             48.3145    115.243     91.07       1.727/1.636   ' sik
DV 9993-9995   52.88363153368         91.3531     1.727/1.648
M  9993-9995-9991             48.3146    115.244     91.0705     1.727/1.636   ' sik
DV 9993-9995   52.88350653318         91.3531     1.727/1.648
M  9993-9995-9990             90.5034    80.296      88.5038     1.727/1.658   ' sic
DV 9993-9995   52.88364153372         91.3532     1.727/1.648
M  9993-9995-9990             90.5034    80.295      88.5039     1.727/1.658   ' sic
DV 9993-9995   52.8832865323          91.3531     1.727/1.648
M  9993-9995-9989             126.3751   118.331     88.2941     1.727/1.635   ' sik
DV 9993-9995   52.88312653166         91.3532     1.727/1.648
M  9993-9995-9989             126.3752   118.331     88.2941     1.727/1.635   ' sik

# _____________  Station 9989  _____________
#M AT-FROM-TO                 Angle      Slope Dist  Zen Angle   HI/HT
DV 9989-9993   118.33355833234        91.3052     1.642/1.72
M  9989-9993-9990             41.2644    70.947      91.1301     1.642/1.648   ' sic
M  9989-9993-9992             325.3159   92.526      91.4439     1.642/1.645   ' sik
DV 9989-9993   118.33349333208        91.3051     1.642/1.72
M  9989-9993-9990             41.2645    70.947      91.1301     1.642/1.648   ' sic
M  9989-9993-9992             325.3202   92.526      91.4438     1.642/1.645   ' sik
DV 9989-9993   118.33316333076        91.305      1.642/1.72
M  9989-9993-9988             235.1257   101.827     89.2221     1.642/1.739   ' sik
DV 9989-9993   118.33344333188        91.305      1.642/1.72
M  9989-9993-9988             235.1257   101.827     89.222      1.642/1.739   ' sik
DV 9989-9993   118.33249332808        91.305      1.642/1.72
M  9989-9993-9987             211.5231   116.000     88.5338     1.642/1.755   ' sik
DV 9989-9993   118.33272832902        91.305      1.642/1.72
M  9989-9993-9987             211.523    116.001     88.5335     1.642/1.755   ' sik
DV 9989-9993   118.33250332812        91.3052     1.642/1.72
M  9989-9993-9986             184.484    118.866     88.3652     1.642/1.755   ' sik
DV 9989-9993   118.33308333044        91.3049     1.642/1.72
M  9989-9993-9986             184.484    118.866     88.3652     1.642/1.755   ' sik
DV 9989-9993   118.33236332756        91.3051     1.642/1.72
M  9989-9993-358              303.3848   35.624      89.065      1.642/1.841   ' pin
DV 9989-9993   118.33225332712        91.305      1.642/1.72
M  9989-9993-358              303.3846   35.625      89.065      1.642/1.841   ' pin
DV 9989-9993   118.33314333068        91.3052     1.642/1.72
M  9989-9993-9985             146.1516   41.056      88.2143     1.642/1.694   ' nik
DV 9989-9993   118.33273332904        91.3049     1.642/1.72
M  9989-9993-9985             146.1519   41.056      88.2142     1.642/1.694   ' nik
DV 9989-9993   118.33274332908        91.305      1.642/1.72
M  9989-9993-9984             140.0848   95.402      88.5451     1.642/1.522   ' sik
DV 9989-9993   118.33276832918        91.3047     1.642/1.72
M  9989-9993-9984             140.085    95.402      88.5451     1.642/1.522   ' sik
DV 9989-9993   118.33217832682        91.3049     1.642/1.72
M  9989-9993-9981             151.3455   161.673     88.1601     1.642/2.02    ' pin
DV 9989-9993   118.33276832918        91.3049     1.642/1.72
M  9989-9993-9981             151.3457   161.673     88.1601     1.642/2.02    ' pin

