University of Southern Queensland

Faculty of Engineering and Surveying

A comparison of remotely sensed terrestrial spatial information

A dissertation submitted by

Will Paul Dorahy

In fulfilment of the requirements of

Courses ENG4111 and 4112 Research Project

Towards the degree of

Bachelor of Spatial Science (Surveying)

30th October, 2008

Abstract

Today’s users of spatial data request information sooner, more accurate and safer than ever before. New technologies equip spatial professionals with the ability to achieve this. Terrestrial laser scanning and terrestrial photogrammetry offer similar advantages when it comes to remotely sensed data acquisition.

Terrestrial photogrammetry has a history of use as a remote sensing tool, and with the emergence of cheaper, high quality digital cameras; photogrammetry has become accessible to a wider range of users. Terrestrial Laser Scanning is comparably new to the spatial science industry, with its many advantages fast becoming recognised by professionals. Its usability is limited to the economic cost of the scanner and the surveyor’s confidence in their ability to guarantee the data captured by the scanner. This project will seek to compare the accuracy that can be expected from single point measurement for both technologies.

The testing included a grid of targets that was used for both technologies. These targets were coordinated by Total Station with reflectorless EDM. Three of the targets were used to orientate the information collected from the two technologies to a common reference system, with coordinates of the points not included in the orientation directly compared to the original coordinates.

The results of this project validated the superior accuracy of the terrestrial laser scanner. Results also indicate that terrestrial photogrammetry offers reasonable accuracy levels suitable for many functions as a low cost alternative.

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111 & ENG4112 *Research Project*

Limitations of Use

Certification

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

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

William Paul Dorahy

Student Number: 0050041557

Signature

30th October, 2008

Date

Acknowledgements

This research has been carried out under the principal supervision Dr. Frank R Young and Mrs. Xiaoye Liu.

Appreciation is also due to Clinton Caudell for help with the equipment, Francois Du Bois for his help with the laser scanner and Luke from constant 3D for his support and advice with the photogrammetry software.

I would like to thank Christine and Doc for the opportunity, Lee and Louise for the support, C. Norris for the inspiration and all academic staff that have equipped me with the skills to complete my studies.

Will Dorahy

Table of Contents

List of figures

List of tables

Glossary of terms

3D: - Three dimensional. A description of the spatial environment in reference to its three dimensions.

Co-ordinate system: - A set of numerical values that describe the position of a point in three dimensions.

EDM: - Electronic Distance Measure. A device that will range a distance from an instrument.

Point cloud: - A set of three dimensional points in space.

DSM: - Digital Surface Model. A model that is created by the linking of many three dimensional points to create a surface.

CCD: - Charged-Coupled Device. An array of photoelectric light sensors that act to serialize parallel analogue signals. It is used in most modern digital cameras.

ICP: - The Iterative Closest Point is a function that attempts to match two 3D point surfaces by iteratively minimising the sum of the squares between the points.

PAM: - Piecewise Alignment Method. A method used to align the three dimensional point clouds of two geo-referenced models created by multi-temporal scanned models. Uses the ICP method.

EAI: - Equal Angle Increments is a term used to describe a type of movement. The terrestrial laser scanner used in this project utilises EAI to measure angles.

Phase Shift: - The shift in phase with reference to an electro-magnetic wave.

JPEG: - Joint Picture Expert Group is a commonly used method for compression of images.

RMS: - Root Mean Squared is a statistical measure of the magnitude of a varying quantity.

Chapter 1: Introduction

1.1 Outline

This project seeks to compare terrestrial photogrammetry and laser scanning techniques of obtaining spatial data. Both these technologies come under the label of remotely sensed terrestrial information. Similarities between the two technologies have justified research into the usefulness of each in different situations.

1.2 Introduction

Today's society demands things to be done faster, better and safer. In reference to spatial science, this means that professionals in the industry need to collect and use spatial data sooner, more accurate and safer than ever before. New technologies equip professionals with the ability to achieve this. As a result, the industry is changing to provide better spatial solutions to real world problems.

Previous technologies have been successfully introduced into the industry and moved to mainstream surveying. A classic example is the use of the Global Positioning System (GPS) which is now in widespread use. When the technology was first introduced, many professionals had little knowledge of its accuracy, what caused inaccuracies, and how they could be managed. Due to research and the obvious advantages that GPS provides, it is now considered an industry standard in some applications, as spatial scientists are able to identify and manage sources of errors and guarantee the accuracy of its data to clients.

1.3 Project Background

Laser scanner technology is relatively new to the industry with rapidly increasing use. Mitchell (2003) declares that terrestrial laser scanners "…could well be the cause of the next revolution in surveying". The terrestrial laser scanner has not only performed many conventional surveying tasks, but has allowed data collection, that before had not been thought of. Mitchell describes s terrestrial laser scanners as “black boxes”, as most of the important functionality is inaccessible to the user. This is good in that it allows the easy use of the equipment by people with little surveying knowledge. This advantage, however, is contradicted by the dangers of the complexity of the system and the amount of components that can malfunction. This follows that professionals using the system must have an extensive knowledge of the system and the potential errors that can occur. Mitchell (2003) states that “Surveyors clearly need to be able to guarantee the measurements they generate; they need some way of controlling the errors even from a black-box.”

Photogrammetry was the first remote sensing technique established and is historically as old as modern photography itself. The use of photogrammetry has been limited to the quality of the equipment and the procedures in place to analyse and correct the equipment. It has been this aspect and the quality of the cameras that have been evolving over the years.

Remotely sensed terrestrial survey techniques (photogrammetry and laser scanning) have many similarities in the advantages they offer. Both the technologies perform similar tasks to traditional survey techniques; however, have potential to execute these faster. By remotely sensing objects, the equipment offers safety over traditional options, where the objects or environment are unfavourable for people to be, for example, high walls in open cut mines.

In terms of the data captured by the two technologies similarities exist in the nature of the three dimensional values being collected and a “point cloud” of these are captured. Laser scanners will scan a prescribed area with collected points in a controlled array. These points will have X, Y, Z coordinate values as well as some data acquired from the nature of the returned laser.

1.4 The problem

Both terrestrial photogrammetry and laser scanning share similarities and is the reason for the investigation. The procedures for the acquisition of data have similarities; the data that they produce is very comparable and they are both able to remotely sense the spatial data they are obtaining.

The surveyor will perform some similar functions in the fieldwork stages of a project in terms of choosing instrument position and set-up. This being said, however, there are some differences between the two technologies in the data collection stage.

Photogrammetry is for all sense and purpose, instant data collection; however, two or more photographs are required for processing. Laser scanning is also very quick and is much faster than rival conventional survey techniques.

The way that the data is actually acquired is totally different. Photogrammetry relies on processing in the office in order to create points from the photographs. Scanners, however, collect and store the data whilst in the field, with processes such as registration and modelling completed post-survey.

1.5 Objectives

The objective of this project is to form a basic comparison between the two technologies. A review of literature on the two technologies and their application needs to be completed in order to design a testing scenario of the two technologies in controlled environments. From these tests, the method of comparison needs to be completed in which assures accurate results.

1.6 Conclusion

As stated, the purpose of this project is to compare terrestrial laser scanning and terrestrial photogrammetry. This comparison will primarily be focused on the accuracy of the two technologies; however, through research and in using the equipment, opinions will be formed on other factors such as simplicity, efficiency and cost.

The results of this project will establish the differences in accuracy for single point positions and hence will provide assistance in the choice for which technology to use for specific purposes.

Chapter 2 - Literature Review

2.1 Introduction

Both Terrestrial photogrammetry and laser scanning are in popular use by surveying professionals for similar applications. Literature provides examples of these uses from across the world and the success of these applications. There are also many references to the accuracy of both the technologies individually. As a direct comparison, information is not as common, but still prevalent.

This chapter will offer a review of relevant literature available on the technology in order to gain an understanding of the history of the technologies, the theory behind them, their current uses and the perceived futures.

2.2 Terrestrial laser scanning

A terrestrial laser scanner is a land based laser scanner that is able to remotely sense the three dimensional properties of objects and environments. This is achieved by way of measuring horizontal and vertical angles and reflected distances. Laser scanners collect high resolution, high accuracy data in both light and day conditions.

In theory, laser scanning uses similar principles as modern total station surveying methods; however, the way in which the scanner repetitively automates the processes is unique to the technology. The resultant data from laser scanners are commonly known as “point clouds”, as they resemble a cloud of scattered points post-collection. Point clouds are able to be used in order to create three dimensional models by way of fitting solid objects to points.

Laser scanner technology has many current and potential uses. The applications cover a range of functions in conventional and non-traditional fields such as:

- Modelling of heritage listed buildings.

- Modelling of environments and structures for virtual reality computer modelling.
- Documenting archaeological finds.
- Forensic crime scene investigations.
- Surface and structural deformation monitoring.
- Observation of tree growth and health.
- Modelling of plant infrastructure.
- Engineering as constructed surveys.

These uses are just some of the applications of the technology, with further research into laser scanner software and functionality increasing its realised use. There are many cases of the technology being used for data capture that was previously very limited.

2.2.1 Laser scanner theory

Terrestrial laser scanners acquire spatial data remotely by an emitted pulse returning a distance. By rotating a prism in the scanning unit, the vertical angle will change, enabling the capture different positions on an object. With the rotation of the scanner unit on its horizontal axis, a ‘grid’ of points will be collected over the surface of the object or environment on a coordinate system relative to the scanner as seen in Figure 2.2-1. Scanners use equal angle increments (EAI) in vertical and horizontal planes in order to create this apparent grid.

There are two basic types of terrestrial laser scanners in common use. These are time of flight and phase-based scanners. On the basic level, both methods work very similar, with the way in which a laser is sent and returned via a rotating prism common in both technologies. The major difference is the way in which the distance is calculated. This difference causes the variations between the two types.

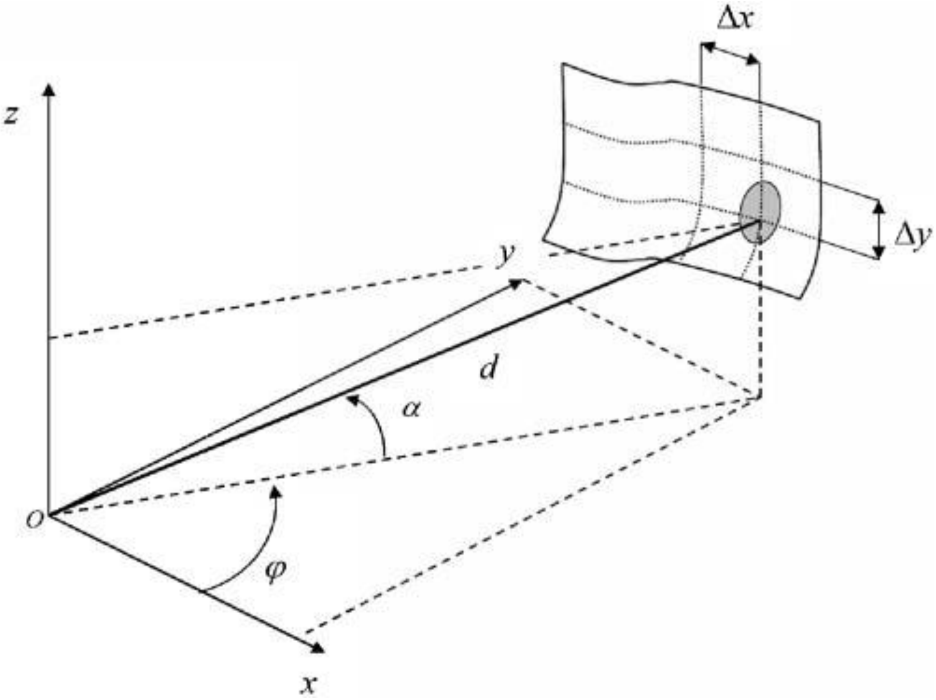


Figure 2.2-1: Principle of the time-of-flight terrestrial laser scanner.

A nanosecond laser pulse is sent in the direction whose angular coordinates are Q and a; if a target reflects the signal, its distance d is computed from the time of flight. The Cartesian coordinates (x,y,z) of the reflector are obtained from the spherical ones (d, Q, a). Teza, G. et al. (2006)

2.2.1.1 Time of flight scanners

Time of flight scanners are the most commonly used scanner and operate by calculating a time of flight to range a surface. A laser pulse is emitted from the scanner with the prism inclined at known angles. The laser pulse is reflected off a surface and returned to the prism, with the time of flight able of the pulse to be calculated. The time of flight can then be calculated due to the speed we know light will travel in the atmosphere. Lichti (2002) identifies that the range, ρ, is derived by the two way flight time of the pulse, Δt as represented by the formula

$$\rho = \frac{1}{2} c\Delta t \qquad (1)$$

The time of flight method works by sending and receiving a laser pulse in order to calculate distance, thus the rate that points are able to be captured is dependent on the speed in which this operation is able to take place. Time of flight scanners commonly record points in the order of *50 000* points per second. These types of scanners are acknowledged as having a longer range than phase based scanners. The Leica Scan Station 2 used for this project has a quoted distance of up to 300m, however, some terrestrial laser scanners claim up to 1000m. Because of the nature of the technology, the accuracy is determined by how accurately time is able to be measured by the instrument.

2.2.1.2 Phase based scanners

Phase based scanners use the same principle to calculate the angles, however the way in which the distance is calculated is quite different. Distance is calculated in a similar way to an EDM in total stations. A Sine wave is transmitted from the instrument with the phase of the returned wave compares to that of the transmitted wave. From this a ‘phase shift’ can be determined in order to determine a distance. Figure 2.2-2 demonstrates the concept of phase shift.

