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Accuracy Assessment of 3D Laser Scanning Data Utilising Different Registration Methods.

A dissertation submitted by

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ABSTRACT

Terrestrial laser scanning is a relatively new concept for surveyors, with scanners capable of capturing large amounts of three-dimensional coordinated data quickly.

When surveying with satellites (GPS) was introduced as a new surveying tool, professional surveyors took a while to grasp the concepts, and rely on the information portrayed. Now 3D laser scanning technology has arrived, the same confidence reservations are being revealed.

While laser scanning is used extensively overseas, Australian surveyors have not embraced the technology as quickly due to the unknown capabilities and accuracies that can be achieved, when compared to existing equipment. Cloud models are the results of data capture utilising a technique of flooding the surveyed area with millions of coordinated points. Multiple cloud models must be stitched together to create an objects or environments outer surface. The question of how to combine all these points without losing accuracy and integrity resolves in the method of registration.

This project aims to examine the results of 3D laser scanned data, using different registration methods, to demonstrate the accuracies that can be obtained, relative to traditional survey methods. This dissertation constitutes a review of three different registration techniques available and compares the results of measurements taken from the different techniques.

The registration was conducted by placing targets mounted to features and tripods, at arbitrary locations around an established building, and surveyed in using a Trimble S6 Total Station. These same targets were then scanned from different locations to produce cloud models which were then registered. The registration methods used varied in the way they were constrained and are to be known as the:

- Cloud to Cloud Registration.
- Target Registration, and
- Georeferenced Registration.

These registration methods were then compared by way of calculating the straight line distance to the survey traverse distance records, to verify the accuracy and any anomalies that might occur. This was a test to confirm and give confidence in this new technology.

The measurements achieved from each method produced similar results but were less than the registration error vectors, giving inconclusive results.

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ENG4111 Research Project Part 1 & ENG4112 Research Project Part 2

Limitations of Use

Certification

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

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

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Mark Sinderberry

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GOSSARY OF TERMS

3D:- Three-dimensional. Descriptive of a region of space that has width, height and depth.

As Built:- a model which captures the exact physical shape of an object.

Co-ordinate System:- A set of numerical values used to denote a location in 3D space.

Cartesian co-ordinate system:- three orthogonal 'world axis' (the X, Y and Z axes) are used to define the position of a point relative to the intersection of these axes, or origin.

Electronic Distance Measuring (EDM):- a device that measures straight line distances, using laser frequencies.

Georeferencing:- the assignment of coordinates of an absolute geographic reference system to a geographic feature.

Laser Scanning:- is the use of a laser to collect dimensional data in the form of a "point cloud"

Point:- A one-dimensional point in co-ordinate space.

Point cloud:- A set of three-dimensional points describing the outlines or surface features of an object.

Registration:– The process of making one set of data align with another, such that both sets are in a common co-ordinate system.

Reverse Engineering:- the process of measuring and then creating a CAD model of an object that reflects how the object would be designed originally.

Spherical Co-ordinate system:- a coordinate system for representing geometric figures in three dimensions using three coordinates; the radial distance of a point from a fixed origin, the zenith angle from the positive z-axis, and the azimuth angle from the positive x-axis.

Surface Model:- a CAD model of an object that is defined by its bounding surface.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Technology is continually changing and the spatial industry has had its share of change over the past 20 years. When Global Positioning Systems (GPS) were introduced as a new surveying tool, professional surveyors took a while to grasp the concepts and relied on the assurance of accuracies and techniques gained, from product company representatives and documentation. Now that the laser scanning phenomenon has arrived, the same reservations of confidence are being shown.

3D laser scanning has opened the door for a broader range of surveying tasks, in areas not considered possible before. It is now becoming accepted in industries such as TV and Film, Forensics, Architecture and Archaeology. However, its biggest impact has been in the detailing of engineering construction, where the 'as-built' survey has proven both economical and highly efficient. This is due to the ability for the scanner to capture large quantities of data in shorter timeframes, whilst still maintaining its accuracy.

By analysing some of the registration methods used from laser scanned data, Surveyors will have confidence in the technology and spread the word so as to help better promote the tool. This dissertation provides the results from a detailed analysis of laser scanned data showing the variations between different registration techniques and their accuracies.

1.2 Justification

Scanning is a new technology that survey companies in Australia are still hesitant to take on. The cost is reducing, but it is still an expensive outlay without proof of accuracy and confirmed benefits.

In this technological age, data is the key ingredient to conduct a successful business. Scanning technology has certainly allowed the spatial sciences industry and surveyors to gather enormous amounts of data, in very short time periods, and in so has allowed the technology to enhance better business propositions.

A company has a greater competitive edge by obtaining large amounts of data, and having the quality to match. This has lead to question of '*How accurate is laser scanned data?'* This is a leading question, and opens itself to an array of definitions of data accuracy, and what exactly are we analysing?

Laser scanners are currently used to obtain dense 3D point cloud data, of the surface of objects. The problem with the immense amount of data collected is the manipulation and transformation of multiple scans. Multiple scans are single scans obtained from different positions, within a local coordinate frame, of the same feature from different angles. For a full 3D effect of an object to be modelled, each scan needs to be transformed into the same coordinate system. This is achieved by a process called registration.

There are different methods of this registration process, and it is the accuracies of these methods that have lead to the fabrication of this dissertation. With the examination of the data obtained and the measurements taken, this project will provide confidence for spatial scientists to use this new scanning technology.

1.3 The Problem.

Traditional methods of surveying relied upon a common coordinate system, using a traversing method containing rigorous guidelines, to combine point measurements from individual station setups, to map or detail the required objects and features.

Utilising new technology leads to the unknown methods and therefore accuracies of conducting the same point measurements from individual station setups.

This project aims to examine the accuracy of data obtained from scanning objects from various angles, using different registration methods, to provide information on the process and install confidence in spatial scientists who are considering utilising this technology.

1.4 Research Objectives.

The aim of this project is to examine the accuracy of 3D laser scanned data using different registration methods to provide assurance in new technology, relative to traditional survey methods. This will be achieved through completing the following stages indicated below:

1. Undertake a review of different scanning technology that currently exists and registration methods employed.

2. Select the appropriate building and conduct a traditional traverse, to provide three dimensional coordinates for comparison.

3. Compare common target measurements from the scanned data using different registration techniques.

4. Analyse distance measurements between the artificial targets using, cloud to cloud registration, target registration and georeferenced target registration methods, and compare to measured distances obtained from the traditional surveying method.

5. Comment on the accuracy measurements from the three registration methods used.

1.5 Conclusions Chapter 1.

This dissertation aims to analyse the accuracy measurements obtained from laser scanned data utilising three different registration methods, in order to inspire confidence in surveyors with this new technology. The research intends to conduct laser scanning of a residential building from multiple setups, and compare the resultant distances obtained of targets from each method. The first method is to simply register the cloud models together without any constraints. The second by constraining scanned targets only and the third method utilises established control for a fully constrained georeferenced dataset.

A review of literature for this research will identify the theory of scanners and the different types available, their uses and useful ranges. Also it will identify the different types of scanners that are available and perceived accuracies, and finally describe the types of registration methods that are currently utilised and how they were developed.

The outcomes of this study will show the analysis conducted using these different registration techniques, so that a greater understanding and confidence in the equipment can be gained and an appreciation of which method may be employed for the next scanning job.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction.

Over the past ten years there has been a rapid advancement in hardware technology and software development. This has enabled engineers to develop faster, better and more precise machinery for use in this fast paced life that we now lead. They have produced machines for the spatial science profession that enables data to be captured more quickly and accurately than ever before. The laser scanner is one such machine that has now been produced, but with advancement in such machines, the software and confidence in the results, has primarily been from the developers and salesman point of view. Very few professionals have had the chance to conduct tests and analyse the results for themselves.

I have fortunately had this opportunity, and was confronted with an issue of not understanding the algorithms used or mathematics behind this technology. As a surveyor given the ability to capture massive amounts of data quickly, the question of "*How accurate are laser scanners?*" came about. Most surveyors I know are very inquisitive of such matters, as their profession is based upon it. I dissertation does not concentrate on the laser accuracy, but more on the results of data manipulation from multiple scans. This is done via the software using registration techniques. There are many methods of registration using complicated algorithms, which will not be discussed in this project, however, the choices of registration methods led to the question of, "*What is the best registration method to use for data accuracy and integrity?*"

This chapter will review the existing literature on the types and uses of laser scanners, accuracy and some of the registration techniques that are available. But firstly, what is a laser Scanner?

2.2 Terrestrial Laser Scanner.

A laser scanner is a device that collects 3D information of an object, or environment, by way of measurements using horizontal and vertical angles, and reflected distance measuring lasers. It can not only collect data on location and shape, but some scanners can represent the visual appearance of objects (i.e. colour) via inbuilt cameras. Scanners have the ability to capture data during night or day conditions, and can measure high resolution to the millimetre with high precision, up to ranges of approx. 1000m with reasonable accuracy. They use low powered laser frequencies and high speed timing electronics to achieve these measurements. They are efficient and productive and make the acquisition of large amounts of data fast and easy to use.

The data collected, *point clouds*, can be used in the construction of digital 3D models, useful for a wide variety of applications, by way of obtaining information about an object, or environments, area, volume, position, design, shape or relative relationship to other objects. This point cloud data, and the measurement made from it, have allowed applications to be conducted for:

- Remote surveys,
- Industry design,
- Reverse engineering and prototyping,
- Computer vision,
- Crime Scene and Forensics,
- Traffic Crash Investigations,
- Entertainment,
- Archaeology,
- Historical architecture preservation, but most commonly for
- Construction and As Constructed surveys.

A 3D laser scanner creates a point cloud of geometric samples on the surface of the subject, which are then extrapolated to form the shape of the object. They are similar to cameras in that they only have the ability to collect information of surfaces that are directly visible, meaning they cannot capture objects hidden behind other objects. A camera is restricted to collecting visible colour information within its limited field of view, while a laser scanner also collects 3D positional information about a surface within its field of view. A scanners field of view can be as great as 360° horizontally and 320° vertically. This degree of vision, by the scanner, only requires simple mathematics to relate all the point data together by way of integrating it into a coordinated system.

A spherical coordinate system is used to relate this point cloud data together, and is defined by having the scanner positioned at the origin. If vectors out from the front of the scanner are denoted by $\Phi=0$ and $\theta=0$ (refer to Figure 2.1), then each point **P** in the cloud model is associated with ($\boldsymbol{\Phi},\boldsymbol{\theta}$). Together with distance, denoted by ρ, spherical coordinates fully describe the three dimensional position of each point in the cloud model by a local coordinate system relative to the scanner. These can be transformed to a rectangular coordinate system giving x, y, z position.

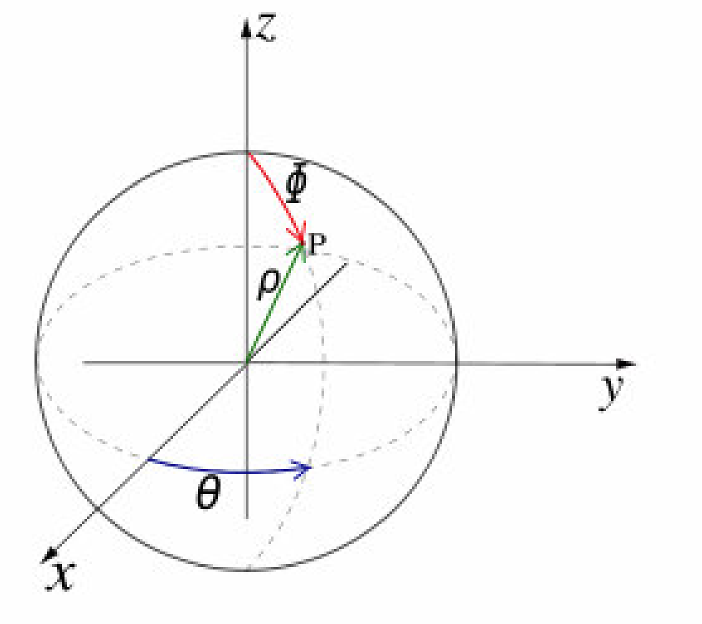


Figure 2.1 Spherical Coordinate System

2.3 Laser Scanner Theory.

Laser scanners are fast becoming a prominent tool that surveyors are utilising as a surveying instrument. Each scanning device operates by shining a focused laser light on the object or environment being measured, then detects the reflected light and computes the distance. By rotating the scanner angles both vertically and horizontally, different positions on the object a captured and transformed into a local coordinate system. Different products vary in their ability to capture, manipulate and process data. Their functionality varies in the speed that they capture, reliable distance range, and accuracy, however, there are primarily two types of scanners produced: Time of flight (TOF) devices and phase-based, or more correctly termed modulation-based (MB) devices. These two types represent the majority of scanners available today and are generally used by surveyors. There is a third type known as a triangulation scanner used for high detailed data capture. Table 2.1, replicated from Fröhlich (2004), summarises a possible classification list of laser scanners, based on the measurement principal, which includes the range and accuracy of these devices, and current manufactures.

Scanner Type	Range (m)	Accuracy (mm)	Manufacturers
Time of Flight	< 100	< 10	Callidus, Leica Mensi, Optech, Riegal
	< 1000	< 20	Optech, Riegl
Phase Based	<100	<10	IQSun, Leica VisImage, Zoller+Fröhlich
Triangulation	< 5	< 1	Mensi, Minolta

Table 2.1 Classification of laser scanners
Source ISPRS Vol.XXXVI – 8/W,22004

2.3.1 Time of Flight Scanners (TOF).

Time of flight scanners are the most popular measurement systems currently used due to their ability to measure long ranges. They operate by emitting a brief pulse of light onto an object which then strikes the surface and is reflected back towards the scanner, Lichti (2002). It then uses the speed of light ($3.10^8\ ms^{-1}$) and the time taken for the scanner to detect this reflected pulse to determine the distance travelled. The actual distance to the object is simply calculated by multiplying the speed of light by half the 'time-of-flight' between the signals transmission and reception as shown in Figure 2.2.

