University of Southern Queensland

Faculty of Health, Engineering and Sciences

Assessment of the FARO 3D Focus Laser Scanner for Forest Inventory

A dissertation submitted by

Thomas Stanley

In fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Spatial Science, Surveying

Submitted: October, 2013

ABSTRACT

The research project focused on the use of Terrestrial Laser Scanning, for use in forest inventory for monitoring of forests. Typically, TLS has been used in the built environment, eg building information modelling, mining, architecture and engineering. In recent years advancements in TLS technology have allowed it to be applied to a greater amount of applications, including natural resource management and monitoring of forest resources.

Forests are one of Australia's most valuable natural assets. They are highly valued and have many uses and benefits for our society. Just over 20% of Australia is covered by native forest. There is an increasing need to measure and monitor the extent and condition of Australia's forests. A National Forest Inventory (2003) highlighted the importance of having consistency in the collection of forest data. In 2006, the Continental Forest Monitoring Framework (CFMF) was identified by State and Federal governments of Australia as a means to streamline and standardise the collection methods of forest related information. Could TLS be of use here?

A stand of planted rainforest trees in central Murwillumbah, northern NSW, was chosen as the scan site. Approximately 7 scans were undertaken on the 60m x 60m site in an attempt to create a 3D point cloud of the entire stand. See figure 1 for a view from the Scanner.

Despite some issues with registration, enough data was captured to be representative of a 40m radius sample plot. Many measurements and forest characteristics were able to be extracted to an accurate standard.

To be used long term to gather forest related data, further investigation is required to ascertain the optimal type of instrument, plot size, resolution settings, number of scans for a site, software, targets used and other best practices required to generate an optimal repeatable method for forest data capture, comparison and storage.

The TLS would be suitable for under canopy measurements and long term monitoring, measuring and data extraction of forest based data. TLS is able to gain a snapshot of a particular forest location then perform that same snapshot and compare the change over time. If a rigorous system is developed for monitoring forestry, TLS would definitely have advantages.

University of Southern Queensland

Faculty of Health, Engineering and Sciences

ENG4111 Research Project Part 1 &

ENG4112 Research Project Part 2

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 acknowledge.

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.

Thomas Stanley

Student Number: 0050049068

AKNOWLEDGEMENTS

This research was carried out under the principal supervision of Xiaoye Liu of the University of Southern Queensland.

TABLE OF CONTENTS

ABSTRACT
LIMITATIONS OF USE
CANDIDATES CERTIFICATION
GLOSSARY OF TERMS

CHAPTER 1

INTRODUCTION
1.1 Introduction
1.2 Research Aim
1.3 Justification
1.4 Research Objectives

CHAPTER 2

LITERATURE REVIEW
2.1 Introduction
2.2 Terrestrial Laser Scanner current uses
2.3 Laser Scanner Theory
2.3.1 Time of Flight Scanners
2.3.2 Phase Based Scanners
2.4 Forest Inventory
2.5 Forest Scanning
2.6 Summary
2.7 Conclusions

CHAPTER 3

RESEARCH DESIGN & METHODOLOGY
3.1 Introduction
3.2 The Test Area
3.3 Equipment & Validation
3.4 Established Control
3.5 Field Procedures
3.6 Conclusion

CHAPTER 4

RESULTS & DATA ANALYSIS
4.1 Introduction
4.2 Registration
4.2 Accuracy
4.3 Data Extraction
4.4 Conclusion

CHAPTER 5

CONCLUSIONS, DISCUSSIONS AND RECOMMENDATIONS

5.1 Introduction
5.2 Discussion
5.3 Implications
5.4 Further Research and Recommendations

REFERENCES

APPENDICES

GLOSSARY OF TERMS

CHAPTER 1

INTRODUCTION

1.1 Introduction

Technology is rapidly developing in the Surveying world today. Whilst Terrestrial Laser Scanning (TLS) has been around for many years, it continues to be refined. It has become a more widely used technology for many applications where rapid data capture is required. With Surveyors utilising new technology and methods to measure, 3D laser scanning has become another accepted method of data capture in the surveying industry in Australia, with many companies embracing the new technology. It has become widely used in a range of applications including building modelling, architecture, deformation modelling, mining surveys and volumes as well as crime scene analysis.

One of the biggest areas of use of the TLS has been in the 'as built' type surveys of plant and factory machinery where the large amount of data able to be captured in a short period of time makes this a very cost effective and efficient practice. Also the 3D visualisation benefits of the data enables users to better understand the results than the traditional 2D surveys. Point Cloud technology has advanced greatly and millions of points are able to be captured by a single or multiple scan of an object and rendered with colour to offer the user a realistic 3D plan of the site.

3D Laser Scanning of solid objects such as buildings has proven to be an effective method of capturing data and modelling buildings for heritage or remodelling purposes. However the use of 3D TLS for forest modelling and data capture is a relatively new and still developing field. Several studies have been undertaken to sample forest characteristics and monitor their health and growth over time, and also to randomly sample forest structure and species locations.

1.2 Research Aim & Objectives

This project aims to assess the FARO 3D Focus Laser Scanner as a tool for forest inventory. Forest inventory has traditionally been carried out using slow measuring and note taking type methods by individuals using numerous measuring tools. Weiz (2009) noted that TLS could hold more practical advantages over these traditional methods. For example TLS, provided carried out by qualified and trained personnel, could be repeatable, more efficient and not subject to personal differences in measuring techniques.

This project also intends to analyse the accuracy of typical forest inventory data that is able to be extracted by the FARO laser scanner. These typical inventory may include, basal area, DBH, species richness, tree height, tree taper, stand density index, tree crown and canopy measurements to name a few.

TLS has been proven to be a useful tool for the building modelling applications, architecture, factory and plant 'as built' surveys. These objects being scanned are hard, fixed and as a result of their highly reflective surfaces, are able to be scanned with high resolution and quite accurately with TLS. Vegetation, however, is softer, less reflective and moves with the wind. It is intended to examine how this will affect the TLS results and whether this technology has any limiting factors.

Research objectives for this project include:

- Research the types of Terrestrial Laser Scanners
- Research how terrestrial laser scanners work
- Test the FARO 3D Focus TLS in a forest environment focusing on;

    - Extraction of typical forest inventory data
    - Comparison of DBH from scan to manual measurements
    - Analyse the accuracy of registration process with vegetation
- Analyse the usefulness of captured data
- Analyse the field work to office work ratio with the FARO 3D Focus TLS
- Comment on the benefits/disadvantages of the FARO TLS

1.3 Justification

Measurement technologies over the years have changed dramatically from the ancient Egyptian method of using knotted ropes to steel bands through to electronic distance measurement and nowadays Global Positioning Systems, airborne LiDAR and Terrestrial Laser Scanning.

While the first commercial TLS's appeared on the market approximately 15 years ago (Staiger 2011), drastic improvements have occurred over the last 10 years. These improvements have been related to measurement speed, accuracy and general usability of the instruments. It is anticipated that this technical progress will continue into the future and hence the need to document the performance of TLS's.

Staiger highlights that we are now into the fourth generation of TLS's and improvements have been made over the years to the size, weight, data storage type and capacity, power supply, frequency and range of measurement as well as the incorporation of digital images to some new scanners. This technological progress combined with powerful software programmes allows users a greater range of applications for Terrestrial Laser Scanners.

It would be fair to say that traditional surveyors in Australia have been slow to embrace this technology and many have never been exposed to a TLS. TLS has been utilised and proven in engineering, mining, architecture and crime scene analysis, however its use in measuring forests has been fairly recent. This project seeks to measure the effectiveness of the FARO 3D TLS in a typical forest environment.

The purpose of national forest monitoring has a wide range of social, economic and environmental benefits. Cost-effective methods for data collection have been a major focus in forest monitoring research (e.g. Ranneby et al. 1987, Gillis et al. 2005, Kleinn et al. 2005). Balancing requirements on accuracy and precision for the monitored variables with the cost of obtaining data from the field poses a classical problem of forest inventory. The framework of sustainable forest management has been used to define information requirements for the Global Forest Resources Assessment process, in which countries report based on their national information sources (FAO 2006c).

Therefore, national forest monitoring systems need to be designed to deliver cost-effective and quality-controlled information. Other emerging needs of forest management relate to climate change, carbon stock monitoring and best land use practices.
According to the FAO-led Global Forest Resources Assessment 2000, results show that forests are not systematically monitored in the majority of countries and that current monitoring of forests seems not sufficiently accurate or precise for an international protocol that would administer finances based on monitoring results of forest area or forest carbon storage.

National forest monitoring systems, as defined above, should systematically and repeatedly measure and observe forest resources, their management, uses and users. However, many countries have not established such systems, or have systems that only partially can be characterized as a national forest monitoring system (FAO 2006c).

1.4 Conclusion

This research Project aims to assess the FARO 3D Focus Laser Scanners ability to operate in a forest environment and specifically to extract typical forest inventory data. The project also intends to assess the performance of the TLS as a new method for rapid data capture and comment on the results. TLS instruments claim to drastically reduce fieldwork time however it has been assumed by many surveyors that the office time involved in reducing the data to a useable form would be greatly increased. This will be tested and commented on in the findings.

A thorough review of the literature will research the types of scanners available today, noting their differences and intended applications. This review will also discuss the use of TLS for forest research and measurement as well as other general applications of TLS and accuracies achieved with their use.

It is intended that this research will highlight the ability of the FARO 3D terrestrial laser scanner to capture a thickly vegetated area in a rapid amount of time and at an accurate level. This research will demonstrate how the FARO TLS could be used for numerous engineering and surveying applications and thus should not be disregarded as an acceptable mode of measurement by surveyors today.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Recent developments in TLS technology have made these accurate and efficient survey instruments more affordable (Chow, Lichti & Teskey 2012). With such a wide variety of scanners available today, and different brands and types to choose from, there is a lot that must be understood before a decision can be made with regards to which is the best type of TLS to use. Much research has been done over the last ten years with relation to TLS accuracy, self-calibration methods and point cloud registration techniques, however the technology is updating so fast that even this research outdates quickly, as new products and more powerful processing software become available.

This Literature Review is broken up into three parts;

1 Current industry uses of TLS

2 Laser Scanning theory; - Time of flight scanners & Phase based scanners

3 TLS in forest environments

The large amount of data acquired by the TLS makes it such a powerful tool to the spatial scientist. However being able to fully understand the instruments capabilities and limitations is mandatory to the spatial scientist of today's world. Therefore, the further these instruments are tested, researched and utilised in real world applications, the more they will become an integral tool for the surveyor and spatial scientist.

Recently, the application of TLS has been applied to forest management studies. Some research has been conducted with relation to accuracy and data acquisition in a forest environment. Basic tree structures and canopy modelling has been investigated. Many of these studies also simultaneously compare different types of scanners, contributing to the research and understanding of TLS's on the market.

