University of Southern Queensland Faculty of Engineering and Surveying

Laser Scanning for Forest Structure Analysis

A dissertation submitted by

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In fulfilment of the requirements of

Courses ENG4111 and ENG4112 Research Project

Towards the degree of

Bachelor of Spatial Science (Honours), Surveying

Abstract

Terrestrial laser scanning is one of the most recent technological advancements within the spatial science industry. Its current use within the forest analysis field is limited.

Collecting data to create a forest inventory can be a long and strenuous process with current procedures relying on outdated and inefficient techniques. Terrestrial laser scanning is a technique that has the potential to greatly enhance this data collection process.

In this study, a forested area of 6700m^2 in eastern Toowoomba has been scanned to extract tree height, diameter at breast height, basal area and volume. The same data has been collected using contemporary techniques so that terrestrial laser scanning's suitability can be assessed.

The measured components were compared and discrepancies were identified. When compared to traditional methods, laser scanning overestimated height by 0.196m (2.42%). Diameter at breast height, basal area and volume were all underestimated by 0.061m (13.33%), 0.044m^2 (24.35%) and 0.374m^3 (22.47%) respectively. The differences in height and diameter at breast height are acceptable. The differences in excess of 20%, namely basal area and volume, are unacceptable with further research required to identify both the cause and the solution.

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0061021174

Acknowledgements

I would like to acknowledge that this research was carried out under the supervision of Dr. Xiaoye Liu. Her continued guidance has been irreplaceable.

I would also like to acknowledge the assistance provided by Dr. Zhenyu Zhang and Mr. James Derksen during the scanning procedure.

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Chapter 1 - Introduction

1.1 Introduction

In the modern era technology is advancing extremely quickly. These advancements allow for old techniques and practices to be replaced with safer, quicker and more efficient ones. One such technology is terrestrial laser scanning (TLS).

Laser scanning is a process which allows for rapid data collection. Millions of data points can be measured to high accuracy and precision in minutes. Data such as this is extremely useful in obtaining a detailed understanding of the features measured.

Not only does laser scanning offer quick data collection, it is also excellent at providing a visual representation of the data collected. Such high quantity point clouds allow anyone observing the point cloud to identify exactly what the object is. This visual aspect, combined with the high accuracy and precision data allows for effective and efficient data manipulation.

Forest analysis is extremely important in the modern era. Continuing environmental concern is of high priority to governments and private corporations. Structure health, growth rate, decay rate and biomass are a small number of important forest elements identified during an analysis. Such data must be recorded at a high detail to ensure the structure can be analysed correctly. Current techniques involve manual measurements and extensive effort and resultantly have vast room for improvement. Laser scanning offers the potential to improve the data capture stage of forest analyses and also offers detailed analysis tools.

1.2 Research Aim

The aim of this study is to assess laser scanning's suitability when recording a forest structure. This will be achieved by executing the following objectives:

a) Identifying the following components of the structure using laser scanning and traditional methods:
   - Tree height.
   - Diameter at breast height.
   - Basal area.
   - Tree volume.

b) Comparing the acquired data and assess laser scanning's suitability

1.3 Justification

Completing a forest inventory can be a long and strenuous process, especially if required to be completed by one person. Detailed information needs to be recorded on each member of the structure. This involves measuring, taking photos and analysing the individual structure. The data then needs to be transferred to a computer, analysed again and recorded. This needs to be completed for all members of the forest structure being analysed.

Terrestrial laser scanning has been used to improve this process by making it more efficient. This is through quick data collection and the ability to easily manipulate the captured data. Another benefit of the technology is the high level of both accuracy and precision.

As the process of using terrestrial laser scanning to capture forest data becomes more common, the techniques used will improve. This research is no exception and aims to not only analyse the results obtained from the data, but also the suitability of the process to the application.

1.4 Dissertation Overview

This dissertation features six main chapters. A brief description of these chapters is given below:

Chapter 1: Introduction – Provides an introduction to the research area. Research aims of the study are highlighted. Background information regarding the topic and justification of the research is also discussed.

Chapter 2: Literature Review – Identifies the key components as well as a summary of the literature review conducted for this research. The three areas of interest are: laser scanning, forest analysis and laser scanning's current applications within forest structures.

Chapter 3: Methodology – The methods used to meet the aims of the study are identified in this chapter. The study area as well as the techniques used to both capture and analyse the data are discussed.

Chapter 4: Results – Provides the data obtained using the stated methodology is presented within this chapter.

Chapter 5: Discussion – The raw data obtained is compared and contrasted to identify relationships. Resultantly the suitability of laser scanning can be identified.

Chapter 6: Conclusion – Provides a conclusion to the dissertation as well as recommendations for future research.

Chapter 2 - Literature Review

2.1 Introduction

A literature review was conducted with regard to five key areas: the explanation of laser scanning, the types of scanners available and how they work, the current applications of laser scanning, forest inventorying and structure analysis as well as the application of laser scanning within the aforementioned field. Consequently the aim of this chapter is to provide insight on studies conducted in this professional field by analysing conducted research and studying previous findings.

2.2 What is Laser Scanning?

A laser scanner is hardware that is used to collect 3D data of a real world object. This allows the object to be analysed effectively and efficiently using powerful software.

Laser scanning is considered a new technology within the spatial science and engineering world despite Electronic Distance Measurement (EDM) being around since the 1960s. This is because it did not become used in this professional field until the late 1990s (SurvTech Solutions 2014). The reason this occurred was because the technology could not be used effectively until computer storage systems and bandwidth improved (SurvTech Solutions 2014).

Laser scanners can capture points at rates of up to one million per second (Leica 2010). Such a high quantity of points requires a large amount of storage with individual raw data files often exceeding one gigabyte.

Consequently the technology is not as ‘mobile’ as data collected by GPS or total station. Data captured with these two instruments would take weeks of work to create the same point cloud that is achieved by laser scanning. Consequently, total station and GPS point clouds only identify key points. This results in smaller file sizes which are heavily streamlined when compared to laser scanner point clouds. The storage required to store scanned point clouds is evidently one limitation associated with the technology.

If storage issues are overcome, the models created allow for a very detailed analysis of the real world. This high level of detail has been the force behind laser scanning’s growth. The technology has improved with scans taking less time and outputting large quantities of information with high accuracy and precision.

2.3 Types of Laser Scanners

There are three principle types of scanners: Time-of-Flight, Phase Based and Triangulation (Payne 2009). Appendix 2 provides a diagram explaining how time-of-flight and phase based scanners measure distances. Scanners that slightly alter these principles also exist. These are known as Waveform Processing scanners scanners.

2.3.1 Time-of-Flight Scanners

Time-of-flight scanners measure distances by analysing the time taken for a light pulse to bounce from the target object and return to the scanner (Payne 2009). This time is halved and by using the speed of light a distance can be calculated (3D Systems 2011). This distance is combined with a vertical and horizontal bearing to create a 3D point in the same position as the target object. A time-of-flight scanner is best used when large distances need to be measured.

Figure 1. The Leica Scanstation c10 – a time-of-flight scanner. (Leica 2010).

California Department of Transportation (2011) stated that the maximum range is typically 125-1000m. The Leica ScanStation C10 (Figure 1) can measure distances up to 300m. The drawback of time-of-flight scanners is their slower data acquisition. The Leica ScanStation C10 can capture 50,000 points per second (Leica 2010) and is a relatively fast time-of-flight instrument.

The accuracy of time-of-flight scanners is determined by the system's ability to accurately measure the time of the returning signal (Payne 2009). Payne (2009) also states that although the accuracy varies across different systems, typical accuracy for a time-of-flight scanner is 4-10mm over 300m.

Current time-of-flight scanners possess on-board cameras. Photos are taken before or after the scan within the parameters defined by the user. These photos are then overlayed on the point cloud to create an extremely detailed file for use within appropriate software.

2.3.2 Phase Based Scanners

A phase based scanner records measurements by emitting a single, constant beam. The change of phase of the laser light is measured to allow the scanner to calculate a distance (Jones 2010). This is done by the scanner modulating the emitted laser light into multiple phases and comparing the phase shifts of the returned laser energy (California Department of Transportation 2011). California Department of Transportation (2011) also stated that the distance is then calculated by the scanner using phase-shift algorithms to determine the distance based on the unique properties of each individual phase.

Figure 2. The Leica HDS 6200 – a phase based scanner. (Leica 2010).

As a result of the laser light constantly being emitted it is possible to capture points extremely quickly. This rapid rate of point capture is a feature of the Leica HDS 6200 which is capable of recording up to 1,000,000 points per second (Leica 2010).

2.3.3 Triangulation Scanners

Laser triangulation scanners are used predominantly for short range applications. They are less accurate, have a lower resolution and generate higher noise than the three other types of scanners however they are extremely portable (3D Systems 2011). Such scanners are available in handheld options and consequently require less preparation. They are also less sensitive to ambient light.

Triangulation scanners measure distances, which allows them to create points, by using a laser line or single laser point to scan across and object. A sensor then detects the reflected light and calculates the distance from the object to the scanner using trigonometric triangulation (3D Systems 2011). For this to occur, the distance and angle between the sensor and laser source must be known extremely precisely. These known parameters allow the machine to identify the angle of the laser when reflected off the object and detected by the sensor. Resultantly, a position can be calculated for the scanned point.

2.3.4 Waveform Processing Scanners

Waveform processing scanners are also referred to as echo digitisation scanners. These instruments use pulsed time-of-flight technology and internal real-time waveform processing techniques to identify multiple returns or reflections of the same signal pulse, resulting in the detection of multiple objects (California Department of Transportation 2011).

Figure 3. The Riegl VZ-400 – a waveform processing scanner. (Reigl 2014).

Waveform processing scanners are also capable to measure points at an extremely high rate. California Department of Transportation (2011) identified that waveform processing scanners can possess a pulse rate of 300,000 as well as an echo detection capability of 15 returns per pulse. This allows data collection rates to achieve, and potentially exceed, 1.5 million points a second (California Department of Transportation 2011).