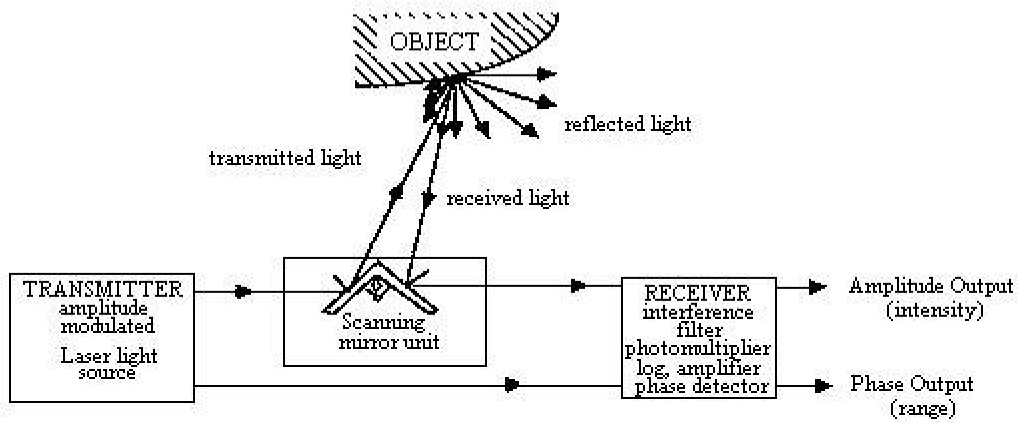


Figure 2.2 A Laser rangefinder based on time of flight
Source: School of informatics, University of Edinburgh

Lichti also explains that scanners use equal angle increments (EAI) in both the horizontal and vertical plane, via the use of a rotating mirror, to deflect the laser beam in equal arcs which is used to determine the resolution. By combining the distance with EAI, three dimensional coordinates of each single point on the surface of the object can be determined. Depending on the resolution used, it can potentially generate a large array of data points, or cloud models.

TOF scanners produce the longer electronic distance measuring (EDM) ranges, generally in the order from 100 to 300m, but some products are able to get out to ranges of 1000m. The trade off for these longer ranges is that the distance between points on the object (point spacing) becomes spatially greater, and is generally used for larger areas for surface modelling. Surprisingly, with the larger range, they still maintain reasonable accuracy. Typical TOF laser scanners (at time of writing this) measure up to 10,000 ~ 100,000 points every second, but have a slower capture rate. This is due to the time it takes for the laser to reflect back off an object which is constrained by the speed of light.

Figure 2.3 and 2.4 show the newest products for TOF scanners produced by Leica and Trimble. Examples of product specification datasheets are attached at Appendix B, and show the vast array of technical information that is available for each product.

Figure 2.3 Leica ScanStation 2 TOF scanner

Figure 2.4 Trimble 3D GX TOF Scanner

2.3.2 Phase Based Scanners.

Phased based scanners have the same technology as used in total stations, digital theodolites and interferometers. The principals behind these scanners to determine distance, according to GIA (2006), uses a modulated carrier wave. The scanner transmits a signal, which oscillates as a sine wave, and the phase of the received wave is compared with the phase of the transmitted wave. This difference is known as a phase shift, and is measured to determine the range to the object. It has been previously determined that the range is proportional to the out-of-phase angles. Figure 2.5 shows the two sine waves as being transmitted and received and the resultant phase shift angle represented as Φ. As an example, the greater the angle is between the phase shift, the further away the object is calculated to be.

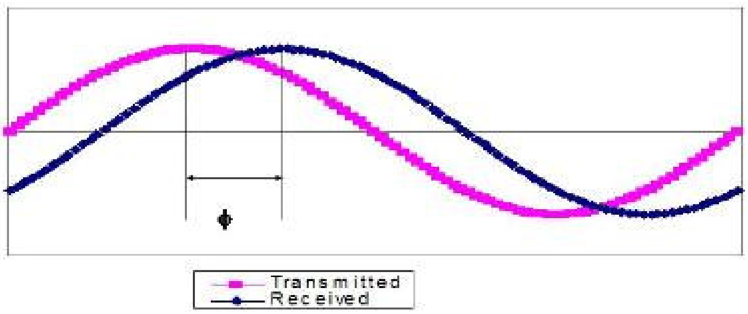


Figure 2.5 Phased Based Measurement
Source: Spar Point Research LCC

For higher accuracies, the angle correlations are calculated over short wave forms. This is because for longer waveforms a much powerful signal would be required, which is dangerous, and the signal to noise ratio would increase, giving lower accuracy. Phase based scanners therefore have much shorter ranges, effective up to 50 m, however compensate this by acquiring much greater accuracy and incredibly fast scanning speeds, up to 500,000 points per second. Figure 2.6 shows the newest Leica HDS6000 phase-based scanner that was utilised for this project.

Figure 2.6 Leica HDS6000 Phase Based Scanner

2.3.3 Triangulation Scanners.

These were among the first scanners developed by the National Research Council of Canada in 1978 and use an active laser light to explore the environment. 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 dependant on how far away the laser strikes the objects surface. This technique is called triangulation because a triangle is created between the laser dot, camera and laser emitter.

This operation can be further explained using Figure 2.7 which illustrates 3D Laser triangulation. By knowing the distance between the detector and laser (triangulation distance), as well as the lasers deflection angle (δ), a simple Cosine Rule is applied to calculate the distance to the object. This is then combined with the horizontal and vertical angles, then transformed, and hence calculated to a local (x,y,z) coordinate system.

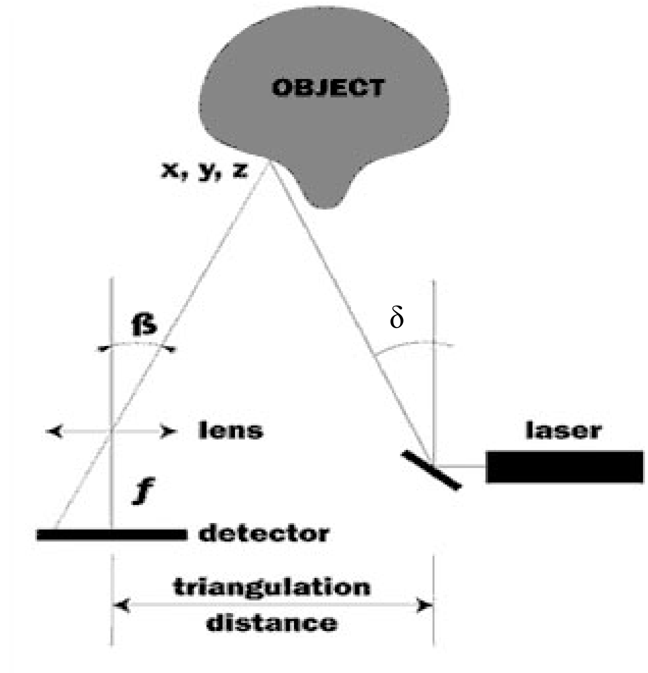


Figure 2.7 3D Laser Triangulation
Source : Inition Web Site

2.4 Accuracy.

As mentioned so far, the scanner has the potential to measure large numbers of points on an object, or environment, in short periods of time. The question of "How accurately are these points measured?" may be a thought users have asked themselves, when contemplating the use or purchase of this equipment. Boehler and Marbs (2003) mention an investigation that has gone into laser scanner accuracy, carried out through i3mainz in Germany. They have standardised the testing procedure to calculate the quality of measurements obtained from various scanners on different test targets. They have realised that due to the different angular increments and spot sizes, not all 3D scanners have the same abilities to resolve small object details. While it is possible to conduct multiple scans of same object from different angles, it is impossible to record the exact same point, therefore, deviations can occur. They then conclude that these deviations can be an indication of accuracy.

There are many topics in truly defining laser scanning accuracy, some of which can be the angular accuracy, range accuracy, resolution or spot size, and edge effects.

All of which can be influenced by the manufactured, or environmental conditions such as temperature, atmosphere, interfering radiation, or the reflectivity of the object surface.

Angular accuracy, range accuracy and resolution are covered in basic surveying studies, however, edge effect is an inherent problem that is referred to in Chow (2007), being caused by the laser spot size falling on edges of objects causing incomplete measurements. He states that an object that has sharp features, such as a building corners or edges, could be missed or partially measured by the laser beam. He goes on to advise that this effect could be minimised through using the smallest possible resolution, which would unfortunately cause greater file sizes, or to model the features in the office by planar patch matching. This type of error is one of the bases for the refining of registration algorithms.

There have been many published studies on the accuracy of laser scanned data with published results, for detail information refer to Balzani *et al*. (2001), Johansson (2002), Kern (2003), Lichti *et al*. (2000, 2002). Appendix B gives accuracy statements on the HDS6000 Used in this project), Scanstation 2 and Trimble GX scanner.

2.5 Registration.

When collecting data it is often difficult to capture an entire object from a single scan. Sometimes several scans or even hundreds, from many different locations, are required to capture the entire surface of an object or environment. Each scan is taken from a different view of the object, capturing different sections of the surface. These scans have to be integrated into a common reference system using a process called registration. When obtaining data from these multiple scans, and the entire object is required, it becomes very difficult to sample every nook, every crack and every face of the object. Thus, the laser scanner is almost always required to be moved around the object requiring the registration process to be conducted.

There have been many proposed registration algorithms, however, due to the potential of there being millions of scanned points of an environment or object, are not suitable or efficient methods to be used. Besl and McKay (1992) introduced the Iterative Closest Point (ICP) algorithm to register two sets of points on a free form surface, deigned as '… a general-purpose, representation-independent method for the accurate and computationally efficient registration of 3-D shapes…' This was a good base algorithm to use, but required good initial values to be effective, therefore, there have been many variations developed from this. Extensions of this algorithm are now widely used and continually being refined for registration of multiple sets of surface data. Modifications to the ICP algorithm have been made to improve the rate of convergence and to compute the initial transformation parameters to partially register the overlapping sets of points.

Chen and Medioni (1992) demonstrated the registration of partially overlapping range image data. A modified cost function was used to compute the registration which minimises the squared distance of the surface normal. This cost function gives improved rates of convergence.

The next generation of registration involves no initial point values and minimal interaction for the registration process. A method for this semi-automatic registration has been suggested by Rabbani *et al.* (2005), where they model geometrical objects, representing spheres, cylinders and edge planes, then use these modelled object to register the scans. This method is a little like reverse engineering, where the data is extracted before the scans are registered.

Dold and Brenner (2006), proposed a method of fully registering terrestrial scanned data using planar patches and image data, to be used as initial transformation values. They describe a process of extraction planar patches from cloud data in individual scans, then use search techniques to find corresponding patches in two overlapping scan positions. They also mention using the image data to improve the registration process by moving and shifting the patches for a best fit.

2.6 Summary: Chapter 2

Terrestrial scanners are being used as another tool for surveyors. Their functionality and operation has been reviewed during this chapter, demonstrating that there are several different scanners available, all with unique capabilities, but essentially capturing and producing the same data. Technology is advancing so rapidly recently, that the hardware and software is continually changing in design, method and capability. During this project, both Trimble and Leica produced a new version of their terrestrial scanner, and newer versions of the software were released. One of the advances in the software was the calculation of registration algorithms, with a fully automated registration process being developed. The accuracy behind these scanners is currently under constant testing with i3mainz in Germany, and have been considered reliable.

2.7 Conclusions: Chapter 2

The review of this literature has shown that this technology is rapidly advancing, even during this project, and that scanners are now being utilised for applications in many different professions. The requirement to control the large amounts of data, has led to the development of smarter, quicker and more efficient algorithms, especially for the registration of multiple scans. The registration process has also advanced, and new methods are currently being developed, which require less interaction for the completion of the integration. These newer registration methods are the basis for the research which looks at the accuracy obtained by three registration methods.

CHAPTER 3

RESEARCH DESIGN AND METHODOLOGY

3.1 Introduction.

The aim of this chapter is to discuss the equipment, design and methodology used for the acquisition and registration of captured data. In this work, I have focused on the calculations and analysis of distance measurements taken from targets set up around a residential building once registration has occurred. The registration methods differ by varying the constraints on targets. Multiple scans were taken around the building site for the purpose of registration, and a survey control traverse was undertaken for comparative data. Refer to field cards at Appendix C.

Due to time restrictions, and expense in hiring equipment, all scanning was completed within one day, with software training held on the preceding day. Software licences were freely supplied and reissued as 30 day trials, for the duration of this project. The new concept of scanning led to a complete refocus of procedures, and utilising the software for the analysis was a big task to learn. Company representatives were regularly called upon to give assistance in the use and software functionality to enable me to continue the analysis process. Only the data import, quick start and registration modules were used.

I was fortunate enough to acquire two (2) different scanners, one time-of-flight, and the other a phase based scanner. This allowed for a comparison of methods to be made between both types, and to analyse the registration results. However, due to calibration issues, this was not possible to complete and is described further in Chapter 3.4.

3.2 Equipment.

As previously mentioned, there were to be two types of scanners used for this project. Both of these systems were arranged to be available at my workplace, as part of a demonstration, to showcase the new technology and capabilities. I was able to utilise them both as part of a training and education agreement for this project.

Trimble GX 3D SCANNER

This is a TOF scanner, shown in Figure 3.1, and is able to capture data at a rate of up to 5000 points per second, to an extended range of 350m. This was more than adequate for the scanning of the residential building and seemed appropriate for such a simple task. It came with the Trimble software called "*Pointscape*" and *Realworks*", which are point manipulation and registration software programs, and also a temporary 3 month licence. Paul Andrews from Ultimate positioning Systems in Melbourne showed me how to use the scanner and educate me in the manipulation of the software. The technical specification datasheet for this scanner can be found at Appendix B.

Figure 3.1 Image showing the setup of the Trimble DX 3D Scanner.

Leica HDS6000 SCANNER

This is a phase based scanner, as shown in Figure 3.2, and is able to capture data at a rate of up to 500 000 points per second, but only with a maximum range of 50m. The software used for this scanner was called "*Cyclone*". This was used to manipulate and register the enormous amounts of scanned data with ease. The technical specification datasheet can be found in Appendix B.

Figure 3.2 Image showing the Leica HDS6000 Scanner setup at residential building.

3.3 Targets.

Two types of targets were used in this scanning project. The initial scanning, using the Trimble GX, sited 6 x 38.1 mm spherical targets, mounted on magnetic bases. These were used because of to their ability to be placed on metal surfaces at varying angles. The advantage of having spherical targets is in their ability to be scanned from any position without having to be rotated, which could cause errors. The left image, in Figure 3.3, shows a digital photo of a spherical target, and on the right, a similar target scanned at high resolution. These were both attached to the bottom of a gutter using the magnetic base.

Figure 3.3 Image and cloud model of 38.1 mm spherical targets.

In Figure 3.4, the flat black and white targets shown were used with the HDS6000 scanner.

Figure 3.4 Cloud model and image of a flat black and white target.

Both sets of targets can be used for scanning purposes, as they give a good geometrical shape for easy identification, from which to extract a central vertex point. Many makeshift targets are also available i.e. foam balls, billiard balls, discs, etc…, however, the purpose specific targets, of known dimension, are best used to reduce any possible geometric errors.

3.4 Initial Problems.

The Trimble GX 3D scanner was initially the scanner of choice for this project, due to compatibility with existing Trimble equipment at the workplace.

This scanner was transported from Melbourne to Adelaide by freight, and in the process, caused the internal components to become unsettled. It has always been the case that calibration testing be carried out (excluding GPS) before any survey measurements are conducted, especially after travel, therefore, a site calibration was conduced to test that the instrument would perform up to expectations.