2.2 Terrestrial Laser Scanner Current Industry Uses

Typically TLS instruments have been used in industries such as **architecture, engineering, construction, manufacturing, structural monitoring, heritage preservation, forensics** and virtually all capital projects requiring rigorous design processes (Spatial Resources).

Some of the main benefits of TLS data acquisition is the increased speed of data capture, accuracy of plans, elevations, profiles, volumes and area calculations able to be extracted from scans. Civil Engineering and Surveying firms use TLS for cost effective surveys to develop TIN meshes of roadway surfaces. They are also capable of safely acquiring data that cannot always be easily accessed such as bridge beams, rock faces and highway information.

The construction industry has used TLS as a tool for reduction of costs by eliminating 3D design errors and to accelerate projects completion timeline. Also when a project is complete, an accurate record of the as built project can be recorded for future reference.

An example of TLS for monitoring purposes can be seen with Rosser, Petley, Nim, Dunning and Allison (2005). The authors monitored hard rock cliff coastal erosion using TLS. Coastal rock cliffs represent 75% of the worlds coastline and as such are an important feature.

Manufacturing:

In the manufacturing industry, spatial companies who have embraced TLS technology, such as 3D Spatial based in Melbourne Australia, carry out dimensional inspection, which is a specialised part of their industrial metrology services (3D Spatial). This is a tool which uses TLS for the verification of dimensions for quality control with manufacturing parts. The 3D capabilities and accuracy of the instruments allow for visualisation of complex machinery parts and also allow the detection of any manufacturing defects. This allows the company to give the client the confidence that a part meets the required specifications for its performance.

Heritage preservation:

The historic site of Pinchango Alto, located 400km south of Peru's capital Lima, was mapped and modelled as part of an archaeological project in 2006 (Eisenbeiss & Zhang). Because of the sites difficult terrain and accessibility problems it was mapped using a combination of UAV with LiDAR and TLS. TLS represents a non-contact, low invasive method of capturing historic sites for future preservation and records.

Another example of using TLS for cultural heritage preservation is the Cathedral of Modena, which is included within the UNESCO World Heritage List since 1997, and is one of the most important pieces of Romanesque culture in Europe. The scanning of the Cathedral of Modena in 2012 enabled the capture of the building in high detail as well as providing the base for a structural monitoring program for deformation of the building.

Other examples of TLS for heritage preservation include the 1999 scanning of Michaelangelo's statues by Marc Levoy (koller 2004). This included the famous depiction of David, and the scan was of a high enough resolution to allow the artists' chisel marks to be distinguished.

Forensic:

Leica C10 instruments are now being used in the United States by Georgia's Bureau of Investigation. They are used to scan and recreate crime scenes for solving crime, prosecuting criminals and also to assist jurys in visualising exactly what the crime scene was like using Leica's Truview web based scan share program (Leica Geosystems).

3D modelling:

According to FARO, movie makers and video game producers are able to rapidly scan and import entire movie sets, characters and even objects into various computer generated imagery platforms using FARO laser scanner technology.

2.3 Laser Scanner Theory

There are currently three main types of primary ranging instruments being used in the spatial science industry;

1. Time-of-Flight return scanners
2. Continuous wave phase-shift scanners, and
3. Time-of-Flight waveform scanners.

Some important environmental factors that affect TLS *range* and *quality* include;

- Light; daylight reduces scan range and increases noise in the scan. This however can be augmented by scanning on overcast days or in evening or low light conditions where possible.
- Surface qualities of the scanned object; for example shiny, highly reflective surfaces are more difficult to scan. This may be augmented through changing the angle and range to the object.
- Colour; darker objects reflect less light. A solution to this to decrease the range to the object and/or add powder coating if possible.
- Movement; scanner and target object must be stationary for optimal results.

2.3.1 Time of Flight Scanners

Time-of-Flight return scanners emit a pulse of laser energy light which measures the time it takes to travel from the scanner to the object and back again, allowing the scanner to calculate a distance. This method allows the scanner to measure greater distances (up to 300m Leica C10). Current technology allows for up to 50000 points per second of data capture.

Figure 1 An example of time of flight scanner is the Leica P20 Image courtesy of leica geosystems.

The time-of-flight 3D laser scanner is an active scanner that uses laser light to probe the subject. The laser rangefinder finds the distance of a surface by timing the round-trip time of a pulse of light. A laser is used to emit a pulse of light and the amount of time before the reflected light is seen by a detector is measured. Since the speed of light is known, the round-trip time determines the travel distance of the light, which is twice the distance between the scanner and the surface (Wikipedia).

Strengths and weaknesses

Time-of-flight and *triangulation* range finders each have strengths and weaknesses that make them suitable for different situations. The advantage of time-of-flight range finders is that they are capable of operating over very long distances, on the order of kilometers. These scanners are thus suitable for scanning large structures like buildings or geographic features.

The disadvantage of *time-of-flight* range finders is their accuracy. Due to the high speed of light, timing the round-trip time is difficult and the accuracy of the distance measurement is relatively low, on the order of millimeters.

Time-of-flight scanners accuracy can be lost when the laser hits the edge of an object because the information that is sent back to the scanner is from two different locations for one laser pulse. The coordinate relative to the scanners position for a point that has hit the edge of an object will be calculated based on an average and therefore will put the point in the wrong place. When using a high resolution scan on an object the chances of the beam hitting an edge are increased and the resulting data will show noise just behind the edges of the object. Scanners with a smaller beam width will help to solve this problem but will be limited by range as the beam width will increase over distance. Software can also help by determining that the first object to be hit by the laser beam should cancel out the second.
At a rate of 10,000 sample points per second, low resolution scans can take less than a second, but high resolution scans, requiring millions of samples, can take minutes for some *time-of-flight* scanners.

When scanning in one position for any length of time slight movement can occur in the scanner position due to changes in temperature. If the scanner is set on a tripod and there is strong sunlight on one side of the scanner then that side of the tripod will expand and slowly distort the scan data from one side to another. Some laser scanners have level compensators built into them to counteract any movement of the scanner during the scan process (Wikipedia).

Time of flight scanners, according to (Newham, Armston etc 2011) , emit a pulse of laser energy and use electronics to measure the discrete time of flight of a return echo from an intercepted target. Some instruments of this type allow for the detection of multiple returns from a single pulse. These instruments provide high accuracy over long range, for example up to 1 km and the pulse frequency may be up to 100, 000 points per second. According to Cote, 2009, and Watt and Donoghue 2005, time of flight category scanner has seen the largest application to vegetation structure measurement.

2.3.2 Phase Based Scanner

Phase based scanners utilise a constant beam of laser energy light. They determine the distance by measuring the constant waves of varying lengths that are projected. Upon contact with an object, the laser beam is reflected back to the laser scanner. The distance from the laser scanner is accurately calculated by measuring the phase shifts in the waves of infrared light.

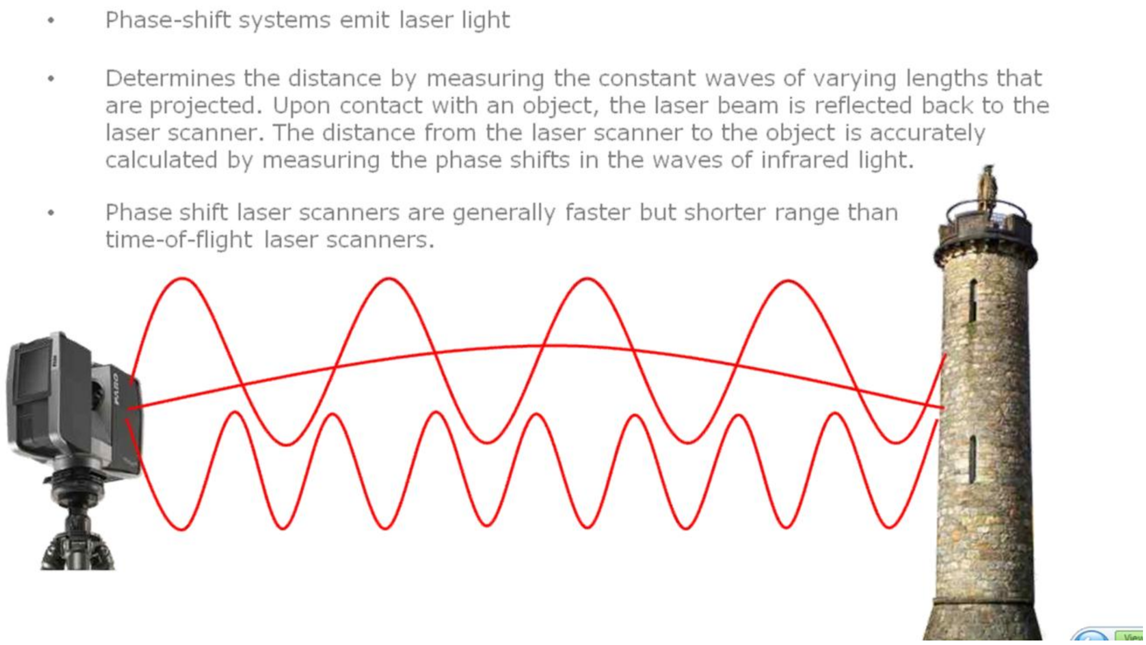

Figure 2 An example of a Phase based laser scanner. Source Geomatics.

The change of phase of the laser light is measured, allowing the scanner to calculate the distance (Geomatics). The advantage of this method is that the speed of data capture is much higher, with phase based scanners capable of acquiring as much as 1 million points per second. This comes with a limitation of only being capable of accurately measuring over shorter distances e.g 80-100m.

Laser Phase-shift 3D Scanners

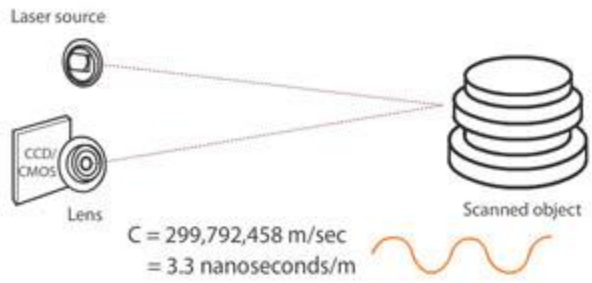

Figure 3 How the laser scanner works.

Laser phase-shift systems are another type of time-of-flight 3D scanner technology, and conceptually work similarly to pulse-based systems. In addition to pulsing the laser, these systems also modulate the power of the laser beam, and the scanner compares the phase of the laser being sent out and then returned to the sensor.