The main limitation of echo digitising scanners is the inability to discriminate between returns of the same laser pulse. This is a result of objects that are closely spaced. Figure 4 provides an example of such a situation.

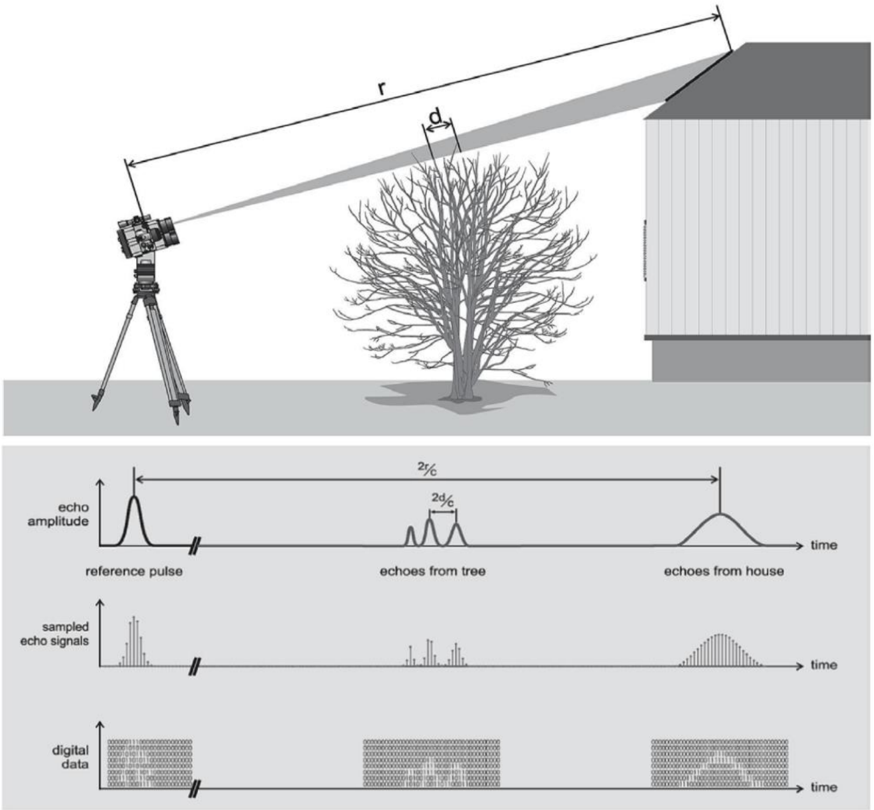


Figure 4. Multiple echo detection – (California Department of Transportation 2011).

In Figure 4, “d” is the discrimination limit which is a function of laser emitter and receiver operating parameters. California Department of Transportation (2011) stated that returns from objects that are closer together than the laser scanner’s multiple object discrimination limit will create false points in the data. The problem of false points can be reduced however it is beyond the scope of this dissertation.

2.4 Current Applications of Laser Scanners

Laser scanners have been around for approximately twenty years (SurvTech Solutions 2014) allowing a multitude of their uses to be tested. Before the equipment becomes staple use in an environment, it must be vigorously tested to assess the suitability of the equipment to the application. Once testing is completed and the results are satisfactory, the device can progress from uncommon use in the area to common practice.

2.4.1 Engineering Applications

Within the engineering world terrestrial laser scanning has a multitude of applications. Some of these require an extremely high accuracy while others require an accuracy of lower standards. These categories have been divided and explained below.

2.4.1.1 Strict High Accuracy Requirements

The accuracy required for engineering work is ±0.0091m horizontally and ±0.0061m vertically (California Department of Transportation 2006). Resultantly an extremely accurate and precise instrument must be used. This can greatly increase costs as some cheaper forms of equipment may not meet the specifications required. Consequently they would not be suitable to the task.

California Department of Transportation (2011) deemed that the following applications require engineering level accuracy:

- Pavement Analysis Scans
- Roadway/pavement topographic surveys
- Structures and bridge clearance surveys
- Engineering topographic surveys
- Deformation and monitoring surveys
- As-built surveys

The data captured by these surveys is critically analysed and resultantly must represent the real world as closely as possible.

2.4.1.2 Tasks of Lesser Accuracy

Tasks suitable to laser scanning requiring less accuracy include:

- Corridor study and planning surveys
- Earthwork surveys
- Environment surveys
- Sight distance analysis surveys
- Urban mapping and modelling

This can be due to: working with loose materials, analysing moving objects or conducting planning or modelling surveys (California Department of Transportation 2011).

2.4.2 Non-Engineering Applications

A laser scanner has various uses outside of the engineering environment. These applications range across various fields, utilise different types of scanners and have varying accuracy standards.

Laser scanning has been effectively used to monitor coastal erosion. Rosser et. al. (2005) analysed a coastal cliff face made up of hard rock. The cliff was monitored over a period of 16 months and it was concluded that laser can quantify cliff failures to a previously unobtainable precision.

Analysing cultural heritage is extremely important as it provides us with information on the quality of the structure. By analysing the structure it is possible to identify repairs that need to be conducted to help preserve the object. Castagnetti et. al. (2012) observed the Cathedral of Modena and were able to create a model that can be used for monitoring deformation. The highly detailed data was also used to analyse structural integrity and compute anomalies in structural geometry.

Crime scenes must be analysed to a high detail to ensure that correct verdicts are reached by judge or jury. By utilising laser scanning to its full potential, it is possible to create a virtual representation of a crime scene allowing for detailed analysis. Agosto, Ajmar, Boccardo, Tonolo, & Lingua (2008) identified that this virtual recreation can be more compelling for juries and also allows for investigators to virtually 'revisit' a crime scene.

Forest analysis is a tedious process, requiring a large number of man hours. Data must be recorded accurately and to a high detail. By using laser scanning, Newnham et. al. (2012) concluded that laser scanning is well suited to the application and has the potential to save time and increase accuracy.

2.5 Forest Structure Analysis

Forest structures are analysed and recorded into a forest inventory. These inventories detail important information about the structure and are an investment to support current and future forest resource opportunities (BC Forest Conversation 2013). BC Forest Conversation (2013) also states that forest inventories are the primary source of information for determining acceptable annual harvest levels while at the same time maintaining healthy forests and healthy communities. The uses of a forest inventory reinforce its need to be accurate and well documented.

2.5.1 Types of Inventories

Forest inventories, although large, are targeted to achieve a single purpose. Resultantly there are multiple types of inventories. Food and Agriculture Organisation of the United Nations Forestry Department (2014) identifies eight types of forest inventory contained within two different categories. The first category, harvesting, features pre-concession, logging planning and management planning inventories. Management inventories make up the second category and compile growth studies, biodiversity surveys, social surveys, post-harvest and diagnostic sampling inventories.

2.5.2 Inventory Objectives

Eight types of inventories have been identified with each inventory designed for a specific purpose. Consequently each inventory has its own objective. However, ‘objectives must be quite clear irrespective of whether an inventory is proposed for an existing forest management unit or for a new concession' (Food and Agriculture Organisation of the United Nations Forestry Department 2014). Food and Agriculture Organisation of the United Nations Forestry Department (2014) outline three specific guidelines that should be considered when determining inventory objectives. The first is that objectives need to be determined jointly by the people who will use the results, not just by the inventory specialists. Second is that objectives should be prioritised so that important information is not missed and that unnecessary information is not collected. The final guideline is to ensure that the inventory is both practicable and achievable. All aspects of the inventory and the collecting process must be sound to ensure that time and money is not wasted.

2.5.3 Components

Inventories are designed to achieve a specific purpose. Consequently the key components of inventories vary. However some components are applicable to a number of inventories reinforcing their importance.

Maniatis (2010) identified diameter at breast height (1.3m from forest floor), height and wood density essential in determining carbon pools. Measurement of tree diameters is an important variable for determining forest growth, and care is needed to ensure that an accurate tree measurement history is assembled (Food and Agriculture Organisation of the United Nations Forestry Department 2014). The horizontal area of a tree trunk is defined as the basal area and is calculated by converting the diameter at breast height to an area.

When measuring tree height and resultantly volume, the structure is assumed to be a cylinder and the volume is then determined. However Brack (1999) outlined four types of tree volume and resultantly volume is calculated dependant on the purpose. Biological volume is the volume of stem with branches trimmed at the junction with the stem. Merchantable volume excludes volume within irregularities of the bole shape caused by normal growth as well as irregularities not part of natural growth. Gross volume estimates include decayed and defective wood whereas net volume excludes decayed and defective wood. Different purposes are calculated in different ways, with some volumes requiring vigorous work with complex formulae.

2.6 Laser Scanning of Forest Structures

The suitability of using laser scanning technology to analyse and monitor forest structures has been assessed a number of times. Multiple studies have been conducted, differing in both purpose and method with each study increasing knowledge and understanding of using terrestrial laser scanning to analyse forest structures.

Thies and Spiecker (2004) conducted a study which featured two hypotheses. The first was that terrestrial laser scanning and the corresponding data analysis is ready to be used in standardised forest inventory sampling. The second outlined that data quality as well as characteristics related to the technique of laser scanning widen the data base for forest management applications and ecological investigations. With regards to the first hypothesis, Thies and Spiecker (2004) concluded that the technology allows for an accurate analysis and has a number of potential possibilities. To establish this process, Thies and Spiecker (2004) stated that robust models for data analysis as well as improvements in hardware technology are required. By proving the second hypothesis, Thies and Spiecker (2004) were able to show that repeated measurements at different times but identical scanner positions can be compared directly which eliminates human discrepancy when recording inventory data. Furthermore it was identified that data acquisition and analysis is independent from subjective influences of the measuring person. Lastly, and possibly the most important finding, was that by using terrestrial laser scanning, a large data pool is created which can be used for a vast number of investigations.