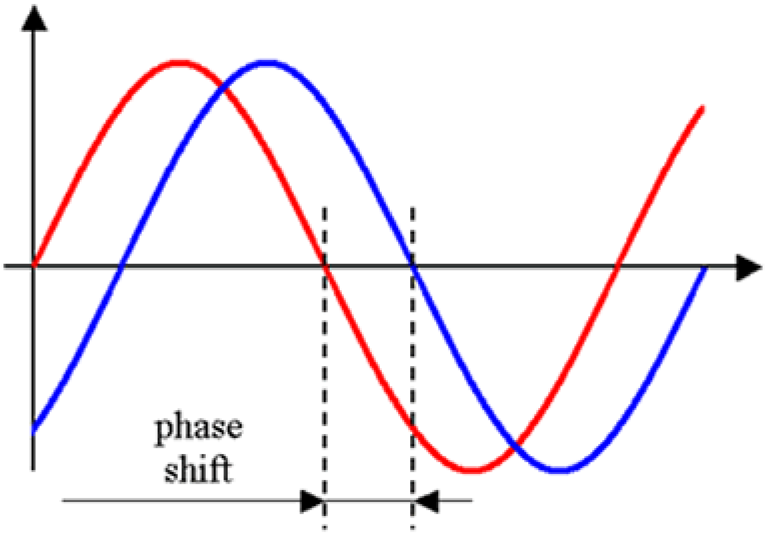


Figure 2.2-2: Calculating phase shift to calculate distance in phased based scanners.
Source: http://mirror.bom.gov.au/weather/radar/about/images/phase_shift.gif

This method has proved to be of higher accuracy than the time of flight method. Due to the nature of the technology, this accuracy is only available over shorter distances, with most models quoting under 100 metres. Because of the method in which the laser is emitted, phase based scanners have a much higher rate of capture in the order of 500 000 points per second.

2.2.2 Accuracy

Different manufacturers will quote different accuracies and are often not comparable. As mentioned above, spatial scientists need a way of guaranteeing the data that they provide their clients. Therefore it is of high importance to understand the causes of inaccuracies in laser scanners and how they can be minimised.

Boehler and Marbs (2003) on the paper *Investigating laser scanning accuracy*, identifies the need for accuracy of the technology to be explored. I3mainz, in conjunction with the University of Applied Sciences, Mainz, Germany have created a standardised test used to compare terrestrial laser scanning accuracies.

The paper recognises that it is difficult to identify the exact ‘numerical’ accuracy of terrestrial laser scanning due to the inability of scanners to duplicate the exact same point in successive scans. This being said, however, fine scanning of targets have made this increasingly achievable. Tests have been designed to identify different aspects of scanner accuracies. These accuracies were identified as angular accuracy, range accuracy, resolution, edge effects, surface reflectivity and environmental conditions.

The angle that the laser pulse is emitted is determined by the angle of the rotating device and the mechanical axis of the instrument. This follows that the angular accuracy of the laser scanner is dependent upon the ability of these components to accurately define the angle in which the laser signal is emitted. Any problem with the axes or bearings of the instrument will cause angular errors.

The accuracy of the ranging of surfaces is quite vital in the positioning of surfaces. Focusing on time of flight scanners, being the type used for any testing in this project, computing range is reliant on the ability to accurately determine the time of flight. The reflectivity of the surface will affect the systematic range errors. This follows that a universal zero error cannot be determined as in conventional methods of determining distances (Boehler and Marbs, 2003). It is known that white surfaces return strong reflections, whilst black will return a weaker signal. The effects of colour surfaces will vary depending on the spectral characteristics of the laser (Boehler and Marbs, 2003). The angle in which the laser strikes the surface will also affect the accuracy of the range.

Range is affected largely by environmental factors such as temperature, atmospherics, and interfering radiation. Boehler and Marbs (2003) identify that deviations will occur with variations in the temperature of the scanner itself. Scanners will also only function properly within a certain temperature range specified by the manufacturers' specifications. Atmospherics affect the accuracy, due to temperature and pressure variations affecting the propagation speed of light.

Resolution is commonly used in relation to laser scanners as the ability to detect small objects and object features from point cloud data. Boehler and Marbs (2003) describe the two factors that will influence the resolution of data as the smallest possible increment of the angle and the size of the laser beam on the object. Resolution will vary greatly form model to model and should be able to be modified by the user to suit different purposes. High resolution scans will obviously capture many more points, resulting in larger files and longer scan times. Therefore, it is often a trade-off between resolution and field time. This attribute has been determined by the scanning of objects with fine elements as seen in Figure 2.2-3 below.

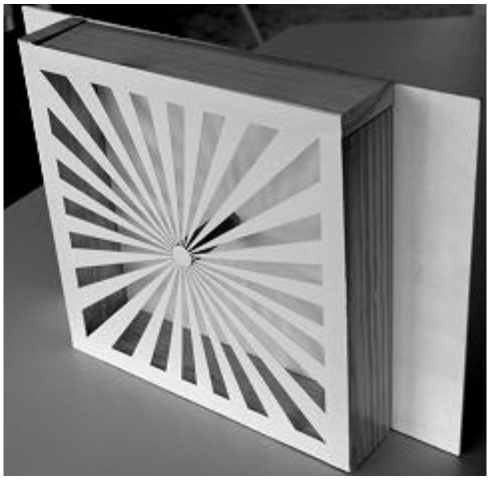


Figure 2.2-3: Scanner resolution test template.

The predicament with edge effects is that the laser spot has a definite thickness, and due to this the laser beam may fall half on the edge of an object and the rest on an object behind it, returning a false distance. This results in phenomena known as phantom points, and causes points on the edges of objects to be in error. Most software packages cope with this by the fitting of planes to surfaces creating points where they meet instead of using points on the extents of the object as the defined 'edge'. The more focused that the laser beam is, results in better edge effects.

Kern (2003) recognises a check for range measurements from a plane target perpendicular to the observation direction scanned with the resulting standard deviation of the differences in ranges.

2.2.3 Registration

Terrestrial laser scanners are only able to collect points in line of sight and within range. This means that for larger jobs, it is necessary to have multiple scans. The problem then exists in how to combine the point clouds from the scans into a single model. The process that achieves this is known as registration, and uses common points in different scans in order to create the single cloud model with the same orientation and position. Algorithms have been established in order to achieve this.

2.2.4 Other terrestrial laser scanner research

When the technology has been applied to current demands for data collection, where traditional methods are predominately in use, the laser scanner has proved to be quite effective. The journal article in the International Journal of Remote Sensing: "*Terrestrial laser scanner to detect landslide displacement fields: a new approach.*" makes evident one use of the technology (Teza, G. et al., 2006). The article informs of the increasing use of terrestrial laser scanners in the monitoring of "hydrogeological instability phenomena such as landslips". Laser scanners are used in circumstances such as these due to the ability to remotely sense large amounts of dense spatial information. The data processing of this application is quite complicated as it attempts to compare a three dimensional point cloud of two geo-referenced models collected at different times. The Piecewise Alignment Method (PAM) is introduced as the method used to align the multi-temporal scanned models. PAM utilises the Iterative Closest Point (ICP) algorithm to align the models. The method uses a complete model as a reference with subsequent scans divided into sub-areas with a side of a few metres. These sub-areas are then individually aligned to the reference model using the ICP algorithm. A diagrammatic view of ICP algorithm is shown in Figure 2.2-4 below.

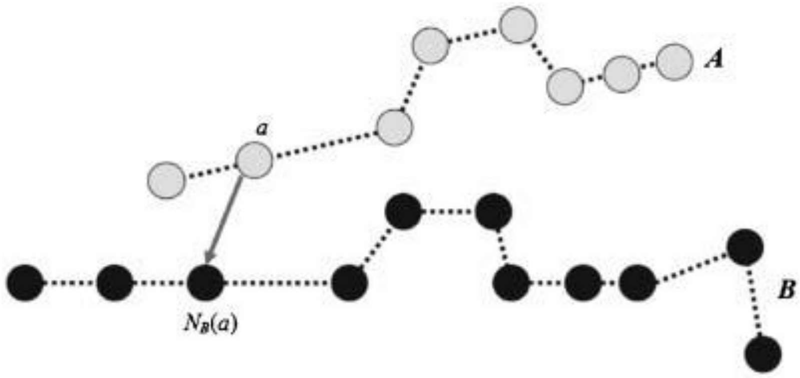


Figure 2.2-4: Principle of the ICP alignment technique.

For each point in A (data set), its nearest neighbour is found in B (reference set). The sum of the squared distances between nearest neighbours is considered (cost function), and the objective is to minimize this cost function over all the rototranslations of A relative to B. (Teza, G. et al., 2006).

Chow, K. (2007) presents a paper on the use of terrestrial laser scanners for the use of the Highways Department of Hong Kong. The research involved four common projects used within the department. These were the collection of information of a high-speed highway, roadside slopes, uneven road surfaces and overhanging cables. The research investigated the effectiveness of the laser scanner as applied to each project. Chow concluded that the "...terrestrial laser scanner will used more widely for the highway engineering survey applications in the department."

2.2.5 The Leica Scan Station 2

The terrestrial laser scanner that will be used in the research will be the Leica Scan Station 2. The scanner is a pulsed time of flight scanner and is classed a class 3R laser. The function and processing software used is Cyclone.

Some important product specifications quoted by the manufacturers are listed below:

- Accuracy of single measurement: 6 mm Position, 4 mm distance.
- Modelled surface precision/noise: 2 mm 1 σ
- Scan rate: 50 000 points/second (maximum)
- Maximum sample density: <1 mm^2
- Field of view: 360˚ horizontal, 270˚ vertical.

Figure 2.2-5: Leica Scan Station 2.

For a full product specification sheet of the Leica Scan Station 2 see Appendix B.

2.2.6 Field techniques

The Leica Scan Station 2 uses special, high definition targets in order to complete the registration process as seen in Figure 2.2-6 below. These targets use contrasting materials, allowing the program to identify the targets, and re-scan the target at high resolution in order to achieve higher accuracy. From this information, various field techniques can be used for the orientation of the system.

Figure 2.2-6: The HDS targets used as control points.

Firstly, the scanner will perform a complete scan of the full area as defined by the user. From this, the user can pick a point near the target and the scanner will move through the ‘fine scan’ process, finding the centre of the high definition targets. Once all targets are identified various field techniques can be identified to perform different field techniques, similar to that of conventional surveying. Some of these field techniques include traversing and resection.

2.3 Terrestrial photogrammetry

Photogrammetry, as the first remote sensing tool, has been established for practically as long as photography itself. It was realised by taking two or more photographs, the images can create three dimensional models of a surface.

Terrestrial photogrammetry has been extensively used in cases where it is preferred or necessary that intimate contact is not made with the environment that is required to be modelled. Applications for terrestrial photogrammetry are similar to that as mentioned earlier in uses for terrestrial laser scanning.

In terrestrial photogrammetry, control points need to be identified in the photos in order to solve for the position and orientation of the cameras. This will be a major influence to the accuracy of the final data, as the amount of redundant points and the accuracy in which the targets were initially coordinated forms the basis of the orientation of the images.

Chong, A et. al, (2003) discusses the "…potential of digital photogrammetric recording of historic buildings and monuments … in New Zealand". The paper '*Digital Architectural Photogrammetric Recording of Historical Buildings and Monuments*' commented on the photogrammetric recording of World Heritage Sites listed by The International Committee for Monuments and Sites (ICOMOS). The study shows that digital photogrammetry is a cost-effective and user-friendly method of recording complicated architectural designs. This type of study is quite widespread as the need to make records of historical buildings becomes more important

Areas where terrestrial photogrammetry is the necessary method of data acquisition include objects with an instantaneous temporal resolution. Papa et. al. (2002) identifies terrestrial photogrammetry techniques as a "... flexible and robust approach for measuring the static and dynamic characteristics of future ultra-lightweight and inflatable space structures (a.k.a. Gossamer structures), such as large membrane reflectors, solar sails, and thin-film solar arrays." The data of this type of structure may not be able to be recorded by a laser scanner because of the dynamic nature of its structure.

Corripio, J (2004) investigated the use of terrestrial photogrammetry in the measuring of the snow surfaces on an alpine glacier. The paper is entitled “Snow surface albedo estimation using terrestrial photography” and concluded that this method showed good agreement to methods already being used for this purpose. Albedo is a physical property of an object to diffusely reflect light from the sun, similar to the term spectral reflectance. Corripio describes terrestrial photogrammetry as a “flexible and inexpensive remote sensing tool”.

.

2.3.1 CCD and Image file formats

CCD is the technology that a most digital cameras use in order to acquire images. CCD is an acronym for Charged-Coupled Device. It is basically an array of photoelectric light sensors that act to serialize parallel analogue signals. The quality of the CCD is expressed in terms of how many pixels that the CCD contains. Information collected by the CCD is stored in the camera in digital form.

Most modern digital cameras use JPEG file formats. JPEG or Joint Picture Expert Group is a form that the processing software, PhotoModeler uses to import images into the program. JPEG does have it downside, however, which comes in the way that it compresses images. This is achieved by grouping similar pixels in terms of colour and storing them as the same colour. This reduces the quality of the original image, with rounded objects often being displayed with more “squareness” due to the grouping of similar pixels. This can make it harder to identify some points in the images when referencing. JPEG is, however, the most commonly used format, especially on the web and will therefore be used in the project.

2.3.2 Software and camera

There are many software packages on the market in which allow for the self-calibration of cameras and the processing of the images into spatial data. Papa et. al. (2002), in the paper entitled *Photogrammetry Methodology Development for Gossamer Spacecraft Structures,* identifies the software *Photomodeller* used for processing. With the software, photographs are taken of a pattern with known geometric properties. This calibration information is then used by the software to increase the accuracy of the data being acquired.