This was done over a makeshift base line with stations approximately 100m apart. The procedure is similar to the two peg test for a level. Unfortunately, due to lack of experience and time constrains, the on-site calibration failed to pass the onboard testing procedure. The reasons for this failure were unknown, but an error message of "*no precision values obtained*" was displayed on the calibration test software. This result ultimately rendered the scanning event and future observations ineffectual. It was decided to carry on with the scanning and analyse the calibration error at a later date. The calibration and scanning data was sent, by the staff at Ultimate Positioning in Melbourne, to their parent company in France to analyse the error and hopefully correct the calibration problem. The reply indicated that the data could not be rectified and suggested that total rescanning would be required. This was not possible due to the cost already spent on the project, and could only be possible if further funding and time became available. This did not occur, and no data obtained from the Trimble GX 3D scanner was used in any of the analysis for this project.

The Leica HDS6000 did not require a calibration test and the onboard self checking process was successful, therefore, all the data collected for this project and analysed was produced from this scanner.

3.5 Control Setup.

Initial assessment of the residential building showed that there was minimal vegetation on site, and the establishment of control was straight forward, and only required five (5) stations. Prior planning of the control locations around the building was conducted, to accommodate the positions of the scanner for the best solution to capture as much of the building surface as possible. Field cards showing the placement can be viewed in Appendix B.

The control was placed using permanent marks, and traditional measurements of internal angles and distances were observed using a Trimble S6 Total Station. The internal angles and distances were then adjusted using a simple Bowditch Adjustment, and a local coordinate system was given with Station 1 (**S1**) as the origin of 2000m East, 5000m North and 100m Elevation and arbitrary bearing of 0° was given towards Station 5 (**S5**). A level traverse was also conducted using the Leica digital level and adjusted to close. Coordinates were then calculated to the rest of the control points and are shown in Table 3.1

Station No.	Easting (m)	Northing (m)	Elevation (m)	Comments
S1	2000.000	5000.000	100.000	Concrete Nail in Driveway
S2	2034.912	5007.284	97.740	Metal Pin in Lawn
S3	2034.748	5021.423	98.077	Metal Pin in Garden Bed
S4	2015.610	5018.693	98.934	Gin in tiled pathway
S5	2000.000	5015.344	100.226	Metal Pin in Garden Bed

Table 3.1 Station Control Coordinates.

Three (3) additional flat black and white targets were placed at positions to give variations in height and positional geometrics, to be used in the analysis to compare distance measurements on fully registered models.

3.6 Data Capture.

Scanning took place from control stations S1, S2, S3 and S5. S4 was not used as a scan station, as this was placed for the closure of the traditional traverse, and did not give a good field of view for scanning. Each station conducted both a ‘high’ scan and a ‘highest’ scan. The difference between the two scan settings is the increased resolution obtained. As noted on the ‘Scan Clouds Log’ field card in Appendix B, the power level and noise factor were also changed, and were to be used as a comparative solution, however, these adjustments caused fatal errors in some scans, and could not be used in any of registration processes.

The scans used for the registration process were comparable in their settings, and the final set were captured with a HIGH scan resolution, LOW Power functionality and LOW noise. This was chosen to give a reasonable resolution and reduced file sizes, with multiple shots per point and averaged to reduce scan noise. Scan noise is simply the capture of rouge points that are reflected off objects other than the intended object i.e. large dust particles.

The scanner was setup on a tripod over each control station, with targets placed on adjacent control stations, as per traditional traversing techniques. Scans were conducted using the on board system instead of a connected laptop, to speed up he process, and documented on the field cards attached at Appendix B. Each scan took approximately 13mins to complete, with a time factor of 20mins from setup to pack up, at each station. Each scan filename is indicated by the time stamp given at each setup.

Due to the incredible speeds the scanner achieved, it was deems unproductive to scan targets individually (as was done in the past) or to scan a particular Field of view (FOV), therefore, the entire 360° x 320° FOV was scanned, with up to 20,800,000 points per scan being recorded.

Files were downloaded onto a laptop computer using the Cyclone V5.7 software and a project database was setup. Table 3.2 shows the comparison between files sizes and points acquired at each scan station.

Scan Name	File Size	No. of Points
12.02.27.zfs	217Mb	24 173 282
12.43.41.zfs	216Mb	20 734 614
13.07.20.zfs	216Mb	22 249 311
13.54.02.zfs	201Mb	25 720 192

Table 3.2 Scan file sizes and Number of Points captured.

3.7 Registration.

As mentioned previously, and in conjunction with the Leica manual, registration is the process of integrating multiple scans into a single coordinate system. This integration is derived using a system of constraints, which can be pairs of equivalent objects or overlapping point data that exist between two scans. The registration process computes the optimal overall alignment transformations for each component scan in the registration, such that the constrained objects are aligned as closely as possible in the resulting scan.

3.7.1 Cloud to Cloud Registration.

Cloud to cloud registration is the creation and management of *cloud constraints* between overlapping point clouds without the need for artificial targets. This registration process requires the selection of similar (tie) points from overlapping scans, to be used as constraints. At least 3 tie points are required to provide initial transformation alignment parameters, as long as they successfully constrain the overlapping scans in all six degrees of freedom, as shown in Figure 3.5 (translation in X, Y and Z directions, and rotation angles around the X, Y, and Z axis).

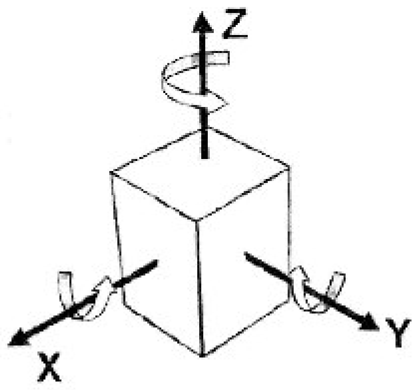


Figure 3.5 Displays the six degrees of freedom
Source: Leica Registration training module

Scan pair 13.07.20.zfs and 13.54.02.zfs were registered first and initially had 3 tie points. These points, however, did not satisfy the six degrees of freedom due to their linear alignment. This was rectified by selecting four (4) more tie points at different 3D geometric positions, as shown in Figure 3.6.

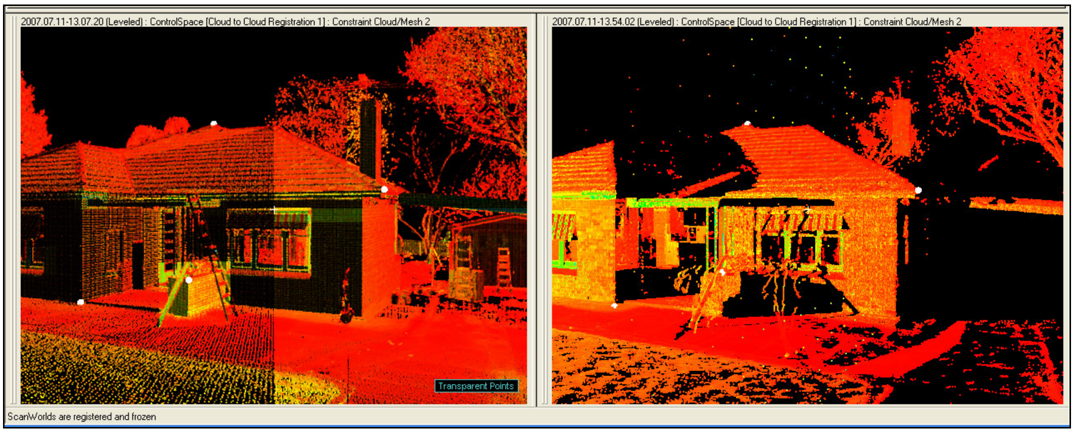


Figure 3.6 Four extra tie point locations on overlapping scans 13.07.20 and 13.54.02.

Once the initial selection was carried out and initial values accepted, the software was capable of automatically adding more tie points, by conducting a search of the entire overlapped area, for geometrically consistent objects. This process was conducted for each pair of overlapping scans until all possible pair combinations were filled with multiple constraints. At this point the registration program was initiated to transform all the scans into a similar coordinated system. Using rigorous algorithms and an iterative process, a successful result was achieved displaying preliminary error vectors for each pair, as shown in Table 3.3. These could then be interactively checked and adjusted for visual errors. This process was not required for any of the registration methods.

Constraint ID	ScanWorld	ScanWorld	Type	Status	Weight	Error	Error Vector
Cloud/Mesh 3	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Cloud: Cloud/Mesh-Cloud/...	On	1.0000	0.000 m	aligned [0.011 m]
Cloud/Mesh 4	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.07.20 (Leveled)	Cloud: Cloud/Mesh-Cloud/...	On	1.0000	0.000 m	aligned [0.011 m]
Cloud/Mesh 2	2007.07.11-13.07.20 (Leveled)	2007.07.11-13.54.02 (Leveled)	Cloud: Cloud/Mesh-Cloud/...	On	1.0000	0.000 m	aligned [0.011 m]

Table 3.3 Error vector displayed from cloud to cloud registration.

The error vector results are fully described in a Registration Diagnostics dialogue box, and give a more detailed description of the registration calculations that occur. These include the mean absolute error, scans involved in the registration, constraints relationship and descriptions, constraint errors, error vectors and individual scan transformation details. The registration vectors obtained in this first process showed a good correlation between scans, however, a further optimization process was carried out to tighten the cloud alignments, by using a rigorous iteration algorithm. This process allowed for the best possible fit to be conducted, for complete registration to occur, utilising all cloud constraint combinations. The histogram showed in Figure 3.7 compares the measured error vectors against the number of points used, and is continually updated as the iterative process repeats. A graph showing a higher percentage of points in the lower part of the measured error range provides confidence that a good registration is achieved between the overlap of the scan pair. The final diagnostic showed an 11mm RMS error in the registration process. This value is slightly larger than expected, but is understandable due to the large amount of vegetation that was captured during the scan. A better result may have been achieved if all vegetation was removed. The RMS error was lower than the registration tolerance for this project and was therefore accepted. The software allows for tighter tolerances to be made, however, were not done for this project.

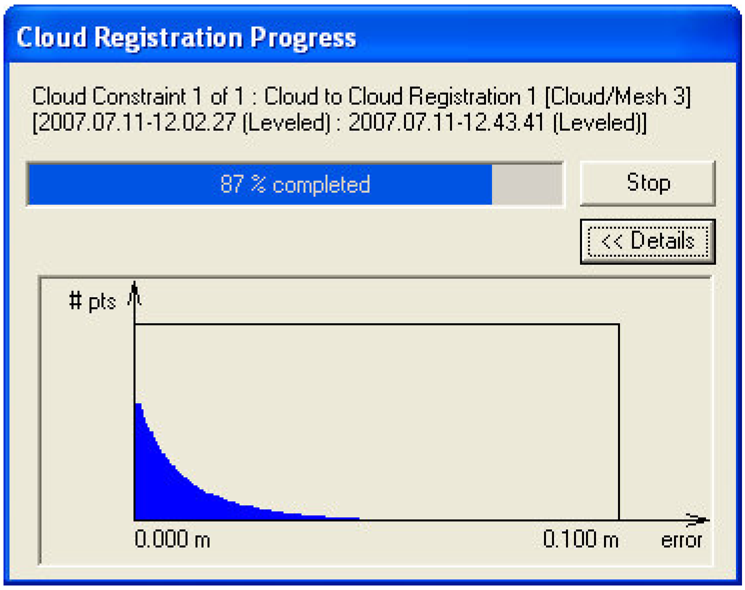
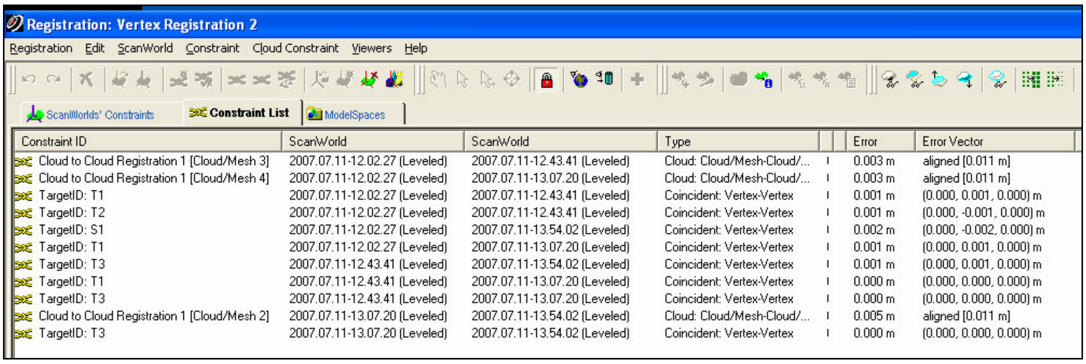


Figure 3.7 Histogram generated by optimising the registration process between two scans.

From here, the vertices for targets S1, S2, S3, S5 and T1, T2 and T3 were extracted and distance measurements were acquired between targets. Results of these measurements are shown in Chapter 4.

3.7.2 Target Registration.

The next method of registration was to use the targets as constraints. The initial setup of the project was the same, however instead of using tie in points from the cloud models, the initial transformation values were to come from the vertices of the targets themselves. The software contains algorithms to identify the centre of the targets and place a vertex point there. All vertex points, within each scan, were identified with a unique number so that correlation between unique identifiers was achieved when the registration process started. The targets identified unfortunately did not give enough information to be used as the initial values for the transformation process, because they did not satisfy the geometry for six degrees of freedom. This was overcome by using the initial transformation values obtained from the cloud to cloud registration. As can be see in Table 3.4, the initial registration produced errors of the targets in the order of 1mm to 2mm. The cloud to cloud registration constraints were then eliminated and the target registration constraints only were then optimised. This final process showed a diagnostic result with a mean absolute error of 14mm. This is only marginally larger than the cloud to cloud registration method, but is expected because of the additional constraints from the target vertex points. This was again as a result of including the vegetation as part of the cloud model, however, is still acceptable.


Registration: Vertex Registration 2

Registration Edit ScanWorld Constraint Cloud Constraint Viewers Help

ScanWorlds' Constraints | Constraint List | ModelSpaces

Constraint ID	ScanWorld	ScanWorld	Type		Error	Error Vector
Cloud to Cloud Registration 1 [Cloud/Mesh 3]	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Cloud: Cloud/Mesh-Cloud/...	I	0.003 m	aligned [0.011 m]
Cloud to Cloud Registration 1 [Cloud/Mesh 4]	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.07.20 (Leveled)	Cloud: Cloud/Mesh-Cloud/...	I	0.003 m	aligned [0.011 m]
TargetID: T1	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Coincident: Vertex-Vertex	I	0.001 m	(0.000, 0.001, 0.000) m
TargetID: T2	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Coincident: Vertex-Vertex	I	0.001 m	(0.000, -0.001, 0.000) m
TargetID: S1	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.54.02 (Leveled)	Coincident: Vertex-Vertex	I	0.002 m	(0.000, -0.002, 0.000) m
TargetID: T1	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	I	0.001 m	(0.000, 0.001, 0.000) m
TargetID: T3	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.54.02 (Leveled)	Coincident: Vertex-Vertex	I	0.001 m	(0.000, 0.001, 0.000) m
TargetID: T1	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	I	0.000 m	(0.000, 0.000, 0.000) m
TargetID: T3	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	I	0.000 m	(0.000, 0.000, 0.000) m
Cloud to Cloud Registration 1 [Cloud/Mesh 2]	2007.07.11-13.07.20 (Leveled)	2007.07.11-13.54.02 (Leveled)	Cloud: Cloud/Mesh-Cloud/...	I	0.005 m	aligned [0.011 m]
TargetID: T3	2007.07.11-13.07.20 (Leveled)	2007.07.11-13.54.02 (Leveled)	Coincident: Vertex-Vertex	I	0.000 m	(0.000, 0.000, 0.000) m

Table 3.4 Error vector displayed from Target registration.