# _____________  Station 9981  _____________
#M AT-FROM-TO                 Angle      Slope Dist  Zen Angle   HI/HT
DV 9981-9989   161.67200168542        91.442      2.019/1.635
M  9981-9989-9986             313.411    90.074      91.1705     2.019/1.755   ' sik
```

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M  9981-9989-9988               326.0303    181.238      91.1311     2.019/1.666     ' sik
DV 9981-9989   161.67141668308     91.442     2.019/1.635
M  9981-9989-9986               313.411     90.073       91.1704     2.019/1.755     ' sik
M  9981-9989-9988               326.0304    181.238      91.1309     2.019/1.666     ' sik
DV 9981-9989   161.6717216843      91.4419    2.019/1.635
M  9981-9989-9987               315.5652    144.903      91.045      2.019/1.678     ' sik
DV 9981-9989   161.67126668248     91.4419    2.019/1.635
M  9981-9989-9987               315.5652    144.902      91.045      2.019/1.678     ' sik
DV 9981-9989   161.67163668396     91.442     2.019/1.635
M  9981-9989-9985               1.4821      120.853      91.4556     2.019/1.692     ' nik
DV 9981-9989   161.67132668272     91.4418    2.019/1.635
M  9981-9989-9985               1.4821      120.853      91.4556     2.019/1.692     ' nik
DV 9981-9989   161.6715466836      91.442     2.019/1.635
M  9981-9989-9213               261.5745    33.018       89.3152     2.019/1.786     ' pin
M  9981-9989-9980               68.3102     50.554       93.1941     2.019/1.618     ' sik
DV 9981-9989   161.67082668072     91.4419    2.019/1.635
M  9981-9989-9213               261.5745    33.018       89.3152     2.019/1.786     ' pin
M  9981-9989-9980               68.3102     50.554       93.194      2.019/1.618     ' sik
DV 9981-9989   161.67126168246     91.4419    2.019/1.635
M  9981-9989-9004               162.5454    10.751       89.5201     2.019/1.809     ' pin
DV 9981-9989   161.67121668228     91.4418    2.019/1.635
M  9981-9989-9004               162.5454    10.752       89.5201     2.019/1.809     ' pin
DV 9981-9989   161.6707966806      91.442     2.019/1.635
M  9981-9989-9003               80.0231     97.913       92.2048     2.019/2.035     ' pin
DV 9981-9989   161.67057667972     91.4419    2.019/1.635
M  9981-9989-9003               80.0236     97.911       92.2045     2.019/2.035     ' pin

# ____________  Station 9003  ____________
#M AT-FROM-TO                 Angle         Slope Dist    Zen Angle    HI/HT
DV 9003-9981   97.92366169308      87.3102    1.914/2.144
M  9003-9981-9979               75.4229     74.209       89.5746     1.914/1.674     ' sik
M  9003-9981-9980               11.4616     49.430       88.4144     1.914/1.555     ' sik
DV 9003-9981   97.9233666919       87.3102    1.914/2.144
M  9003-9981-9979               75.4225     74.209       89.5747     1.914/1.674     ' sik
M  9003-9981-9980               11.4613     49.430       88.4143     1.914/1.555     ' sik

# ____________  Station 9979  ____________
#M AT-FROM-TO                 Angle         Slope Dist    Zen Angle    HI/HT
DV 9979-9003   74.21068684156      90.0207    1.676/1.915
M  9979-9003-9984               94.5534     49.782       88.4928     1.676/1.55      ' sik
DV 9979-9003   74.21040684044      90.021     1.676/1.915
M  9979-9003-9984               94.5534     49.781       88.493      1.676/1.55      ' sik
DV 9979-9003   74.21023183974      90.0212    1.676/1.915
M  9979-9003-9978               246.2052    80.722       92.2416     1.676/1.684     ' dpy
DV 9979-9003   74.2100218389       90.0213    1.676/1.915
M  9979-9003-9978               246.2051    80.722       92.2417     1.676/1.684     ' dpy

# ____________  Station 9978  ____________
#M AT-FROM-TO                 Angle         Slope Dist    Zen Angle    HI/HT
DV 9978-9979   80.72236288816      87.355     1.686/1.675
M  9978-9979-9989               56.0318     121.192      88.4722     1.686/1.638     ' sik
DV 9978-9979   80.72280788994      87.3551    1.686/1.675
M  9978-9979-9989               56.0316     121.191      88.4722     1.686/1.638     ' sik
DV 9978-9979   80.72191788638      87.355     1.686/1.675
M  9978-9979-330                215.0922    100.187      93.1524     1.686/1.987     ' psm
M  9978-9979-9977               208.0625    48.819       92.1605     1.686/1.69      ' sifi
DV 9978-9979   80.72139288428      87.355     1.686/1.675
M  9978-9979-330                215.0918    100.187      93.1528     1.686/1.987     ' psm
M  9978-9979-9977               208.0625    48.820       92.1605     1.686/1.69      ' sifi

# ____________  Station 330  ____________
#M AT-FROM-TO                 Angle         Slope Dist    Zen Angle    HI/HT
DV 330-9978    100.19591078204     86.4014    1.854/1.686
M  330-9978-332                 90.3641     156.858      90.1224     1.854/2.06      ' sic
M  330-9978-9977                6.3656      52.104       85.4253     1.854/1.69      ' sifi
DV 330-9978    100.194150775       86.4008    1.854/1.686
M  330-9978-332                 90.3647     156.858      90.1218     1.854/2.06      ' sic
M  330-9978-9977                6.37        52.104       85.4251     1.854/1.69      ' sifi

# ____________  Station 9988  ____________
#M AT-FROM-TO                 Angle         Slope Dist    Zen Angle    HI/HT
DV 9988-9989   101.82681865323     90.3733    1.754/1.664
M  9988-9989-9986               74.0558     95.224       89.0246     1.754/1.597     ' sik
DV 9988-9989   101.82702365364     90.3733    1.754/1.664
M  9988-9989-9986               74.0559     95.223       89.0244     1.754/1.597     ' sik
DV 9988-9989   101.82583865127     90.3733    1.754/1.664
M  9988-9989-9976               203.5452    65.967       89.3101     1.754/1.62      ' sik
```