There are numerous software packages that could be appropriate for use for the project such as *Australis,* and the affect that this will have on the accuracy of the data will have to be taken into account when comparisons are made to laser scanning.

The software chosen to use in this project will be Photomodeller version 6. This software represents itself as a package on the market that offers a good standard as to use for the comparison. A trial version was made available by Constant 3D services, Brisbane for the completion of testing associated with this project. The software has functionality from importing images all the way through to creating the final project requirements. The requirements of PhotoModeler, as well as photogrammetry in general will be discussed later in this chapter.

The camera to be used for this testing in this project needs to be easy to operate, common and good value for money. The camera needs to be able to take reliable and consistent photographs of reasonable quality with simple operation and functionality. The camera needs to be easy to operate so as to show that the average person will be able to learn to use the camera quickly and easily. A common, middle-high range camera is ideal for this testing as the need to replicate someone with a small budget (a camera that many people may already own as to minimise outlay costs). The ideal megapixel range is between 5 and 10 megapixels to ensure good quality images are required. (PhotoModeler Documentation)

The camera used for the testing in this project was the Samsung S85 as pictured in Figure 2.3-1. This camera is 8.2MP and fell between the desired range of 5MP and 10MP.

Figure 2.3-1: The Samsung s85 8.2 MP camera

2.3.3 Calibration

In the general case, a calibration is a process that establishes the relationship between a measuring device and the units in which the device will be measuring. A camera calibration is needed in photogrammetry in order to determine the characteristics of the camera in order to turn it into a measuring device. (PhotoModeler documentation)

Fraser, C. has performed extensive research into the use of digital cameras for terrestrial photogrammetry. On his paper *Digital camera self-calibration* (1997), Fraser investigates and reviews the application of analytical self-calibration to digital cameras. Mentioned are the revolutions in close-range photogrammetric image acquisitions over the (then) 25 years since the introduction of analytical camera self-calibration.

A camera calibration is used to determine such parameters such as the focal length of the lens, the digitising scale and the principle point. In addition to these, greater accuracy can be achieved by obtaining further parameters that describe the distortion characteristics of the lens, as no lens can be manufactured absolutely perfectly. The focal length of a camera is a measure of how much the lens will converge light. The digitising scale is the format size (Fw, Fh), and in the case of digital cameras the format size of the CCD. The principal point (Xp, Yp) is the point where the optical axis of the lens intersects the photograph, that is, the reference point in the image to which all marks and lens distortion parameters are related. Lens distortion factors include radial distortion's one to three (K1, K2, K3). The decentring distortion (P1, P2) is similar to, but much smaller than radial distortion. (PhotoModeler documentation)

In order to perform this calibration, Photomodeller utilises a standardised pattern to be imaged by the camera. This is called a calibration grid and photos are taken of the grid from different positions and orientations. The best calibration will be using a calibration grid at the same focus settings (i.e. same distance from camera to object), however, this is often not practical, as in this case. For practical applications, achieving a moderate level of accuracy, it may be necessary to use a calibration grid at a smaller distance and use it at another.

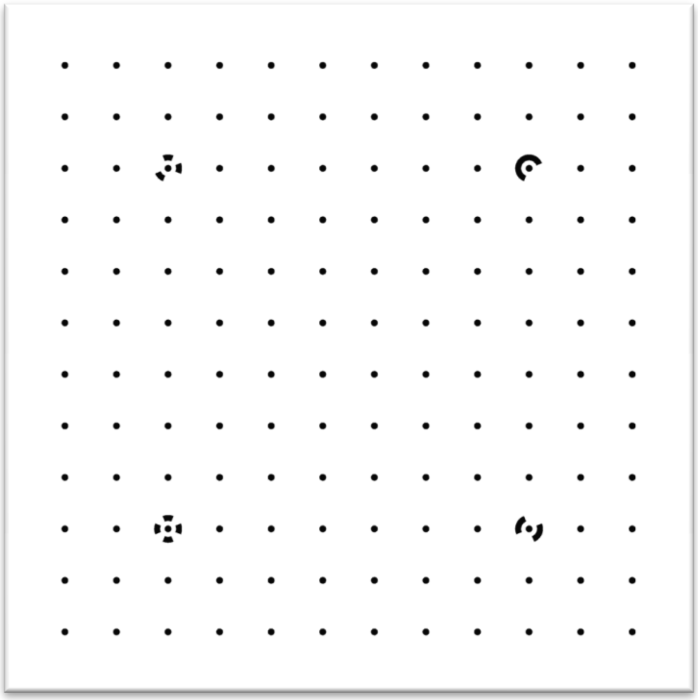


Figure 2.3-2: Calibration grid used by PhotoModeler to perform a calibration.

It is possible that if the model or scene sizes are quite different to the calibration grid size that a field calibration can be performed. This process can only occur when sufficient ‘good’ points and photos in the project. This calibration works in a similar way to using the calibration grid, with the use of points in the field to solve the internal parameters of the camera. A field calibration can be a replacement for a full camera calibration in some circumstances. For projects that require high accuracy, a field calibration can be quite important to achieve the high-end accuracy necessary. A field calibration is not always possible or appropriate. The requirements as identified in PhotoModeler of a field calibration are:

- There should be at least five photographs,
- The photographs should all be taken with the same camera at one focal length setting,
- The photographs should be at strong angles to the subject,
- The photographs should all be at similar distance to the subject (and hence all at the same focus setting),
- The distance of the camera from subject should be similar to the distance used in your real projects,
- There should be one or two photos that have rolled angles (portrait type shots), and
- There should be at least 25 well marked and referenced points on all photos, with the points having each at least four references.
  (PhotoModeler documentation)

2.3.4 Image requirements

It is well recognised by spatial scientists that measurments will always contain error and it is inevitable that this can never be removed. What can be achieved, however is error minimisation. By controlling the angle between the camera stations orientation it is possible to minimise any errors in the camera’s position and hence orientation. The closer the angle of the camera’s to right angle, the smaller that the error in the camera's position will affect the accuracy of the resultant calculated point. Figure 2.3-3 shows this situation, where the position of station 1 has been incorrectly.

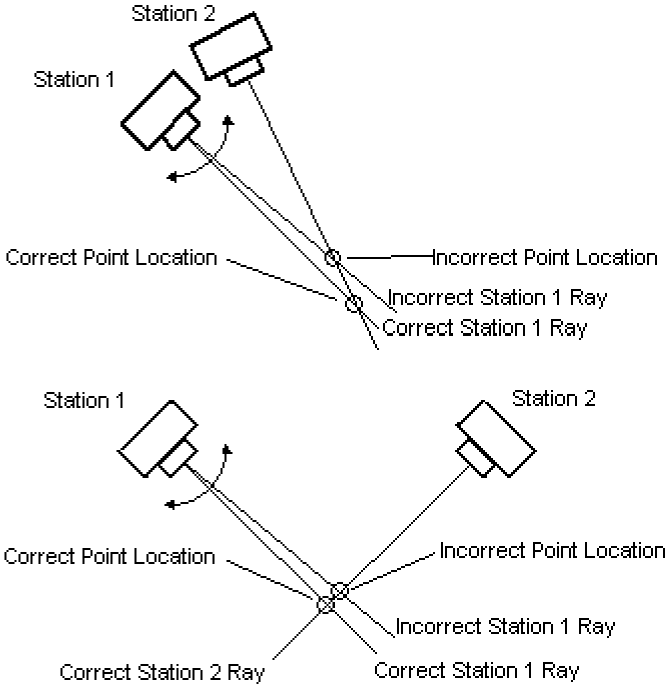


Figure 2.3-3: Effect of camera angle on accuracy by PhotoModeler.
Source: PhotoModeler Documentation

PhotoModeler suggests a set of guidelines to consider when taking the photographs for processing. These guidelines assist users in performing the field work, especially when they do not have extensive knowledge in the area. These guidelines are:

- Try to get the angles between the shots as close to right angles (90 degrees) as possible,
- Take at least three photographs but it is a good idea taking more than you think you'll need to avoid having to return to the site to take more,
- try to get all important points on at least three photographs,
- Try to get as much overlap between adjacent photographs as possible,
- Try to get photographs from both above and below the object, if possible,
- Take many photographs of the object but use at most four at the start until you determine you need others, and accurately measure the distance

> between two clearly visible points in the scene for later use as scale in your project. (PhotoModeler Documentation)

PhotoModeler explains that if you are measuring just one face of an object then three Camera Stations would normally suffice. Figure 2.3-4 below depicts such a camera layout:

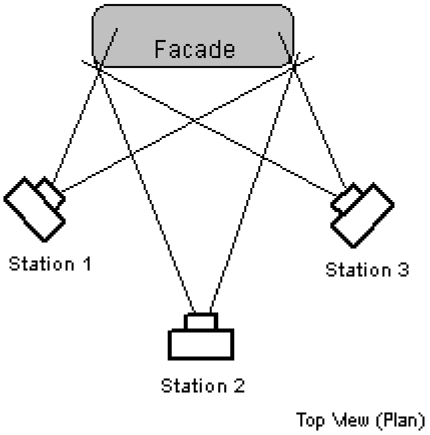


Figure 2.3-4: Camera station positions for a facade recommended by PhotoModeler.
Source: PhotoModeler Documentation

> “All of the points on the face of the object show up in three photographs. The Camera Stations are not all at right angles (station 1 and 3 are close to this ideal) but they are in good positions none the less.” (PhotoModeler Documentation)

When measuring a more complex scene or object, then more care needs to be taken when choosing the camera positions.

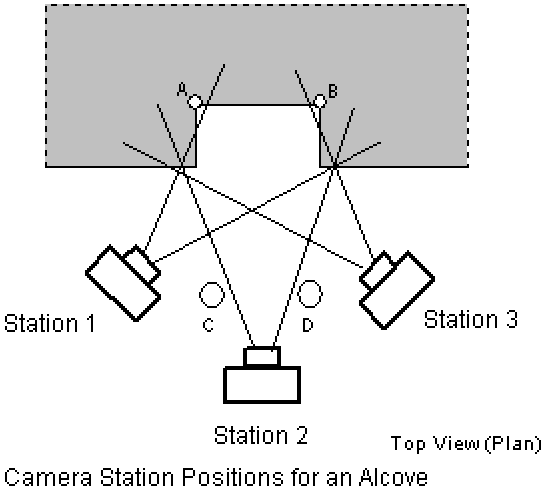


Figure 2.3-5: Camera station position for an alcove as recommended by PhotoModeler
Source: PhotoModeler documentation

It can be seen in Figure 2.3-5 above, that station 2 has been placed so that it can imaged in both points A and B, whilst the other two stations are needed to image one of the points in order to solve the three dimensional problem.

2.3.5 DSM requirements (in help file)

The end use of both these technologies is often to produce a DSM or Digital Surface Model. PhotoModeler defines the following as important factors when producing images for DSM purposes:

> “The key with DSM photography and project set up is to recognize that PhotoModeler works best with photographs that have good angle separation (30 to 100 degrees) so that relative orientation can work, but DSM works best with photographs that have smaller angle separations. The two ways to resolve and work with these seemingly conflicting goals are, a) combine both types of photos in one project (parallel ‘stereo’ pairs for DSM in addition to wide angle photographs for orientation, or b) use control points (which allow much narrower angles between camera stations).”
> (PhotoModeler documentation)

Figure 2.3-6 below show good, acceptable and poor setups for a pair of camera stations used in the process of obtaining a dense surface point cloud from that surface.

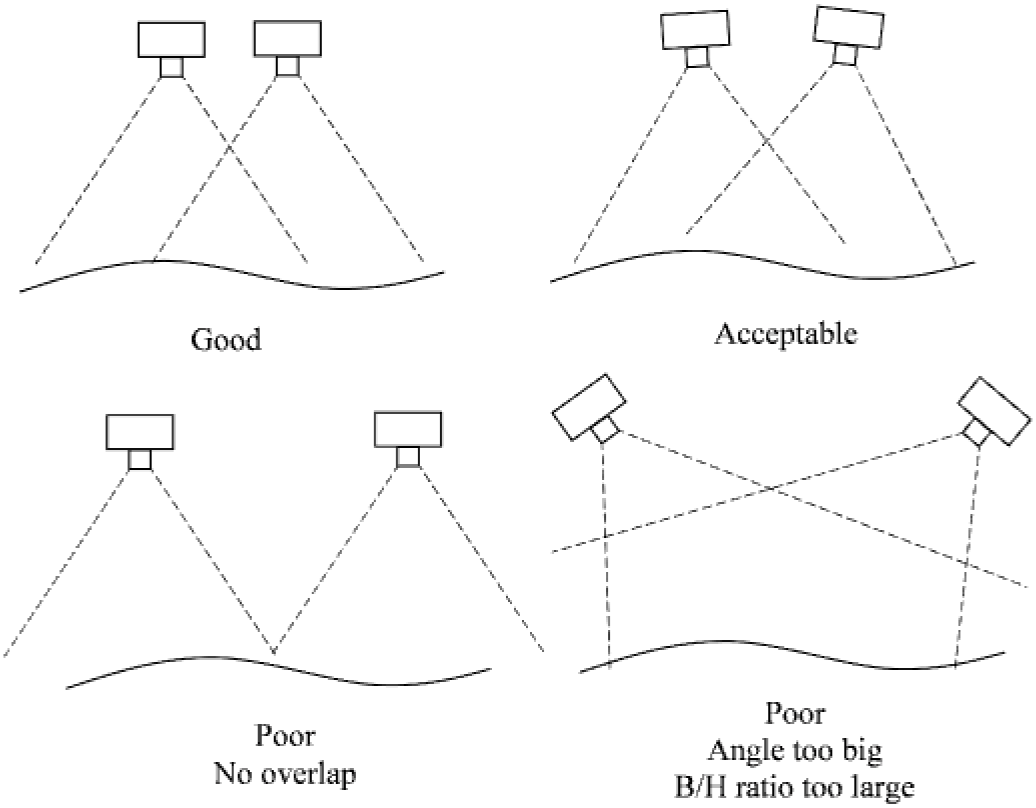


Figure 2.3-6: Quality of results from different camera positions for a DSM
Source: PhotoModeler documentation

2.3.6 Orientation requirements

2.3.6.1 Interior orientation

PhotoModeler, and indeed all photogrammetry, works by identifying points on two or more photos that represent the same physical object in space. This could include, corners of buildings, placed targets or anything that can be easily identified in more than one image.