Newnham et al. (2012) observed not only the suitability of terrestrial laser scanning within a vegetated environment, but also which type of scanner was more suited to the application. Two time of flight scanners and two phase based scanners were used for the study. One finding of this study was that 'time of flight instruments, at the time, provided the best characterisation of vegetation structure, mainly in the upper parts of the canopy, where multiple beam interceptions are not accommodated well by the phase-shift scanners' (Newnham et al. 2012).

Burt et al. (2013) analysed the ability to construct tree members using TLS and 3D modelling. The study also assessed allometric relationships which relate DBH and height to biomass. This is a key factor to inventory estimates of forest biomass. After assessing multiple structures, it was concluded that it was possible to generate tree reconstruction to within 10% of the actual volume of the tree. The key limitation was of the study was that 'inducing a 1cm global registration error leads to an 8.8% increase in total volume' (Burt et al. 2013). By combining this study with previous studies, Burt et al. (2013) believe that there is a possibility to provide a number of opportunities ranging from independent biomass estimation through to validation of allometric scaling.

Cote et al. (2009) designed a system to accurately reconstruct trees from TLS. This system was designed to help with the various forms of noise that is generated when scanning forest structures. This includes both wind and the smaller tree constituents such as branches, twigs and foliage. Data obtained from the scans was found to be usable and provided an appropriate representation of the structure. Once the reconstruction system was applied, evaluations were performed on the new data. The outcome of the study was that 'the results of these evaluations confirm the appropriateness of the proposed tree reconstruction model for the generation of structurally and radiatively faithful copies of existing plant and canopy architectures' (Cote et al. 2009).

Raumonen et al. (2013) followed in the footsteps of Cote et al. (2009) and analysed the success of reconstructing tree structures from laser scanner data. The method that was developed and assessed involved reconstructing the visible parts of the tree by creating a flexible cylinder model of the tree. These cylinders also extended into the branch structure of the tree to reconstruct the whole tree not including vegetation. The new technique was determined to be successful in constructing trees from laser scanner data and allowed for easy identification of multiple tree attributes.

2.7 Conclusion

This chapter has identified and discussed the literature relevant to the research topic. Background information on scanners and their current applications have been highlighted. Alongside this, the need for forest analysis and basic inventory components were discussed. Furthermore, laser scanning's current use within a forest structure was brought forward.

Chapter 3 - Methodology

3.1 Introduction

This chapter will identify the processes undertaken to fulfil the research aim. It will feature:

- Study Area
- Equipment
- Field Procedures
- Post Processing
- Comparison Methods

3.2 Study Area

The study area selected is located on the eastern side of Picnic Point, Toowoomba.

Figure 5. Toowoomba's location within Queensland

(Toowoomba Motor Village 2014)

An estimation of the size of the area has been calculated using satellite photos. These estimations resulted in the area being approximately $6700m^2$.

This site is also moderately steep as a result of being on the side of a mountain. The location features areas of both dense and open canopy. Areas on the ground are also open as well as fairly populated with tree structures.

Figure 6. Satellite view of the study area (Google Earth 2014)

The varying terrain and densities combined with varying tree heights and thicknesses allows for unbiased testing. Twenty individual structures of varying height and diameter will be analysed. The fluctuating measurements will assist in removing consistent errors that may occur.

Figure 7. One section of the area being analysed.

3.3 Equipment

The FARO Focus 3D laser scanner has been used in this study. This scanner is a phased based scanner capable of recording 976,000 points per second. When properly calibrated, the Focus 3D records these points with an accuracy of +/- 2mm. Alongside the scanner twelve reference spheres (140mm diameter) were used to assist in registration.

To record data using traditional methods a Laser Tech Inc. Tru Pulse 360° distometer was used. Such an instrument is able to calculate vertical height on-the-fly requiring no calculations during data acquisition or post processing. Alongside this instrument a flexible tape measure was used to locate breast height and measure the DBH.

It has been assumed that all equipment is correctly calibrated as performing such a task is beyond the scope of this research.

3.4 Field Procedures

3.4.1 Laser Scans

A total of seventeen scans were conducted with the field of view ranging from 100 to 360 degrees. These scans were completed over two days. Both days were slightly overcast and 25°C.

The largest of the files are the 360 degree scans which took just under ten minutes to complete. These scans captured approximately 170 million points with scans of smaller fields of view taking less time and making fewer measurements. Alongside the points, the Focus 3D also captures photos of the area scanned. These photos are overlayed onto the point clouds to create a real-world view of the data.

Figure 8. The FARO Focus 3D conducting a scan.

The scan locations were planned to ensure minimal blind spots. Across the two days, scanning took roughly twelve hours.

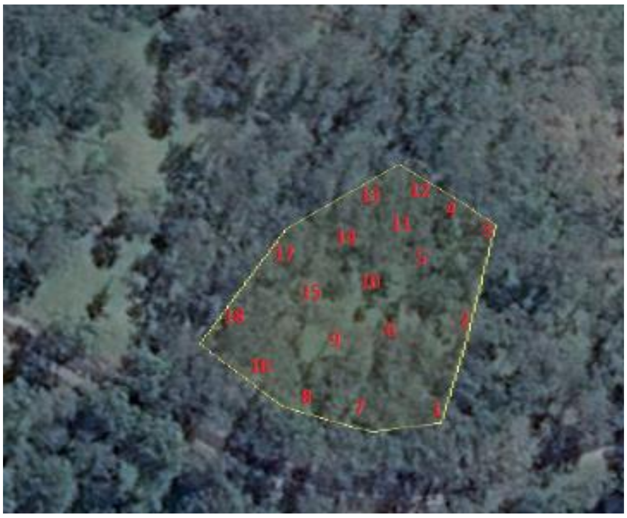


Figure 9. Scan locations within the study area.

Scans are aligned to one another by using reference spheres provided with the scanner. These spheres are 140mm in diameter and feature special reflective properties, allowing them to be detected by the software. The scans are aligned by subsequent scans featuring spheres in the same location. A common point is established and the scans can be registered. To do this at least three spheres must be common between scans. Once scans are registered a cluster is created (Appendix 3).

Twelve reference spheres were used for this study. Consequently spheres had to be moved around the study area as scans were completed. This was due to the large study area and the limited number of spheres. This did not cause any failures with registration however the cluster from the first day could not be registered with the cluster from the second day. The data analysis was not affected by this complication.

3.4.2 Traditional Analysis

Forest inventory data must be collected using the current and traditional methods to assess the suitability of the laser scanner. An assessment needs to be made about the quality and size of the tree. To do this the following information is collected using the described technique. This data took approximately two hours to identify.

3.4.2.1 Tree Height

The distometer used is able to calculate vertical height of an object. To achieve this three measurements are made. The first is to sight the object and calculate the distance to the object. Afterwards an angle is sighted to the top and bottom of the tree with simple trigonometry calculating the vertical distance.

3.4.2.2 Diameter at Breast Height

The DBH is calculated by first marking a point on the tree 1.3m from the forest floor. A tape is then wrapped around the trunk at this height to obtain the circumference. This can be done to a higher accuracy by marking multiple points around the tree at the same height. Once the circumference is calculated, dividing the value by Pi will return the DBH.

3.4.2.3 Volume

Tree volume can be easily calculated by assuming the structure is a perfect cylinder. Multiplying the basal area by the height gives the volume of the structure.

3.5 Post Processing

3.5.1 Scan Analysis

FARO Scene is software provided by FARO used to analyse scans conducted with their equipment. This software allows the user to analyse the generated point cloud. It is also possible to overlay colour photographs on these point clouds to achieve a realistic view.

These files containing both point clouds and photos are very large. Once registration is completed the files become even larger. All scanned data collected and processed was in excess of 78GB. Consequently an extremely powerful computer had to be used. This was an overclocked desktop computer featuring 16GB of RAM and an i7-4770K CPU. Such a powerful computer allowed registration to be completed in one hour. A further thirty minutes was required to identify tree characteristics.

Once the cluster is created through registration, it is possible to overlay the captured photos onto the measured points. This allows for an accurate visual representation of the cluster, rather than a black and white point cloud. These photos are overlayed in three ways, identified as: Quick view, Planar view and 3D view.

3.5.1.1 Quick View

The quick view overlay provides a view from the position of the scanner. The photos are wrapped around the position of the scanner, allowing for 360 degree rotation around the view point. The limitation with this view is that high places, namely the tops of trees, become distorted when the scale is altered to view these high up places. The advantage of this view is the detail provided when performing measurements. When conducting multiple measurements, distances for each measurement are detailed, as well as a vertical and horizontal distance from the starting point. A large scale and small scale example are provided in Appendix 4, alongside a measurement example.

3.5.1.2 Planar View

The planar view also provides a view from the position of the scanner. The difference it has from the quick view is that the photos are wrapped to form a flat, panoramic photo. This greatly minimises distortion when viewing high places as there is no distortion when altering scale. Consequently the top of structures can be interpreted easily, allowing for consistent measurements. This view also identifies the location of other scans within the same cluster. Resultantly it is possible to identify where in the cluster the structure is and can also assist when trying to return to the individual structure. The disadvantage to this view is that less detail is provided when measuring objects. Unlike the quick view, only a total distance is given, rather than the distance of each individual measurement. A horizontal and vertical distance is still provided from the first to last measurement. Refer to Appendix 5 for a small scale image and a measurement example.

3.5.1.3 3D View

The 3D View is used to compile the cluster. The photos are overlayed onto the scan points, however any areas that cannot be overlayed onto points are left blank. It is useful when determining the data each scan was able to identify. Another advantage of this view is that the viewpoint is not limited to the location of the scanner. However when moving through the point cloud the data must reload each time a movement is made, clogging the system. Resultantly obtaining data using this technique is time consuming.

Of these, the quick and planar views will be used to analyse tree structures. These two views provide enough manipulation to allow the structures to be analysed to a high degree. Resultantly DBH and height can be calculated.

3.5.2 Traditional Data Analysis

The traditionally collected data only provides the circumference at breast height. Before processing can occur this measurement must be converted to diameter for all structures. Completing all conversions and documenting the data obtained took approximately two hours.