Again, vertices were extracted and distance measurements were conducted between the targets. These results are analysed in Chapter 4.

3.7.3 Georeferenced Registration.

The last method of registration was conducted in order to see what the results would show when the targets used and were also constrained to use local coordinates. These coordinates were obtained from the traditional traverse using the total station. The initial project setup was again consistent with the previous two methods, except this time the vertices of the targets were given the coordinated values. These targets were then constrained as vertices, with specific coordinate values. Again due to the minimal targets, the cloud to cloud registration values were used to calculate the initial transformation parameters and resultant errors can be seen in Table 3.5.

Registration: Traverse Registration 3

Registration Edit ScanWorld Constraint Cloud Constraint Viewers Help

ScanWorlds' Constraints | Constraint List | ModelSpaces

Constraint ID	ScanWorld	ScanWorld	Type	Error	Error Vector
TargetID: S2	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	0.043 m	(-0.006, 0.001, 0.043) m
Vertex Registration 2 [TargetID: T3]	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	0.039 m	(0.001, 0.002, -0.039) m
Cloud to Cloud Registration 1 [Cloud/Mesh 2]	2007.07.11-13.07.20 (Leveled)	2007.07.11-13.54.02 (Leveled)	Cloud: Cloud/Mesh-Cloud/Mesh	0.038 m	aligned [0.017 m]
Vertex Registration 2 [TargetID: T3]	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.54.02 (Leveled)	Coincident: Vertex-Vertex	0.029 m	(0.001, 0.001, -0.029) m
Vertex Registration 2 [TargetID: T2]	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Coincident: Vertex-Vertex	0.024 m	(0.002, 0.001, -0.024) m
Cloud to Cloud Registration 1 [Cloud/Mesh 4]	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.07.20 (Leveled)	Cloud: Cloud/Mesh-Cloud/Mesh	0.022 m	aligned [0.015 m]
Vertex Registration 2 [TargetID: T1]	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	0.013 m	(0.002, -0.002, 0.013) m
Cloud to Cloud Registration 1 [Cloud/Mesh 3]	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Cloud: Cloud/Mesh-Cloud/Mesh	0.012 m	aligned [0.014 m]
Vertex Registration 2 [TargetID: T3]	2007.07.11-13.07.20 (Leveled)	2007.07.11-13.54.02 (Leveled)	Coincident: Vertex-Vertex	0.010 m	(0.000, -0.001, 0.010) m
Vertex Registration 2 [TargetID: T1]	2007.07.11-12.02.27 (Leveled)	2007.07.11-12.43.41 (Leveled)	Coincident: Vertex-Vertex	0.007 m	(-0.001, 0.000, 0.007) m
Vertex Registration 2 [TargetID: T1]	2007.07.11-12.43.41 (Leveled)	2007.07.11-13.07.20 (Leveled)	Coincident: Vertex-Vertex	0.006 m	(0.002, -0.002, 0.006) m
TargetID: S1	2007.07.11-12.02.27 (Leveled)	2007.07.11-13.54.02 (Leveled)	Coincident: Vertex-Vertex	0.003 m	(0.000, 0.000, 0.003) m

Table 3.5 Error vector displayed from Georeferenced registration.

These initial constraints were then eliminated and only the coordinate values were used as constraints. Target vertices were extracted and distance measurements were conducted between the targets which are analysed in Chapter 4. The final diagnostics results gave a mean absolute error of 21mm. This was due to two factors, all the vegetation surrounding the property captured by the scan, and the accuracy of the traverse. This registration error was seen to be a reasonable solution and accepted as part of this project.

3.8 Conclusion.

This chapter covered the equipment used during this project and the initial problems that occurred with the calibration of the Trimble TOF scanner. It conveyed the methodology used and results for the acquisition of the coordinated control, then the procedure for scanning the building and targets. Each method of registration was explained and the initial error results for each method were stated. A summary of these results are shown in Table 3.6 below. It was found that the errors were larger than first expected, but concluded that they could be reduced if the vegetation cloud data was removed before the registration process. It does give a good and reasonable indication of the error magnitude obtainable, if the vegetation was a critical requirement, or main focus, for the scanning. Each of the scan sets were registered together utilising different constraints in order to obtain the cloud model data required to carry out the analysis in the next chapter. This analysis is based on the distance measurements between targets obtained from each of the registration methods.

Registration Method	RMS (mm)
Cloud to Cloud	11
Target	14
Georeferenced	21

Table 3.6 Summary of RMS Error results for each registration method

CHAPTER 4

DATA ANALYSIS

4.1 Introduction.

In the methodology Chapter of this project, three methods of registration were described, one of which used the control points placed by traditional methods. The cloud models were registered using different constraints, and then extracted distances to targets were measured.

The purpose of this chapter is to provide the results of the distance measurements between targets obtained from each registration method and analyse these results. An explanation, as to why the results obtained were so close, and the advantages and disadvantages of each method will be conveyed. The results will prove that each method of registration has its own usefulness, and that no single method of registration can be entirely used for every scenario of scanning.

4.2 Distance Measurements

Measurements obtained using the Cyclone software, were gained using the 'measure point to point' function. This required the vertices of each target simply to be highlighted, and the measurement function executed. Measurements between all targets were extracted from each of the different registration methods, and Figures 4.1 to 4.3 show the positional and results of these measurements, from Station 1 (**S1**) to all other targets, for each of the three registration methods.

Figures 4.4 to 4.9 show the entire range of distance results, as taken from the software for the cloud to cloud registration method, and Figure 4.10 shows the comparison for the T3 Georeferenced registration method, with the cloud model.

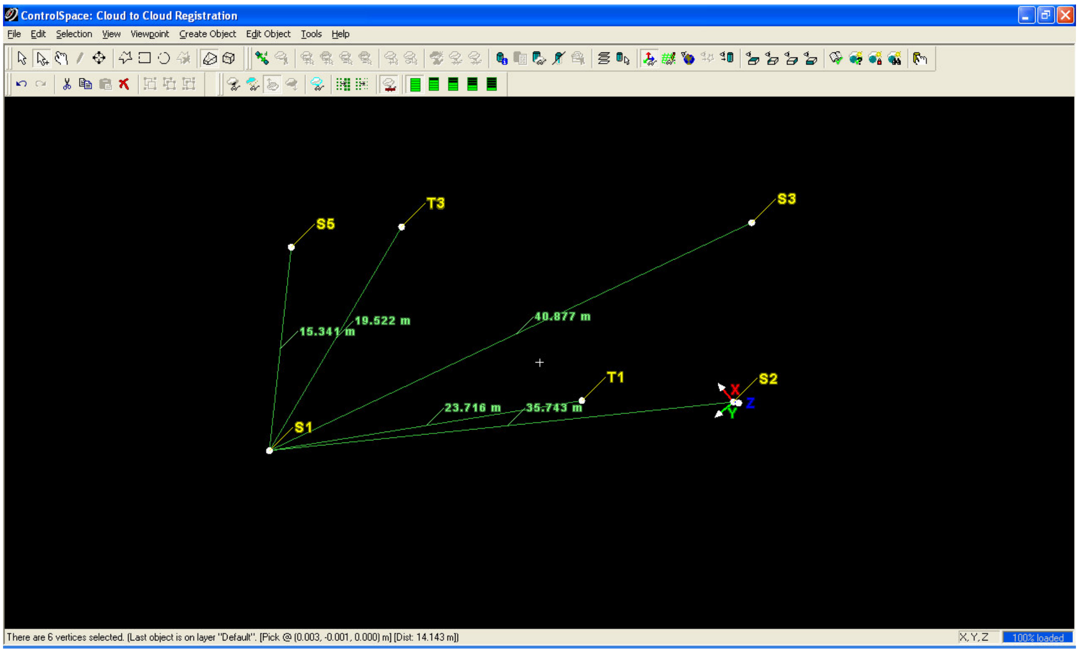


Figure 4.1 Distances measured from S1, using the Cloud to Cloud Registration model.

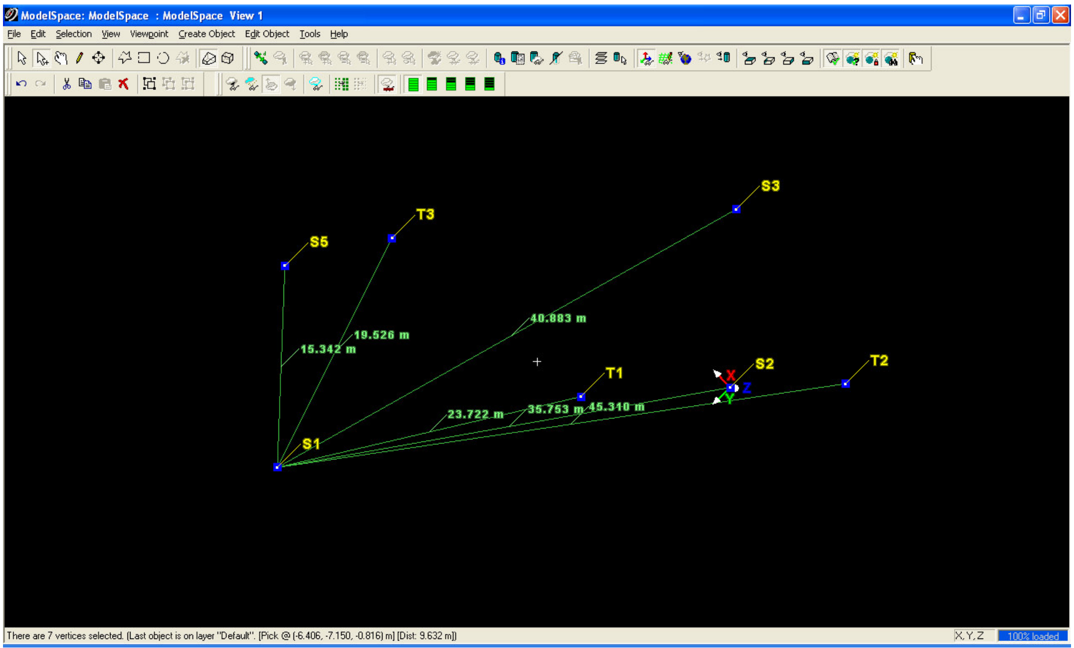


Figure 4.2 Distances measured from S1, using the Target Registration model.

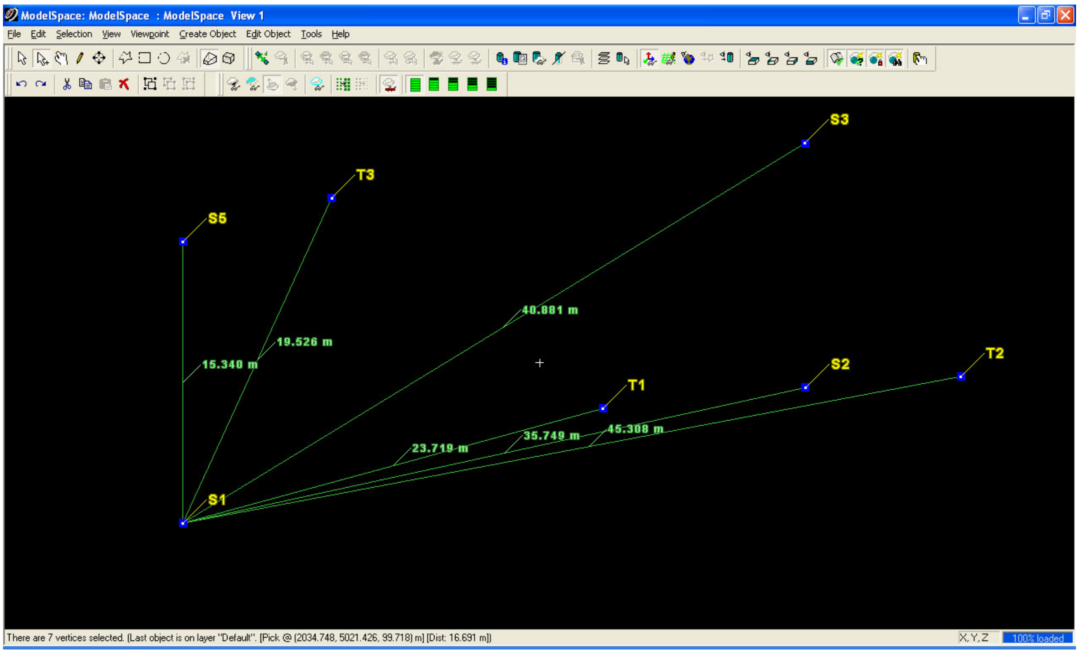


Figure 4.3 Distances measured from S1, using the Georeferenced Registration model.

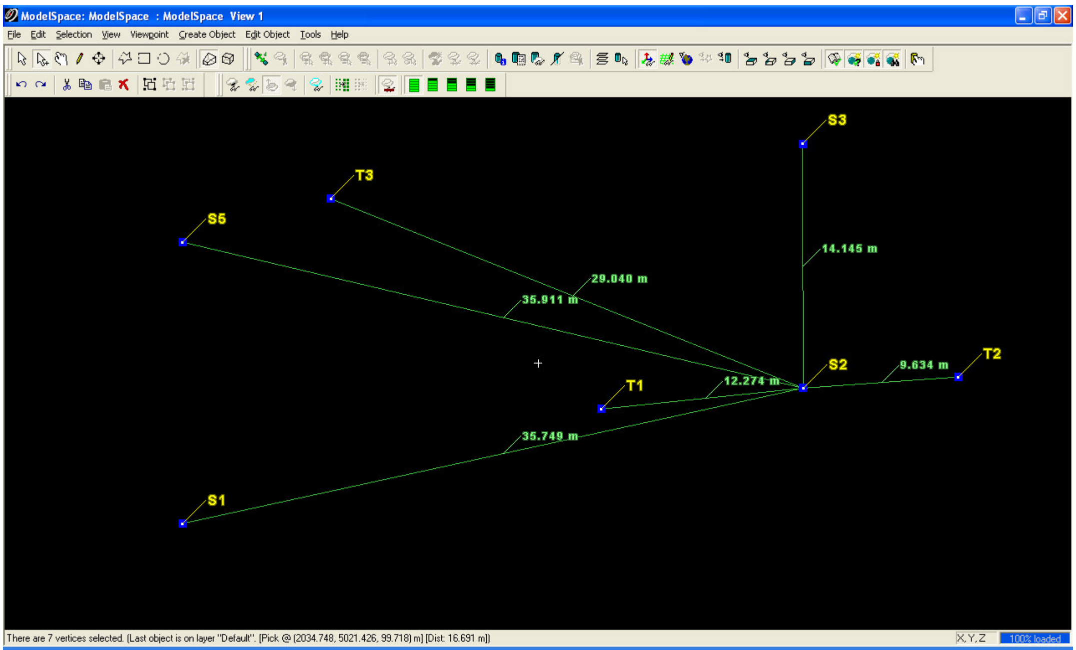


Figure 4.4 Cloud to Cloud registration distance measurements from S2.