Phase based scanners employ a continuous wave laser with intensity modulated at a series of frequencies (Newham et al 2011). The shift in phase of the returned modulations are used to calculate the distance or range. This category of scanner is capable of scanning at much higher frequencies that time of flight instruments. This allows capture of up to 1 million points per second and is the phase based TLS's main quality. The range of this category is usually in the vicinity of 80-120m. Phase based scanners are susceptible to noisy data and hence gaps are sometimes more difficult to resolve. This is usually addressed within the post processing and firmware and may involve removing points based upon the characteristics of neighbouring points.

Figure 4 the Leica HDS 6200 is an example of a phase shift scanner. Source Leica Geosystems.

2.4 Forest scanning

A number of TLS research projects have been undertaken in forest environments and will be outlined below. These all vary greatly in purpose and method and have contributed to the knowledge of TLS applications in forest environments.

In 2011, Newnham, Armstrong, Muir, Goodwin, Tindall, Culvenor, Pushel, Nystrom & Johansen conducted a study for the CSIRO in an attempt to analyse the use of TLS for broadscale assessments of vegetation structure, above ground biomass, carbon monitoring, vegetation restoration and habitat value. They acknowledged the need for a rapid and repeatable ground based measurement tool in order to increase spatial and temporal sampling of vegetation structure. The authors believed that TLS would provide more detail than traditional sampling methods, which would improve assessment as well as long term monitoring of change in vegetation and biomass.

Of interest in this study were the TLS's ability to estimate the number of trees per hectare, the distribution of stem diameters at breast height (DBH), tree heights and vertical distribution of foliage cover, all of which are important aspects of vegetation structure and can help to more accurately estimate above ground biomass.

This study was particularly important in the research in TLS as at the time it is one of few studies that compare multiple TLS instruments for vegetation structure assessment.

According to Weiz (2009), the most important factors in TLS of forests are the ability to measure Diameter at Breast Height (DBH), Basal Area and tree height. These comprise the main items in a typical forest inventory. Traditionally these would be measured manually and in a time consuming manner. Weiz commented on the fact that TLS has not been used widely as a method for forest inventory and the future would see this method used as a tool for monitoring of forests.

TLS allows rapid data acquisition and measures a greater area than would normally be measured in a typical plot sample using traditional manual forest inventory techniques. Weiz also continued to state the possible benefits of forest industry workers such as pre harvest scanning, stand monitoring to allow timber plantations to be harvested in a timely and cost effective manner, proving a valuable tool for plantation planning schemes.

Weiz's study was conducted in Germany on a plot 30 metres by 30 metres of Douglas-Fir trees. Two scanning principles were investigated; a single central scan and a multiple can method consisting of four scan stations spread evenly through the stand as well as the central scan station. It is interesting to note that this particular used the FARO LS 880 HE 80, utilising phase based laser technology and which is typically used for short range scanning i.e, up to 100m.

Upon completion of the field work, Weiz compared the standard deviation, standard error and the confidence intervals of the results from the single scan and the multiple scan approaches. Weiz reported that tree tops were difficult to ascertain from the scan data due to canopy clutter. Other issues encountered in the study were the negative effects of tree obstruction, known as the shadow effect. This is where some parts of the area are not scanned as they are not visible from all scan stations.

The author found that TLS underestimated the DBH of the trees compared to manual tape measure methods. The optimised multiple scan method appeared to give a significant reduction in any difference from the taped measurements. Weiz concluded that the TLS achieved ‘accurate estimates’ of typical forest inventory parameters such as DBH, basal area, and tree density. It was also concluded that the TLS method was suitable for DBH monitoring over time.

Sources of error found by the author were the various incorrect points at the edges of trees where laser returns may come partly from the tree edge and partly from another tree located directly behind. The author noted the understorey was quite clear from thick ground cover, allowing beneficial conditions for TLS and recommended that the method not be attempted in complex forest scenarios.

Thies and Spiecker (2004) investigated the accuracy and possibility of using TLS for generating standard forest inventory data. They investigated the hypothesis that TLS are accurate enough and ready to be used for the said purpose. They also argued that the data quality had the potential to widen the fields of forest management applications as well as ecological investigations.

Thies and Specker outlined the full benefits of using TLS for forest applications which incorporated sustainable recreational uses of forests, maintenance of biodiversity, and long-term management of forest protection programs as well as sustainable supply of useable timber to industry.

This study undertaken by Thies and Spiecker (2004) (also in Germany), highlighted three tiers of information that could be obtained from TLS of forests. These include

- *Locality data*; such as definition of the sample site through local coordinates, forest type or category, i.e temperate dry forest.
- *Plot specific information*; such as site conditions, soil, slope, ground vegetation, tree density etc, and
- *Single tree parameters*; including specific forest inventory data such as tree height, DBH, species, height of canopy and many more.

Like Weiz (2009), Thies and Spiecker implemented and compared a single scan approach as well as a multiple scan and registration into a 3D point cloud. They concluded that the multiple scan method, although slightly more time consuming, guarantees considerably better data quality due to the overlapping point clouds offering more information about the trees, i.e scanning from more than one direction.

They continued to state that the multiple and single scan modes both offered accurate results and the purpose of the study should be considered when choosing an appropriate method. Compared to manual measurements of the DBH, the authors also encountered differences in scan derived DBH. This is due to inconsistent laser beam returns on the edges of trees similar to that encountered by Weiz (2009). Overall Thies and Spiecker reported their multiple scan

DBH measurements by laser scanner to be satisfying when compared to convential measurement techniques.

In concluding, Thies and Spiecker commented that TLS's will offer many benefits in forest management in the future, including repeatability of measurements and consistency in long term monitoring of forest data.

Tree structure and the shadow effect were investigated by Vanderzande, Hoet, Jonckheere, Van Aardt and Coppin (2006) using TLS. An artificial tree was constructed and different angle setups and scans were undertaken of the tree and subsequently analysed. The aim of the project was to gain greater understanding of the design of TLS setups in practical forestry applications. The authors also commented on the subjective current manner in which forest inventory data is collected and how this inhibits the comparison of any data due to differences in collection methods.

Vanderzande et al (2004), described TLS technology as being capable of generating a unique and comprehensive mathematical description of tree structures. The authors aimed to investigate how the geometric measurement pattern (GMP) influenced the accuracy of the extracted structural variables. Furthermore it was found that the 3D point density would vary decreasing as the scanner moved up into the canopy. They determined the best method of obtaining an accurate 3D model of the understorey, lower and upper canopy was derived from a combination of ground based TLS and aerial LiDAR from above. The authors made a point of also mentioning the enormous potential of TLS contributing to an objective and repeatable technique of describing tree structure.

In 2006, Henning & Radtke (2006) investigated the use of TLS to better improve the link between leaf-level processes, canopy structure and forest growth. A 20m x 40m plot was scanned using ground based LiDAR in both leaf on and leaf off states of the plot which consisted of broadleaved deciduous forest in North Carolina USA. A digital terrain model and canopy height model was derived from the scan and DBH and on average DBH were found to be within 5cm of manually measured figures.

At the time of publication, studies using TLS data from multiple viewpoints to assess canopy structure was rare. The authors confirmed that ground based LiDAR systems like TLS were vital to the field of research of both forestry and laser scanning disciplines, yet maintained that validation of these methods is currently incomplete. They referred to registration methods of multiple scans and inferred that artificial target placement was not accurate and as a result their scans were tied together using natural features which they claimed provided greater flexibility.

In relation to the DTM created by TLS, Henning & Radtke found that highly accurate surfaces can be achieved and cited a number of studies which also obtained high quality DTM data from TLS. They also agreed with Vanderzale (2004) in that a combination of airborne LiDAR and ground based TLS offers a full complimenting dataset. Henning & Radtke commented on the benefits of using TLS for evaluating growth and change in forest canopies, canopy gaps, understory development, as well as insect damage, disease and storm damage. They also acknowledged the benefits and possibilities of long term monitoring of permanent sample plots through the use of coordinate systems.

Henning & Radtke were able to use TLS to successfully characterise the spatial variability of canopy structure and to relate this to forest growth and productivity. However, they acknowledged the importance of improving automatic registration methods as well as developing a system for complete validation of scanner-derived estimates.

In 2004, Ashcroft, Haala, Reulke & Thies investigated the notion of utilising TLS and high resolution panoramic images for the collection of accurate forest inventory data such as tree height, position, diameter and species. It was thought that the LiDAR data could give accurate geometric measurements of forest detail and the texture parameters from the high resolution panoramic images could be applied for species recognition. The auhors were interested to determine whether modern technology could replace traditional measurement techniques associated with forest management.

The authors of this study demonstrated the usefulness of the combination of LiDAR and image capture. The high resolution images captured enabled the recognition of individual tree species based upon the bark texture. The TLS used for the project was the Imager 5003 system from Zoller and Frohlick. Images were captured with the Eyescan camera which was built by the German Aerospace Centre. A benefit of the chosen TLS was its large field of view which was 360 degree horizontal and 310 degrees vertical limit.

Astrup, Coates, Ducey, Larson, Seifert & Pretzsch (2009) conducted a study of two TLS systems on two sites, to assess their performance on measuring typical forest inventory data as well as canopy characteristics. Although both scanners were high resolution 3D instruments, clear differences were observed in impulse penetration, range of measurement and the ability to determine gaps. It was noted that scanner specifications and settings may need to be carefully considered when conducting TLS of forests and may account for some of these differences.

The study, conducted in British Columbia, compared a Reigel LMS360i scanner and a Leica Scanstation (both Time of Flight instruments) to carry out multiple scans at both test sites. Similar to other studies a central scan was taken with other scans spread radially around it. This allowed approximately 10-20 trees to be scanned from all sides. The scan with the Reigel utilised a retroreflective target placement method for registration of the scans, done by matching the centroids of the targets. The Leica Scanstation scan was performed using a closed traverse with a circular target for the foresight and backsight at each scan location. To ensure that key scanner differences were compared, identical post-processing procedures were used for each scan, except for the registration process. To compare the results of the two scanners a 0.1m thick slice of the point clouds was taken at 1.3m above ground level and a 2m thick slice taken at 10m (mid canopy). The 0.1m slice compared the two scanners derived DBH and tree position, whilst the 2m slice compared the canopy size, shape and position from both scanners.