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DV 9988-9989   101.82625865211          90.3733      1.754/1.664
M  9988-9989-9976             203.5453  65.967        89.3102      1.754/1.62     ' sik
DV 9988-9989   101.82688365336          90.3733      1.754/1.664
M  9988-9989-9974             128.0659  119.346       88.4213      1.754/1.72     ' sik
M  9988-9989-9975             147.3511  76.740        88.4705      1.754/1.591    ' sik
DV 9988-9989   101.82634365228          90.3733      1.754/1.664
M  9988-9989-9974             128.0701  119.345       88.4213      1.754/1.72     ' sik
M  9988-9989-9975             147.3512  76.741        88.4706      1.754/1.591    ' sik

# ____________  Station 9974  ____________
#M AT-FROM-TO                Angle         Slope Dist    Zen Angle    HI/HT
DV 9974-9988   119.34564369081          91.1758      1.72/1.752
M  9974-9988-9975             331.2615  53.499        91.0907      1.72/1.591     ' sik
DV 9974-9988   119.34430868814          91.1758      1.72/1.752
M  9974-9988-9975             331.2615  53.499        91.0908      1.72/1.591     ' sik
DV 9974-9988   119.34536369025          91.1758      1.72/1.752
M  9974-9988-9973             236.2901  49.680        90.1522      1.72/1.725     ' nic
DV 9974-9988   119.34545369043          91.1758      1.72/1.752
M  9974-9988-9973             236.29    49.680        90.1522      1.72/1.725     ' nic

# ____________  Station 9973  ____________
#M AT-FROM-TO                Angle         Slope Dist    Zen Angle    HI/HT
DV 9973-9974   49.67968435917           89.4443      1.729/1.72
M  9973-9974-9972             279.5044  57.251        92.543       1.729/0.12     ' onik
DV 9973-9974   49.68016436013           89.4443      1.729/1.72
M  9973-9974-9972             279.5049  57.250        92.5432      1.729/0.12     ' onik
DV 9973-9974   49.68010436001           89.4443      1.729/1.72
M  9973-9974-9971             277.3112  75.187        92.275       1.729/0.12     ' onic
DV 9973-9974   49.67955935892           89.4443      1.729/1.72
M  9973-9974-9971             277.3109  75.188        92.2748      1.729/0.12     ' onic
DV 9973-9974   49.68175936332           89.4537      1.729/1.707
M  9973-9974-9970             263.4634  97.317        91.1727      1.729/1.78     ' nif fd
DV 9973-9974   49.68186936354           89.4536      1.729/1.707
M  9973-9974-9970             263.4633  97.318        91.1726      1.729/1.78     ' nif fd

# ____________  Station 9970  ____________
#M AT-FROM-TO                Angle         Slope Dist    Zen Angle    HI/HT
DV 9970-9973   97.31738463438           88.4241      1.78/1.722
M  9970-9973-9976             255.1033  68.420        89.4327      1.78/1.687     ' sik
DV 9970-9973   97.31788963539           88.4242      1.78/1.722
M  9970-9973-9976             255.1033  68.420        89.4326      1.78/1.687     ' sik
DV 9970-9973   97.31813963589           88.4242      1.78/1.722
M  9970-9973-9972             339.3034  45.215        90.5418      1.78/0.12      ' onik
DV 9970-9973   97.31766963495           88.4243      1.78/1.722
M  9970-9973-9972             339.3034  45.216        90.5417      1.78/0.12      ' onik