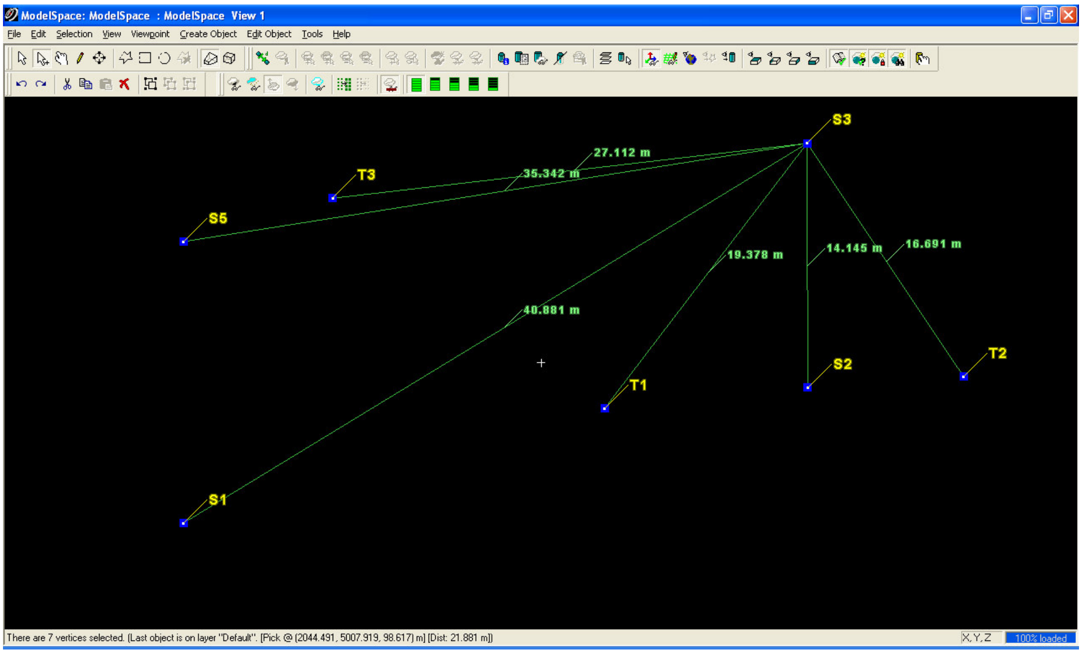


Figure 4.5 Cloud to Cloud registration distance measurements from S3.

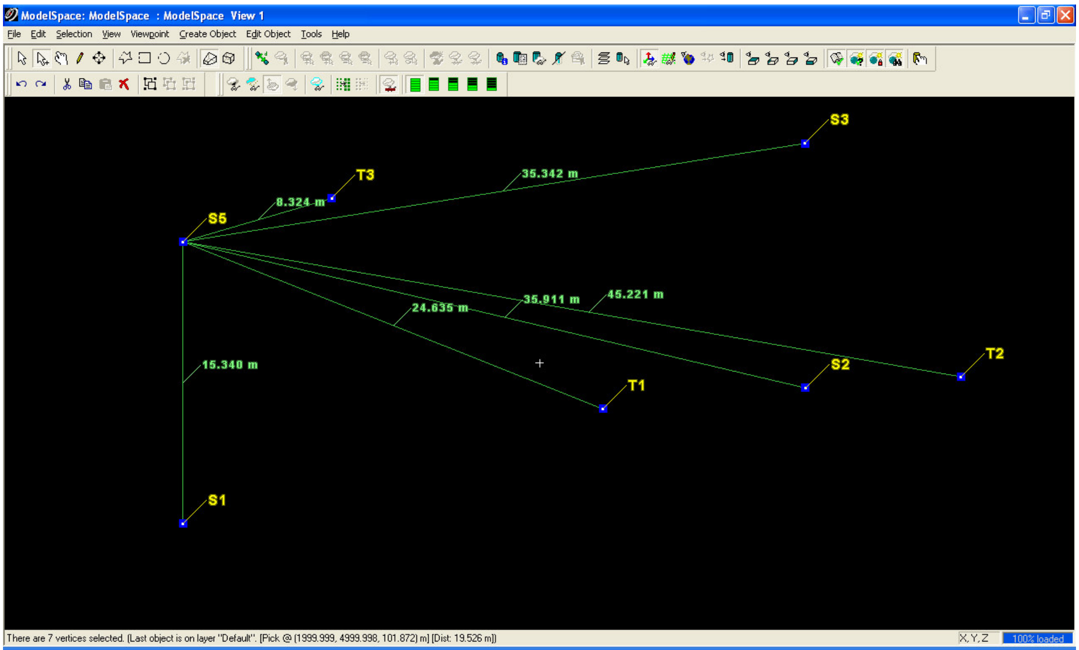


Figure 4.6 Cloud to Cloud registration distance measurements from S5.

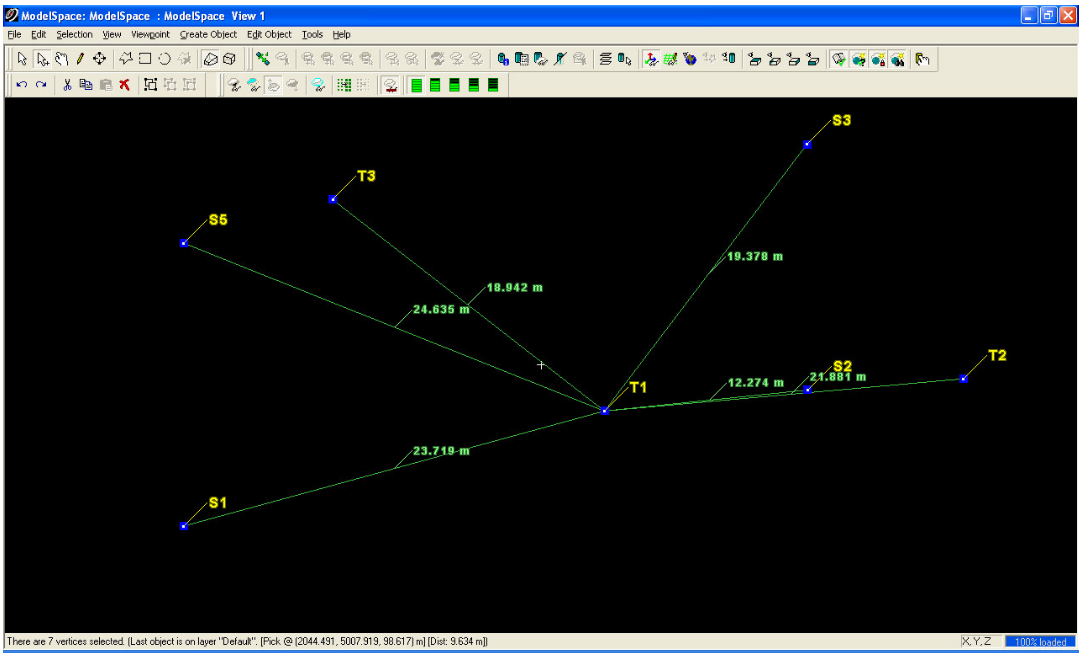


Figure 4.7 Cloud to Cloud registration distance measurements from T1.

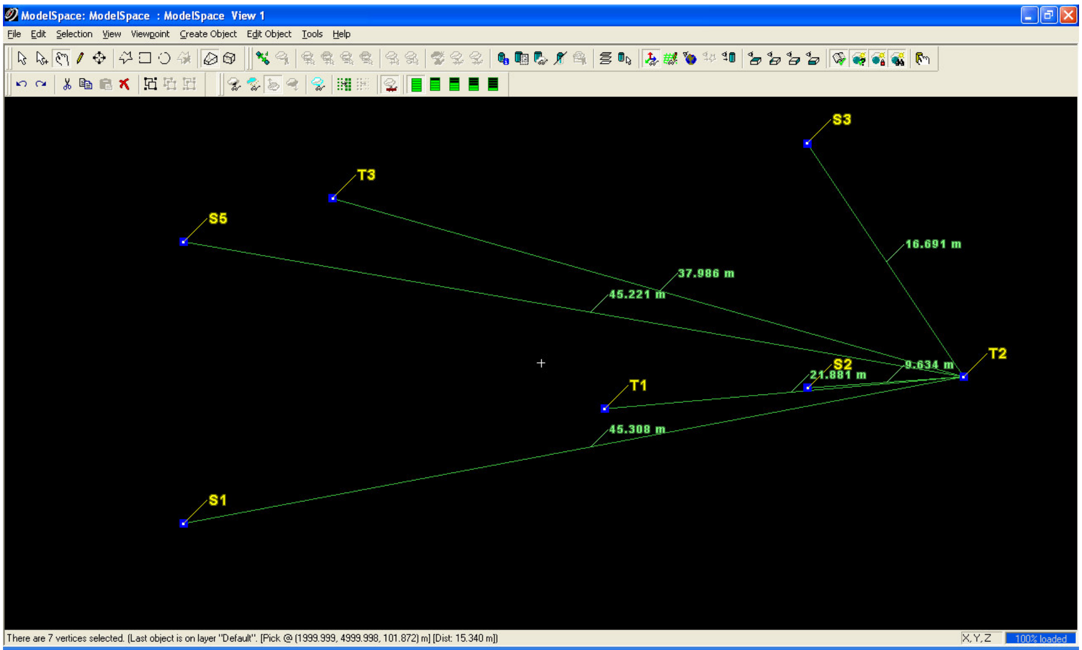


Figure 4.8 Cloud to Cloud registration distance measurements from T2.

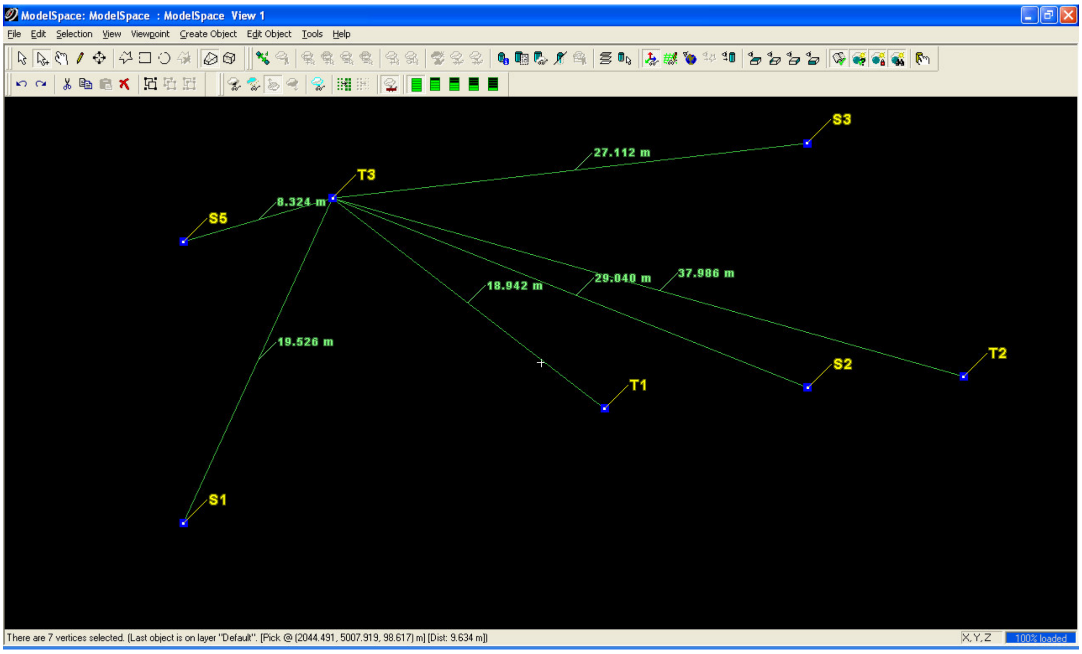


Figure 4.9 Cloud to Cloud registration distance measurements from T3.

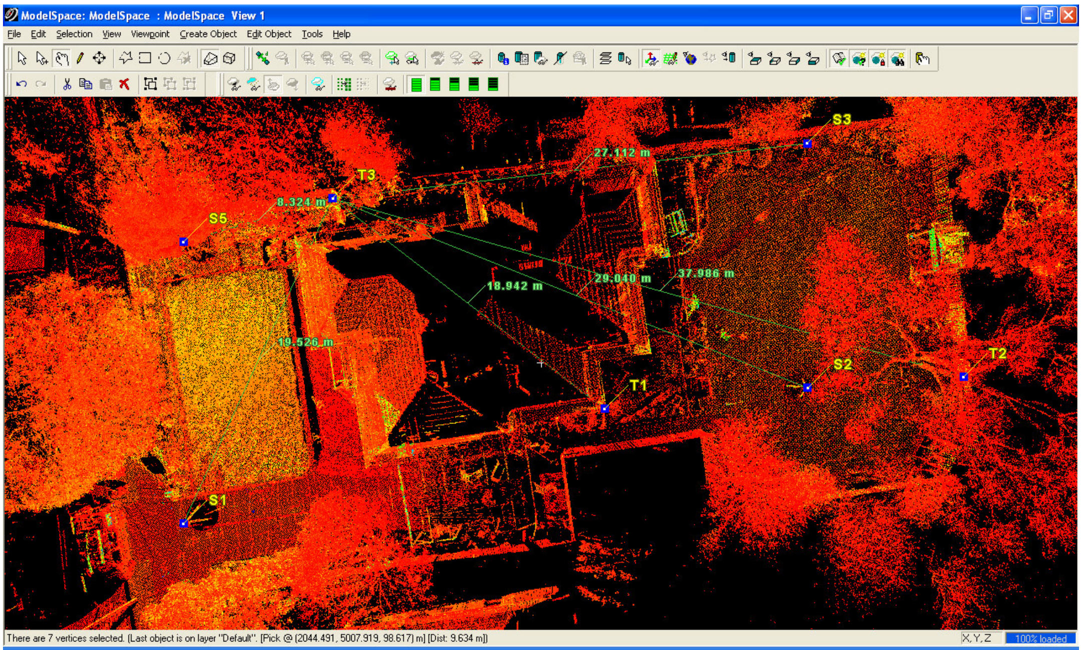


Figure 4.10 Georeferenced registration measurements from T3, with cloud model.