2.5 Conclusion

Many studies have been undertaken using TLS on vegetation and forest environments. This is still an evolving technique for forestry and environmental measurements utilising an evolving technology. We must continue researching and testing different technologies for various purposes in order to achieve and refine best practice management. It has been stated that existing forest inventory methods have their limitation;

Use of forest inventory data overcomes many of the problems present in ecological studies. Data from forest inventories are generally more abundant and are collected from large sample areas (subnational to national level) using a planned sampling method designed to represent the population of interest. However, inventories are not without their problems. Typical problems include:

- Inventories tend to be conducted in forests that are viewed as having commercial value, i.e., closed forests, with little regard to the open, drier forests or woodlands upon which so many people depend for non-industrial timber.
- The minimum diameter of trees included in inventories is often greater than 10 cm and sometimes as large as 50 cm; this excludes smaller trees which can account for more than 30% of the biomass.
- The maximum diameter class in stand tables is generally open-ended with trees greater than 80 cm in diameter often lumped into one class. The actual diameter distribution of these large trees significantly affects aboveground biomass density.
- Not all tree species are included, only those perceived to have commercial value at the time of the inventory.

- Inventory reports often leave out critical data, and in most cases, field measurements are not archived and are therefore lost.
- The definition of inventoried volume is not always consistent.
- Very little descriptive information is given about the actual condition of the forests, they are often described as primary, but diameter distributions and volumes suggest otherwise (e.g., Brown et al. 1991, 1994).
- Many of the inventories are old, 1970s or earlier, and the forests may have disappeared or changed (FAO).

CHAPTER 3

RESEARCH DESIGN & METHODOLOGY

3.1 Introduction

This project aims to assess the FARO Focus 3D terrestrial laser scanner for vegetation measurement. The instrument will be borrowed from the University of Southern Queensland's Faculty of Engineering in Toowoomba.

The Instrument has never been used by the author, and as such has never actually used a TLS. This area of research is intended to give the author an excellent understanding of TLS types, accuracy, field work and office post processing in order to increase and broaden experience in the field of spatial science.

A visit to the University of Southern Queensland's Faculty of Engineering and Surveying in May 2013 was undertaken to get a demonstration of the FARO 3D. I met with Xiaoye Liu and Zhenyu Zhang, Staff at USQ, who discussed the use of spherical targets for the scan and also the geometrical layout of scan stations for the desired test site.

Due to time restrictions and the scanning was carried out in a single day. A FARO Scene V5.1 30 day trial licence was downloaded for free from FARO's website. As this was a completely new task there were a lot of unknowns associated with using the scanner, downloading and processing the results and as such the learning curve was quite steep. Had I known more about using a TLS more consideration would have gone into specific aspects of the survey design and methodology.

As demonstrated above, there has been numerous research experiments carried out using TLS over the last decade. These have each focused on separate aspects of TLS, such as accuracy, registration methods, comparison of time of flight vs phase based measurement. It is intended for this particular research to examine the ability of the FARO TLS to measure and extract *vegetation* similar to a forest environment.

3.2 The Study Area

The chosen test area is in Murwillumbah which is the area of employment of the author. A local community area known as knox park exists in the centre of the township. Within Knox Park is an area of approximately 60m x 50m and consists of native Australian rainforest species known as the “peace walk”. The area was planted in the 1980’s and consists of approximately 150 trees that are on average 20 metres high. There is a clear understorey making the scanner a good instrument for this job. There is a slight slope on the ground with a footpath meandering through the forest area.

Adjacent to the Peace Walk is a concrete skate park to the east, to the north is a large pond, and to the west, running North-South is Nullum Street. To the south of the peace walk is an old community building and also a newly built (2013) community centre.

Figure 5 Knox park tree stand, Murwillumbah, NSW.

The test site has been comprehensively surveyed in detail with an existing DTM. Although individual trees have not been located in this survey, it is intended to survey the location of a selection of trees for comparison of the position derived from the FARO 3D TLS.

3.3 Equipment

Equipment required for the scan is the Faro Focus 3D TLS and twelve spherical (140mm) targets for the registration process. A check calibration will not be carried out on the instrument prior to its use, as it is beyond the scope of the course and time restrictions apply. It will be assumed that the instrument is in good adjustment as it is well kept and used regularly at USQ.

Figure 6 The FARO Focus 3D

Local survey control exists in the area from a survey undertaken for the purposes of a Lease Plan of the new community centre. The control is on AHD and MGA orientation/coordinate system. It is intended to get the scan onto this local coordinate system.

A trial run of the scanner was carried out in my garage to refresh my memory on the scanners controls and settings to ensure smooth operations on site at knox park. The scan was performed successfully and I was able to examine further the scanners settings and options. The settings were fairly simple and easy to use. I was able to understand what they all meant and what they would be needed for.

The FARO Focus 3D is a high speed 3D scanner for detailed measurement and 3D documentation. It utilises laser technology to produce incredibly detailed 3-dimensional images of complex environments and geometries within minutes. The resulting image is an assembly of millions of points in colour which provide an exact digital reproduction of existing conditions.

3.4 Forest feature extraction

It is intended to use the TLS to extract forest parameters suitable for use in a typical forest inventory. These forest inventories are used;

- to measure a forest stands timber resources
- monitor a forests growth
- monitor forest health
- contribute to national forest data
- to evaluate habitat and other natural resources

The features able to be extracted from the TLS included:

1. tree volume/density
2. Basal Area
3. DBH
4. Crown features
5. Tree heights
6. Species identification
7. Biomass

3.5 Field Procedures

It is intended to use approximately 7-9 scan setups to ensure enough overlap of data, and also to avoid the effect of ‘shadowing’, where parts of trees are hidden from view. 4-5 scans will be used around the external perimeter of the stand. A further 3-4 scan setups will be used throughout the internal part of the stand to best cover the area and gain enough overlap to successfully plot the majority of the trees. It is imagined that some shadowing will occur, however it is intended to be kept to a minimum by adequate geometry of the scan locations.

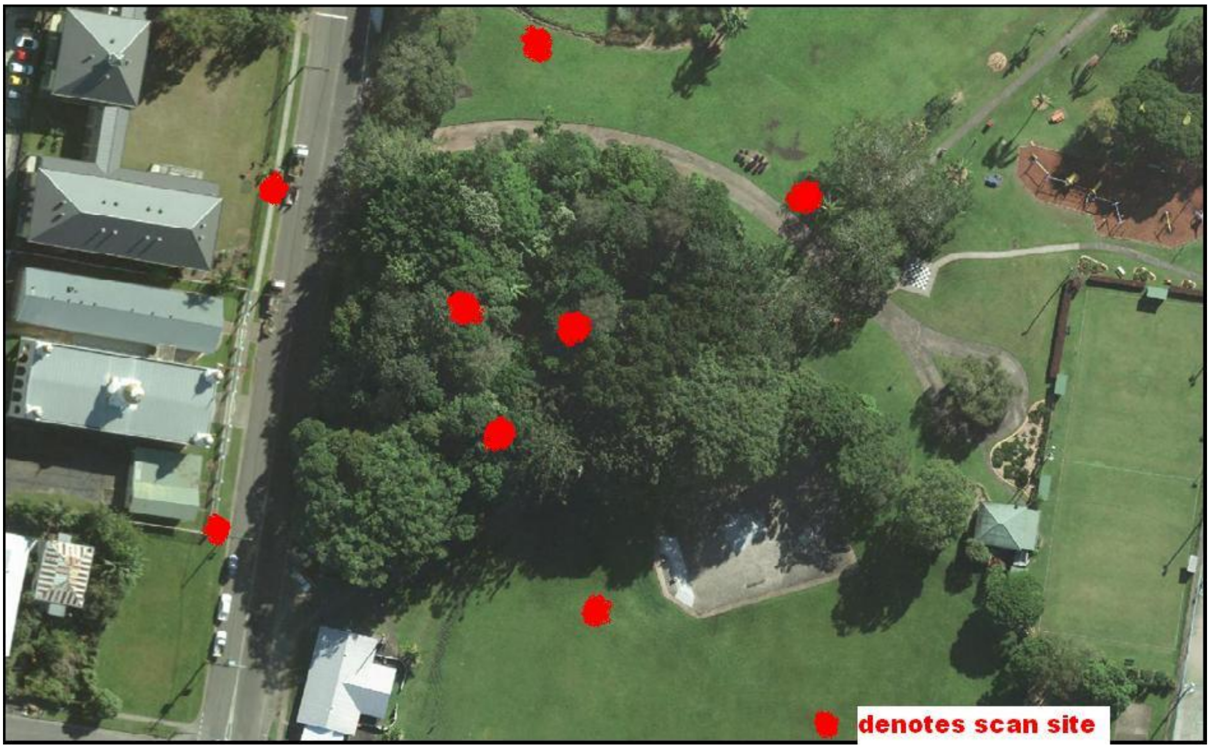

Figure 7 Map of Scan sites

3.6 Conclusion

The equipment was tested at home in my garage and a scan was able to be carried out and previewed afterwards on the scanners screen. The test area had been chosen and inspected. It was confidently felt that I would be able to accomplish the task of scanning the entire forest stand in knox park in order to obtain a 3D point cloud capable of yielding measurements capable of use in a forest inventory.

CHAPTER 4

RESULTS & DATA ANALYSIS

4.1 Introduction

The scan of knox park was carried out at approximately 10am on the 15th June 2013. It was a clear day with a slight breeze and 21 degree temperature. A total of five scans were performed around the perimeter of the forest stand and three scans inside the forest stand.

Figure 8 scan station under the canopy

The scanner was set to a mid to high level resolution setting to have a balance of quality but with reduced file size as it was anticipated to be a drain on my PC. The scan utilised functions such as “indoor” scan settings for inside the forest stand where the light was low.

“outdoor” scan setting was chosen for the external forest stand scans as the light levels were high.

The scans took approximately 10-12 minutes each including colour photo capture time. All up the project was scanned in approximately two hours. This was slightly longer than anticipated however due to placement of the spherical targets for each setup, extra time was needed.

4.2 Registration

Registration is the process of joining the scans together. Much like a traditional survey where a large amount of radiations (measured points) measured from one control station are matched with those measured from a second control station, placing both sets of radiations in a spatially correct relationship.

As the control stations (scan locations) are not known coordinates, they are matched to adjoining scan stations through geometric registration of common points (being the targets). It is required to have a minimum of four common targets for adjoining scans however it was recommended to use six.

Once the scan data was loaded to the Scene software the process of registration was undertaken. Three scans (scans 7 – 9, those internal to the forest stand) successfully registered quite accurately. The spherical targets were able to be detected and matched to adjoining scans.

The external scans (scans 1 – 5) were unable to be registered to one another. They were able to be viewed and measured however no spatial relationship to adjoining scans could be extracted to enable a full 3D point cloud.

It was believed that the scans failed to register due to the distance of the spherical targets from the scanner. It was estimated that the distance of targets to the scanner was approximately 30 metres (which was believed to be adequate for registration). The scan targets were placed randomly, at varying heights above the ground, and where possible, on metallic objects taking advantage of their magnetic base.

Figure 9 three targets required for registration as a minimum (FARO).