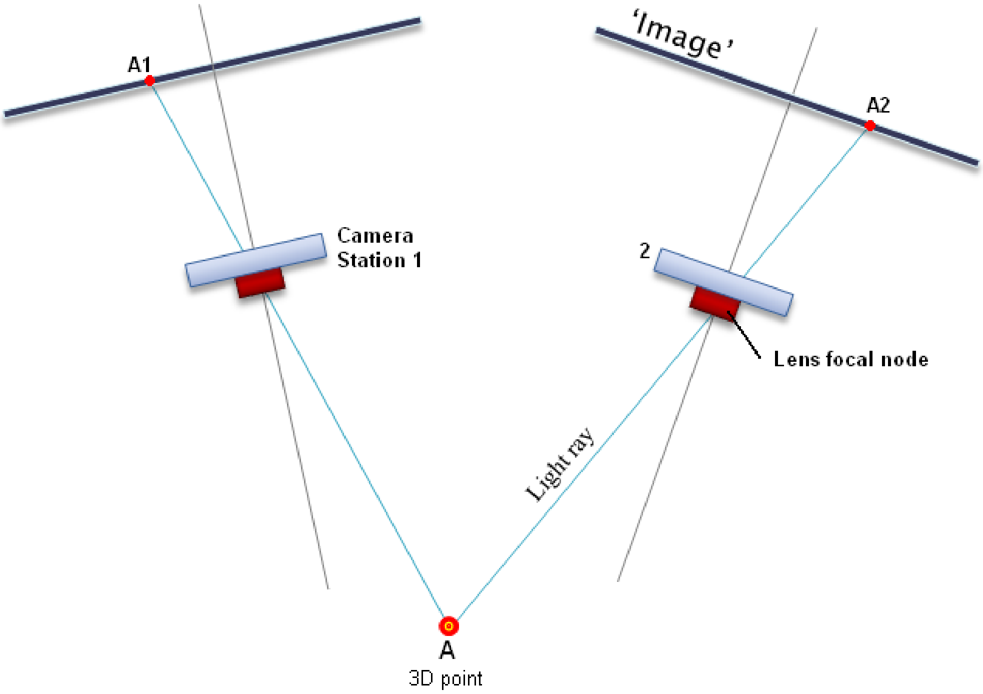


Figure 2.3-7: Part of the fundamental theory of photogrammetry

In Figure 2.3-7 above, a simplistic representation of the real situation is present. Assume that point A, a point in space has been imaged by both camera stations 1 and 2. As seen, the light rays make the points A1 and A2 on the two images respectively. Once these points are identified on each image, and the distance from the principle point (the middle of the image) can be found, the problem can then be solved if the positions of the cameras and the camera focal length are known. In the real-world situation, however, the cameras position and orientation are unknown and the problem is in three dimensions. It is therefore a requirement that many more points are necessary in order to solve for camera position and orientation in an arbitrary coordinate system. To solve the three dimensional problem and hence be able to measure scenes and objects, both the camera position and orientation as compared to the reference points needs to be solved. The cameras position in terms of P(X, Y, Z) and orientation in terms of the rotation around the three axis omega (ω), phi (φ) and Kappa (κ) need to be found. Omega represents the rotation around the X axis, phi around the Y axis and Kappa around the Y axis. Once this problem has been solved for all cameras, then the images are able to be used to model the objects or scene.

2.3.6.1.1 Exterior orientation

In order for the arbitrary reference system achieved in the interior orientation to fit in with an existing coordinate system, then exterior orientation is required. The process often used to achieve this is known as a three point affine transformation. This process is used to translate, scale, and rotate the arbitrary system onto the required project coordinate system.

Jacobsen, K (2001) describes exterior orientation as an adjustment of an objects coordinate system with the 6 parameters: projection center coordinates (X0, Y0, Z0) and the rotations around the 3 axis (omega, phi and kappa). In a three point affine transformation, a seventh parameter, scale, is used.

The three components of the process control this process using three known points that appear on the project. A *translation* moves a point on an arbitrary system onto the same point as identified on the desired coordinate system as defined by survey data. As an example, if point A_0 (X_0, Y_0, Z_0) is identified as the same point A_1 (X_1, Y_1, Z_1) then the transformation from A_0 to A_1 would be related to A_{01}(ΔX_{01}, ΔY_{01}, ΔZ_{01}). The next stage in the transformation is the *scale* which will set the correct units and measurement for the project. The process requires two known points in order to scale the distance between the two points on the arbitrary system to that of the same two points on the project coordinate system. The final stage is the *rotation* component which is used to define the plane that the project coordinate system refers to. This is achieved by rotating the system around the point used in the translation process making a rotation around the X, Y, and Z axis (omega, phi, Kappa respectively).

PhotoModeler explains this process of using a three point affine transformation in order to move data onto an existing reference system.

> “The three point method defines the full affine transformation:
> translation, scale and rotation of the model. It is a complete

> replacement for the position, distance, and scale method as described above.
>
> It is important to understand how the translation, scale and rotation are computed in the three point case so you can achieve best results. We will call the three points in the model M1, M2 and M3 and the three entered XYZ coordinates in the dialog as C1, C2 and C3. These correspond to the Point 1, Point 2 and Point 3 on the Three Point tab respectively. The transformations in order are:
>
> 1. Coordinates are translated such that M1 coincides with C1.
>
> 2. Coordinates are scaled such that the distance between M1 and M2 and the distance between C1 and C2 are the same.
>
> 3. Coordinates are rotated such that the vector between M1 and M2 coincides with the vector between C1 and C2.
>
> 4. Coordinates are then rotated such that the plane defined by M1, M2 and M3 coincides with the plane defined by C1, C2 and C3."
>
> (PhotoModeler documentation)

2.4 Comparing accuracies

There have been many investigations into the accuracies of Terrestrial laser scanners and terrestrial photogrammetry. A direct comparison between the technologies has not been as extensively researched. Remondino et. al (unknown year) provides a comparison between the two technologies as applied to the modelling of cultural heritage structures and items. This provides a guideline of how previous tests have been conducted.

Terrestrial photogrammetry has long been used for purposes such as recording the spatial properties of heritage sites. Remondino et. al. compares the use of photogrammetry and laser scanning to the heritage site of the ancient church of Pozzoveggiani, Padua, Italy. Remondino et. al. Contrasts the technologies in the following comparison.

> "**Photogrammetry** is a well proved and reliable technique for 3D object reconstruction
> Advantages: easy to use, very portable surveying system, analog or digital imagery, wide availability of commercial processing/modeling software.
> Disadvantages: camera calibration, time consuming (semi-automated) measurements, image resolution
>
> **Laser scanning** technology as promising alternative for many kind of surveying/modeling applications
> Advantages: fast acquisition of a huge amount of 3D data, recording of intensity (gray values) and color data (digital images), high LOD of the data combined with quite good metric accuracy (depending on the used instrument)
> Disadvantages: data handling, registration, modeling, edges, noise"

2.5 Conclusions

This chapter has explored the technology behind the equipment being used in this project as well as the variety of existing and potential uses. The information gathered in this chapter will remain useful in the proceeding chapter, where it will be used to form a methodology to compare the accuracies.

Chapter 3 – Methodology

3.1 Introduction

The aim of this chapter is to design a methodology to compare the two types of terrestrial spatial information. The desired outcome of the methodologies should be the ability to directly compare the results of the technologies in a controlled environment with absolute consistency. In order to achieve this, a test must be developed that uses common information to base the testing upon, in order to give solutions of common points.

3.2 Test design

In designing the test it was recognised that there is a need to create something that is simple. It should be as basic as possible, whilst still meeting the required outcomes. Ideally, it should also be repeatable, which will allow for the test to be used in the future for the possibility of alternate equipment or even alternate technologies. Finally, the test needs to be suitable for both Terrestrial laser scanning and terrestrial photogrammetry. If all these requirements are met then a suitable design has been created.

3.3 Terrestrial laser scanner

As mentioned in the literature review, the terrestrial laser scanner being used for the project research will be the Leica ScanStation 2. The functioning and processing software used is Cyclone. The hardware will be the Panasonic Tough book which is needed in the field to support Cyclone to operate the scanner.

The Leica ScanStation 2 offers a modern application and functionality of laser scanning theory. The Leica ScanStation 2 was made available for use by the University of Southern Queensland, Engineering and Surveying faculty. The manufacturer specifies an accuracy of single measurement of: 6mm position, 4mm distance, which is a good start to be able to determine the accuracy that can be expected. Higher accuracy was expected due to the nature of the conservative quote by the manufacturer. The scanner also has the ability to return a colour intensity value which is useful for both the softwares target acquisition as well as interpretation of scanned data. Along with these values, photographs taken in the initial stages of the scanning process by the instrument are able to be overlayed on these points for greater interpretation and modelling assistance.

Cyclone is the functional and processing software used by the Leica ScanStation 2. The software, in this case, is loaded onto the Panasonic Tough Book. From the moment the scanner is set up, powered up and connected to the laptop, all its functions are controlled through the Cyclone software.

3.4 Photogrammetry

3.4.1 Camera

As mentioned in the literature review, the camera to be used for this testing in this project needs to be easy to operate, common and good value for money. The Samsung S85 was selected, as it met all these criteria and was available. It represents an average camera in the marketplace with features that are likely to be widespread. At 8.2 megapixels, the camera creates high quality images easily able to be used by the software to obtain higher accuracy results. The camera also has the functionality of the fitting to a tripod which is essential in both calibration and field work.

3.4.2 PhotoModeler

PhotoModeler is a program that will be used for the processing of the images in this project. PhotoModeler is a software package that is readily available at a reasonable price for its functionality.

3.5 Test

As mentioned before, the ultimate method of comparing these technologies is to design a test where the same controlled environment is used as a test site for all methods. It is also ideal that the maximum number of variables kept the same in both the technologies. Ultimately, it would be great if a variety of test could be conducted, however due to the limited time available to the project the scope will need to be limited.

A basic X, Y, Z positional comparison will be the simplest test available. This test will be conducted in an outside environment against a flat surface. Targets were set up on the wall in an adequately spaced grid pattern.

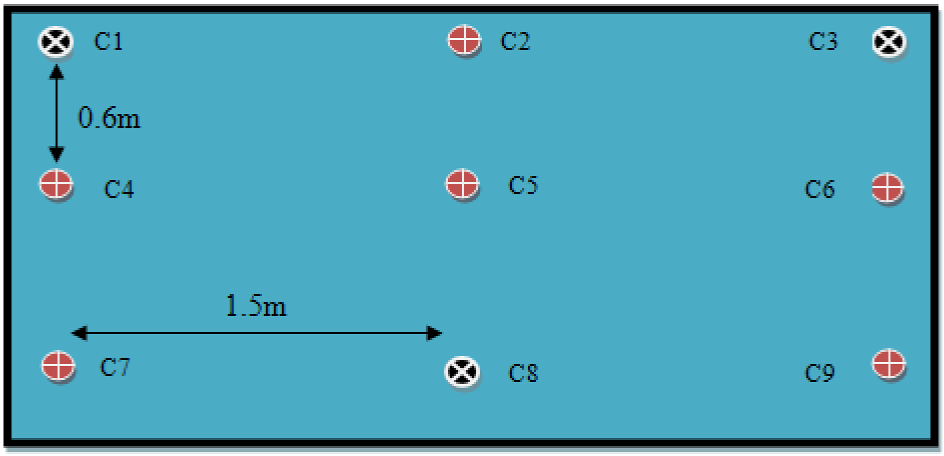


Figure 3.5-1: Diagrammatic representation of the test scenario

3.6 Field Procedures

3.6.1 Test setup

The test location is the southern-eastern wall of the chemical store opposite the engineering block at the USQ campus, Toowoomba. This site was chosen as it was out of the way, yet still relatively close to the survey store, for easy transportation of the laser scanner.

Firstly, the high definition targets are placed in a grid pattern against the wall at the test location. The grid pattern, as shown in Figure 3.5-1 has a 1.5 metre horizontal separation and a 0.6 vertical separation. The targets were identified as C1-C9.

In order to reference the targets, reflectorless EDM technology must be utilised. For this purpose, the Trimble S6 was used in the first stages of field procedure. Although this technology cannot provide the accuracy of using conventional prisms and EDM, it is an accepted industry practice for a situation where prisms are not practical such as this. The HDS targets proved quite easy to aim to as they had a clearly visible central mark. Figure 3.6-1 below shows this grid as it appeared in the field.