# ____________  Station 9976  ____________
#M AT-FROM-TO                Angle         Slope Dist    Zen Angle    HI/HT
DV 9976-9970   68.42042684058           90.164       1.686/1.781
M  9976-9970-9988             220.2156  65.968        90.3446      1.686/1.712    ' sik
M  9976-9970-9974             292.4542  121.366       89.0128      1.686/1.704    ' sik
DV 9976-9970   68.42054184081           90.164       1.686/1.781
M  9976-9970-9988             220.2156  65.968        90.3445      1.686/1.712    ' sik
M  9976-9970-9974             292.4543  121.366       89.0129      1.686/1.704    ' sik

# ____________End of file created by PmmSurvey. ___________
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7.6. Appendix F

StarNet Traverse Report

STAR*NET-DEMO Version 6.0.36
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Run Date: Sat Oct 24 2009 19:10:49

Summary of Files Used and Option Settings

Project Folder and Data Files

```
Project Name       RIEGL TRAVERSE
Project Folder     C:\USERS\HERMLING - LAPTOP\DESKTOP\STARNET
Data File List  1. C:\Users\...\Scanner Traverse 2D.dat
```

Project Option Settings

```
STAR*NET Run Mode                     : Adjust with Error Propagation
Type of Adjustment                    : 2D
Project Units                         : Meters; DMS
Coordinate System                     : LOCAL
Default Project Elevation             : 35.0000 Meters
Apply Average Scale Factor            : 1.0000000000
Input/Output Coordinate Order         : East-North
Angle Data Station Order              : At-From-To
Distance/Vertical Data Type           : Slope/Zenith
Convergence Limit; Max Iterations     : 0.010000; 10
Default Coefficient of Refraction     : 0.070000
Earth Radius                          : 6372000.00 Meters
Create Coordinate File                : Yes
Create Ground Scale Coordinate File   : No
Create Dump File                      : No
```

Instrument Standard Error Settings

```
Project Default Instrument
  Distances (Constant)                :    0.010000 Meters
  Distances (PPM)                     :    0.000000
  Angles                              :    4.000000 Seconds
  Directions                          :    3.000000 Seconds
  Azimuths & Bearings                 :    4.000000 Seconds
  Centering Error Instrument          :    0.000000 Meters
  Centering Error Target              :    0.000000 Meters
```

Summary of Unadjusted Input Observations

Number of Entered Stations (Meters) = 10

Fixed Stations	E	N	Description
951	498705.0400	6966901.9210	

Free Stations	E	N	Description
950	498654.5439	6966920.0970	
952	498791.5383	6966873.5690	
953	498747.3330	6966872.0500	
954	498646.9682	6966907.2810	
955	498600.5729	6966954.4980	
956	498547.6758	6967016.5620	
957	498524.1242	6967066.0690	
958	498579.8418	6967001.5720	
959	498631.9665	6966940.9240	

Number of Angle Observations (DMS) = 10

At	From	To	Angle	StdErr
951	952	950	181-38-46.00	4.00
952	951	953	339-53-13.00	4.00
953	954	951	15-53-13.00	4.00
954	953	951	345-55-41.00	4.00
954	953	955	206-09-14.00	4.00
955	956	954	175-56-35.00	4.00
956	955	957	194-59-57.00	4.00
956	955	958	335-26-02.00	4.00
958	957	959	180-08-35.00	4.00
959	958	950	173-21-47.00	4.00

Number of Distance Observations (Meters) = 19

From	To	Distance	StdErr
951	952	91.0310	0.0100
951	950	53.6730	0.0100
952	951	91.0380	0.0100
952	953	44.2380	0.0100
953	954	106.3690	0.0100
953	951	51.7940	0.0100
954	953	106.3620	0.0100
954	951	58.3140	0.0100
954	955	66.2080	0.0100
955	956	81.5500	0.0100
955	954	66.1980	0.0100
956	955	81.5570	0.0100
956	957	54.8570	0.0100
956	958	35.5060	0.0100
957	958	85.2920	0.0100
958	957	85.2710	0.0100
958	959	79.9680	0.0100
959	958	79.9690	0.0100
959	950	30.7180	0.0100

Number of Azimuth/Bearing Observations (DMS) = 1

From	To	Bearing	StdErr
951	952	S71-51-08.00E	FIXED

Adjusted Coordinates (Meters)