4.3 Measurement Results and Analysis

Each measurement was checked in both a forward direction and backward direction, from target to target, to ensure the correct distance was obtained and recorded. They were then compared against the calculated coordinates from the control established. Table 4.1 to 4.3 summarises the results of each method.

Cloud to Cloud Registration						
FROM	Target 1	Target 2	Target 3	Station 1	Station 2	Station 3
Target 1		21.880	18.947	23.716	12.270	19.376
Target 2	21.880		37.990	45.305	9.636	16.690
Target 3	18.947	37.990		19.526	29.042	27.114
Station 1	23.716	45.305	19.526		35.743	40.877
Station 2	12.270	9.636	29.042	35.743		14.143
Station 3	19.376	16.690	27.114	40.877	14.143	
Station 5	24.634	45.222	8.321	15.341	35.909	35.341

Table 4.1 Cloud to Cloud registration distance results.

Target Registration						
FROM	Target 1	Target 2	Target 3	Station 1	Station 2	Station 3
Target 1		21.881	18.941	23.722	12.274	19.376
Target 2	21.881		37.986	45.311	9.633	16.690
Target 3	18.942	37.986		19.526	29.041	27.113
Station 1	23.722	45.311	19.526		35.753	40.883
Station 2	12.274	9.633	29.041	35.753		14.144
Station 3	19.376	16.690	27.113	40.883	14.144	
Station 5	24.633	45.221	8.323	15.342	35.912	35.342

Table 4.2 Target registration distance results.

Georeferenced Registration						
FROM	Target 1	Target 2	Target 3	Station 1	Station 2	Station 3
Target 1		21.881	18.942	23.719	12.274	19.378
Target 2	21.881		37.986	45.308	9.634	16.691
Target 3	18.942	37.986		19.526	29.040	27.112
Station 1	23.719	45.308	19.526		35.749	40.881
Station 2	12.274	9.634	29.040	35.749		14.145
Station 3	19.378	16.691	27.112	40.881	14.145	
Station 5	24.635	45.221	8.324	15.340	35.911	35.342

Table 4.3 Georeferenced registration distance results.

The control placed was not deemed to be the final solution, however, it was used to give the scanned results something to be compared against. Table 4.4 shows a summary of these results.

From	To	C2C	Target	Geo	CONTROL	Ave (m)	Diff (mm)
S1	S2	**35.743**	**35.753**	**35.749**	***35.735***	35.745	10
S1	S3	**40.877**	**40.883**	**40.881**	***40.866***	40.877	6
S1	S5	**15.341**	**15.342**	**15.340**	***15.346***	15.342	2
S2	S3	**14.143**	**14.144**	**14.145**	***14.144***	14.144	2
S2	S5	**35.909**	**35.912**	**35.911**	***35.916***	35.912	3
S3	S5	**35.341**	**35.342**	**35.342**	***35.341***	35.342	1

Table 4.4 Summary of results compared to Control

As can be seen above, there was very little difference in the overall results. Although from S1 to S2 it shows the largest difference of 10mm. This was caused by noise across the target as somebody walked past. This was rectified by utilising the denser scan of the target, taken immediately after realising this as a possibility, and importing it into the scan model. A vertex point was then extracted for the centre of the target, however, results show that there may have been a slight error in the alignment.

The overall differences were still well within the error vectors of the registration RMS diagnostics shown earlier. This gives an inconclusive result as to whether these measurements can be used to determine if the registration method used influences the relative distance calculations.

The entire target to target results for each method are shown in Table 4.5, and summarise all the measurements for each method.

From	To	C2C	Target	Geo	CALCED	Ave (m)	Diff (mm)	STDDev (mm)	Var (mm)
T1	T2	21.880	21.881	21.881		21.881	1	0.57735	0.00033
T1	T3	18.947	18.941	18.942		18.943	6	3.21455	0.01033
T1	S1	23.716	23.722	23.719		23.719	6	3.00000	0.00900
T1	S2	12.270	12.274	12.274		12.273	5	2.30940	0.00533
T1	S3	19.376	19.376	19.378		19.377	2	1.15470	0.00133
T1	S5	24.634	24.633	24.635		24.634	2	1.00000	0.00100
T2	T3	37.990	37.986	37.986		37.987	5	2.30940	0.00533
T2	S1	45.305	45.311	45.308		45.308	6	3.00000	0.00900
T2	S2	9.636	9.633	9.634		9.634	3	1.52753	0.00233
T2	S3	16.690	16.690	16.691		16.690	1	0.57735	0.00033
T2	S5	45.222	45.221	45.221		45.221	1	0.57735	0.00033
T3	S1	19.526	19.526	19.526		19.526	0	0.00000	0.00000
T3	S2	29.042	29.041	29.040		29.041	2	1.00000	0.00100
T3	S3	27.114	27.113	27.112		27.113	2	1.00000	0.00100
T3	S5	8.321	8.323	8.324		8.323	3	1.52753	0.00233
S1	S2	35.743	35.753	35.749	35.735	35.745	16	7.83156	0.06133
S1	S3	40.877	40.883	40.881	40.866	40.877	15	7.58837	0.05758
S1	S5	15.341	15.342	15.340	15.346	15.342	5	2.62996	0.00692
S2	S3	14.143	14.144	14.145	14.144	14.144	2	0.81650	0.00067
S2	S5	35.909	35.912	35.911	35.916	35.912	6	2.94392	0.00867
S3	S5	35.341	35.342	35.342	35.341	35.342	1	0.57735	0.00033

Table 4.5 Target to target distance summary

Using the Standard deviations and Variances as determinates to analyse the measurements, it appears that the minimal variation are still inconclusive as to whether the registration methods used, bear any influence on the final model as relative distances are all within RMS tolerances.

4.4 Advantages and disadvantages

Each registration method has its own advantages and disadvantages, and could be used in most situations. Thee different methods have been developed out of requirements to best suit applications that are unique.

The cloud to cloud registration method is best suited to areas where georeferencing is not required, and there are a lot of easily identifiable feature to be used as tie points. It is a quick way to scan objects where time is an issue and relative measurements and 3D model extraction only, is required. The minimal setup allows for greater scanning coverage or increased scan stations, but requires a more meticulous checking procedure to be conducted.

The target registration method also allowed for quick scanning, but requires time for targets to be set up. This method was once the workflow procedure for scanning, however, with the advancement in registration algorithms, targets are not always required. The use of targets is still required in areas where there is little in the way of distinctive features. The targets then help to provide good vertex tie points for the initial transformations. They are also good points to be used for check measurements.

The fully georeferenced registration method allows for a better control of the process and checks on the control points. The targets and scanner may be set up over the control points or be resected in, similar to a traverse survey. The advantage of this is that the registration can be completed in the field by assigning coordinates to the targets when scanning them, however, requires more time to establish the control beforehand.

As can be seen in Figure 4.11, there was a great amount of vegetation that was scanned and used in the registration process. As a result it gave larger than predicted errors.

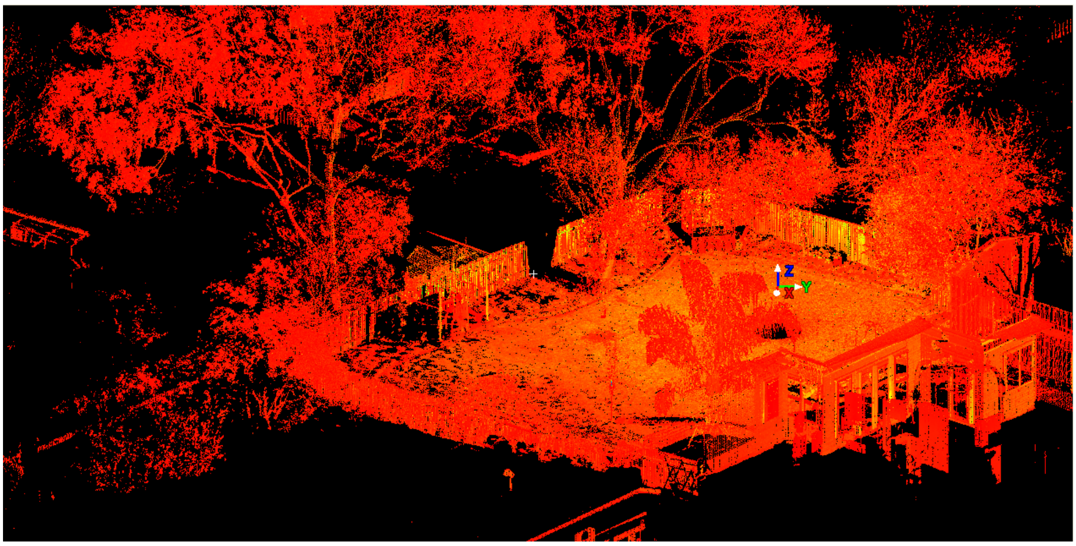


Figure 4.11 Vast vegetation coverage in cloud model.

4.5 Conclusion

The aim of this project was to assess the accuracy of terrestrial laser scanned data while utilising different registration methods. Since there was only a single set of scans conducted on a single site, from one type of scanner, and the limited timeframe from which to conduct the testing, it is inconclusive to draw any reasonable conclusion from the results.

The initial results obtained from all the registered data showed that there was not a great deal of variation between distance measurements. It was predicted that the georeferenced registration method would show some form of deviation, due to the external constraints, however, the results did not distinctively prove this. The initial registration of the cloud to cloud method showed a greater than expected RMS result of 11mm, which was assumed to be caused by the vegetation coverage in the scanned FOV.

It was discovered that there were too few targets in the scan FOV for the other two registration methods to be capable of obtaining initial transformation values. By using the initial transformation values of the cloud to cloud registration method, the initial parameters of the target based registration methods were calculated and the registration successfully completed.

As the initial error vectors obtained for each registration method were larger than the variations in distance measurements between targets, it is concluded that further scanning of different features with a greater number of targets is required.

CHAPTER 5

CONCLUSIONS, DISCUSSIONS AND RECOMMENDATIONS

5.1 Introduction.

The aim of this project arose from the requirement to prove to surveyors, and the spatial science industry, that there may be a difference in measurements gained from scanned data depending on which registration method is used. There have been many methods developed of the years and each method was designed to handle the data efficiently and to produce a better result. This project was therefore designed to assess the accuracy of 3D laser scanning data by utilising different registration methods.

5.2 Discussion.

Scanning is a new technology that takes the acquisition of point measuring to the extreme. The method of collecting point data using a total station requires the surveyor to accurately point the instrument at a target placed on or near an object (or by reflectorless means), then press a button to capture the position. This is a slow process that has been identified by surveyors and has led to the development of the scanning system. This technology has been developed from aerial photography and laser range finding equipment that have the capability to capture coordinated data points at a higher altitude and rate. Current terrestrial laser scanning systems can acquire data up to 500,000 points per second, and at much closer ranges, which gives great resolution for detailed objects. This has led to the redundancy of point by point measurements and exposed the usability of scanning for many different applications and professions.

This project was conducted at a residential building site, were a simple control survey was conducted in order to gain coordinated for specific points. These coordinated points were used for a comparison of laser scanning data, which had been registered by three different means. The different registration methods included a simple cloud to cloud registration, a registration method that was only constrained by targets setup on the control points, and a fully georeferenced registration method were by the coordinates obtained by traditional traverse methods were used to constrain the registration process.

Upon registration, the distances were measured to targets and analysed to see if there was any difference in accuracy between the methods. It was predicted that the georeferenced registered data would show the influence from the inaccuracies in the control survey as a secondary constraint. It was discovered that due to the large vegetation coverage, the variations in distance measurements, were less than the error vectors obtained in the registration process and therefore gave an inconclusive result as to wether any of the registration constraints influenced the final scanned model.

5.3 Further research and recommendations.

The inconclusive result gives clear indications that further research is required to prove if there is in fact a difference in accuracy using different registration methods. It would be recommended that a variety of geometric objects be scanned using different types of scanners and to utilise a great deal more targets to use as constraints for the registration process. This would give an increased data sample from which a more accurate analysis could be made. A further recommendation would be the use of a faster computer to manipulate the massive amounts of data.

APPENDIX A

PROJECT SPECIFICATION

FACULTY OF ENGINEERING AND SURVEYING

<u>ENG4111/4112 Research Project</u>
PROJECT SPECIFICATION

FOR: ***Mark SINDERBERRY***

TOPIC: Feasibility and accuracy assessment of 3D Laser Scanning utilising different registration methods.

SUPERVISOR: Dr. Frank Young

SPONSORSHIP: FYFE Pty Ltd

PROJECT AIM: This project aims to examine the accuracy of data obtained from scanning 3D objects using different resolutions and registration methods to determine best practise, relative to traditional survey methods.

PROGRAMME: (**Issue A, 26th March 2007**)

1. Literature review on current 3D Laser Scanning methods and technology.
2. Select appropriate basic object to carry out initial accuracy assessment.
   - Measure by tape straight line edges.
   - Scan object in 3 different resolutions (course, medium, fine)
   - Analyse relative accuracy.
3. Select roadway overpass/bridge previously surveyed by traditional methods.
   - Setout control targets and tape targets for registration methods.
   - Scan sections of roadway, bridge and targets.
   - Scan using different resolutions (course, medium, fine).
   - Analyse relative accuracy between different resolutions.
   - Analyse absolute accuracy between different registration methods.
   - Analyse Time and Risk for laser scanning Vs traditional survey methods.
4. Select piping works or non regular surface to scan.
   - Scan surface using different resolutions (course, medium, fine).
   - Register scanned data by edge matching and tape targets.
   - Measure distances and shapes on surface using manual methods (tape).
   - Analyse relative accuracy between different resolutions.
5. Discuss results and determine best scanning methods.