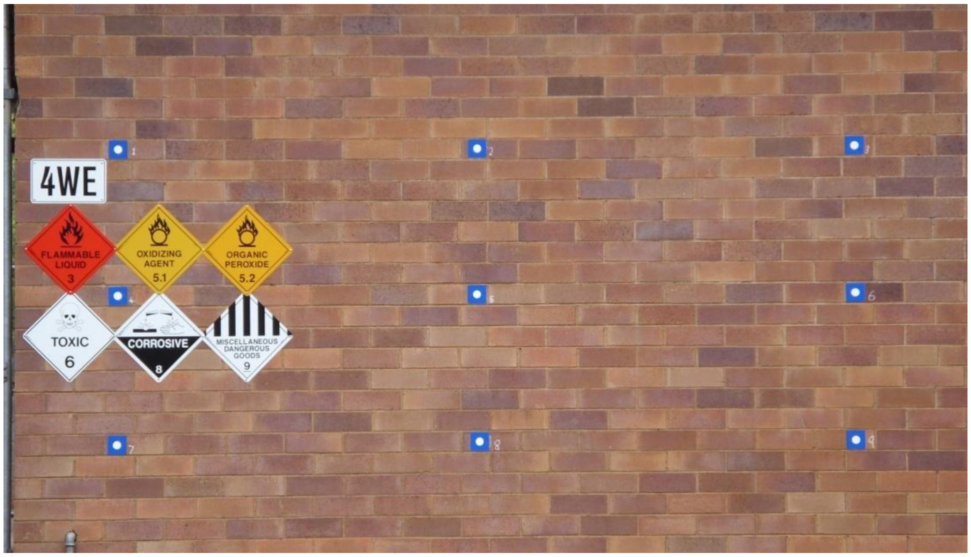


Figure 3.6-1: Photograph of the test site.

Once these points were located by the Trimble S6, they were stored in a text file on the Panasonic Toughbook in order to be used later in the testing. The coordinates were arbitrary, in the form of Easting, Nothing and Elevation. The total station was set up approximately 12m from and normal to the wall used in the test in order to standardise the control.

3.6.2 Terrestrial laser scanner

The Leica ScanStation 2 was setup at a point 10m from and normal to the wall. Once the scanner was properly set-up and levelled, testing was able to be initiated. Firstly, the area was imaged using the scanners imagery function. Once the correct settings on the image are acquired, especially exposure, the image is used by the user to identify the area that is required to be scanned with the scanners possible 360˚ X 270˚ field of view. This image is used throughout the field work of the laser scanner and also with processing and model building used for such projects. Once the desired area has been selected, it can be scanned by the instrument. The chosen spacing for the scanned points was selected at 0.03 metres by 0.01 metres. This was the initial scan, with quite a wide spacing to reduce the time that the scanner will take to complete the scan, whilst still acquiring plenty enough data to perform target identification.

The next stage in the process was to acquire all the targets in the test. This involved selecting a point near to the targets and using Cyclone to perform a ‘fine scan’ of the area in order to determine the centre of the HDS targets accurately. This is achieved by the scanner firstly scanning the area around the selected point to identify where the target is. The target, then achieving the position of the inner circle of the target does a fine scan on this region at the scanners highest level of resolution, thus returning the point in which the colour intensity matches that of the centre point of the target. The field setup for the laser scanner can be viewed below in Figure 3.6-2.

Figure 3.6-2: Testing procedure set-up for the laser scanner

This process is repeated for all targets with each taking approximately 45 seconds to complete including the human functions of selecting the point and using the interface to command the scanner. All nine of the targets were acquired, so it was ready to move onto the next stage of the field procedure.

A resection of three of the points c1, c3, and c8 was used in order to orientate the scanned data with the positions collected by the total station. The results of this can be seen in Figure 3.6-3 below. After the resection was completed, the points not included in the resection (C2, C4, C5, C6, C7, C9) became points that could be used to directly compare with the points collected by the total station.

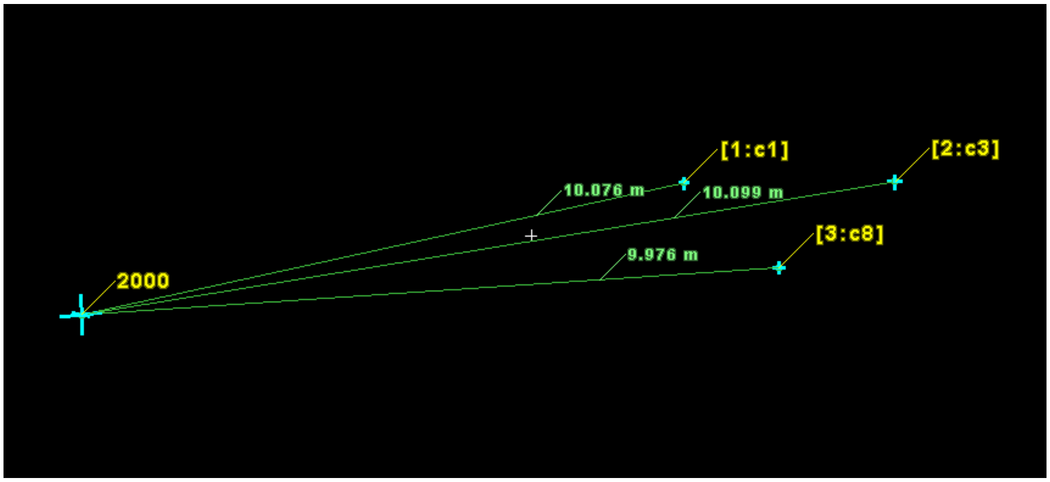


Figure 3.6-3: The model of the resultant resection in the Cyclone software.

3.6.3 Terrestrial photogrammetry

3.6.3.1 Calibration

The photogrammetry side of the testing had its similarities, however, was reasonably different to that of the terrestrial laser scanner due to the nature of the differing technologies. Initially, before the photographs of the actual test site could begin, a calibration of the camera was required.

As mentioned in the literature review in 2.3.3 Calibration, a field calibration is possible if the scenario meets certain criteria. In this situation, a field calibration is not suitable; however a scenario could quite easily be created that met the requirements and would significantly add to the accuracy.

In order to calibrate the camera of choice (Samsung s85) the calibration grid was printed out at A3 scale. The calibration was then carried out by taking a total 12 photos from all angles of the grid and from all orientations (landscape, portrait left, and portrait right). For a calibration report see APPENDIX C. The photos were taken indoors and with the camera supported by a tripod set at approximately 0.7m from the ground, angled toward the calibration grid. The report indicated that the total photo area covered by points was 70%, which is less than the recommended 80%.

The results of the calibration, however, suggested that this did not create a poor calibration. This was indicated by the overall point marking residual RMS of 0.145 pixels, a point tightness maximum of 0.00081 m and an overall point precision with a vector length of 8.51×10^{-5}m. So the calibration was therefore used for the field component of the testing.

3.6.3.2 Field procedure

Once the calibration was successful, the field component of the work was able to be completed. Because only one face of an object needs to be measured, the requirements in the field are slightly simpler to that of more complex shaped objects. The basic requirement for the field procedure is similar to that in Figure 2.3-4 in the literature review section, with three camera stations ideal for the project. These stations are to have good coverage and adequate angles between the cameras. The recommended angle, as identified earlier, is as close to right angles as possible. In the case of a facade, however, it is much more practical and accurate to include three camera positions with a smaller angle between the cameras.

The procedure followed for the photogrammetry included an initial marking of preferred locations for the camera stations. This should be at a distance that is comparable to the terrestrial laser scanner and meets the preferred positions as identified by Photomodeller.

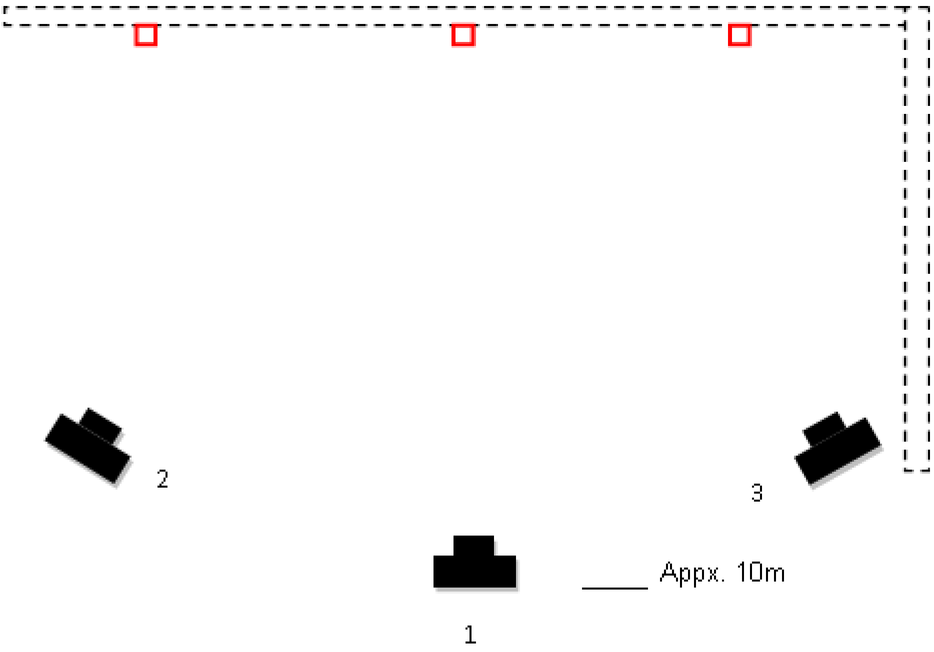


Figure 3.6-4: Diagram of approximate camera stations used for the field procedure.

***Red squares indicate targets.**

As indicated by Figure 3.6-4 above, the setup is relatively simple and straightforward. Camera station 1 is setup at a point right angle to and at the desired distance from the object in order to include all point marks. Using a 30 metre tape, the distance can be measured out and then swung from the central point on the wall to points either side of the first marking (stations 2 and 3). These points can be sprayed with marking paint once the correct position is achieved. In order to obtain the photographs, it is a simple matter of setting the camera onto a tripod at a specified height and placing the setup onto the pre-identified marks, making sure all control points are in the frame and taking the photograph. It is important to ensure the camera settings, for example, zoom settings are consistent in all photographs. It is also important that functions on some cameras such as image stabilisation, auto-rotation and sharpening are turned off.

Because there is no way of storing point numbers in the camera, it is necessary to have a predetermined order when taking the photos as not to get confused when it comes to the processing stage. The time it takes to complete the field work between deciding on stations and actually taking the photos is quite small. A conservative time estimate for this process would be five minutes, but realistically, could take well under one minute if conditions allow and someone that is experienced with the procedures and requirements is performing the task. Photos are grouped in folders once downloaded to the computer, in order to simplify organisation for future use.

3.6.3.3 Processing

The next stage of the terrestrial photogrammetry process is the processing stage. This is without a doubt the largest, and most time consuming stage of the method. All processing is done in PhotoModeler as a points based project. Firstly, the three images need to be imported into PhotoModeler. The images were stored in JPEG format and were imported into a point based project in which was created. The images were automatically matched with the camera calibration of the Samsung s85 previously performed. The solutions of the camera calibration were compared with that of previously achieved and stored in a text file for this purpose.

Once all photos were in the program, the referencing function could begin. In reference mode all points were selected on all images. After six points, the images can be referenced; however, all nine were referenced to improve the quality of the process. Once all the points were referenced, the images can be processed. This gave a solution for all three camera positions in reference to the points.

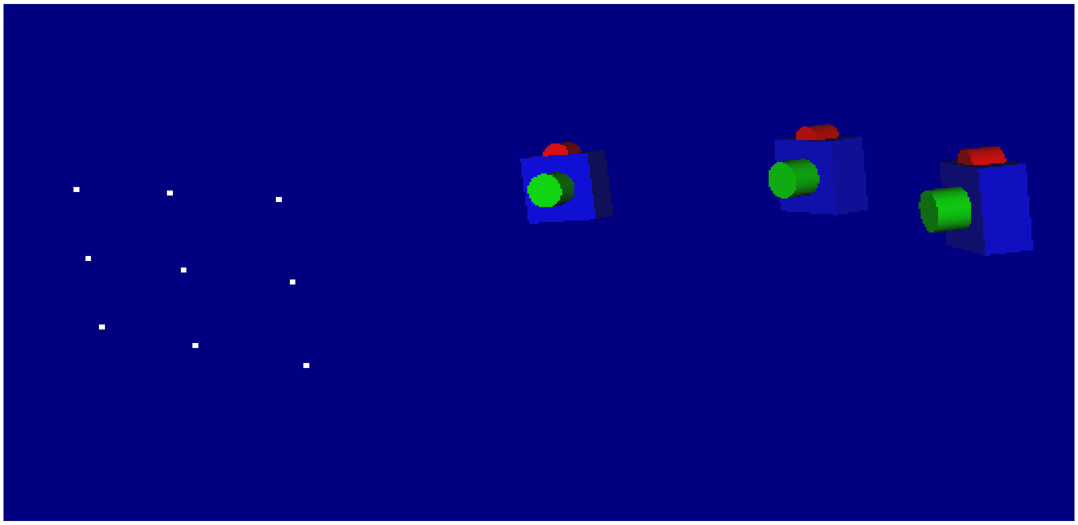


Figure 3.6-5: Screenshot from PhotoModeler 3D model of cameras and control stations

With all points referenced, the process has been completed to make a model if so desired, which can be seen in Figure 3.6-5 above. In order to put the points on a coordinate system, however, further processing is required. In order to be consistent with the process of the scanner, only three points can be used to complete the function. Therefore, an affine transformation needs to be used. Points C1, C3 and C8 were the points chosen as they are the same as used for terrestrial laser scanner in Cyclone.

From this information, the PhotoModeler software can determine the correct positions of the other targets. Because these points will now be on the same reference system to both the coordinates given by the laser scanner and the initial conventional survey by the Trimble S6 using reflectorless the comparison can be successfully completed.

3.7 Conclusion – Chapter 3

This chapter outlined how the methodology was formed for this project. The methodology designed a testing situation that would be able to compare the accuracy of the two systems with correctness and consistency. The following chapter provides the results of this testing.

Chapter 4 – Results and Analysis

4.1 Introduction

In the methodology chapter of this project, it was discussed an appropriate way to compare the accuracies of the two terrestrial technologies. A discussion of the testing component resulted in the adoption of a point comparison test. This test compared the results obtained from the two methods against the accepted location of the points as derived by a conventional and established method.