It was later discovered that the FARO scanner required a fixed number of measured points on each of the spherical targets in order to recognise them for registration. The resolution of the scan settings could have had an impact on this. Meaning if a higher resolution was chosen, more points would have been measured on the spheres, thus allowing for registration to occur.

It was found that there is no set distance from the scanner for targets to be placed. However, the registration process is a function of a number of variables. The factors that affect registration and target placement are;

- Minimum number of targets is 3. However it is recommended to use more in case one or more fail or cannot be seen or are moved during scanning, rendering them unusable.
- Avoid placing targets in regular shapes such as squares as there would be four possible solutions to matching the scans.
- Avoid placing targets in straight lines.
- Vary the height of the targets.eg some high, some low.
- Use unique patterns for each scan. Never use the same pattern as registration will match all the scans on top of each other.
- Must be visible for both scan locations.

From this above guidelines on placing scanner targets, we can see that it is similar to a traditional survey technique known as a resection. Here known points are geometrically measured to deduce an unknown position. This is basically the same as target based registration of TLS.

FARO has predefined settings in its Scene software that determine the success of the “mathematical fit” of targets in a scan. The biggest determinant is the number of points that land on the spherical target. For this reason the main factors affecting the success of the registration process are;

1. Scanner resolution and quality
2. Distance to the target from the scanner
3. Environmental conditions
4. Size of the target.

The distance from the scanner that targets should be placed is determined by these factors. As a guide, Faro recommends that when scanning at ¼ resolution, that targets be about 20m max distance. At 1/8 resolution it is recommended they be 10m max. However, the environmental conditions and size of the targets need to be considered also. Larger targets could potentially be placed further from the scanner. In bright sunny conditions, targets may not be visible due to too much light or reflectance, causing targets to be undetectable. In these conditions they should be moved closer to the scanner and sheltered from excessive light if possible. It is recommended to set the minimum number of targets required for registration within these guidelines, and place further out redundant targets. There appears to be no hard and fast rule, but rather the user assess the situation, environment and scan settings.

Available scanner resolutions of the FARO 3D scanner are 1/1, ½, ¼, 1/5, 1/6, 1/8, 1/10, 1/16, 1/20 and 1/32. Quality options allow from -3x to 8x. quality setting allows the user to balance between quality and speed of the scan. The chosen settings for the forest scan were a mid level of ¼ resolution and 4x quality, allowing for 7 minute scans and approximately 10,240 points measured per 360 degree rotation of the scanner.

The three scans that successfully registered were decided to be the ones treated for measurement and data extraction. These scans were numbered scans 7, 8 and 9. The distances between these scan stations are as follows;

7-8	12.1m
8-9	11.8m
9-7	15.8m

Figure 10 distance between scans

It must be noted that these three scan stations form a triangle and they all had the same 8 spherical targets for their scans. This clearly provided for excellent registration geometry.

4.3 Accuracy

The spheres that registered the successful three scans inside the forest stand gave a registration fit tolerance quality of under 12mm. This was quite good and all data appeared to be positioned correctly. Time did not permit for spatially orienting the scan and comparing to local coordinates. The only accuracy checks were in relation to the tree and foliage characteristics.

4.4 Data Extraction

A number of measurements were able to be extracted from Scene. These were mainly Diameter at Breast Height (DBH), Tree Density, Basal Area, Crown, height and species information.

One of the major features of forest inventory is the measurement of DBH. This measurement, combined with the species can be used to determine tree age, height among other tree characteristics. This was the easiest measurement to extract.

The total area of the scan site was approximately 2500 sq m. however with the external scans failing to register it was only the internal scans that formed the point cloud that were used for the data extraction. This area totalled 260 sq m. This area consisted of data acquired from three scans forming a triangle. Area 1 is defined as the central area bound by the triangle formed by scan sites 7, 8 and 9. These trees had the benefit of measurements from three sides as opposed to measurements from a single or two scans.

Three adjacent triangular areas, known as areas 2, 3 and 4, contained data that was scanned from two directions and as such would be considered accurate for feature extraction. Data which was only visible from one scan station was excluded where possible.

In total the four triangular areas equated to 260m2 and 126 trees scanned from two or more stations. The table below sets out the area size, number of trees and from which scan stations the trees were captured from. All measured data, with the exception of tree heights were extracted from these scan stations (7, 8 & 9) which formed the point cloud. The tree height measurements were best estimated from the external scans as opposed to the scans internal to the forest stand where the full height was unable to be scanned due to the thickness of the canopy cover.

Area	Size	No of trees	Scans
1	83m2	41	7, 8 & 9
2	48m2	28	7 & 8
3	59m2	30	8 & 9
4	71m2	27	7 & 9

Table 1 Scan area breakdown

As you can see, the largest area 1 had 41 trees fully scanned from three surrounding scan stations giving good spatial data.

DBH measurements

The DBH measurements are Diameter at Breast Height, typically 1.3m from the ground. DBH measurements were made manually on 10 trees from each of the four areas scanned by two or more stations. These DBH measurements were compared to those extracted from Scene.

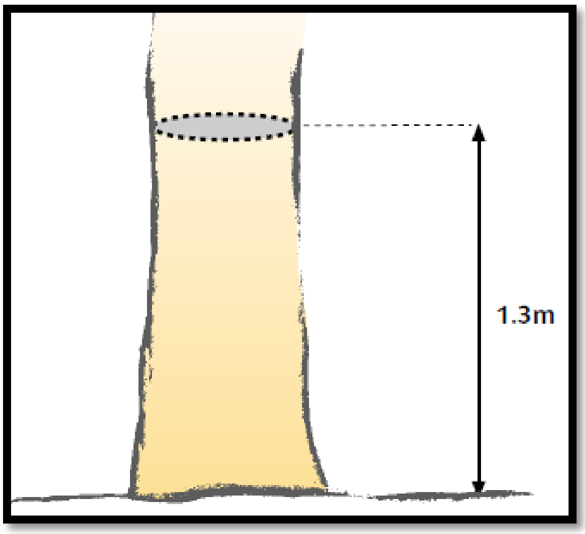

Figure 11 Diameter at breast height (DBH)

The DBH measurements were made using a tape measure to measure the circumference of the tree, which was then converted to the diameter. Below are the DBH calculations comparing the results of the manual measurements and the scan. As you can see, the average difference between the two methods for measuring DBH is about 20mm with the sampled 10 trees in Area 1. The delta column in the table shows the difference between the two methods for each tree. The standard deviation was not much greater than this average at 24mm. Trees measured ranged from approximately 100mm in diameter to 850mm. Simply by looking at the tree sizes you can see a small correlation between the tree size and the difference in measurements to scan derived DBH. This difference is larger with the larger trees or proportional. It also must be considered that trees are often not exactly round and irregular in shape.

Area 1	scans 7, 8 & 9	area	no trees		
		83.5 m2	**41**		
tree	**circumference meas**	**DBH calc**	**scan DBH**	**delta**	
1	1.536	0.489	0.478	0.011	
2	0.882	0.281	0.273	0.008	
3	0.967	0.308	0.319	-0.011	0.011
4	0.37	0.118	0.105	0.013	
5	2.008	0.639	0.691	-0.052	0.052
6	2.759	0.878	0.845	0.033	
7	1.697	0.540	0.515	0.025	
8	1.326	0.422	0.402	0.020	
9	1.376	0.438	0.445	-0.007	0.007
10	0.905	0.288	0.279	0.009	
			AVG	**AVG**	
			0.4352	0.019	
				STDEV	
				0.024	

Table 2 Area 1 DBH comparison

The following tables are for areas 2, 3 and 4. Similar trends occur with the errors, averages and standard deviations.

Area 2	scan7/8	area	no trees		
		48.5 m2	28		
tree	**circ meas**	**DBH calc**	**scan DBH**	**delta**	
20	0.927	0.295	0.289	0.006	
21	0.742	0.236	0.262	-0.026	0.026
22	0.489	0.156	0.167	-0.011	0.011
23	0.559	0.178	0.192	-0.014	0.014
24	1.123	0.358	0.356	0.002	
25	1.34	0.427	0.437	-0.010	0.010
26	0.872	0.278	0.283	-0.005	0.005
27	0.911	0.290	0.315	-0.025	0.025
28	0.663	0.211	0.227	-0.016	0.016
29	0.669	0.213	0.204	0.009	
			AVG	**AVG**	
			0.273	0.012	
				STDEV	
				0.012	

Table 3 Area 2 DBH comparison

Area 3	scan8/9	area	no trees		
		59 m2	30		
tree	**circ meas**	**DBH calc**	**scan DBH**	**delta**	
30	1.052	0.335	0.342	-0.007	0.007
31	1.167	0.372	0.398	-0.026	0.026
32	1.562	0.497	0.483	0.014	
33	1.621	0.516	0.528	-0.012	0.012
34	1.002	0.319	0.317	0.002	
35	1.197	0.381	0.380	0.001	
36	1.327	0.422	0.418	0.004	
37	1.725	0.549	0.542	0.007	
38	1.986	0.632	0.672	-0.040	0.040
39	2.826	0.900	0.934	-0.034	0.034
			AVG	**AVG**	
			0.501	0.015	
				STDEV	
				0.019	

Table 4 Area 3 DBH comparison

Area 4	scan7/9	area	no trees		
		71	27		
tree	circ meas	DBH calc	scan DBH	delta	
40	2.235	0.712	0.745	-0.033	0.033
41	2.873	0.915	0.947	-0.032	0.032
42	1.295	0.412	0.417	-0.005	0.005
43	1.399	0.445	0.437	0.008	
44	1.788	0.569	0.577	-0.008	0.008
45	1.347	0.429	0.420	0.009	
46	3.102	0.988	1.018	-0.030	0.030
47	1.818	0.579	0.589	-0.010	0.010
48	1.12	0.357	0.342	0.015	
49	3.589	1.143	1.078	0.065	
			AVG	AVG	
			0.657	0.021	
				STDEV	
				0.029	

Table 5 Area 4 DBH comparison

Analysing the tables above, we can see from 40 trees selected and compared from each of the four areas, the averages range from 12mm to 21mm. The standard deviations range from 12mm to 29mm. The error or difference from scan derived to manually measured DBH appeared to be proportional to the tree size. The larger the tree the larger the difference. One consideration is the possibility of errors creeping in during manual measurement, or from clicking on a wrong point in the point cloud, which is possible.

Tree density measurements

The tree density measurements were obtained for areas 1-4. The way this was calculated was by assuming the ten trees for each area were a random sample and multiplying the sum of their area by the total number of trees in that area. This was then used to calculate a tree density for each area.

Example Area 1

Total tree area = 1.847m2 (10 trees)

Total area = 83.5m2

Total of 41 trees

Density formula = (1.847 * 4) = 7.388m2 (41 trees)

83.5 / 7.388 = 11.302% tree density

The tables below demonstrate the four area tree density calculations.