AGREED

____________________ (student) ____________________ (supervisor)

Date: / / 2007 Date: / / 2007

Co-examiner: ____________________

APPENDIX B

PRODUCT SPECIFICATION DATASHEETS

Leica ScanStation 2

Leica HDS6000

Trimble 3D GX Scanner

Leica ScanStation 2
Product Specifications

General	
Instrument type	Pulsed, dual-axis compensated, very-high speed laser scanner, with survey-grade accuracy, range, and field-of-view
User interface	Notebook or Tablet PC
Scanner drive	Servo motor
Camera	Integrated high-resolution digital camera

System Performance	
Accuracy of single measurement	
Position*	6 mm
Distance*	4 mm
Angle (horizontal/vertical)	60 µrad/60 µrad, one sigma
Modeled surface precision/noise**	2 mm, one sigma
Target acquisition***	2 mm std. deviation
Dual-axis compensator	Selectable on/off Resolution 1", dynamic range +/- 5'
Data integrity monitoring	Periodic self-check during operation and startup

Laser Scanning System	
Type	Pulsed; proprietary microchip
Color	Green
Laser Class	3R (IEC 60825-1)
Range	300 m @ 90%; 134 m @ 18% albedo
Scan rate	Up to 50,000 points/sec, maximum instantaneous rate Average: dependent on specific scan density and field-of-view
Scan resolution	
Spot size	From 0 - 50 m: 4 mm (FWHH - based); 6mm (Gaussian - based)
Selectability	Independently, fully selectable vertical and horizontal point-to-point measurement spacing[1]
Point spacing	Fully selectable horizontal and vertical; <1 mm minimum spacing, through full range[1]; single point dwell capability
Maximum sample density	<1 mm[1]
Field-of-view (per scan)	
Horizontal	360° (maximum)[1]
Vertical	270° (maximum)[1]
Aiming/Sighting	Optical sighting using QuickScan™ button
Scanning Optics	Single mirror, panoramic, front and upper window design Environmentally protected by housing and two glass shields
Scan motors	Direct drive, brushless
Data & power transfer to/from rotating turret	Contact-free: optical data link and inductive power transfer
Communications	Static Internet Protocol (IP) Address
Integrated color digital imaging	User-defined pixel resolution: Low, Medium, High[1] Single 24° x 24° image: 1024 x 1024 pixels (1 megapixel) @ "High" setting Full 360° x 270° dome: 111 images, approx. 64 megapixels, automatically spatially rectified
Status Indicators	3 LEDs (on stationary base) indicate system ready, laser "on", and communications status
Level indicator	External bubble and via laptop

Electrical	
Power supply	36 V; AC or DC; hot swappable; two (2) Power Supply units provided with system
Power consumption	<80W avg.
Battery type	Sealed lead acid
Power ports	Two (2) simultaneous use, hot swappable
Typical duration	>6 hours, typical continuous use (room temp.)
Power status indicators	Five (5) LEDs indicate charging status and power levels

Environmental	
Operating temp.	0° C to +40° C
Storage temp.	-25° C to +65° C
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing
Shock	40 G's (max. to scanner transport case)
Dust/humidity	IP52 (IEC 60529)

Physical	
Scanner	
Dimensions	10.5" D x 14.5" W x 20" H 265 mm x 370 mm x 510 mm w/o handle and table stand
Weight	18.5 kg, nominal
Power Supply Unit	
Dimensions	6.5" D x 9.25" W x 8.5" H 165 mm x 236 mm x 215 mm w/o handles
Weight	12 kg, nominal

Standard Accessories Included

Scanner transport case
Tribrach (Leica Professional Series)
Survey tripod
Ethernet cable for connection of scanner to notebook PC
Two Power Supply cases. Each includes:
  Power Supply
  Cable for battery connection to scanner
  Power Supply charger
User manual
Cleaning kit
Cyclone™-SCAN software

Hardware Options

Notebook PC
Tablet PC
HDS scan targets and target accessories
Service agreement for Leica ScanStation 2
Extended warranty for Leica ScanStation 2

Notebook PC for Scanning$^{\Delta}$	
Component	**required (minimum)**
Processor	1.4 GHz Pentium M or similar
RAM	512 MB SDRAM
Network card	Ethernet
Display	SXGA+
Operating system	Windows XP (SP1 or higher) Windows 2000 (SP2 or higher)

Cyclone-SCAN

Independent vertical and horizontal scan density[1]
Scan filters: range, intensity[1]
Selection of scan area via scribed rectangle or pre-sets[1]
Atmospheric correction
Customizable longitude/latitude grid lines
Targeted, single-shot pre-scan ranging[1]
Script management for auto scan sequencing[1]
View scanner locations and field-of-view
Level of detail (LOD) for fast visualization
Auto rechecking (re-acquisition) of targets[1]
Auto acquisition of HDS targets[1]
Target identification
Traverse[1]
Field Setup - Resection[1]
Field Setup - Known Backsight[1]
Field Setup - Known Azimuth[1]
Traverse and resection reports
Stakeout and id-point
Point to and dwell on preselected coordinates
Direct coordinate/station entry[1]
Dual-axis compensation on/off
Engage/disengage turret
Target and instrument height input
Lighting control for digital images
Acquire and display digital image
Set image resolution (high, medium, low)
Support of external digital images
Real-time 3D visualization while scanning[1]
Fly-around, pan & zoom, rotate clouds, meshes, models in 3D
View point clouds with intensity or true-color mapping
Auto creation of panoramic digital image mosaic[1]
Global digital image viewer[1]
Point-and-scan QuickScan to set horizontal FoV[1]
User-defined quality-of-fit checks
Measure & dimension: slope dist., ΔX, ΔY, ΔZ
Create, manage annotations and layers
Save/restore views
Save screen images
Undo/redo support

Direct Import Formats

Cyclone native IMP object database format, Cyclone Object Exchange (COE) format
ASCII point data (XYZ, SVY, PTS, PTX, TXT)
Leica's X-Function DBX format, Land XML, ZFS, ZFC, 3DD

Direct Export Formats

ASCII point data (XYZ, SVY, PTS, PTX, TXT), DXF
Leica's X-Function DBX format, Land XML, PTZ

Indirect Export Formats

AutoCAD (via AutoCAD, COE for MicroStation plug in)
MicroStation (via COE for MicroStation plug-in)
PDS (via MicroStation, COE for MicroStation plug-in)
AutoPLANT (via AutoCAD, COE for AutoCAD plug-in)

All specifications are subject to change without notice.
All ± accuracy specifications are one sigma unless otherwise noted
[1] SmartScan Technology™ feature
* 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

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Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com/hds

- when it has to be **right**

Leica Geosystems

Leica HDS6000
Product Specifications

General	
Instrument type	Compact, phase-based, dual-axis sensing, ultra high-speed laser scanner, with survey-grade accuracy and full field-of-view
User interface	Onboard touch panel, or external notebook or Tablet PC, or PDA
Scanner drive	Servo motor
Data storage	Integrated hard drive
Camera	No integrated camera; Cyclone SCAN supports use of external camera

System Performance	
Accuracy of single measurement	
Position*	6mm, 1m to 25m range; 10mm to 50m range
Distance*	≤4mm at 90% albedo up to 25m; ≤5mm at 18% albedo up to 25m; ≤5mm at 90% albedo up to 50m; ≤6mm at 18% albedo up to 50m
Angle (horizontal/vertical)	125 μrad/125 μrad, one sigma
Modeled surface precision/noise**	2mm at 25m; 4mm at 50m for 90% albedo, one sigma; 3mm at 25m; 7mm at 50m, for 18% albedo, one sigma
Target acquisition***	2mm std. deviation
Dual-axis sensor	Selectable on/off; 3.6" resolution
Data integrity monitoring	Self-check at start-up; optional checks using Cyclone-SCAN

Laser Scanning System	
Type	Phase-shift
Laser Class	3R (IEC 60825-1)
Range	79m ambiguity interval 79m @90%; 50m @18% albedo
Scan rate	Up to 500,000 points/sec, maximum instantaneous rate; Average time: see "Selectability Table" below
Scan resolution	
Spot size	3mm at exit (based on Gaussian definition) + 0.22mrad divergence; 8mm @25m; 14mm @50m
Selectability	5 pre-set spacings per table

	Pts/360° (vert., horiz.)	Scan time (full dome)
"Preview"	1250	25 sec
Middle (4x)	5000	1 min 40 sec
High (8x)	10000	3 min 22 sec
Super High (16x)	20000	6 min 44 sec
Ultra High (32x)	40000	26 min 40 sec

Point spacing at range	@10m	@50m
"Preview"	50.6x50.6mm	250x250mm
Middle (4x)	12.6x12.6mm	62x62mm
High (8x)	6.3x6.3mm	31.4x31.4mm
Super High (16x)	3.1x3.1mm	15.8x15.8mm
Ultra High (32x)	1.6x1.6mm	7.9x7.9mm

Field-of-view (per scan)	
Horizontal	360° (maximum)
Vertical	310° (maximum)
Aiming/Sighting	Optical horizontal sighting using QuickScan™ feature
Scanning Optics	Vertically rotating mirror on horizontally rotating base; Environmentally protected by shield
Scan motors	Direct drive, brushless; proprietary
Power transfer	Onboard rotating turret or external to non-rotating base
Data transfer	Ethernet or USB 2.0 device (two ports)

Data storage capacity (onboard)	60 GB, min
Communications	DHCP client/server; Ethernet or Bluetooth
Status indicators	4-line alphanumeric display for laser status, system power & status 1 LED for laser status
Level indicator	External bubble; digital readout on touch panel or via laptop

Electrical	
Power supply	24V DC; 90 - 260V AC
Power Consumption	50 W
Battery Type	Integrated: Li-ion External: sealed lead acid
Duration	Internal: 1.5 hrs, typical External: 4 hrs, typical
Power status indicators	LEDs indicate charging status and capacity levels

Environmental	
Operating temp.	0° C to +40° C
Storage temp.	-20°C to +50°C
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing

Physical	
Scanner	
Dimensions	7.5"D x 11.5" W x 13.8" H 190mm D x 244mm W x 351.5mm
Weight	14 kg, nominal (includes integrated battery)
Battery (external)	
Dimensions	9.5" D x 10" W x 12" H 240mm D x 260 mm W x 300mm H
Weight	16 kg, nominal
AC Power Supply	
Dimensions	9.5" D x 5" W x 6" H 240mm D x 127 mm W x 152mm H
Weight	2.5 kg, nominal

Standard Accessories

Scanner and accessory carrying case
Additional rechargeable integrated battery
Charging/power cable, ethernet cable, A/C cable
Battery charger / A/C power supply
Battery charging cradle for internal battery
Cyclone™-SCAN software
Cleaning kit

Hardware Options

Notebook PC, Tablet PC, or PDA
HDS6000 scan targets and target accessories
Service agreement for Leica HDS6000
Extended warranty for Leica HDS6000
Tribrach (Leica Professional Series)
Survey tripod (Leica Professional Series)
External battery

Notebook PC for scanning Δ	
Component	**required (minimum)**
Processor	1.7 GHz Pentium M or similar
RAM	1024MB SDRAM
Network card	Ethernet
Display	SXGA+ (64 MB or greater video RAM rec.)
Operating system	Windows XP Professional (SP1 Or higher) Windows 2000 (SP3 or higher with up to date security patches)

PDA for scanning (rec.)

HP iPAQ Pocket PC Series
Windows Mobile 5.0 for Pocket PC; iPAQ Wireless application; Bluetooth wireless technology

Cyclone-SCAN

Scan density control from five (5) pre-sets
Scan filters: range, intensity[1]
Scan speed control (default or low)
Laser power control (normal or low/close-in)
Selection of scan area via scribed rectangle or pre-sets[1]
Customizable longitude/latitude grid lines
Pre-scan range probe
Script management for auto scan sequencing[1]
View scanner locations and field-of-view
Level of detail (LOD) for fast visualization
Auto rechecking (re-acquisition) of targets[1]
Target identification
Traverse[1]; traverse & resection reports
Field Setup - Resection; Known Backsight; Known Azimuth[1]
Direct coordinate/station entry[1]
Dual-axis sensor on/off
Stakeout and ID point
Target and instrument height input
Support of external digital images
Fly-around, pan & zoom, rotate clouds, meshes, models in 3D
View point clouds with intensity or true-color mapping
Point-and-scan QuickScan to set horizontal FoV[1]
User-defined quality-of-fit checks
Measure & dimension: slope dist., ΔX, ΔY, ΔZ
Create, manage annotations and layers
Save/restore views; save screen images; undo/redo support

Onboard touch panel control

Vertical, horizontal FOV
Scan density: 5 levels
Dual-axis sensor on/off
Laser power setting for normal or close-in mode

PDA control

Vertical, horizontal FOV
Scan density: 5 levels
Dual-axis sensor on/off
Laser power setting for normal or close-in mode
Display jpeg thumbnail of scan image

Direct Import Formats

Cyclone native IMP object database format, Cyclone Object ASCII point data (XYZ, SVY, PTS, PTX, TXT);
Leica's X-Function DBX format, LandXML, ZFS, ZFC, 3DD

Direct Export Formats

ASCII point data (XYZ, SVY, PTS, PTX, TXT);
Leica's X-Function DBX format, LandXML, PTZ

Indirect Export Formats

AutoCAD (via COE for AutoCAD plug-in)
MicroStation (via COE for MicroStation plug-in)
PDS (via MicroStation, COE for MicroStation plug-in)
AutoPLANT (via AutoCAD, COE for MicroStation plug-in)

Ordering Information

Contact Leica Geosystems or authorized representatives

All specifications are subject to change without notice.
All +/- accruacy specifications are one sigma unless otherwise noted.