The purpose of this chapter is to provide results of the comparison between the technologies. Included will be an explanation of what the results show about the two and what implications this will have. The results presented in this section will provide a likely comparison of what can be expected in terms of accuracies from the two technologies.

4.2 Conventional method

As discussed in the Methodology chapter, the conventional and established method for single point measurement on a surface is reflectorless technology. Although, this is relatively new to the industry, most modern Total Stations have the functionality, and hence most major surveying firms would have access. Table 4.2-1 shows the results of the survey. The control points c1, c3 and c8 will be used for the orientation of the data produced from the two technologies and the remaining points used to form a comparison between them.

	X (m)	Y (m)	Z (m)
c1*	997.361	5011.761	702.381
c2	998.810	5011.909	702.380
c3*	1000.330	5012.064	702.383
c4	997.358	5011.736	701.788
c5	998.805	5011.910	701.787
c6	1000.330	5012.065	701.787
c7	997.356	5011.758	701.186
c8*	998.812	5011.909	701.188
c9	1000.325	5012.066	701.191

Table 4.2-1: Control points measured by the Total Station using reflectorless technology.

4.3 Terrestrial Laser Scanner

The field procedure of the laser scanner commenced with the initial scan. This process required setting up the scanner at the desired location and selecting the desired area to be scanned. As far as results, a point cloud as can be seen in Figure 4.3-1 below was acquired which is needed before other processes can progress.

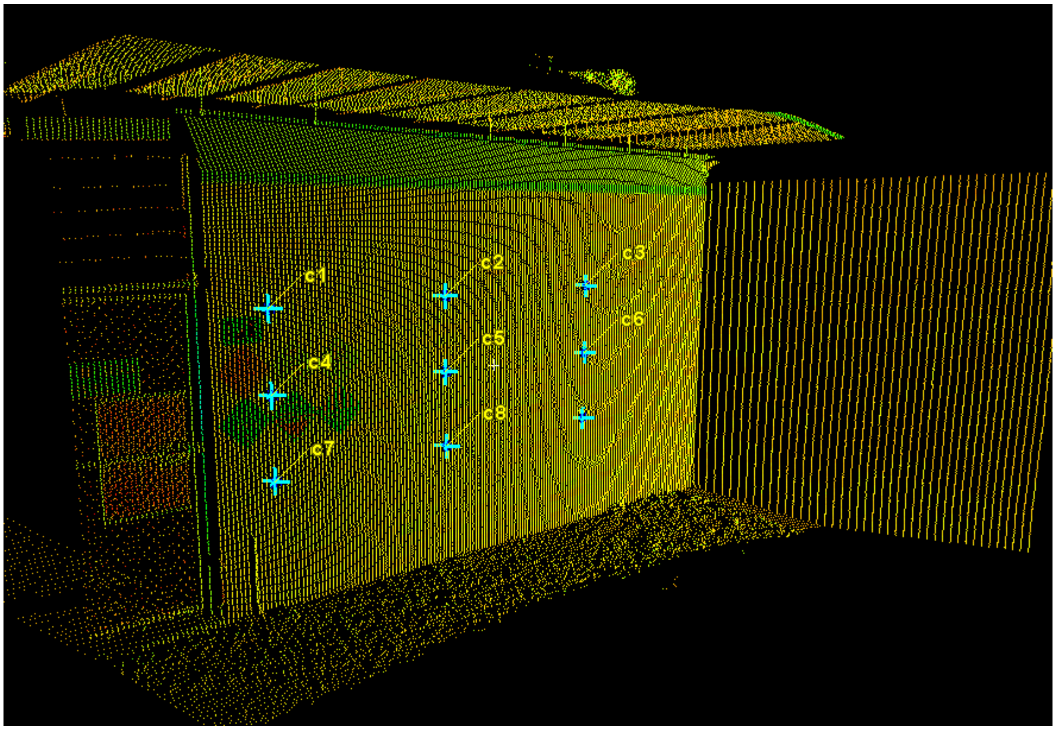


Figure 4.3-1: The result of the scan, and acquisition of targets.

The point cloud was used in order to identify the targets and complete a fine scan of the immediate region. The fine scan collects high density point data around the target and can accurately locate the centre due to the nature of the targets and the technology in the Cyclone processing software. Now that the targets were acquired, the data was ready to be placed on the desired coordinate system.

A resection using the points c1, c3 and c8 was conducted to place the points on the desired coordinate system. The report of the resection can be viewed in APPENDIX C. After the resection, the remaining points could be compared with the control points. These are shown in Table 4.3-1 shown below.

	X (m)	Y (m)	Z (m)
c1*	997.361	5011.761	702.381
c2	998.809	5011.909	702.380
c3*	1000.330	5012.064	702.383
c4	997.358	5011.759	701.789
c5	998.805	5011.910	701.787
c6	1000.330	5012.066	701.787
c7	997.357	5011.758	701.186
c8*	998.812	5011.909	701.188
C9	1000.325	5012.067	701.191

Table 4.3-1: Results of terrestrial laser scanner

4.4 Terrestrial Photogrammetry

The field procedure for the terrestrial photogrammetry was quite different to that of the laser scanner, for as soon as the photographs had been taken, the field component was over, with all processing completed afterward. Prior to the field component, a calibration was needed in order to convert the digital camera into a measuring instrument. The results of the calibration can be viewed in the calibration report in Appendix B. Once the photos were added to the project in PhotoModeler, and the calibration recognised, the processing could begin. The points were then referenced using the reference tool, allowing for an interior orientation. The report of the processing of the photos can be viewed in APPENDIX C.

Once the photos are orientated with each other and hence any measurements relative, the project can be transformed onto the desired coordinate system. This was achieved by a 3 point affine transformation using the points c1, c3, and c8 in order to maintain similarities with the processes associated with the terrestrial laser scanner. The points now being on the same coordinate system as the control and hence the terrestrial laser scanner can be used. These values are shown in Table 4.4-1 shown below.

	X (m)	Y (m)	Z (m)
c1*	997.361	5011.761	702.381
c2	998.8101	5011.915	702.3801
c3*	1000.332	5012.064	702.3779
c4	997.3584	5011.756	701.7882
c5	998.8053	5011.914	701.7857
c6	1000.33	5012.065	701.7833
c7	997.3561	5011.752	701.1865
c8*	998.812	5011.909	701.188
c9	1000.324	5012.061	701.1877

Table 4.4-1: Results of terrestrial photogrammetry.

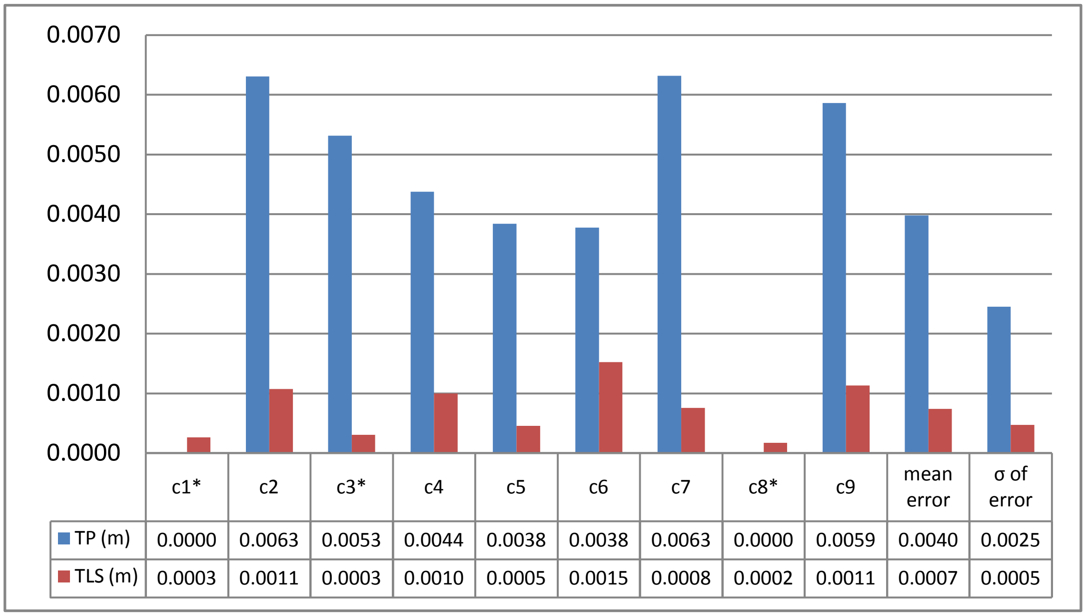
4.5 Comparison

With all the data from the two technologies on the same reference system, the point coordinates can be directly compared. Table 4.5-1 below, shows a comparison of the magnitude of error between the control points and the results achieved by the two technologies. A full list of this comparison can be viewed in APPENDIX D.

	TP (m)	TLS (m)
c1*	0.0000	0.0003
c2	0.0063	0.0011
c3*	0.0053	0.0003
c4	0.0044	0.0010
c5	0.0038	0.0005
c6	0.0038	0.0015
c7	0.0063	0.0008
c8*	0.0000	0.0002
c9	0.0059	0.0011
mean error	0.0040	0.0007
σ of error	0.0025	0.0005

Table 4.5-1: Combined results of range error

As can be seen, the terrestrial laser scanner shows much higher point accuracy than offered by terrestrial photogrammetry. This being said, however, the error associated with the photogrammetry is still quite reasonable, with an average error of 4mm and a standard deviation of error 2.5mm. The terrestrial laser scanner offered superior results in terms of accuracy with an average error of 0.7mm with a standard deviation of error of 0.5mm. The results can be viewed in graphical form in Figure 4.5-1 below.



	c1*	c2	c3*	c4	c5	c6	c7	c8*	c9	mean error	σ of error
🟦 TP (m)	0.0000	0.0063	0.0053	0.0044	0.0038	0.0038	0.0063	0.0000	0.0059	0.0040	0.0025
🟥 TLS (m)	0.0003	0.0011	0.0003	0.0010	0.0005	0.0015	0.0008	0.0002	0.0011	0.0007	0.0005

Figure 4.5-1: Combined results of range error

4.6 Discussion

APPENDIX D includes a full copy of results from exported from an excel document. The results of the photogrammetry show that the majority of errors of the photogrammetry are in one axis, with only minimal in other directions.

As can be seen graphically in Figure 4.5-1, the control points c1, c2, c8 were used to reference the two data sets to the project coordinate system. Referring to section 2.3.6 Orientation requirements in the literature review, the nature of the affine transformation uses two points (in this case c1 and c8) to perform a scale adjustment. This adjustment may still have some errors in the third point used in the transformation (c3) due to errors in the measuring system. In the case of the terrestrial laser scanner, the three points are used to form a ‘best fit’ of the three points known as a least squares adjustment. This results in small errors in each of the control points (c1, c3, c8) as is the nature of the adjustment.

4.7 Conclusions – results

The aim of this project was to compare methods of remotely sensing spatial data by terrestrial means. The test set to achieve this directly compared the accuracy that could be obtained in collecting single point data. As seen in Figure 4.5-1 above, the terrestrial laser scanner offered higher levels of accuracy, whilst terrestrial photogrammetry showed sufficient accuracy that would acceptable for many purposes.

Chapter 5 - Conclusions, Discussions and Recommendations

5.1 Introduction

This chapter aims to provide a summary of the project with discussion on the results of the project, what the project means and recommendations for further research. The aim of the project as a whole was to compare methods of obtaining remotely sensed terrestrial spatial information. The comparison was primarily focussed on comparing the two accuracies, however, in completing the research and conducting the fieldwork, information was gathered in order to make comments on other factors such as simplicity, efficiency and cost of the two technologies.

5.2 Discussions

Chapter four provided details of the results of the testing. It was shown that the terrestrial laser scanner was much more accurate than the technique of terrestrial photogrammetry for single point measurement. Even though laser scanning proved more accurate, the results obtained from the photogrammetry were positive. The data concluded that accuracy suitable for many purposes could be obtained with the technology at this range.

From the time spent using equipment involved, their usefulness was noticed from the field work to the final processing. The first point is quite obvious in that terrestrial photogrammetry is much more accessible to the average user than laser scanning. This is due to the cost involved (quite a difference) and the knowledge that the user requires when using the software and hardware. In terms of simplicity, photogrammetry also offers many advantages, with the use of common-market cameras that the average person should be familiar with. The main drawback to photogrammetry is the amount of work that is required when processing the images with the calibration and referencing stages. Laser scanning, on the other hand, performs most operations in the field, with the ability to view a complete model of the project on a desired coordinate system as you acquire the data. Terrestrial laser scanning, as identified in this project, offers a higher level of accuracy for point positioning.

5.3 Further research and recommendations

Both the forms of terrestrial remote sensing have many obvious needs for continuation of research. This study barely scratches the surface of all that is involved with the technologies.

Aligned with this project paper, further research could involve a more in depth comparison. Things that can be investigated is accuracy of a generated model using DSM functions, errors associated with edge noise, full cost analysis of associated products and many others.

5.4 Summary

This Chapter established a summary of the project with a discussion of results and what they mean as well as suggested further research into the two technologies. In conclusion, this project provided a comparison of the two technologies in terms of point positioning accuracy which will inform and assist users with procedures for a terrestrial, remotely sensed project.

REFERENCES

Boehler W. & Marbs, A. 2003. ‘Investigating Laser Scanner Accuracy’, i3mainz

Chong, A, McFadgen, B, 2003 ‘Digital Architectural Photogrammetric Recording of Historical Buildings and Monuments’ *New Zealand Surveyor* No. 293 June 2003

Corripio, J, 2004, ‘Snow surface albedo estimation using terrestrial photography’ *International Journal of Remote Sensing*, Volume 25, Number 24, 2004, pp. 5705-5729(25) Taylor and Francis Ltd.