Area 1	
DBH calc	Basal area
0.48901624	0.18781767
0.28080229	0.06192859
0.30786374	0.0744401
0.11779688	0.01089827
0.63928685	0.32098255
0.87838268	0.60597877
0.5402738	0.22925441
0.42215855	0.13997196
0.43807705	0.15072694
0.2881248	0.06520054
sum =	1.84719979
x 4 =	**7.38879916**
density =	11.3008891

Table 6 Area 1 tree density

Area 2	
DBH calc	Basal area
0.29512894	0.06840904
0.2362305	0.04382903
0.1556829	0.01903583
0.1779688	0.02487583
0.35752945	0.10039533
0.42661573	0.14294323
0.27761859	0.06053227
0.29003502	0.06606794
0.21107927	0.03499299
0.21298949	0.03562921
sum =	0.59671071
* 2.8 =	**1.67078998**
density =	29.0281847

Table 7 Area 2 tree density

Area 3	
DBH calc	Basal area
0.33492518	0.08810194
0.37153773	0.10841658
0.49729386	0.19422989
0.51607768	0.20917994
0.31900669	0.07992625
0.38108883	0.11406235
0.42247692	0.14018316
0.54918816	0.23688208
0.63228271	0.3139876
0.89971347	0.6357675
sum =	2.12073731
* 3 =	**6.36221192**
density =	9.27350437

Table 8 Area 3 tree density

Area 4	
DBH calc	Basal area
0.71155683	0.3976574
0.91467685	0.65709061
0.41228908	0.13350377
0.44539955	0.15580789
0.56924546	0.25450073
0.42884432	0.14444057
0.98758357	0.76601557
0.57879656	0.26311267
0.35657434	0.09985965
1.14262974	1.02541797
sum =	3.89740684
* 2.7 =	**10.5229985**
density =	6.74712633

Table 9 Area 4 tree density

Whilst the canopy is quite dense the understorey is quite sparse. This contributes to the overall good conditions for the scan to successfully view many trees. For example figure 1 below demonstrates a clear understorey and a low density consistent with the tables above.

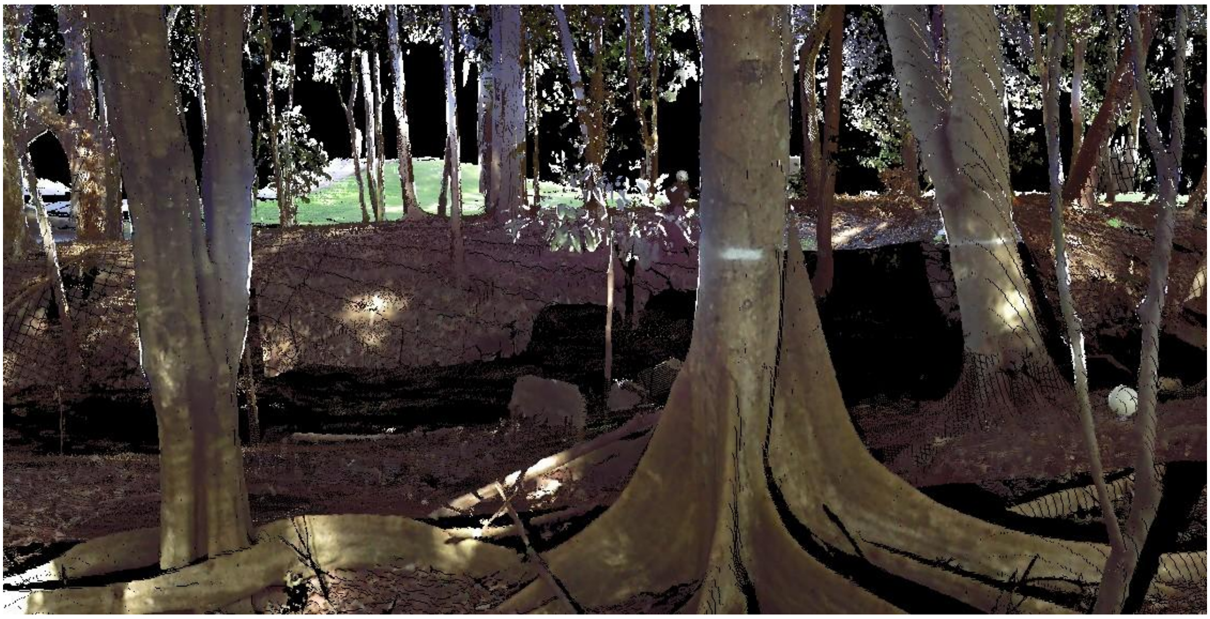

Figure 12 view from scan site – a rendered point cloud with colour applied

Figure 13 view from scan site **-** from the scanners colour photos

Basal Area measurements

Tree Basal Area is the cross sectional area of a single tree at breast height. Basal area measurements can be useful in monitoring a stands volume over time as well as estimating the volume of a single tree.

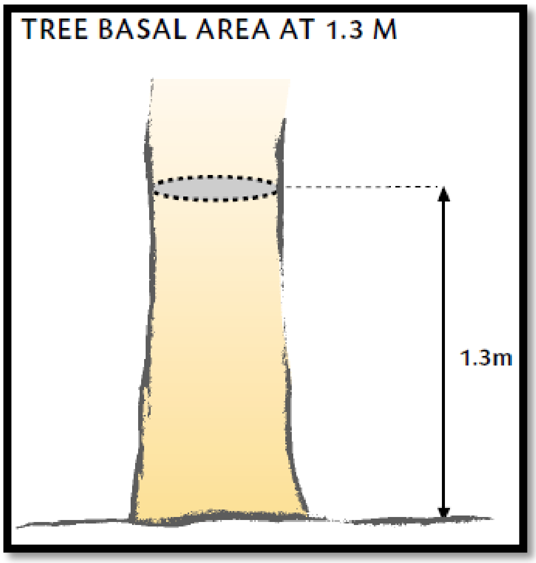

Figure 14 basal area of a tree

The basal tree areas were calculated in the tree density calculations. There were ten trees from each area that had the basal area calculated using the measured, not scanned, DBH. The difference in scanned and calculated/measured DBH would be minimal when calculating the basal area.

Height measurements

Tree Height measurements were measured using a total station to measure selected trees on the external perimeters of the forest stand. The scans which failed to register provided some good data on tree height, whereas those that registered were unable to reach the tree tops due to canopy thickness. The external scans were far back enough to see the full height of many trees in the stand.

tree heights		
reflectorless	point cloud	Difference
27.544	27.128	0.416
28.968	28.789	0.179
26.347	26.816	-0.469
27.119	27.675	-0.556
27.667	27.386	0.281
28.267	27.379	0.888
26.267	26.301	-0.034
25.738	25.639	0.099
		SD
		0.46779941

Table 10 tree height comparison

Crown measurements

Several crown measurements were made from within the 3D point cloud to compare against those made with a total station. The diagram below demonstrates the typical crown measurement of a tree. The crown is the spread of the canopy of a particular tree.

Ten trees were measured using total station measurements. These were compared to the corresponding crown measurements in the 3D point cloud. The results are demonstrated in the following table.

Tree 1	Crown in 3D point cloud	Crown by manual measure
Tree 2	3.650	3.459
Tree 3	4.567	4.657
Tree 4	2.987	2.899
Tree 5	3.583	3.507
Tree 6	3.146	3.201
Tree 7	3.739	3.826
Tree 8	4.054	3.989

Table 11 Crown comparisons

As you can see the results are similar but not exactly the same. This would be due to variance in measuring the same common points. The measurements were difficult to extract from the 3D point cloud. The measurements were also quite difficult to extract from the manual measurements. This difficulty could mean these results are not really comparable.

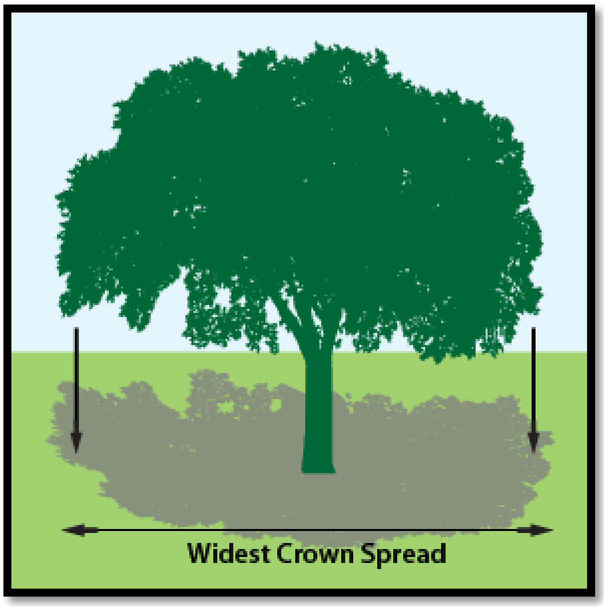

Figure 15 diagram of tree crown (American Forests)

Species recognition

A number of species were easily recognised from the 3D point cloud, the colour photos from the TLS and the black and white intensity images. The amount of detail of trunk and colour was quite helpful in the identification process as was the shape of the tree and the foliage cover where visible.

Approximately 15 different species were able to be readily identified by a qualified arborist at the authors place of employment.

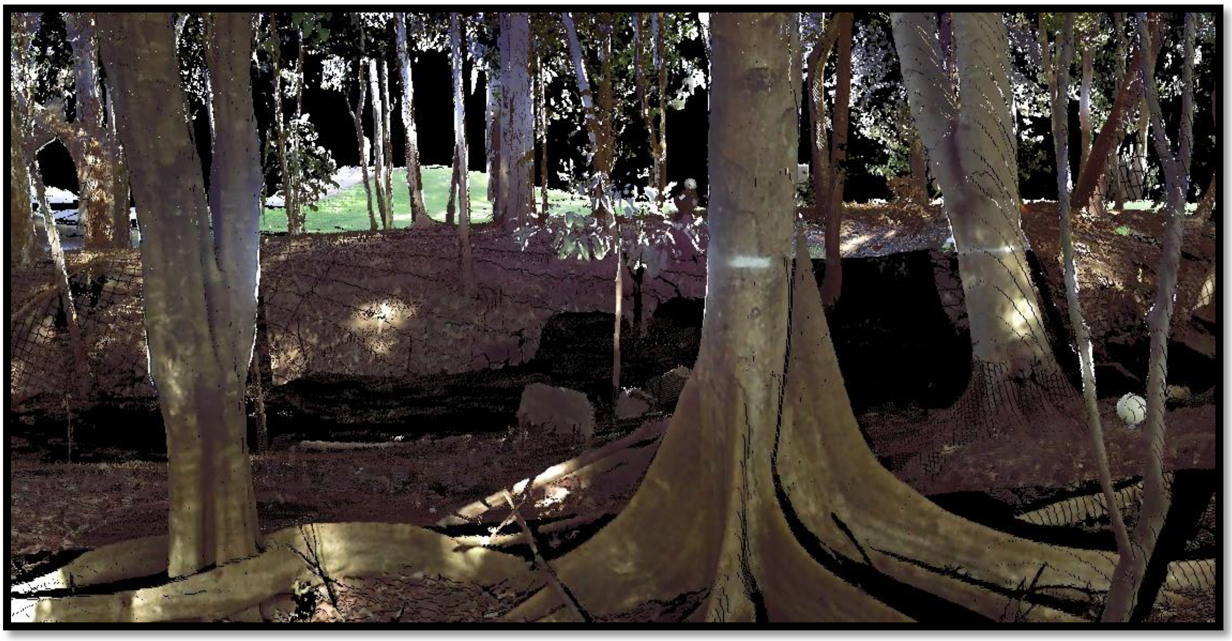

Figure 16 colour rendered 3D point cloud snapshot showing trunk detail used to identify species.