[1] SmartScan™ technology feature
Δ Minimum requirements for modeling operations are different. Refer to Cyclone data sheet specifications.
* At 1m - 50m range, one sigma
** One sigma; subject to modeling methodology for modeled surface
*** Algorithmic fit to planar HDS gray & white targets

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

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Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com/hds

- when it has to be **right**

Leica Geosystems

TRIMBLE GX 3D SCANNER

PERFORMANCE

Range (typically, under standard clear conditions[1,2])

	350 m to 90% reflective surface[3] (w/ OverScan)
	200 m[4] to 35% reflective surface[3]
	155 m to 18% reflective surface[3]
Scanning speed	up to 5000 points per second
Standard deviation[5]	1.4 mm @ ≤50 m: 2.5 mm @ 100 m 3.6 mm @ 150 m: 6.5 mm @ 200 m
Single point accuracy	position = 12 mm @100 m: distance = 7 mm @ 100 m Hz angle = 12" (60 µrad): Vt angle = 14" (70 µrad)
Target acquisition	std dev. <1 mm (Trimble targets)
Modeled surface precision	± 2 mm (depending on method)[2]
Leveling	circular level in tribrach: 8' dual-axis compensator (user selectable); resolution 0.3" (1 cc); operating range ±14' Real-time automatic level compensation
Data integrity	periodic zero index calibration real-time thermo-compensation
Scan enhancement	atmospheric corrections (user definable) user-definable multishot averaging autofocus: user-controlled or auto-implementation
Scan resolution	spot size: 3 mm @ 50 m
Spot size with autofocus:	0.3 mm @ 5 m; 0.9 mm @ 15 m; 1.5 mm @ 25 m Point spacing: down to 3.2 mm @ 100 m (available 1.6 mm vertical = 18 pts/cm^2 / 105 points/sq.in) Scan row (hz): 200,000 points ; Scan row (vt): 65,536 points

SYSTEM SPECIFICATIONS

Laser	type: pulsed 532 nm, green Class: IEC 60825-1 – Class 3R; 21 CFR §1041.10: Class 2
Field of view	360° x 60° continuous single scan
Optics	patented scanning optical system
Data transfer	USB link for available extensions
Digital imaging	real-time integrated color video with 5.5x optical zoom
Status indicators	system ready, laser on, comm. status

PHYSICAL

Servo-Driven 3D Laser

Scanner	dimensions: 323 D x 343 W x 404 H mm weight: 13.0 kg (28.7 lb); power consumption: <100 W
Power supply	super compact unit. AC 90–240 V, 50–60 Hz; DC 24 V nominal dimensions: 169 D x 65 W x 37.5 H mm; weight: 0.7 kg (1.5 lb)
Instrument case	rugged and portable, rolling; dimensions: 645 D x 490 W x 435 H mm; weight: 14.2 kg (32.4 lb)
Environmental	operating temp: 0 °C to 40 °C; storage temp: –20 °C to 50 °C light: fully operational under all light conditions sealing: IP53 (I.E.C.); shock: IEC 60721-3-2: 2M2 (scanner) 2M3 (scanner in case) transportation compliant humidity: non-condensing atmosphere

Standard accessories	rolling instrument case; super-compact power supply unit with AC cables; Trimble tribrach; ethernet cable for connection of scanner to data collector; 50 adhesive flat targets; Trimble 3D Scanner Field Software installation kit
Optional accessories	Trimble® Recon® and TSC2 special extended caps for wired connection; PocketScape field software; Trimble 3D scanner backpack; car battery cable kit; target kits (planar, spherical); batteries; WiFi unit

FIELD SOFTWARE

PointScape field software for the Trimble GX 3D scanner runs on a Notebook PC. PocketScape field software runs on the Trimble Recon and TSC2[6] controllers. Both applications offer advanced scanning functionality:

Efficient Survey workflow:

- Electronic level
- Dual axis compensation
- Atmospheric corrections
- Station setup and resection routines

Framing tools:

- Rectangular framing
- Video zoom control
- Sphere, target and single point measurement

Scanning options:

- Trimble SureScan technology[7]
- Pre-set or custom scan settings
- Return intensity and colored point cloud
- Estimated scan time and resolution control

Additionally, PointScape offers the following advanced features:

- Live video streaming
- Automatic panorama
- Automatic scan imaging
- Fast interactive framing on video, 3D point cloud, panorama or image
- Polygonal framing
- Multiple scan framing
- Automatic target and sphere recognition
- Real-time 3D visualization, pan and zoom, even while scanning
- Visualization of scanner location
- True color or intensity mapped point cloud display
- Simulated surface rendering and environmental lighting
- Measure and inverse computations
- Target re-check

1 Standard clear: No haze. Overcast or moderate sunlight with very light heat shimmer.
2 Range and precision depend on atmospheric conditions, size of targets and background radiation.
3 Kodak Gray Card, Catalog number E1527795.
4 Specifications on precision are valid within this optimum range.
5 Figures (typical values) given for standard data capture of four shots, on distance measurement.
6 The Trimble GX Standard instrument only supports the Trimble Recon Controller.
7 The Trimble GX Standard instrument does not offer SureScan technology.

Specifications subject to change without notice.

PN 022543-404 (09/07)

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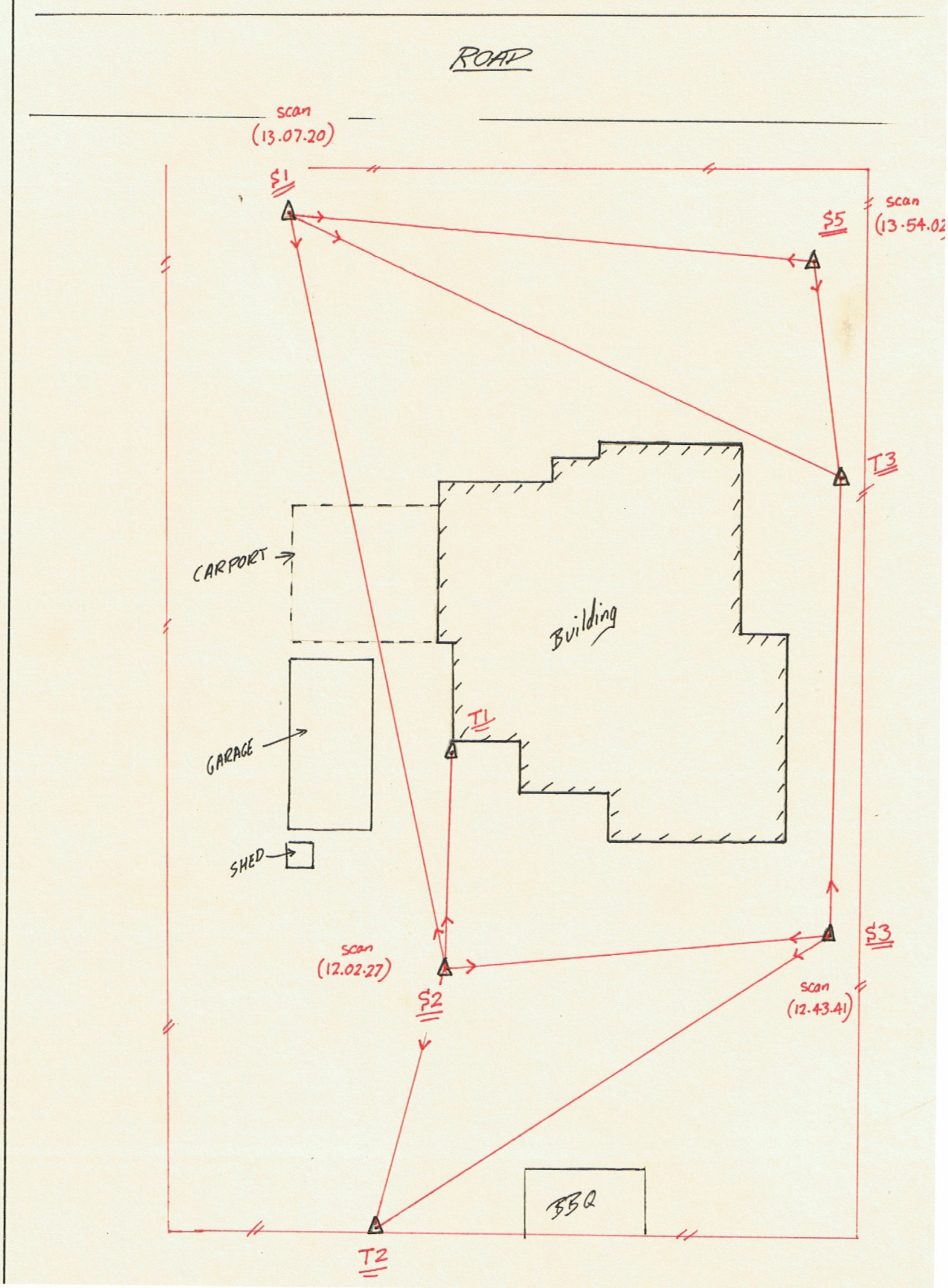
APPENDIX C

FIELD CARDS

Detail Scan Field Card
Traverse Control Field Card
Scan Cloud Log Field Card

DESCRIPTION Detail Scan SHEET 1 OF 3 FILE RAW FILE

LOCATION Residential Building EQ Leica HDS6000 SURVEY TEAM MDS DATE 12/7/07

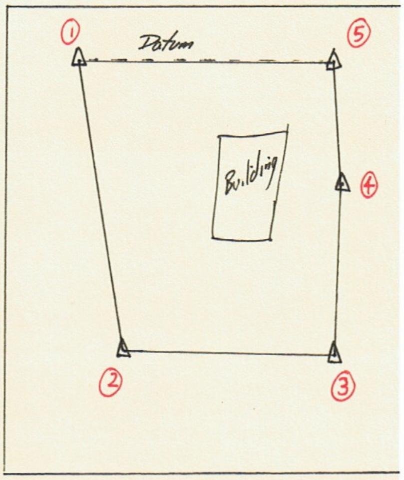


DESCRIPTION Traverse Control SHEET 2 OF 3 FILE RAW FILE

LOCATION Residential Building EQ TRIMBLE S6 SURVEY TEAM MDS/AD DATE 11/7/07

At ① From ∡ 5 to 2

	②	⑤
78° 12' 28"	35.665	15.342
156° 25' 04"	35.664	15.342
(78° 12' 32")		



At ② From ∡ ① to ③

	①	③
101° 07' 00"	35.664	14.141
202° 14' 07"	35.664	14.140
(101° 07' 04")		

At ③ From ∡ ② to ④

	②	④
82° 32' 34"	14.141	19.331
165° 05' 05"	14.141	19.331
(82° 32' 33")		

LEVELS

BS	FS	COMMENT	RL
0.5028		①	100
1.6182	2.7632	2	97.740
2.2685	1.2809	3	98.077
2.0316	1.4112	4	98.934
1.2088	0.7401	5	100.226
	1.4340	1	100.001

At ④ From ∡ ③ to ⑤

	③	⑤
176° 01' 00"	19.331	15.965
352° 01' 59"	19.331	15.967
(176° 01' 00")		

At ⑤ From ∡ ④ to ①

	④	①
102° 06' 24"	15.969	15.343
204° 12' 37"	15.967	15.343
(102° 06' 19")		

Misclose ∡ -30"

STN	EASTING	NORTHING	HT
1	2000.000	5000.000	100.000
2	2034.912	5007.284	97.740
3	2034.748	5021.423	98.077
4	2015.610	5018.693	98.934
5	2000.000	5015.344	100.226

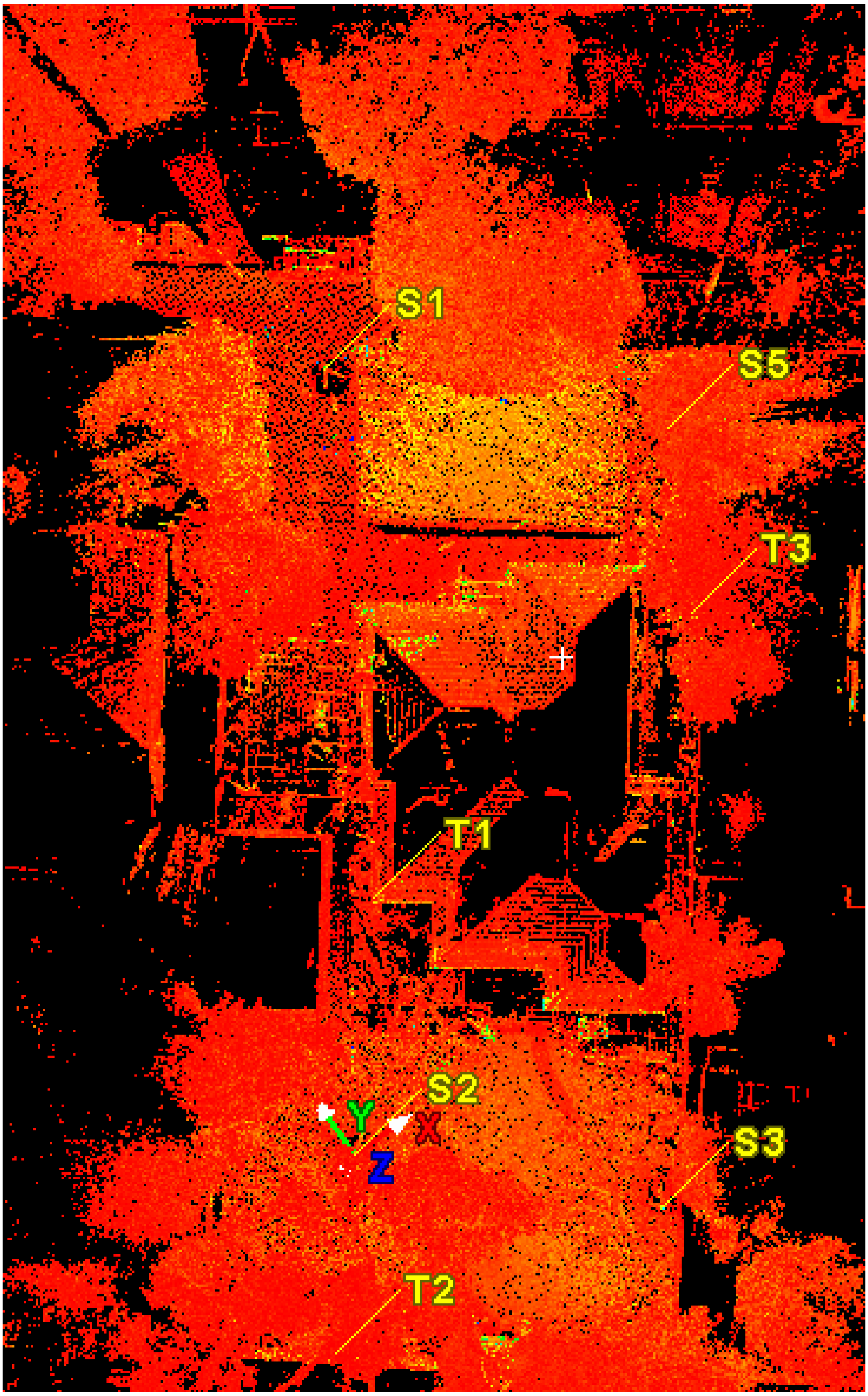
DESCRIPTION Scan Clouds Log SHEET 3 OF 3 FILE RAW FILE

LOCATION Residential Building EQ SURVEY TEAM MDS DATE 12/7/07

SCANWORLD	NO. SCANS	TARGETS ACQUIRED	COMMENTS
At ② scanworld 1 Ht = 1.458m File Name: (12.02.27)	High, Low Power, Low Noise 360° x 320° Highest Low Power, Low Noise 360° x 320° Medium High Power 360° x 320°	$3 Ht = 1.645 $1 Ht = 1.855 $T1 Ht = 0 T2 Ht = 0	— ~~no~~ tilt sensor on — with tilt sensor on — Fatal Error [ABORT]
At ③ scanworld 2 Ht = 1.404m File Name: (12.43.41)	High, Low Power, Low Noise 360° x 320° High, High Power, Low Noise 360° x 320°	$2 = 1.694 ~~$5 = 1.636~~ T3 = 0 T2 = 0	— tilt on — tilt on
At ① scanworld 3 Ht = 1.619m File Name: (13.07.20)	High, High Power, Low Noise 360° x 320° Highest, High Power, Low Noise 360° x 320°	$5 = 1.636 $2 = 1.694 T3 = 0	— tilt on $2 had interferrence whilst scanning target. — Fatal Error [ABORT]
At ⑤ scanworld 4 Ht = 1.400 File Name: (13.54.02)	Highest, High Power, Low Noise 360° x 320° High, High Power, Low Noise 360° x 320°	$1 = 1.855 T3 = 0	— tilt off — tilt on

APPENDIX D

OVERALL LAYOUT OF CONTROL ON FULLY REGISTERED POINT CLOUD DATA


S1
S5
T3
T1
S2
Y
X
Z
S3
T2

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