3.6 Data Comparison

To assess the suitability of laser scanning in capturing and analysing forest structures, a comparison between scanned and traditionally collected data must be performed.

To execute such a task twenty trees will be analysed. These structures will vary in height, shape and diameter to ensure the outcome is unbiased. Height and DBH will be determined so that volume can be calculated. The volume is calculated by first determining the basal area. The basal area is then multiplied by the height of the structure.

Data obtained using the quick and planar views will be compared to the traditional method. An average of the two methods will also be calculated and compared to the traditional data to identify which option is most suitable.

3.7 Conclusion

This chapter identified the methods that will be used to fulfil the research aims. The study area and equipment were identified. Methods used to capture and analyse the data were discussed. Methods used to ensure an accurate comparison were also highlighted.

Chapter 4 – Results

4.1 Introduction

This chapter will present the data acquired using the two methods. Differences between the various data forms will also be identified.

4.2 Traditional Data

Traditional Data				
Tree #	Height (m)	DBH (m)	Basal Area (m^2)	Volume (m^3)
Tree 1	9.2	0.282	0.062	0.0573
Tree 2	9.9	0.393	0.121	1.201
Tree 3	9	0.309	0.075	0.0674
Tree 4	4.9	0.589	0.272	1.334
Tree 5	12.2	0.703	0.388	4.739
Tree 6	5.9	0.579	0.263	1.554
Tree 7	11.9	0.468	0.172	2.045
Tree 8	10.5	0.503	0.199	2.085
Tree 9	10.8	0.344	0.093	1.002
Tree 10	8.9	0.675	0.357	3.181
Tree 11	7.1	0.616	0.298	2.114
Tree 12	7.1	0.417	0.136	0.969
Tree 13	11.5	0.608	0.290	3.337
Tree 14	12.1	0.573	0.258	3.118
Tree 15	11	0.557	0.244	2.679
Tree 16	9.3	0.417	0.136	1.269
Tree 17	3	0.427	0.143	0.428
Tree 18	13.4	0.296	0.069	0.922
Tree 19	4.5	0.449	0.158	0.712
Tree 20	5.9	0.242	0.046	0.271

Table 1. Data obtained from traditional methods.

4.3 Scanned Data

Quick View				
Tree #	Height (m)	DBH (m)	Basal Area (m^2)	Volume (m^3)
Tree 1	9.378	0.252	0.050	0.467
Tree 2	10.003	0.371	0.108	1.081
Tree 3	9.371	0.271	0.058	0.540
Tree 4	5.112	0.554	0.241	1.232
Tree 5	12.473	0.664	0.346	4.317
Tree 6	6.303	0.533	0.223	1.406
Tree 7	12.046	0.387	0.118	1.416
Tree 8	10.658	0.454	0.162	1.724
Tree 9	10.939	0.242	0.046	0.503
Tree 10	8.940	0.543	0.231	2.069
Tree 11	7.16	0.459	0.165	1.184
Tree 12	7.407	0.378	0.112	0.831
Tree 13	11.627	0.550	0.237	2.761
Tree 14	12.19	0.547	0.235	2.863
Tree 15	11.381	0.494	0.192	2.180
Tree 16	9.426	0.331	0.086	0.811
Tree 17	3.012	0.397	0.124	0.373
Tree 18	13.874	0.216	0.037	0.508
Tree 19	4.749	0.412	0.133	0.633
Tree 20	6.165	0.233	0.043	0.263

Table 2. Quick view tree measurements.

Planar View				
Tree #	Height (m)	DBH (m)	Basal Area (m^2)	Volume (m^3)
Tree 1	9.420	0.226	0.040	0.378
Tree 2	9.789	0.353	0.098	0.958
Tree 3	9.298	0.281	0.062	0.576
Tree 4	5.061	0.529	0.220	1.112
Tree 5	12.375	0.647	0.329	4.067
Tree 6	6.339	0.516	0.209	1.325
Tree 7	12.105	0.378	0.112	1.358

Tree 8	10.628	0.435	0.149	1.579
Tree 9	10.962	0.248	0.048	0.529
Tree 10	8.941	0.567	0.252	2.256
Tree 11	7.128	0.500	0.196	1.399
Tree 12	7.367	0.365	0.105	0.770
Tree 13	11.554	0.541	0.230	2.655
Tree 14	12.164	0.519	0.211	2.572
Tree 15	11.399	0.516	0.209	2.383
Tree 16	9.499	0.320	0.080	0.764
Tree 17	3.005	0.394	0.122	0.366
Tree 18	13.868	0.197	0.030	0.422
Tree 19	4.701	0.409	0.131	0.617
Tree 20	6.204	0.229	0.041	0.255

Table 3. Planar view tree measurements.

Average				
Tree #	Height (m)	DBH (m)	Basal Area (m^2)	Volume (m^3)
Tree 1	9.399	0.239	0.045	0.421
Tree 2	9.896	0.362	0.103	1.018
Tree 3	9.335	0.276	0.060	0.558
Tree 4	5.087	0.542	0.230	1.171
Tree 5	12.424	0.656	0.337	4.191
Tree 6	6.321	0.525	0.216	1.365
Tree 7	12.076	0.383	0.115	1.387
Tree 8	10.643	0.445	0.155	1.651
Tree 9	10.951	0.245	0.047	0.516
Tree 10	8.941	0.555	0.242	2.162
Tree 11	7.144	0.480	0.180	1.289
Tree 12	7.387	0.372	0.108	0.800
Tree 13	11.591	0.546	0.234	2.707
Tree 14	12.177	0.533	0.223	2.716
Tree 15	11.390	0.505	0.200	2.280
Tree 16	9.463	0.326	0.083	0.787
Tree 17	3.009	0.396	0.123	0.369
Tree 18	13.871	0.207	0.033	0.464
Tree 19	4.725	0.411	0.132	0.625

Tree 20	6.185	0.231	0.042	0.259

Table 4. Average tree measurements from scanned data.

4.4 Variations

From these measurements, variances can be calculated between the three types of scan measurements and the traditional method.

Figure 10. Variances in height between scanned data and traditional.

Height			
	Quick View	Planar	Average
Mean	0.206	0.185	0.196
Std Dev	0.127	0.146	0.133

Table 5. Mean height variances and standard deviations.

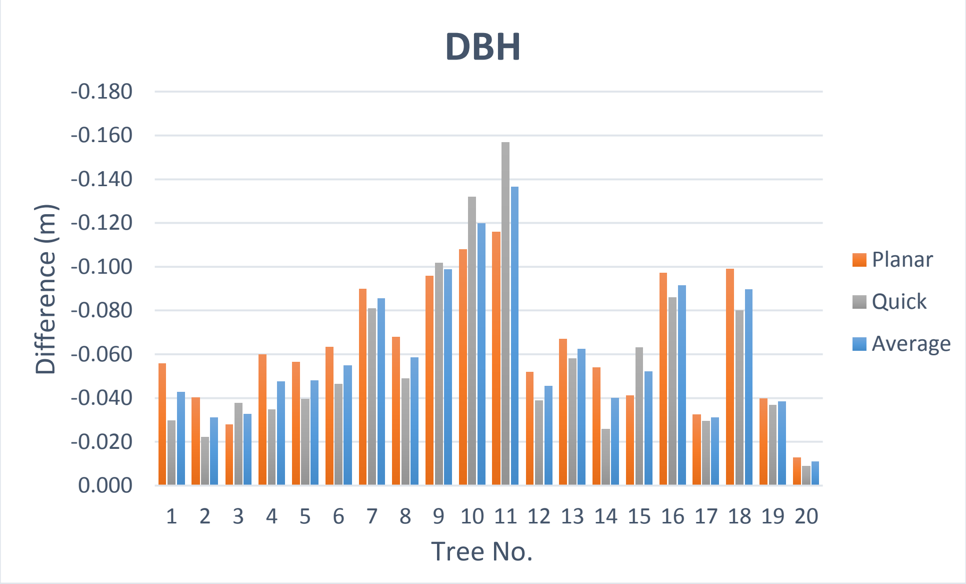


Figure 11. Variances in DBH between scanned data and traditional.

DBH			
	Quick View	Planar	Average
Mean	-0.058	-0.064	-0.061
Std Dev	0.037	0.028	0.032

Table 6. Mean DBH variances and standard deviations.

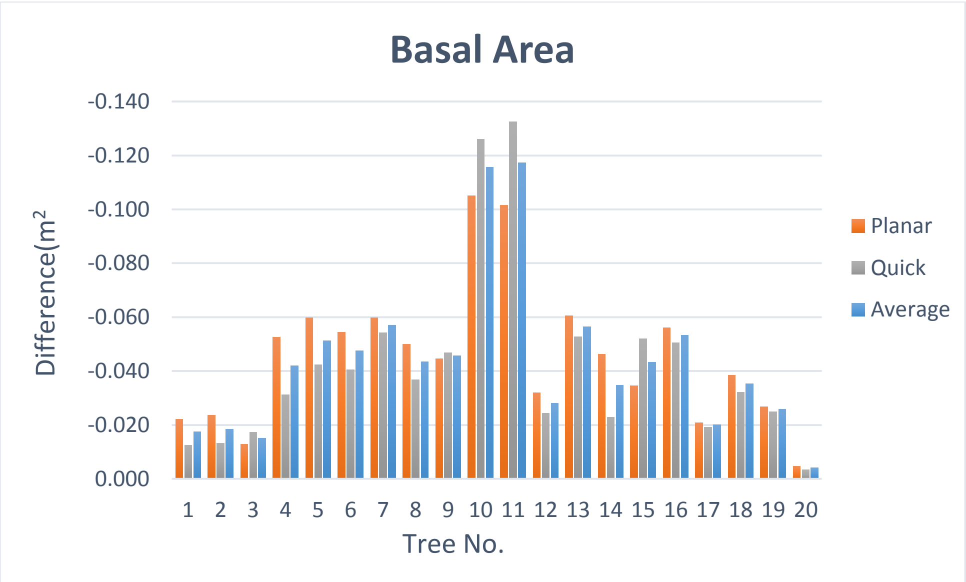


Figure 12. Variances in basal area between scanned data and traditional.