Cyclone software documentation

Fraser, C, 1997. ‘Digital camera self-calibration’. *ISPRS Journal of Photogrammetry & Remote Sensing* 52 (1997) 149-159.

Fraser, C, 2000, ‘Design and implementation of a computational processing system for off-line digital close-range photogrammetry’ *ISPRS Journal of Photogrammetry & Remote Sensing* 55_2000.94–104.

Institute for Spatial Information and Surveying Technology, FH Mainz, University of Applied Sciences, Mainz, Germany.

Jacobsen, K, 2001, ‘Exterior Orientation Parameters’, Institute for Photogrammetry and GeoInformation, University of Hannover, Germany.

Lichti, D, 2002 Ground based laser scanners: Operation, System and Application, *Geomatica* Vol. 56, no. 1, pp. 21 to 33

Mitchell, H. 2003 ‘Laser scanning’ *Position magazine*.

Pappa, R, 2002, ‘Close-Range Photogrammetry & Next Generation Spacecraft’, *Professional Surveyor*, Vol. 22, June.

PhotoModeler v.6 software documentation.

Remondino, F. et. al. ‘3D modelling of close-range objects: Photogrammetry or laser scanning?’ Institute of Geodesy and Photogrammetry, ETH, Zurich, Switzerland.

Teza, G. et al., 2006 ‘Terrestrial laser scanner to detect landslide displacement fields: a new approach’. *International Journal of Remote Sensing*.

Appendix A

Project specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG 4111/4112 Research Project
PROJECT SPECIFICATION

STUDENT NAME: Will Dorahy

TOPIC: A comparison of remotely sensed terrestrial spatial information

SUPERVISOR (S): Frank Young,
Xiaoye Liu

PROJECT AIM: This project seeks to compare terrestrial photogrammetry and laser scanning techniques of obtaining spatial data.

PROGRAMME: **Issue A, March 25, 2008**

1. Review literature on the technologies and their application.
2. Design multiple testing scenarios of the two technologies in controlled environments.
3. Prepare suitable method of comparing and rating the sets of data.
4. Analyse & evaluate,
5. Submit academic dissertation

As time permits,

6. Complete a cost-benefit analysis of the applied test scenario

AGREED

________________ ________________, ________________
(Student) (Supervisors)

__/__/__ __/__/__ __/__/__

Appendix B

Product specification datasheets

Trimble s6

Leica ScanStation 2

Camera specs?

DATASHEET

TRIMBLE S6 TOTAL STATION

KEY FEATURES

MultiTrack™ technology offers the choice between passive and active tracking

MagDrive™ servo technology gives incredibly fast, smooth performance

SurePoint™ accuracy assurance automatically corrects instrument pointing

Upgradable from servo to Autolock® function to Robotic

Integrate GPS technology with GPS Search/GeoLock and the Trimble® I.S. Rover

100% cable-free instrument and Robotic rover

MAGDRIVE SERVO TECHNOLOGY

The Trimble® S6 Total Station redefines instrument performance with unsurpassed integration of servos and angle sensors. The instrument's advanced error compensation provides fast, accurate measurements every time. With the smooth, silent servo motors of MagDrive servo technology, the Trimble S6 offers exceptional speed and accuracy.

CHOOSE TARGET MODE: ACTIVE OR PASSIVE

The Trimble S6 will lock and track a wide variety of targets and conventional prisms to exceptional range. Additionally, surveyors can choose between passive and active tracking with the new Trimble® MultiTrack™ Target. Its flexibility expands opportunities in all surveying applications.

Active Tracking with Target ID:
Always find your correct target
With the Trimble MultiTrack Target you will always find and lock to the correct target. Nearby reflective surfaces, including road signs, cars, warning vests and other on-site prisms, will not disrupt your surveys. Active tracking also offers longer range, and the 360 degree active LED rings ensure that your correct target is tracked from any angle.

GPS Search target location
GPS Search is a feature in Trimble Survey Controller™ field software that works with the Trimble MultiTrack Target to maximise Trimble S6 Total Station speed. GPS Search uses GPS positioning at the robotic rover to locate a prism anywhere, anytime, so that with a Trimble® I.S. Rover, or even a GPS card or Bluetooth® receiver, the Trimble S6 can lock onto the prism in just a few seconds.

HIGH CAPACITY INTERNAL BATTERY WITH INTELLIGENT SYSTEM CHARGER

The Trimble S6 runs for six hours in Robotic mode on one internal lithium-ion battery, with no cables needed. The battery is intelligent, so you can quickly check how much power each battery contains.

With three batteries in the multi-battery holder, you'll spare yourself the task of changing batteries during your work day. Recharge your Trimble S6 and GPS system batteries in the same charger.

SUREPOINT ACCURACY ASSURANCE

The Trimble S6 Total Station aims and stays ... through windy weather, vibrations, handling, and sinkage, by actively correcting unwanted movement. This technology, Trimble's unique SurePoint accuracy assurance, ensures accurate pointing and measurement every time. Reduce aiming error and avoid costly re-measurement for supreme confidence in your results.

DIRECT REFLEX TECHNOLOGY

Direct Reflex (DR) technology from Trimble enables measurement without a prism even to exceptional distances. Hard-to-reach or unsafe targets are no obstacle for the Trimble S6. Measure quickly and safely without compromising accuracy.

COAXIAL OPTICS, EDM, TRACKER, LASER POINTER

Whether measuring in Face 1 or Face 2, or aiming manually or with the tracker, with Trimble S6 what you see is what you measure. The Trimble S6 optics by Carl Zeiss are fully coaxial for full measurement confidence.

INTEGRATED SURVEYING

Only a Trimble total solution offers field-proven optical and GPS integration from field to office. The Trimble controller of your choice connects without cables to your Trimble S6 or GPS system. It can be switched between sensors, collecting all data into one job file for seamless data transfer. Simply use the sensor that best suits your environment or job requirement.

Trimble.

TRIMBLE S6 DR300+

PERFORMANCE

Angle measurement	
Accuracy (Standard deviation based on DIN 18723)	2" (0.5 mgon) 3" (1.0 mgon), or 5" (1.5 mgon)
Angle reading (least count)	
Standard	1" (0.1 mgon)
Tracking	2" (0.5 mgon)
Averaged observations	0.1" (0.01 mgon)
Automatic level compensator	
Type	Centered dual-axis
Accuracy	0.5" (0.15 mgon)
Range	±6' (±100 mgon)
Distance measurement	
Accuracy (S. Dev.)	
Prism mode	
Standard	±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm)
Tracking	±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm)
DR mode	
Standard measurement	±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm)
Tracking	±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm)
>300 m (656 ft)	
Standard measurement	±(5 mm + 2 ppm) ±(0.016 ft + 2 ppm)
Measuring time	
Prism mode	
Standard	1.2 s
Tracking	0.4 s
Averaged observations[1]	1.2 s per measurement
DR mode	
Standard	1–5 s
Tracking	0.4 s
Averaged observations[1]	1–5 s per measurement
Range (under standard clear conditions[2,3])	
Prism mode	
1 prism	2500 m (8202 ft)
1 prism Long Range mode	5500 m (18,044 ft) (max. range)
3 prism	3500 m (11,482 ft)
3 prism Long Range mode	5500 m (18,044 ft) (max. range)
Shortest possible range	0.2 m (0.65 ft)
DR mode (typically)	
Kodak Gray Card (18% reflective)[4]	>300 m (984 ft)
Kodak Gray Card (90% reflective)[4]	>800 m (2625 ft)
Concrete	300–400 m (984–1312 ft)
Wood construction	200–400 m (656–1312 ft)
Metal construction	200–250 m (656–820 ft)
Light rock	200–300 m (656–984 ft)
Dark rock	150–200 m (492–656 ft)
Reflective foil 20 mm	800 m (2,625 ft)
Reflective foil 60 mm	1600 m (5,249 ft)
Shortest possible range	2 m (6.56 ft)

EDM SPECIFICATIONS

Light source	Pulsed laserdiode 870 nm, Laser class 1
Laser pointer coaxial (standard)	Laser class 2
Beam divergence	
Horizontal	4 cm/100 m (0.13 ft/328 ft)
Vertical	8 cm/100 m (0.26 ft/328 ft)
Atmospheric correction	–130 ppm to 160 ppm continuously

TRIMBLE S6 HIGH PRECISION EDM WITH DR

PERFORMANCE

Angle measurement	
Accuracy (Standard deviation based on DIN 18723)	1" (0.3 mgon)
Angle reading (least count)	
Standard	1" (0.1 mgon)
Tracking	2" (0.5 mgon)
Averaged observations	0.1" (0.01 mgon)
Automatic level compensator	
Type	Centered dual-axis
Accuracy	0.5" (0.15 mgon)
Range	±6' (±100 mgon)
Distance measurement	
Accuracy (S. Dev.)	
Prism mode	
Standard	±(1 mm + 1 ppm) ±(0.003 ft + 1 ppm)[5]
Tracking	±(5 mm + 2 ppm) ±(0.016 ft + 2 ppm)
DR mode	
Standard measurement	±(3 mm + 2 ppm) ±(0.01 ft + 2 ppm)
Tracking	±(10 mm + 2 ppm) ±(0.032 ft + 2 ppm)
Measuring time	
Prism mode	
Standard	2 s
Tracking	0.4 s
Averaged observations[1]	2 s per measurement
DR mode	
Standard	3–15 s
Tracking	0.4 s
Averaged observations[1]	3–15 s per measurement
Range (under standard clear conditions[2,3])	
Prism mode	
1 prism	3000 m (9,800 ft)
1 prism Long Range mode	5000 m (16,400 ft)
3 prism	5000 m (16,400 ft)
3 prism Long Range mode	7000 m (23,000 ft)
Shortest possible range	1.5 m (4.9 ft)
DR mode (typically)	
Kodak Gray Card (18% reflective)[4]	>120 m (394 ft)
Kodak Gray Card (90% reflective)[4]	>150 m (492 ft)
Concrete	80–150 m (262–492 ft)
Wood construction	80–180 m (262–590 ft)
Metal construction	80–120 m (262–394 ft)
Light rock	80–120 m (262–394 ft)
Dark rock	60–80 m (197–262 ft)
Reflective foil 20 mm	600 m (1,968 ft)
Reflective foil 60 mm	1200 m (3,937 ft)
Shortest possible range	1.5 m (4.9 ft)

EDM SPECIFICATIONS

Light source	Laserdiode 660 nm; Laser class 1 in Prism mode Laser class 2 in DR mode
Laser pointer coaxial (standard)	Laser class 2
Beam divergence Prism mode	
Horizontal	4 cm/100 m (0.13 ft/328 ft)
Vertical	4 cm/100 m (0.13 ft/328 ft)
Beam divergence DR mode	
Horizontal	2 cm/50 m (0.066 ft/164 ft)
Vertical	2 cm/50 m (0.066 ft/164 ft)
Atmospheric correction	–130 ppm to 160 ppm continuously

GENERAL SPECIFICATIONS

GENERAL SPECIFICATIONS

Leveling
- Circular level in tribrach . . . . 8'/2 mm (8'/0.007 ft)
- Electronic 2-axis level in
  - the LC-display with a resolution of. . . . . 0.3" (0.1 mgon)

Servo system . . . . MagDrive servo technology, integrated servo/angle sensor electromagnetic direct drive

Rotation speed . . . . 115 degrees/sec (128 gon/sec)

Rotation time Face 1 to Face 2 . . . . 3.2 sec

Positioning speed180 degrees (200 gon) . . . . 3.2 sec

Clamps and slow motions. . . . . Servo-driven, endless fine adjustment

Centering
- Centering system. . . . . Trimble 3-pin
- Optical plummet . . . . Built-in optical plummet
- Magnification/shortest
  - focusing distance . . . . 2.3×/0.5 m–infinity (1.6 ft–infinity)

Telescope
- Magnification . . . . 30×
- Aperture. . . . . 40 mm (1.57 in)
- Field of view
  - at 100 m (328 ft) . . . . 2.6 m at 100 m (8.5 ft at 328 ft)
- Shortest focusing distance . . . . 1.5 m (4.92 ft)–infinity
- Illuminated crosshair. . . . . Variable (10 steps)

Tracklight built in . . . . Standard

Operating temperature . . . . –20 °C to +50 °C (–4 °F to +122 °F)

Dust and water proofing IP55

Power supply
- Internal battery. . . . . . . Rechargeable Li-Ion battery 11.1 V, 4.4 Ah
- Operating time[6]
  - One internal battery . . . . Approx. 6 hours
  - Three internal batteries in
    - multi-battery adapter. . . . . Approx. 18 hours
- Robotic holder with one internal battery . . . . 12 hours

Weight
- Instrument (servo/Autolock) . . . . 5.15 kg (11.35 lb)
- Instrument (Robotic) . . . . 5.25 kg (11.57 lb)
- Trimble CU controller . . . . 0.4 kg (0.88 lb)
- Tribrach . . . . 0.7 kg (1.54 lb)
- Internal battery . . . . 0.35 kg (0.77 lb)

Trunnion axis height. . . . . 196 mm (7.71 in)

Communication . . . . USB, Serial, Bluetooth®[7]

ROBOTIC SURVEYING

Autolock and Robotic Range[3]
- Passive prisms . . . . 500–700 m (1,640–2,297 ft)
- Trimble MultiTrack Target . . . . 800 m (2,625 ft)

Autolock pointing precision at 200 m (656 ft) (Standard deviation)[3]
- Passive prisms . . . . <2 mm (0.007 ft)
- Trimble MultiTrack Target . . . . <2 mm (0.007 ft)

Shortest search distance . . . . 0.2 m (.65 ft)

Angle reading (least count)
- Standard. . . . . 1" (0.1 mgon)
- Tracking . . . . 2" (0.5 mgon)
- Averaged observations. . . . . 0.1" (0.01 mgon)

Type of radio internal/external . . . . 2.4 GHz frequency-hopping, spread-sprectrum radios

Search time (typical)[8] . . . . 2-10 s

GPS SEARCH/GEOLOCK WITH THE TRIMBLE MULTITRACK TARGET

GPS Search/GeoLock . . . . 360 degrees (400 gon) or defined horizontal and vertical search window

Solution acquisition time . . . . 15–30 seconds[9]

Target re-acquisition time . . . . <3 seconds

Range . . . . Autolock & Robotic range limits

TRIMBLE I.S. ROVER

(Integrated Trimble GPS/GNSS and Trimble S6 robotic rover)

Trimble S6 Robotic Total Station

Trimble GPS/GNSS System . . . . Any Trimble R8, Trimble R6, or 5800 system

Controller. . . . . Trimble TSC2 or Trimble CU

A Trimble I.S. Rover comprising the Trimble R8 GNSS with the Trimble MultiTrack Target.