4.5 Conclusion

As only three TLS scans were able to be registered and form a point cloud, it was decided to treat the external scans separately. It was still possible to extract measurement from these scans however they were simply not able to be included into the 3D point cloud. Only the central area of the forest stand was able to be transformed into a point cloud. This would be suitable for assessment as a random sample of a forest stand. The fact that only three scans registered was possibly a good thing as the PC used for the point cloud generation struggled with the processing, highlighting the need for a powerful PC.

The amount of data captured and analysed was suitable for representation of a typical forest plot sample. Tree DBH, basal area, heights, crown measurments and some biomass calculations were possible to extract from the 3D point cloud. An online biomass calculator was used to calculate rough estimates of biomass present. This is used widely today in global forest estimates which affect many global policies.

CHAPTER 5

CONCLUSIONS, AND RECOMMENDATIONS

5.1 Introduction

Overall the TLS appears to be an excellent tool for capturing a snapshot of a forest environment at a particular point in time. Three main products result from the TLS;

1. The 3D point cloud
2. The high resolution panoramic colour images, and
3. The black and white intensity images

All three outcome products of the TLS have separate advantages and different uses to the spatial scientist. The 3D point cloud allows navigation throughout the scene as well as the ability to extract direct measurements.

The panoramic images display the scene in realistic colour and allow species recognition as well as measurements to be made. However it must be noted that the accuracy of the measurements made is unsubstantiated in this mode and any measurements would be recommended to be made in the 3D point cloud.

The black and white images allow depth to be established giving a 3D like view of a scene. The intensity values gained from backscattered laser pulses can be used to visually support the analysis of point cloud data.

The sample size used would be similar to that of a typical plot sample for forest monitoring. Over time a scene could be measured and compared repeatedly and consistently using TLS as a forest monitoring tool.

5.2 Discussion

The FARO Focus 3D was able to give a very thorough model of the forest stand of knox park, Murwillumbah. Numerous forest inventory parameters were able to be extracted. These inventory parameters could be used to contribute to a National Forest Inventory that reports on the current state of and any changes in forest conditions in Australia.

In line with the Continental Forestry Monitoring Framework of Australia, the TLS offers an alternative tool for making ground measurements that have been historically made using manual techniques that are out-dated and time consuming.

The FARO Focus 3D has demonstrated a repeatable, efficient and comparable means to capture forest data. This data can be stored and through repeatable and systematic processes, compared to previous data to model forest changes over time in a particular location.

It would be possible to incorporate TLS into a national forest monitoring framework to contribute to a national forest database. As with any process that is to be repeated over time, strict standards and templates should be developed to ensure the validity and integrity of datasets so they can be compared over time.

Some points to be considered in developing a national standard for TLS of forest data include;

1. Type of scanner; time of flight or phase based.

It would be my recommendation that phase based scanners be used due to their superior performance in high density complex environments which are evident in forests. Due to the small sample plot sizes needed for forest sampling (30m x 30m), the range benefits offered by the Time of Flight scanners would be irrelevant. Also the phase based scanners have better edge detection and are often lighter, cheaper and can measure multiple signal returns.

2. Software to be used

This paper used only the Scene program by FARO. Numerous software are available and it may be that any software could be used so long as a common final output file can be used to compare different datasets. Consistency and compatibility will be main considerations here.

3. Plot design

Will a central scan be used for a concentric plot size or will multiple scan sites be used for a square shaped plot? This must be determined and be consistent also. Based upon my results, I would recommend three scan stations evenly spaced in a 30m x 30m plot.

5.3 Further Research and Recommendations

Further research in the field of TLS will continue as the technology changes and gets better. Time will tell if TLS is used more commonly for generic spatial data needs. TLS has been readily adopted in many fields but can be utilised in many more as this paper demonstrates.

Forest mapping has long been a difficult and timely task. With the advances in technology and TLS we can see how a thorough snapshot of a forest scene can be taken in minutes. This can be repeated and it will be consistent, which is needed in forest mapping and reporting in Australia.

It is recommended that testing of different types of TLS be carried out to understand their capabilities for the benefit of other spatial scientists. I would encourage others to test TLS in forest conditions using different types of scanners, different registration methods and different manual methods to compare against.

References

3dspatial.com.au. 2013. *Spatial Capability Statement 2012*. [online] Available at: http://www.3dspatial.com.au/pdf/3D_Spatial_Capability_Statement_2012.pdf [Accessed: 13 May 2013].

A national forest resource assessment for Costa Rica based on low intensity sampling. 2005. *Forest Ecology and Management*, 210 pp. 9-23.

Americanforests.org. 2013. *Measuring Guidelines | American Forests*. [online] Available at: http://www.americanforests.org/bigtrees/big-tree-measuring-guidelines/ [Accessed: 18 May 2013].

Armston, J., Denham, R., Danaher, T., Scarth, P. and Moffiet, T. 2009. Prediction and validation of foliage projective cover from Landsat-5 TM and Landsat-7 ETM+ imagery. *Journal of Applied Remote Sensing*, 3 (1), pp. 033540--033540.

Astrup, R., Coates, D., Ducey, M., Larson, B. and Pretzsch, H. 2009. comparison of forest inventory and canopy attributes derived from two terrestrial lidar systems.

Cote, J., Widlowski, J., Fournier, R. and Verstraete, M. 2009. The structural and radiative consistency of three-dimensional tree reconstructions from terrestrial lidar. *Remote Sensing of Environment*, 113 (5), pp. 1067--1081.

Castagnetti, C., Bertachini, E., Capra, A. and Dubbini, M. 2012. 'terrestrial laser scanning for preserving cultural heritage: analysis of geometric anomolies for ancient structures'. *FIG Working week*.

Chow, J., Lichti, D. and Teskey, W. 2012. Accuracy assessment of the FARO Focus 3D and Leica HDS 6100 panoramic type terrstrial laser scanners through point based and plane based self calibration.

Eisenbeiss, H. and Zhang, L. 2006. 'comparison of DSM's generated from mini UAV imagery and terrestrial laser scanning in a cultural heritage application'. *iternational society for photogrammetry and remote sensing*.

Fao.org. 2013. *Table of Contents*. [online] Available at: http://www.fao.org/docrep/w4095e/w4095e00.htm [Accessed: 29 July 2013].

Faro.com. 2013. *FARO Solutions - Virtual Simulation for the Video Game Industry*. [online] Available at: http://www.faro.com/en-us/solutions/applications/virtual-simulation [Accessed: 23 Oct 2013].

Fig.net. 2013. *FIG Home Page*. [online] Available at: http://www.fig.net [Accessed: 23 Oct 2013].

Gillis, M., Omule, A. and Brierley, T. 2005. Monitoring Canada's forests: The national forest inventory. *The Forestry Chronicle*, 81 (2), pp. 214--221.

Haala, N., Reulke, R., Thies, M. and Aschoff, T. 2004. Combination of terrestrial laser scanning with high resolution panoramic images for investigations in forest applications and tree species recognition. *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, 34 (5/W16).

Hds.leica-geosystems.com. 2013. *Leica HDS6200 - Advanced, affordable ultra-high speed, phase scanner - Leica Geosystems - HDS*. [online] Available at: http://hds.leica-geosystems.com/en/Leica-HDS6200_64228.htm [Accessed: 13 May 2013].

Henning, J. and Radtke, P. 2006. Ground-based laser imaging for assessing three dimensional forest canopy structure. *Photogrammetric Engineering and Remote Sensing*, 72 (12), p. 1349.

Koller, D., Turitzin, M., Levoy, M., Tarini, M., Croccia, G., Cignoni, P. and Scopigno, R. 2004. Protected interactive 3D graphics via remote rendering. 23 (3), pp. 695--703.

Leica-geosystems.es. 2013. *Leica ScanStation P20 - Industry´s Best Performing Ultra-High Speed Laser Scanner - Leica Geosystems - España*. [online] Available at: http://www.leica-geosystems.es/es/101869.htm [Accessed: 23 Oct 2013].

Leica-geosystems.us. 2013. *Leica Geosystems Forensic site | Videos & Articles*. [online] Available at: http://www.leica-geosystems.us/forensic/video_09.html [Accessed: 22 Oct 2013].

Newham, G., Armstrong, J., Muir, J., Goodwin, N., Culvenor, D., Pushel, P., Nystrom, M., Johansen, K. and Tindall, D. 2011. Evaluation of Terrestrial Laser Scanners for Measuring Vegetation Structure. *CSIRO Australia*.

Ranneby, B., Cruse, T., Haagland, B., Jonasson, H. and Sward, J. 1987. Designing a new national forest survey for Sweden. *Sedish University of Agricultural Sciences*, 177 pp. 3-29.

Rosser, N., Petley, D., Lim, M., Dunning, S. and Allison, R. 2005. Terrestrial laser scanning for monitoring the process of hard rock coastal cliff erosion. *Quarterly Journal of Engineering Geology and Hydrogeology*, 38 (4), pp. 363--375.

Smartgeomatics.de. 2013. *Smart Geomatics Informationssysteme GmbH | Energie und Umwelt*. [online] Available at: http://www.smartgeomatics.de/ [Accessed: 13 May 2013].

Spatial Resources. 2013. *3D Laser Scanner*. [online] Available at: www.spatialresources.com/id77.html [Accessed: 13 May 2013].

Staiger, R. 2011. *TERRESTRIAL LASER SCANNER – HISTORY, TYPES AND METHODS*. [report] Germany: University of Applied Sciences Bochum.