Basal Area			
	Quick View	Planar	Average
Mean	-0.042	-0.045	-0.044
Std Dev	0.033	0.025	0.028

Table 7. Mean basal area variances and standard deviation.

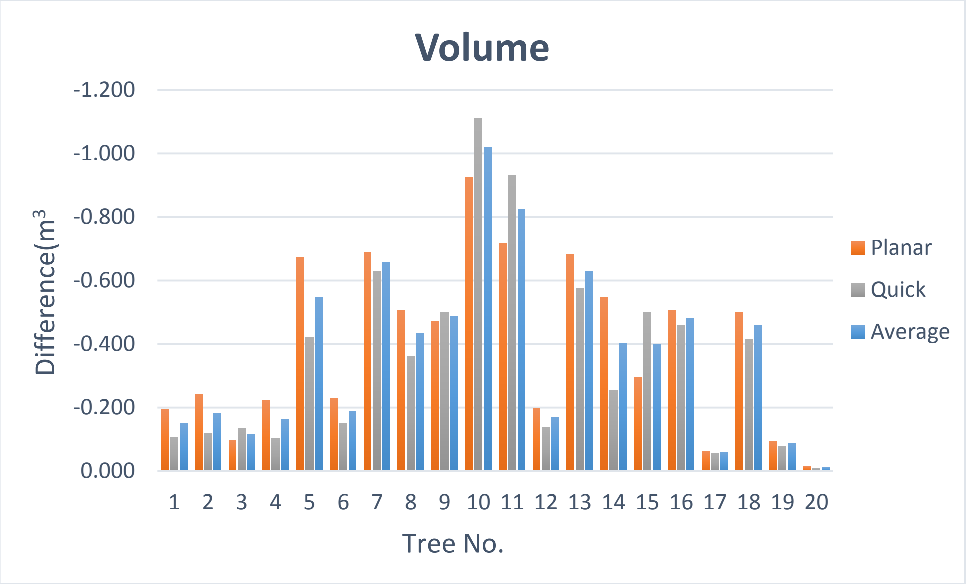


Figure 13. Variances in volume between scanned data and traditional.

Volume			
	Quick View	Planar	Average
Mean	-0.352	-0.393	-0.374
Std Dev	0.292	0.254	0.266

Table 8. Mean volume variances and standard deviation.

Percentage				
Tree #	Height	DBH	Basal Area	Volume
Tree 1	2.163	-15.159	-28.020	-26.464
Tree 2	-0.040	-7.914	-15.203	-15.237
Tree 3	3.717	-10.610	-20.095	-17.125
Tree 4	3.806	-8.045	-15.442	-12.224
Tree 5	1.836	-6.818	-13.172	-11.578
Tree 6	7.136	-9.463	-18.031	-12.182
Tree 7	1.475	-18.254	-33.177	-32.191

Tree 8	1.362	-11.618	-21.886	-20.822
Tree 9	1.394	-28.732	-49.209	-48.501
Tree 10	0.455	-17.755	-32.358	-32.051
Tree 11	0.620	-22.150	-39.394	-39.018
Tree 12	4.042	-10.908	-20.627	-17.418
Tree 13	0.787	-10.275	-19.495	-18.862
Tree 14	0.636	-6.974	-13.462	-12.911
Tree 15	3.545	-9.343	-17.812	-14.898
Tree 16	1.747	-21.940	-39.066	-38.001
Tree 17	0.283	-7.276	-14.023	-13.779
Tree 18	3.515	-30.243	-51.340	-49.629
Tree 19	5	-8.537	-16.346	-12.163
Tree 20	4.822	-4.512	-8.821	-4.424
Mean	2.415	-13.326	-24.349	-22.474

Table 9. Percentage variances between scanned average and traditional.

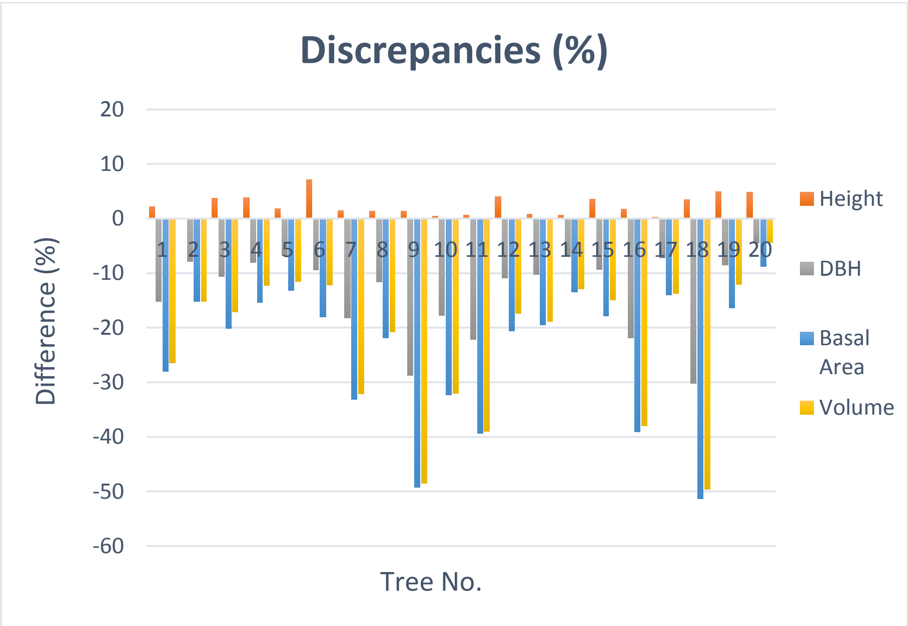


Figure 14. Variation as a percentage between traditional and scanned data average.

4.4 Conclusion

This chapter has presented the data obtained for this study. The data was obtained using traditional methods as well as laser scanning. Both methods analysed height, DBH, basal area and volume.

Chapter 5 – Discussion

5.1 Introduction

The data that was obtained using traditional methods has been analysed to calculate DBH, basal area and volume of twenty tree structures. The same procedures have been followed to allow the same to be done for the data collected using the FARO Focus 3D.

The scanned data has been analysed using two methods made available by the software used. FARO Scene allows for measurements to be made using both a quick view and a planar view. These two methods, along with an average, will be analysed alongside the traditional methods to analyse the suitability of using laser scanning to analyse forest structures.

5.2 Quick View Analysis

The quick view data is outlined in Table 2 with the variances provided in Figures 10 through 13.

5.2.1 Height

The mean height variation of the twenty trees identifies that the quick view data overestimates the height of each tree by 211mm. At first glance this is quite a discrepancy however there are factors that condone this error. The first is that the distometer used can only make measurements to the nearest 100mm. Such a measurement already reduces the potential error by almost half. Secondly, the distometer is susceptible to human error at a higher degree than the scan analysis. To accurately align the distometer with the measurement point, hands must be held steady and the eyes of the user would need to provide perfect vision. A slight movement from the required point to be measured combined with the 100mm accuracy can drastically alter the distance measured. Alongside this, the distometer can only measure vertical heights. If a tree is not completely straight, error is introduced to the measurement.

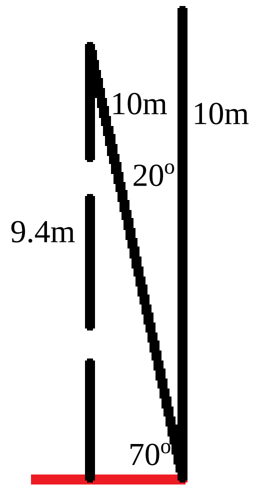


Figure 15. Vertical height error.

An angle as small as twenty degrees can introduce a height difference of 600mm as seen in Figure 15. From the analysed data, the largest variance in height is 474mm on tree #18. Although the angle to the measured point is not great (Figure 16), the height of the tree can easily provide this discrepancy. As the height increases, so too does the variation in vertical height if the angle of deviation remains consistent. In contrast, the smallest difference is 12mm which was measured on tree 17.

Figure 16. Tree #18, the largest quick view variation.

In Figure 17, tree #17 is shown and it is easily identified that the structure is almost completely vertical. Such a characteristic, combined with a low height has resulted in this near perfect measurement.

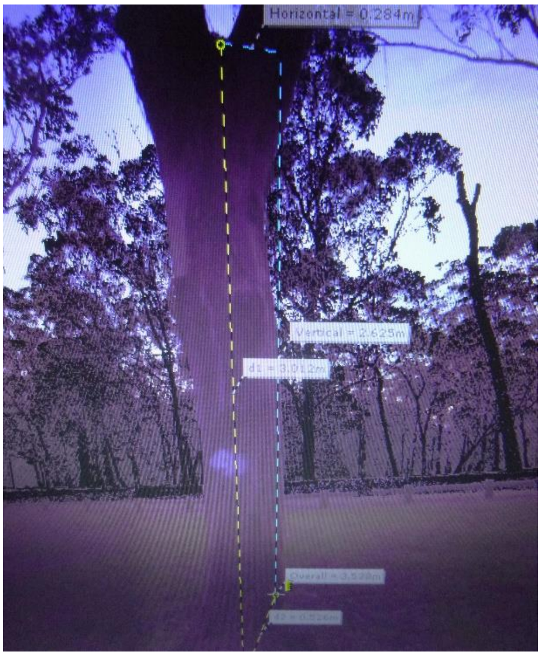


Figure 17. Tree #17, the smallest quick view variation.

When assessing the mean and standard deviation of the quick view variations, the data is positive. The mean identifies that the quick view measurements overestimate the tree height by 206mm. However based on previous statements, it is possible that the distometer underestimates the height by this measurement. Reinforcing this idea is the standard deviation of 127mm. Such a distance is near the measurement accuracy of the distometer without introducing human error. Resultantly, the data suggests that FARO Scene’s quick view measurements can accurately record tree height data, possibly to a higher standard than that of traditional methods.