Station	E	N	Description
950	498654.5434	6966920.0948	
951	498705.0400	6966901.9210	
952	498791.5494	6966873.5655	
953	498747.3445	6966872.0486	
954	498646.9781	6966907.2746	
955	498600.5692	6966954.4900	
956	498547.6581	6967016.5517	
957	498524.0829	6967066.0890	
958	498579.8361	6967001.5575	
959	498631.9641	6966940.9161	

Adjusted Observations and Residuals

Adjusted Angle Observations (DMS)

At	From	To	Angle	Residual	StdErr	StdRes
951	952	950	181-38-46.13	0-00-00.13	4.00	0.0
952	951	953	339-53-12.96	-0-00-00.04	4.00	0.0
953	954	951	15-53-14.14	0-00-01.14	4.00	0.3
954	953	951	345-55-41.92	0-00-00.92	4.00	0.2
954	953	955	206-09-13.94	-0-00-00.06	4.00	0.0
955	956	954	175-56-34.78	-0-00-00.22	4.00	0.1
956	955	957	194-59-57.26	0-00-00.26	4.00	0.1
956	955	958	335-26-02.30	0-00-00.30	4.00	0.1
958	957	959	180-08-35.47	0-00-00.47	4.00	0.1
959	958	950	173-21-47.12	0-00-00.12	4.00	0.0

Adjusted Distance Observations (Meters)

From	To	Distance	Residual	StdErr	StdRes
951	952	91.0380	0.0070	0.0100	0.7
951	950	53.6674	-0.0056	0.0100	0.6
952	951	91.0380	0.0000	0.0100	0.0
952	953	44.2310	-0.0070	0.0100	0.7
953	954	106.3686	-0.0004	0.0100	0.0
953	951	51.7883	-0.0057	0.0100	0.6
954	953	106.3686	0.0066	0.0100	0.7
954	951	58.3082	-0.0058	0.0100	0.6
954	955	66.2048	-0.0032	0.0100	0.3
955	956	81.5551	0.0051	0.0100	0.5
955	954	66.2048	0.0068	0.0100	0.7
956	955	81.5551	-0.0019	0.0100	0.2
956	957	54.8611	0.0041	0.0100	0.4
956	958	35.4999	-0.0061	0.0100	0.6
957	958	85.2803	-0.0117	0.0100	1.2
958	957	85.2803	0.0093	0.0100	0.9
958	959	79.9669	-0.0011	0.0100	0.1
959	958	79.9669	-0.0021	0.0100	0.2
959	950	30.7141	-0.0039	0.0100	0.4

Adjusted Azimuth/Bearing Observations (DMS)

From	To	Bearing	Residual	StdErr	StdRes
951	952	S71-51-08.00E	-0-00-00.00	FIXED	0.0

Error Propagation

Station Coordinate Standard Deviations (Meters)

Station	E	N
950	0.008217	0.003123
951	0.000000	0.000000
952	0.005300	0.001737
953	0.004294	0.002062
954	0.004126	0.003753
955	0.007353	0.007415
956	0.010903	0.010278
957	0.013199	0.014200
958	0.009510	0.009669
959	0.008738	0.006435

Station Coordinate Error Ellipses (Meters)
Confidence Region = 95%

Station	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis
950	0.021366	0.002533	109-52
951	0.000000	0.000000	0-00
952	0.013653	0.000001	108-09
953	0.010514	0.005040	88-13
954	0.010110	0.009173	83-30
955	0.018350	0.017795	37-05
956	0.030221	0.020781	49-44
957	0.040102	0.025371	40-06
958	0.023687	0.023259	167-36
959	0.024953	0.009102	123-35

Relative Error Ellipses (Meters)
Confidence Region = 95%

Stations From	To	Semi-Major Axis	Semi-Minor Axis	Azimuth of Major Axis
950	951	0.021366	0.002533	109-52
950	959	0.020591	0.006582	134-25
951	952	0.013653	0.000001	108-09
951	953	0.010514	0.005040	88-13
951	954	0.010110	0.009173	83-30
952	953	0.016229	0.002087	87-56
953	954	0.017175	0.010801	60-56
954	955	0.015928	0.009602	129-52
955	956	0.015855	0.012528	126-03
956	957	0.014951	0.008711	166-23
956	958	0.012847	0.005556	105-28
957	958	0.017698	0.015045	49-15
958	959	0.016909	0.015627	35-30

Elapsed Time = 00:00:01