Thies, M. and Spiecker, H. 2004. Evaluation and future prospects of terrestrial laser scanning for standardised forest inventories. *International Archives of Photogrammetry, Remote sensing and Spatial Information sciences*, XXXVI (8).

Vanderzande, D., Hoet, W., Jonckheere, I., Van Aardt, J. and Coppin, P. 2006. Influence of measurement set-up of ground based lidar on tree structure derivation. *Agricultural and Forestry Meteorology*, 141 (2-4), pp. 147-160.

WeiSs, J. and Others. 2009. Application and statistical analysis of terrestrial laser scanning and forest growth simulations to determine selected characteristics of Douglas-Fir stands. *Folia Forestalia Polonica (series A)*, 51 (2), pp. 123--137.

Appendices

Appendix A

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: Thomas Stanley

TOPIC: APPLICATION OF TERRESTRIAL LASER SCANNER

SUPERVISOR: Xiaoye Liu

PROJECT AIM: To use the FARO 3D terrestrial scanner and assess its capabilities and usefulness compared to traditional 2D surveying techniques.

PROGRAMME: 13TH March 2013

- To research types of Terrestrial Laser Scanners and their applications
- Compare results with conventional survey methods.
- To investigate the scanners ability to accurate model vegetation in a forest type environment.
- To scan a suitable location with forest and generate a 3d point cloud model.

As Time Permits

- To compare the usefulness of terrestrial scanner for engineering design job within Tweed Shire Council's Design Unit.
- To comment on the feasibility of laser scanner for Tweed shire Council, eg cost benefit analysis.

AGREED:

____________________ (Student) __________________ (Supervisor)

DATE:

____/_____/____ ____/_____/____

University of Southern Queensland
Risk Management Plan

Date:	Faculty/Department:	Assessment completed by:	Contact number:
17-6-2013	Surveying + Engineering	Tom Stanley	0447 137 050

What is the task?	Location where task is being conducted:
Laser Scanning of forest stand.	Murwillumbah NSW

Why is the task being conducted?

Research Project 1

What are the nominal conditions?

Personnel	Equipment	Environment	Other
Tom Stanley Marc Hager + Brent Malone	FARO LS + Targets	outdoors fine weather level ground	

Briefly explain the procedure for this task (including reference to other procedures)

1 Setup the Laser Scanner on 8 different sites within + around the forest stand.

2 Operate the Laser Scanner on the 8 sites

Risk register and Analysis
[ALARP = As Low As Reasonably Practicable]

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? See next page			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses Specific induction / training	Consequences	Likelihood	Rating		
① Setup FARO L.S. 8times	Equipment falling + Causing Injury	Signs for Pedestrians cones/witches hats hi-vis vests, boots	3	C	H	Yes	Never leave Instrument unattended. Read Safe Operation Manual.	1	D	L	Yes	Accept
	Sunburn	hat, sunscreen	1	D	L	Yes	Assess Conditions	1	E	L	Yes	Accept
	Dehydration	carry sufficient water	1	D	L	Yes	Schedule drinks break + Rest time	1	E	L	Yes	Accept.

Element or Sub Element/ Process Step List major steps or tasks in process	The Risk: What can happen and what will be the result – Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze Chemical burn	EXISTING CONTROLS List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers Existing emergency procedures	Risk Rating with existing controls? See next page			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses Specific induction / training	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
			Consequences	Likelihood	Rating			Consequences	Likelihood	Rating		
(2) Operate the Laser Scanner	exposure of laser to eyes.	wear sunglasses not look at L.S stand safe distance from L.S when in use	2	C	M	Yes	Place Signs warning Pedestrians Inform Assistants of danger + Read Manual	1	D	L	Yes	Accept.

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? See next page			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses Specific induction / training	Consequences	Likelihood	Rating		

Element or Sub Element/ Process Step	The Risk: What can happen and what will be the result	EXISTING CONTROLS	Risk Rating with existing controls? See next page			Is it ALARP? Yes/No	ADDITIONAL CONTROLS REQUIRED	Risk Rating with additional controls?			Is it ALARP? Yes/No	Risk Decision: Accept Transfer Treat
List major steps or tasks in process	– Electric shock – Eye infection – Fire / explosion – Physical injury – Cut / graze Chemical burn	List all current controls that are already in place or that will be used to undertake the task eg – List of Personal Protective Equipment (PPE) – Identify types facility, location – Existing safety measurers Existing emergency procedures	Consequences	Likelihood	Rating		Additional controls may be required to reduce risk rating eg – Greater containment (PC2) – Additional PPE – gloves safety glasses Specific induction / training	Consequences	Likelihood	Rating		

Risk Treatment Schedule

Risk No:	Risk (from Risk Register)	Treatment	Person Responsible for Implementation	Timetable for Implementation	Date treatment Completed	Review Effectiveness Effective/Not Effective
1	Equipment falling	Apply due care in Using Equipment	Tom Stanley	2013 14–21st June		
~~2~~ 1	Injury	Apply first aid if needed.	"	"		
1	Sunburn	first aid where needed. hydrate, cold compress, icepacks	"	"		
1	Dehydration	first aid. hydrate	"	"		
2	Laser in Eyes	protect eyes from further damage seek medical assistance	"	"		

Notes:

USQ RISK RATING ADAPTED FROM AS4360:2004

Note: In estimating the level of risk, initially estimate the risk with existing controls and then review risk controls if risk level arising from the risks is not minimal

TABLE 1 - CONSEQUENCE

Level	Descriptor	Examples of Description
1	Insignificant	No injuries. Minor delays. Little financial loss. $0 - $4,999*
2	Minor	First aid required. Small spill/gas release easily contained within wo environmental impact. Financial loss $5,000 - $49,999*
3	Moderate	Medical treatment required. Large spill/gas release contained on ca of emergency services. Nil environmental impact. Financial loss $50,000 - $99,999*
4	Major	Extensive or multiple injuries. Hospitalisation required. Permanent s effects. Spill/gas release spreads outside campus area. Minimal en impact. Financial loss $100,000 - $250,000*
5	Catastrophic	Death of one or more people. Toxic substance or toxic gas release campus area. Release of genetically modified organism (s) (GMO). environmental impact. Financial loss greater than $250,000*

* Financial loss includes direct costs eg workers compensation and property damage and indirect costs, eg impact of loss of research data and accident investigation time.

TABLE 2 - PROBABILITY

Level	Descriptor	Examples of Description
A	Almost certain	The event is expected to occur in most circumstances. Common or occurrence at USQ. Constant exposure to hazard. Very high probab
B	Likely	The event will probably occur in most circumstances. Known history USQ. Frequent exposure to hazard. High probability of damage.
C	Possible	The event could occur at some time. History of single occurrence at occasional exposure to hazard. Moderate probability of damage.
D	Unlikely	The event is not likely to occur. Known occurrence in industry. Infre to hazard. Low probability of damage.
E	Rare	The event may occur only in exceptional circumstances. No reporte globally. Rare exposure to hazard. Very low probability of damage. system failures.

TABLE 3 – RISK RATING

Probability	Consequence				
	Insignificant 1	Minor 2	Moderate 3	Major 4	Catastrop
A (Almost certain)	M	H	E	E	
B (Likely)	M	H	H	E	
C (Possible)	L	M	H	H	
D (Unlikely)	L	L	M	M	
E (Rare)	L	L	L	L	

TABLE 4 - RECOMMENDED ACTION GUIDE

Abbrev	Action Level	Descriptor
E	Extreme	The proposed task or process activity MUST NOT proceed until the supervi the task or process design and risk controls. They must take steps to firstly and if this is not possible to introduce measures to control the risk by reducir to the lowest level achievable. In the case of an existing hazard that is i must be put in place immediately.
H	High	Urgent action is required to eliminate or reduce the foreseeable risk arisinc process. The supervisor must be made aware of the hazard. However, th give special permission for staff to undertake some high risk activities provic work is clearly documented, specific training has been given in the required adequate review of the task and risk controls has been undertaken. This i risk controls identified in Legislation, Australian Standards, Codes of Practic Standard Operating Procedure is required. * and monitoring of its implemen to check the risk level
M	Moderate	Action to eliminate or reduce the risk is required within a specified perioc should approve all moderate risk task or process activities. A Standard Ope or Safe Work Method statement is required
L	Low	Manage by routine procedures.

*Note: These regulatory documents identify specific requirements/controls that must be implemented reduce the risk of an individual undertaking the task to a level that the regulatory body identifies as be acceptable.

The task should not proceed if the risk rating after the controls are implemented is still either HIGH or EXTREME or if any risk is not As Low As Reasonably Practicable (ALARP).

This Risk Assessment score of Low (L) is only on the condition that all existing and additional controls are in place at the time of the task being conducted.

Assessment completed by:	
Name: Tom Stanley	Signature:
Position: Surveyor Tweed Shire Council	Contact No: 0447137 050
Date: 17th - 6 - 2013	
Supervisor	
Name: Xiaoye Liu	Signature:
Position:	Contact No:
Date:	

7 Day Review of Controls:

This Risk Management Plan is to be reviewed not later than seven (7) days after the commencement of the project.

Reviewing Officer	
Name:	Signature:
Position:	Contact No:
Date:	
Supervisor	
Name:	Signature:
Position:	Contact No:
Date:	

12 Monthly Review of this Risk Management Plan:

This Risk Management Plan is to be reviewed every twelve (12) months and whenever a change has been made to the project or workplace.

Reviewing Officer	
Name:	Signature:
Position:	Contact No:
Date:	
Supervisor	
Name:	Signature:
Position:	Contact No:
Date:	

Guidance Notes for review of Controls and Risk Management Plan.

When monitoring the effectiveness of **control measures**, it may be helpful to ask the following questions:

- **Have the chosen control measures been implemented as planned?**
  - Are the chosen control measures in place?
  - Are the measures being used?
  - Are the measures being used correctly?
- **Are the chosen control measures working?**
  - Have any the changes made to manage exposure to the assessed risks resulted in what was intended?
  - Has exposure to the assessed risks been eliminated or adequately reduced?
  - **Are there any new problems?**
  - Have the implemented control measures introduced any new problems?
  - Have the implemented control measures resulted in the worsening of any existing problems?

To answer these questions:

- consult with workers, supervisors and health and safety representatives;
- measure people's exposure (e.g. taking noise measurements in the case of isolation of a noise source);
- consult and monitor incident reports; and
- review safety committee meeting minutes where possible.

Set a date for the review of the **risk management process**. When reviewing, check if:

- the process that is currently in place is still valid;
- things have changed that could make the operating processes or system outdated;
- technological or other changes have affected the current workplace; and
- a different system should be used altogether

Glossary of Terms

TLS; Terrestrial Laser Scanner

DBH; Diameter at Breast Height

TOF; Time of Flight scanner