5.2.2 Diameter at Breast Height

As opposed to height measured with the quick view, the DBH of all twenty trees is smaller than the traditional method. Of the data, all bar three measurements fall outside a 100mm difference with the mean variation calculated as -58mm. Although it is difficult to suggest the reasoning behind this uniform discrepancy, errors in photo overlay could be a likely cause. When measurements were made from one edge of the tree to the other, the results were occasionally extremely wrong. One measurement returned a DBH in excess of sixteen metres. This resulted in selecting a point that was not part of the tree structure, although with an increased scale it appeared it was. The distortion in the increased scale resulted in photo overlays misrepresenting the point clouds and consequently negatively impacting measurements. Tree #20 had the smallest error when calculating DBH with the calculation 9mm less than that of the traditionally collected data. The worst measurement was made on structure 11, with the measurement returning a value 157mm smaller than the traditional method.

Figure 18. Tree #20, the smallest DBH variation.

Figure 19. Tree #11, the largest DBH variation.

By analysing both Figure 18 and 19, it is easy to identify the distortion present in Figure 19 as well as the lack of in Figure 18. There is also shadow present on one edge of the tree in Figure 19 which may have caused a misinterpretation of the structure's limits. Much like the height measurements, there is an error consistency. In this case it is an underestimation of each structure's DBH. With a mean of 58mm and a standard deviation of 37mm, it is quite a significant error. However the current method of obtaining DBH is not always accurate. While the quick view measurement allows for a straight line to be drawn across the tree, parallel to the ground, such a measurement is not possible in the field. A tape measure must be wrapped around the tree and is susceptible to multiple errors. This includes: not being parallel to the ground, not being at 1.3m from the ground, fluctuations in the tape as it is wrapped around the tree, the tape not resting perfectly against the tree edges and if the measurement is made on a hill, the tape may not be representative of a flat plane that is 1.3m from the forest floor on the highest side. Such a high number of possible, if not probable errors suggests that much like the case with height, the scanner measurements, although they seem incorrect, reflect the true measurement of the tree to a greater degree than the traditional methods.

5.2.3 Volume

To calculate the volume of the tree, the DBH is converted to area. Such an area is known as the basal area and is multiplied by the height of the tree to determine the tree volume. The largest variation between quick view analysis and traditional analysis was identified on tree #10. Although this structure had an excellent height measurement (+40mm) and the DBH calculation was not the worst in the population (25mm better than #11), the height of the tree caused the difference to become significant. The volume variation of tree #10 is 1.112m^3 which is 35% of the traditional volume. However by analysing the problems associated with this calculation as well as the remaining volume variances, it appears this measurement is an outlier. Although the height is good and well within the standard deviation and below the mean, the DBH is the exact opposite. The DBH measurement for this structure is 227% of the mean variation and three and a half times larger than the standard deviation. This miscalculation combined with a tree of such a large height easily explains the discrepancy between the two measurement methods.

Tree #20 has a DBH calculation that is near identical to the traditional method and has resulted in the volume differing by a mere $0.008m^3$. The underestimate of the DBH and the overestimate of the height has resulted in this near exact measurement.

The mean volume variation amongst all twenty measurements is an underestimation of $0.352m^3$. However if structure #10 and #11 are removed (the two outliers), this is reduced to $0.278m^3$ which is an immense improvement, a 21% reduction. Resultantly, it can be stated that if the two outliers are removed, the quick view measurements underestimate tree volume by $0.278m^3$. This figure represents 21% of average tree volume ($1.328m^3$) when the outliers are again removed.

5.3 Planar View

The planar view data is outlined in Table 3 with the variances provided in Figures 10 through 13.

5.3.1 Height

As was the case with the quick view measurements, tree #18 featured the greatest difference to the measurement made by traditional methods. The planar view error was a 468mm excess, 6mm less than the error identified in the quick view measurement. Again this is likely due to the large height of the tree combined with an offset angle.

Continuing this trend, the closest representation was the measurement on tree #17. This error was 5mm, 7mm less than the quick view. Such a measurement can be explained by the straightness of the tree as well as its low height.

The average difference (185mm) is also less than the quick view average (206mm). Such a result suggests that the planar view is better suited to measuring height than the quick view.

5.3.2 Diameter at Breast Height

Reflective of quick view measurements, the largest DBH error was on tree #11. However this error (116mm) was 41mm less than the quick view error (157mm). This is an extensive difference, constituting a 26% improvement. Furthermore, the smallest difference is 13mm and much like the quick view, has been made on tree #20. The difference of 4mm between the two measurements is insignificant.

It should be noted however, that the average difference between planar and traditional measurement (64mm) is 6mm higher than the quick view average (58mm), even though the largest DBH discrepancy is 41mm less. Another observation to note is that tree #10 and #11 are not such obvious outliers as they are in the quick view data. However, if the two aforementioned outliers are removed from the planar and quick view data sets, this average is reduced to 58mm and 48mm respectively. Although this does not change the data to an extensive degree, it does suggest that the planar view may provide a better representation of DBH than what is provided by the quick view measurements.

5.3.3 Volume

The average volume discrepancy observed when using the planar view for measurements is -0.393m^3. When compared to the quick view average of -0.352m^3, this is a slight difference (0.041m^3). However if, like in the previous section, the two quick view outliers are removed, the quick and planar view average becomes -0.346m^3 and -0.278m^3 respectively. Consequently the difference in average volume becomes 0.068m^3, a 70% increase. Such data suggests that the quick view is more appropriate if calculating volume.

5.4 Average of Quick and Planar Measurements

For this study, two independent measurements have been made to calculate two factors. The independent measurements, DBH and height, are manipulated to identify basal area and volume. In both independent cases, it was easily identified which measurement closely reflected that of the traditional method. When referring to height, planar view measurements were similar to the traditional results. In the case of DBH, the measurements made within quick view better reflected the traditional measurements.

Such a result does not identify which method is more suited to such an application. However once volume is calculated, it is evident that the quick view measurements hold the smallest margin between itself and traditional analysis. In contrast, the average may better reflect the measurement because planar view was more suited to height calculation and quick view to DBH.

Planar Height & Quick DBH				
Tree #	Height (m)	DBH (m)	Basal Area (m^2)	Volume (m^3)
Tree 1	9.420	0.252	0.050	0.470
Tree 2	9.789	0.371	0.108	1.058
Tree 3	9.298	0.271	0.058	0.536
Tree 4	5.061	0.554	0.241	1.219
Tree 5	12.375	0.664	0.346	4.283
Tree 6	6.339	0.533	0.223	1.414
Tree 7	12.105	0.387	0.118	1.423
Tree 8	10.628	0.454	0.162	1.720
Tree 9	10.962	0.242	0.046	0.504
Tree 10	8.941	0.543	0.231	2.069
Tree 11	7.128	0.459	0.165	1.179
Tree 12	7.367	0.378	0.112	0.826
Tree 13	11.554	0.550	0.237	2.744
Tree 14	12.164	0.547	0.235	2.857
Tree 15	11.399	0.494	0.192	2.184
Tree 16	9.499	0.331	0.086	0.817
Tree 17	3.005	0.397	0.124	0.372
Tree 18	13.868	0.216	0.037	0.508
Tree 19	4.701	0.412	0.133	0.626
Tree 20	6.204	0.233	0.043	0.264

Table 10. Volume calculated using planar height and quick DBH.

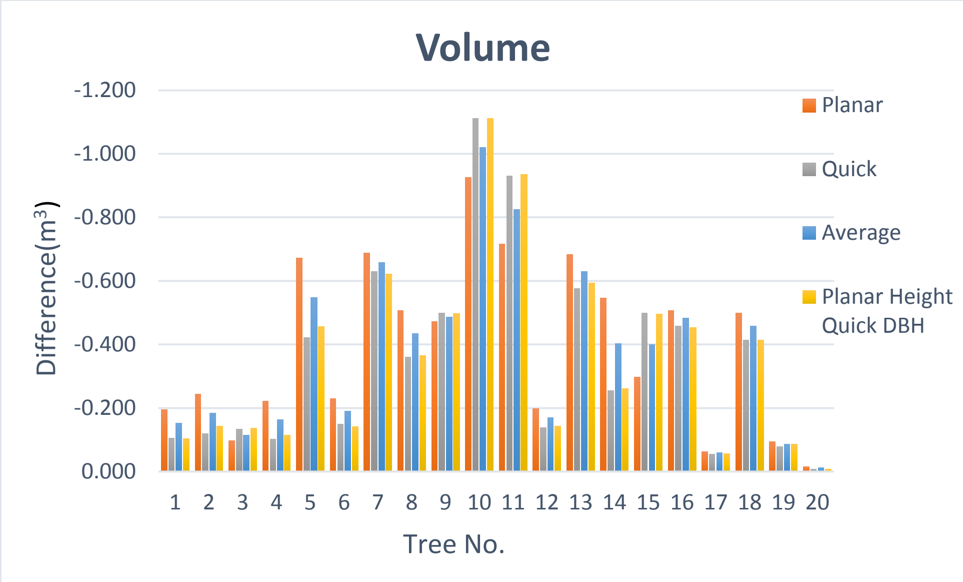


Figure 14. Variances in volume between traditional and scanned data.

Volume				
	Quick View	Planar	Average	Combination
Mean	-0.352	-0.393	-0.374	-0.357
Std Dev	0.292	0.254	0.266	0.291

Table 11. Volume variances between traditional and scanned data.

Although such an idea sounds like it would be the best representation, table 11 does not reinforce this argument. The mean variation of -0.357m^3 is an underestimation 0.005m^3 greater than the data identified using the quick view. Although the standard deviation favours this new calculation by 0.001m^3, it is not enough to justify 0.005m^3. If tree #10 and #11, the outliers, are removed the mean difference becomes -0.283m^3, again an underestimation 0.005m^3 greater than the quick view calculation.