---

1 Repeats for defined number of measurements up to 99.
2 Standard clear: No haze. Overcast or moderate sunlight with very light heat shimmer.
3 Range and accuracy depend on atmospheric conditions, size of prisms and background radiation.
4 Kodak Gray Card, Catalog number E1527795.
5 Limited temperature range for high-precision ±(1 mm + 1 ppm): 5 °C to 45°C (41 °F to 113 °F).
6 The capacity in –20 °C (–5 °F) is 75% of the capacity at +20 °C (68 °F).
7 Bluetooth type approvals are country specific. Contact your local Trimble Authorized Distribution Partner for more information.
8 Dependent on selected size of search window.
9 Solution acquisition time is dependent upon solution geometry and GPS position quality.

TRIMBLE AUTHORIZED DISTRIBUTION PARTNER

NORTH AMERICA
Trimble Engineering &
Construction Group
5475 Kellenburger Road
Dayton, Ohio 45424-1099 • USA
800-538-7800 (Toll Free)
+1-937-245-5154 Phone
+1-937-233-9441 Fax

EUROPE
Trimble GmbH
Am Prime Parc 11
65479 Raunheim • GERMANY
+49-6142-2100-0 Phone
+49-6142-2100-550 Fax

ASIA-PACIFIC
Trimble Navigation
Singapore Pty Limited
80 Marine Parade Road
#22-06, Parkway Parade
Singapore 449269 • SINGAPORE
+65-6348-2212 Phone
+65-6348-2232 Fax

www.trimble.com

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[Δ]

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

760347en – VI.07 – RDV

APPENDIX C

Software reports

Terrestrial laser scanner (Cyclone):

- Resection results

Terrestrial photogrammetry (PhotoModeler):

- Calibration report
- Processing report

RESECTION RESULTS

Printout from Cyclone.

```
Leica Geosystems Cyclone 5.8.1 Resection V1.0
Instrument: USQ SS2 #1251380, IP address: 10.1.202.28
Program Start: 9/11/2008 at 15:29
Using Least-Squares Solution
Station no. : 2000
X= 999.781 m Y= 5001.980 m Z= 701.547 m HI= 0.120 m
Ori.Corr. : 50:39'28.279" DMS
S.Dev. X : 0.000 m
S.Dev. Y : 0.000 m
S.Dev. Z : 0.000 m
S.Dev. Orient. : 0:0'3.759" DMS
3 Point(s) Measured :
##  Point no.  d Hz            d Height  d Distance  Error Flag
1   c1         0:0'5.029" DMS   0.000 m   0.000 m
2   c3         -0:0'4.005" DMS  0.000 m   0.000 m
3   c8         -0:0'1.025" DMS  0.000 m   0.000 m
```

CALIBRATION REPORT

Printout from PhotoModeler

```
Status Report Tree

Project Name: *** Project has not yet been saved ***

Problems and Suggestions (1)
  Project Problems (1)
    The total photo area covered by points is 72%, which is
less than the recommended 80%.
      Try to take photos of the calibration grid so that marked points fill as much
of the photo frame as possible. Also move the grid around the frame so overall
there is good coverage across all photos. This will result in a better calibration as
more of the lens will be calibrated to account for variability throughout the lens.
  Problems related to most recent processing (0)

Information from most recent processing
  Last Processing Attempt: Thu Oct 23 16:26:03 2008
  PhotoModeler Version: 6.2.2.596 - final,trial
  Status: successful
  Processing Options
    Orientation: off
    Global Optimization: on
    Calibration: on (full calibration)
    Constraints: off
  Total Error
    Number of Processing Iterations: 2
    Number of Processing Stages: 2
    First Error: 0.953
    Last Error: 0.953
  Precisions / Standard Deviations
    Camera Calibration Standard Deviations
      Camera1: Samsung S85 [9.30]
        Focal Length
          Value: 7.836935 mm
          Deviation: Focal: 0.001 mm
        Xp - principal point x
          Value: 3.033763 mm
          Deviation: Xp: 0.001 mm
        Yp - principal point y
          Value: 2.100748 mm
          Deviation: Yp: 0.001 mm
        Fw - format width
```

```
          Value: 5.990802 mm
          Deviation: Fw: 2.8e-004 mm
        Fh - format height
          Value: 4.483929 mm
        K1 - radial distortion 1
          Value: 3.328e-003
          Deviation: K1: 1.1e-005
        K2 - radial distortion 2
          Value: -6.579e-005
          Deviation: K2: 7.6e-007
        K3 - radial distortion 3
          Value: 0.000e+000
        P1 - decentering distortion 1
          Value: -8.791e-005
          Deviation: P1: 4.0e-006
        P2 - decentering distortion 2
          Value: -1.250e-004
          Deviation: P2: 4.0e-006

Quality
  Photographs
    Total Number: 12
      Bad Photos: 1
      Weak Photos: 0
      OK Photos: 11
    Number Oriented: 11
    Number with inverse camera flags set: 0
  Cameras
    Camera1: Samsung S85 [9.30]
      Calibration: yes
      Number of photos using camera: 12
      Average Photo Point Coverage: 72%
  Photo Coverage
    Number of referenced points outside of the Camera's calibrated coverage: 0
  Point Marking Residuals
    Overall RMS: 0.121 pixels
    Maximum: 0.496 pixels
      Point 20 on Photo 5
    Minimum: 0.104 pixels
      Point 110 on Photo 11
    Maximum RMS: 0.325 pixels
      Point 20
    Minimum RMS: 0.069 pixels
      Point 110
  Point Tightness
    Maximum: 0.00059 m
```

```
    Point 378
  Minimum: 0.00015 m
    Point 172
Point Precisions
  Overall RMS Vector Length: 7.45e-005 m
  Maximum Vector Length: 0.00013 m
    Point 191
  Minimum Vector Length: 6.85e-005 m
    Point 72
  Maximum X: 6.79e-005 m
  Maximum Y: 6.14e-005 m
  Maximum Z: 9.59e-005 m
  Minimum X: 3.09e-005 m
  Minimum Y: 3.1e-005 m
  Minimum Z: 5.18e-005 m
```

PROCESSING REPORT

Printout from PhotoModeler

```
Status Report Tree

Project Name: 8test1_ver2.pmr

Problems and Suggestions (0)
  Project Problems (0)
  Problems related to most recent processing (0)

Information from most recent processing
  Last Processing Attempt: Thu Oct 23 16:53:30 2008
  PhotoModeler Version: 6.2.2.596 - final,trial
  Status: successful
  Processing Options
    Orientation: on
      Only unoriented photos oriented.
      Number of photos oriented: 3
    Global Optimization: on
    Calibration: off
    Constraints: on
  Total Error
    Number of Processing Iterations: 3
    Number of Processing Stages: 1
    First Error: 0.976
    Last Error: 0.767
  Precisions / Standard Deviations
    Photograph Standard Deviations
      Photo 1: SN850278.JPG
        Omega
          Value: 1.274998 deg
          Deviation: Omega: 0.241 deg
          Correlations over  95.0%: Y:-100.0%
        Phi
          Value: -0.439202 deg
          Deviation: Phi: 0.145 deg
          Correlations over  95.0%: X:100.0%
        Kappa
          Value: -0.071264 deg
          Deviation: Kappa: 0.020 deg
        Xc
          Value: -0.014447
          Deviation: X: 0.005
          Correlations over  95.0%: Phi:100.0%
```

```
  Yc
    Value: -0.040803
    Deviation: Y: 0.008
    Correlations over  95.0%: Omega:-100.0%
  Zc
    Value: -0.001432
    Deviation: Z: 6.2e-004
Photo 2: SN850279.JPG
  Omega
    Value: 0.729498 deg
    Deviation: Omega: 0.131 deg
    Correlations over  95.0%: Y:-99.9%
  Phi
    Value: -23.856647 deg
    Deviation: Phi: 0.098 deg
    Correlations over  95.0%: X:99.6%, Z:97.6%
  Kappa
    Value: -0.765856 deg
    Deviation: Kappa: 0.017 deg
  Xc
    Value: -0.795183
    Deviation: X: 0.002
    Correlations over  95.0%: Phi:99.6%, Z:95.8%
  Yc
    Value: -0.054362
    Deviation: Y: 0.004
    Correlations over  95.0%: Omega:-99.9%
  Zc
    Value: -0.229796
    Deviation: Z: 0.002
    Correlations over  95.0%: Phi:97.6%, X:95.8%
Photo 3: SN850280.JPG
  Omega
    Value: 4.584082 deg
    Deviation: Omega: 0.143 deg
    Correlations over  95.0%: Y:-99.9%
  Phi
    Value: 27.131695 deg
    Deviation: Phi: 0.104 deg
    Correlations over  95.0%: X:99.5%, Z:-97.8%
  Kappa
    Value: -4.534656 deg
    Deviation: Kappa: 0.025 deg
  Xc
    Value: 0.771099
    Deviation: X: 0.002
```

```
          Correlations over  95.0%: Phi:99.5%, Z:-95.7%
        Yc
          Value: -0.071136
          Deviation: Y: 0.004
          Correlations over  95.0%: Omega:-99.9%
        Zc
          Value: -0.259850
          Deviation: Z: 0.003
          Correlations over  95.0%: Phi:-97.8%, X:-95.7%

Quality
  Photographs
    Total Number: 3
      Bad Photos: 0
      Weak Photos: 0
      OK Photos: 3
    Number Oriented: 3
    Number with inverse camera flags set: 0
  Cameras
    Camera1: Samsung S85 [9.30]
      Calibration: yes
      Number of photos using camera: 3
      Average Photo Point Coverage: 70%
  Photo Coverage
    Number of referenced points outside of the Camera's calibrated coverage: 0
  Point Marking Residuals
    Overall RMS: 0.583 pixels
    Maximum: 1.136 pixels
      Point 30 on Photo 2
    Minimum: 0.345 pixels
      Point 17 on Photo 1
    Maximum RMS: 0.806 pixels
      Point 24
    Minimum RMS: 0.242 pixels
      Point 17
  Point Tightness
    Maximum: 0.00085
      Point 24
    Minimum: 0.00014
      Point 20
  Point Precisions
    Overall RMS Vector Length: 0.000537
    Maximum Vector Length: 0.000597
      Point 17
    Minimum Vector Length: 0.000509
      Point 10
```

Maximum X: 0.000249
Maximum Y: 0.000207
Maximum Z: 0.000527
Minimum X: 0.000185
Minimum Y: 0.000165
Minimum Z: 0.000429

APPENDIX D

Extended results

EXTENDED RESULTS

Results tables (full)

The following tables were formed in Microsoft excel imported from both Cyclone and PhotoModeler exported files. All units in metres.

Error values for X, Y and Z positions were found with a range calculated from the square root of the sum of the squares of X, Y, Z.

	X(m)	Y(m)	Z(m)	Error (m)
c1	997.361	5011.761	702.381	
TP	997.361	5011.761	702.381	
Error TP	0.000	0.000	0.000	0.000
TLS	997.361	5011.761	702.381	
Error TLS	0.000	0.000	0.000	0.000
c2	998.810	5011.909	702.380	
TP	998.810	5011.915	702.380	
	0.000	-0.006	0.000	0.006
TLS	998.809	5011.909	702.380	
	0.001	0.000	0.000	0.001
c3	1000.330	5012.064	702.383	
TP	1000.332	5012.064	702.378	
	-0.002	0.000	0.005	0.005
TLS	1000.330	5012.064	702.383	
	0.000	0.000	0.000	0.000

c4	997.358	5011.760	701.788	
TP	997.358	5011.756	701.788	
	0.000	0.004	0.000	0.004
TLS	997.358	5011.759	701.789	
	0.000	0.001	-0.001	0.001
c5	998.805	5011.910	701.787	
TP	998.805	5011.914	701.786	
	0.000	-0.004	0.001	0.004
TLS	998.805	5011.910	701.787	
	0.000	0.000	0.000	0.000
c6	1000.330	5012.065	701.787	
TP	1000.330	5012.065	701.783	
	0.000	0.000	0.004	0.004
TLS	1000.330	5012.066	701.787	
	0.000	-0.001	0.000	0.002

c7	997.356	5011.758	701.186	
TP	997.356	5011.752	701.187	
	0.000	0.006	-0.001	0.006
TLS	997.357	5011.758	701.186	
	-0.001	0.000	0.000	0.001
c8	998.812	5011.909	701.188	
TP	998.812	5011.909	701.188	
	0.000	0.000	0.000	0.000
TLS	998.812	5011.909	701.188	
	0.000	0.000	0.000	0.000
c9	1000.325	5012.066	701.191	
TP	1000.324	5012.061	701.188	
	0.001	0.005	0.003	0.006
TLS	1000.325	5012.067	701.191	
	0.000	-0.001	0.000	0.001