5.5 Time Comparison

Recording data using traditional methods can be a long process, especially if high detail records are required. To record data using the laser scanner approximately twelve hours was required. An extra hour was required to process all scans before data analysis. Once this was completed the data was readily available to process. Obtaining the required measurements using both views took roughly thirty minutes to calculate and record.

Observing the twenty trees using contemporary methods required four hours of work. Two hours to measure trees in the field and then another two of post processing which included calculations and data entry. In total the scanned analysis took thirteen and a half hours whereas the traditional analysis took only four hours. A difference of nine and a half hours is quite large and suggests that scanning is impractical. However if the quantity of data is compared the outcome changes. In three hours traditional methods could only analyse twenty trees. Although scanning took longer, data is available for every individual structure within the study area. The amount of information that can be extracted from the scan is only limited to the size of the scan. Adding to this, the data can be analysed at any time. When using traditional methods the only data that can be analysed is what has been recorded in the field. Although photos can allow for later analysis, no measurements can be executed and if photos do not fulfil the requirements it may be necessary to return to the site.

Such results convey that laser scanning is a more efficient way to capture data. With improved scanning techniques and planning, data capture time could be limited to only slightly longer than the total time of the scans. This study used eighteen scans at approximately ten minutes each although the total capture time took twelve hours. This leaves nine hours unaccounted for but in this instance it was associated to inexperience of the operator.

Although the time taken could be improved in both instances, there is greater room for improvement in the scanning procedures. A true comparison cannot be made unless the same number of individual trees are analysed using both methods but observations on the techniques used in this study propose that laser scanning is more efficient.

5.6 Conclusion

FARO Scene is software used to make measurements on scan point clouds. This can be done in the various views provided which include a quick, planar and 3D view. Using the point clouds observed, the quick and planar views were used to calculate tree height and DBH. This data was then manipulated to determine the basal area and volume for twenty trees within the aforementioned study area.

It was identified that the quick view was more suited to calculating DBH than the planar view. In the case of tree height, the planar view was deemed more appropriate. These results were reached by comparing the measurements made to data that was recorded using traditional forest data collection techniques. An average of the two views, as well as a combination of the two was also compared to the traditional data. However the data obtained using only the quick view best suited the traditional analysis.

Chapter 6 – Conclusions

6.1 Introduction

Overall the research aim of the study has been achieved. Height, DBH, basal area and volume could be calculated using terrestrial laser scanning. The same data was collected using traditional methods. Comparisons were completed to determine laser scanning's suitability at collecting such data.

6.2 Research Findings

The scanned data was analysed using both the quick and planar views provided by the FARO Scene software. When measuring height, both views overestimated the height of the tree. DBH and basal area calculated from scanned data underestimated traditional data. The combination of this resulted in both methods underestimating the volume by approximately 21% on average.

As to which method better represented the structure data, a detailed comparison analysis revealed that quick view measurements resembled the traditional data better. However, although this data better represented the traditional data, this does not mean that such a task was done well. The average discrepancies for height, DBH, basal area and volume were +0.206m, -0.058m, -0.042m^2 and -0.352m^3 respectively. These differences, especially volume, are quite large and greatly alter the results of the inventory, especially when calculating total volume or biomass. Measurements made using the planar view yielded similar errors. Height, DBH, basal area and volume differences were +0.185m, -0.064m, -0.045m^2

and -0.393m^3 respectively. Differences between the two views were not large until volume was measured. Regardless the difference was quite small with differences in height, DBH, basal area and volume measuring 0.021m, 0.006m, 0.003m^2 and 0.041m^3 respectively.

6.3 Further Research and Recommendations

The obtained results were collected from one survey and only a small sample was analysed. Contained within this small sample were large gross errors which reduced the amount of usable data. To accommodate errors of this sort, the study area should be surveyed a number of times. A larger sample combined with multiple analyses of the same structure would alleviate gross errors.

Although the data suggests the scanned data is a poor representation of the structure, this is not a confirmed fact. Analysing the structure using other surveying methods would help distinguish this concept. Obtaining DBH and height using a high accuracy total station would outline which measurements accurately reflect the structure's properties.

Scanned data such as that used for this study is easy to manipulate. It is extremely detailed and can yield a large quantity of information about a subject. In a forest structure tree types can be identified as well as various densities with a detailed analysis. With greater knowledge of the software it is also possible to extract a contour map from the point clouds. If all such data was able to be extracted from the captured information, laser scanning's strength within this environment would be easily identified.

6.4 Conclusion

Terrestrial laser scanning is a relatively new technology however it is already a staple form of measurement in a number of industries. The use of such technology is relatively new within a forested environment but benefits are already prominent. Height, DBH, basal area and volume of trees within a forest structure can be easily measured using point cloud analysis software.

Although easily measured, findings suggest that these forest inventory components are recorded poorly using terrestrial laser scanning. Discrepancies in DBH and large discrepancies in volume were evident. However further studies of a greater detail would be required before such a statement becomes fact.

Appendix

Appendix 1 – Project Specification

University of Southern Queensland

FACULTY OF ENGINEERING AND SURVEYING

ENG4111/4112 Research Project

PROJECT SPECIFICATION

FOR: **Adam John COBURN**

TOPIC: LASER SCANNING FOR FOREST STRUCTURE ANALYSIS

SUPERVISOR: Dr. Xiaoye Liu

PROJECT AIM: This project seeks to analyse a forest structure by using a CAD system. The structure will be recorded using a Laser Scanner.

PROGRAMME: **Issue B. August 14th 2014**

1. Research the background information relating to forest structure analysis, Laser Scanning and Laser Scanning's use within forest structure analysis.
2. Design a field measurement procedure which will require:
    a. Determine scan locations and number of scans required.
    b. Implementing control within the area to be surveyed.
    c. Designing an appropriate layout for scan reference marks.
    d. Conducting the scans.

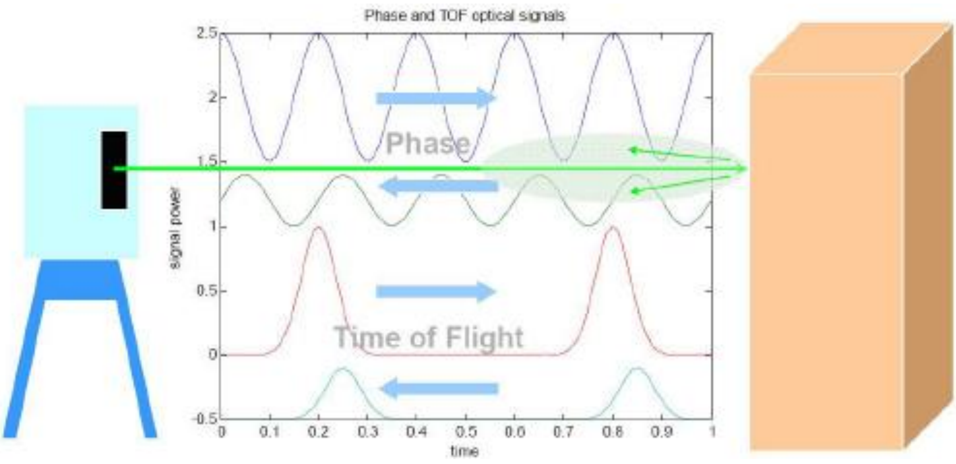
3. Analyse the scanned data to determine:
    a. Height of the trees.
    b. Diameter at breast height.
    c. Basal area.
    d. Tree volume.
4. Record the same data using traditional data collection methods.
5. Compare the data sets to determine the suitability of laser scanning when capturing forest data.

As time permits:

6. Create a TIN of the scanned area to produce a DTM.
7. Use the placed control to geo-reference the scanned data.

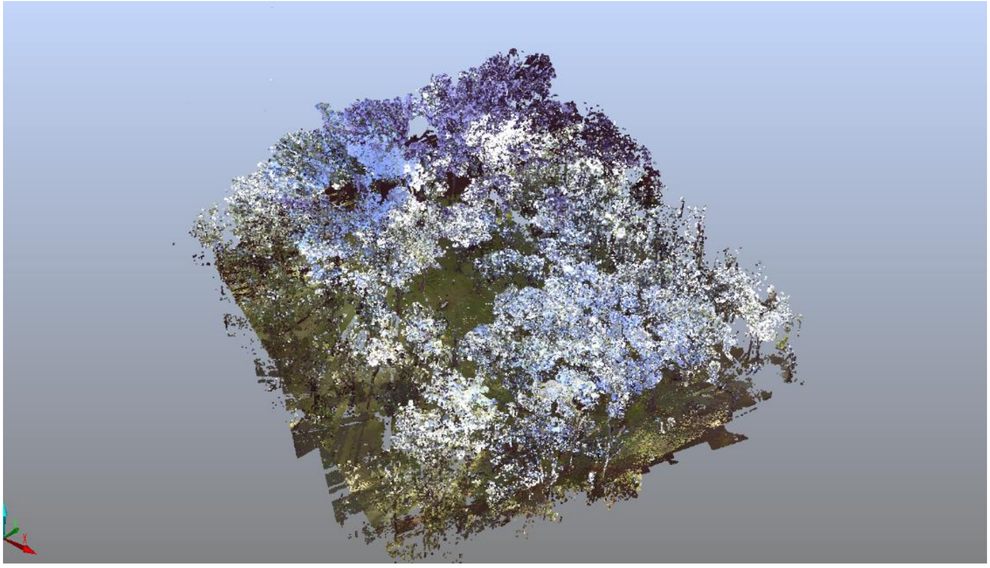
Appendix 2 – How Scanners Measure Distance

How phase based scanners and time-of-flight scanners measure distances.

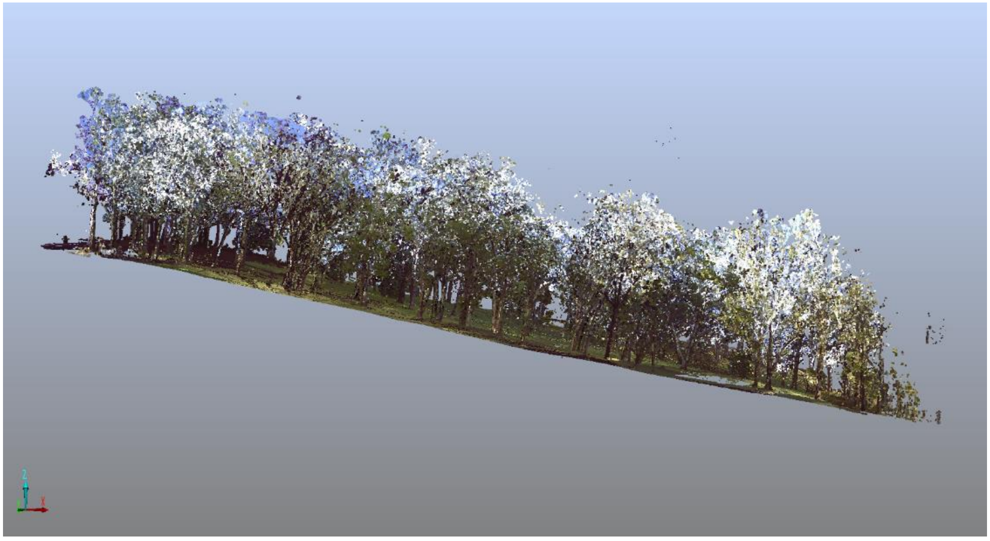


(California Department of Transportation 2011).

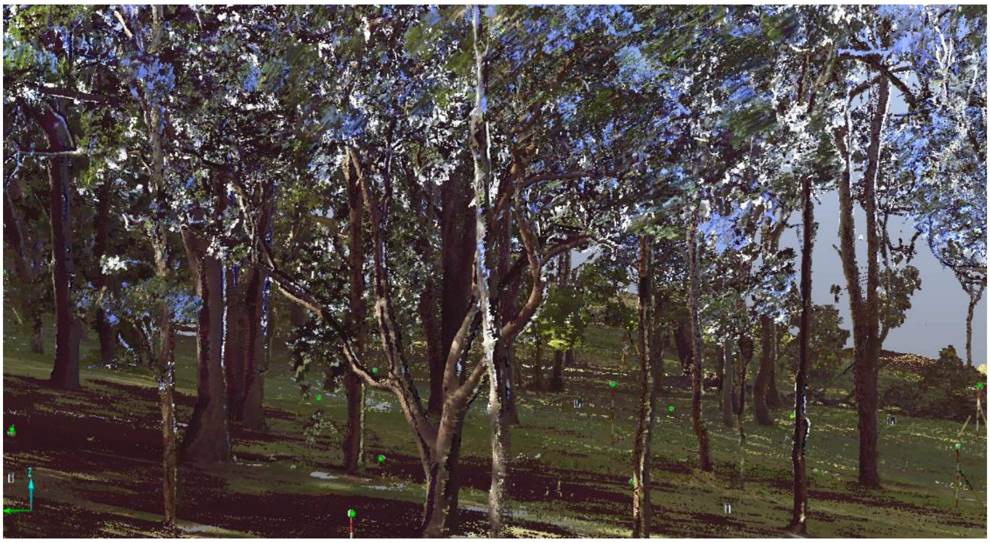
Appendix 3 – FARO Scene Cluster



Top View



Side View

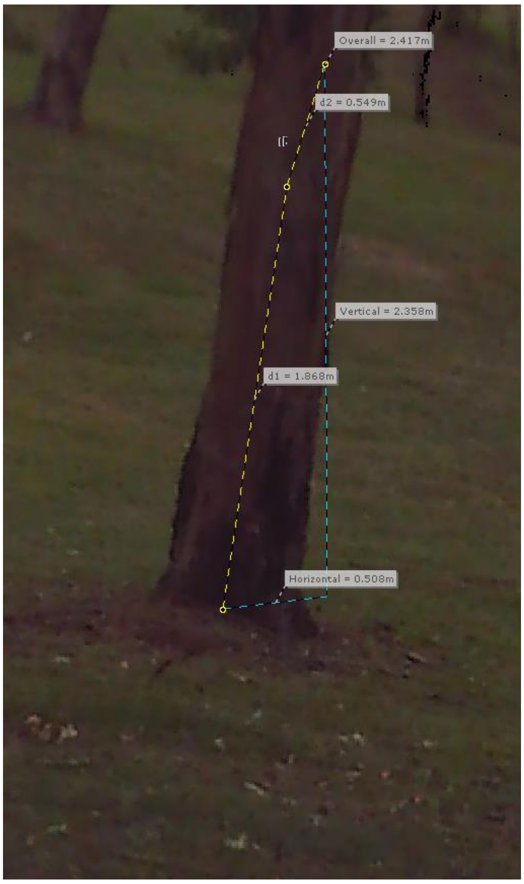


Central View

Appendix 4 – FARO Scene Quick View

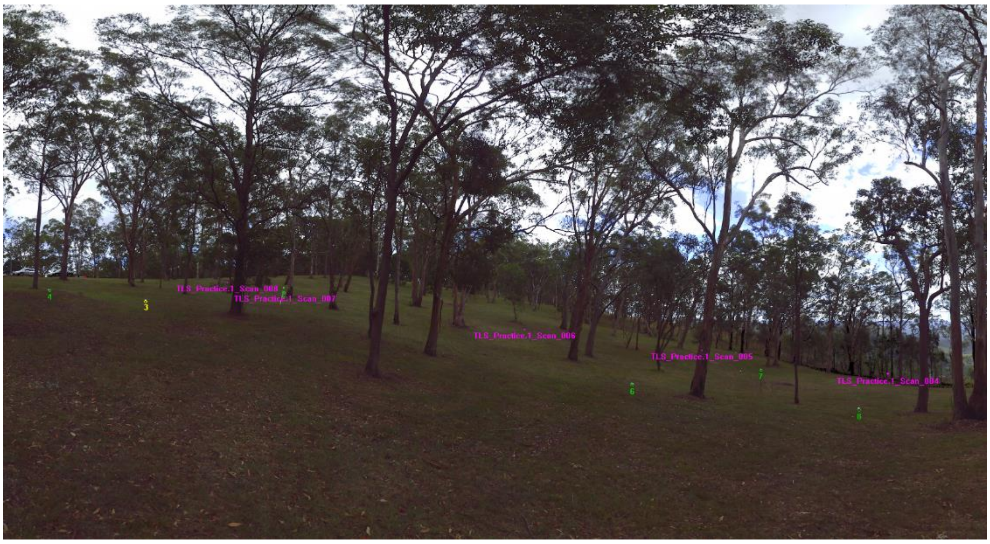
A large scale view.

A small scale view.

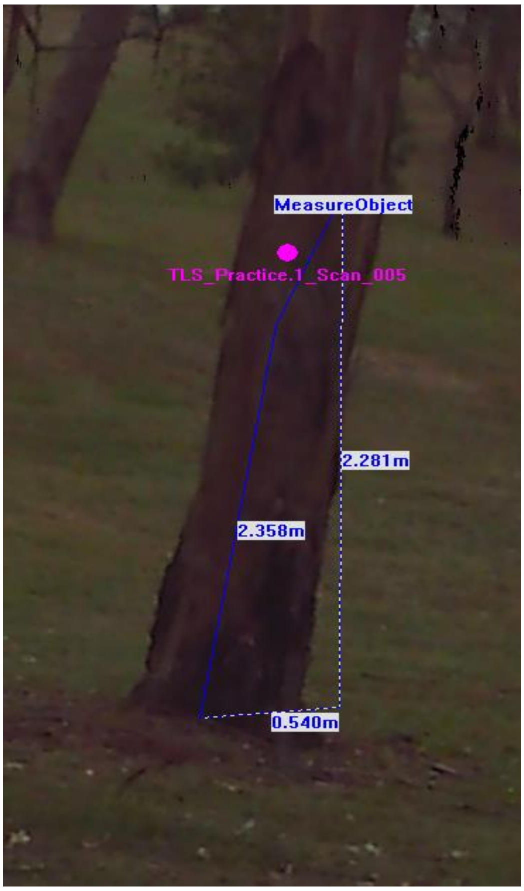


Measurement detail provided.

Appendix 5 – FARO Scene Planar View



The same scan as provided in Appendix 4, viewed at a small scale.



Measurement example on the same structure as Appendix 4.

Appendix 6 – Risk Assessment Documents

Trip hazard risk assessment

Risk Management Chart for Picnic Point Laser Scan

Description of Hazards	People at Risk	Number at Risk	Parts of Body	Risk Level
Tripping	All that are working in the field and passers by	>1	Whole body	Low

Short Term Controls	Long Term Controls	Completion Details
Sign trip hazards Keep setups away from public paths		Faculty of Engineering & Surveying Prepared by: Adam Coburn Date: 3/6/14

Exposure to sunlight risk assessment

Risk Management Chart for Picnic Point Laser Scan

Description of Hazards	People at Risk	Number at Risk	Parts of Body	Risk Level
Exposure to sunlight	All that are working in the field	>1	Exposed areas	Medium

Short Term Controls	Long Term Controls	Completion Details
PPE: Long sleeve clothes, long pants, sunglasses, sunscreen, hat Use shade cover as much as possible Avoid working in the middle of the day		Faculty of Engineering & Surveying Prepared by: Adam Coburn Date: 3/6/14

Exposure to laser light risk assessment

Risk Management Chart for Picnic Point Laser Scan

Description of Hazards	People at Risk	Number at Risk	Parts of Body	Risk Level
Exposure to Laser	People located within 5m of scanner	1	Eyes	Low

Short Term Controls	Long Term Controls	Completion Details
If within 5m of scanner wear the provided darkened glasses. If possible stay outside this 5m zone while scan is being conducted. It is recommended to still wear the glasses.		Faculty of Engineering & Surveying Prepared by: Adam Coburn Date: 3/6/14

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