TAMK University of Applied Sciences
Machine and Production Technology
Product development
Jere Fabritius

Thesis

Terrestrial three-dimensional laser scanning in Aveva PDMS

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Co-operating company Metso Power Oy, development engineer, M.Sc. Teemu Toivo
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TIIVISTELMÄ

Tässä opinnäytetyössä tutkittiin kolmiulotteista laserkeilausta ja sitä miten se voidaan yhdistää Aveva PDMS-laitossuunnitteluohjelmistoon. Työn tarkoituksena oli myös selvittää, millaisia kustannuksia laserkeilaus tuottaa. Lisäksi tässä työssä tutkittiin, mikä laserkeilaus vaihtoehto on Metso Power:n kannalta kustannustehokkain.

Tutkimusmenetelminä käytettiin pääosin kirjallisuusselvityksiä, haastatteluja ja tarjouspyyntöjä. Osa hintatiedoista saatiin aiemmin tehdyistä projekteista.

Työn alussa tutkittiin kolmiulotteisen laserkeilauksen tekniikkaa ja tarkkuutta. Samalla kartoitettiin eri vaihtoehtoja yhdistää laserkeilaus Aveva PDMS-laitossuunnitteluohjelmistoon.

Työn toisessa osassa tutkailtiin neljän eri valmistajan laserkeilain malleja ja niiden hintoja. Toisessa osassa selvitettiin myös mitä kustannuksia laserkeilaus palvelusta aiheutuu tilaajalle. Tuloksista pääteltiin, mikä vaihtoehto on Metso Power:lle kustannustehokkain.

Työn tuloksena havaittiin että laserkeilaus on mittausjärjestelmä, jota Metso Power voi käyttää kolmiulotteisten ympäristöjen digitointiin. Laserkeilauksesta saatavat pistepilvet voidaan tuoda PDMS-järjestelmään kolmella eri tavalla. Ensimmäinen vaihtoehto on mallintaa pistepilvestä kolmiulotteinen malli ja siirtää malli PDMS-järjestelmään. Toinen vaihtoehto on siirtää pistepilvi sellaisenaan PDMS-järjestelmään ja käyttää pistepilveä mallinnus apuna. Kolmas vaihtoehto on tuoda pistepilvi mallintamatta PDMS järjestelmään. Pistepilveä ei tarvitse mallintaa, vaan sitä voidaan käyttää sellaisenaan esimerkiksi törmäys tarkasteluihin.

Mallintamattoman pistepilven tuominen PDMS-järjestelmään vaatii tähän tarkoitukseen kehitetyt ohjelmat. PDMS järjestelmään tarvitaan Aveva Laser Model Interface lisämoduuli. Lisäksi tarvitaan kolmannen osapuolen pistepilviohjelmisto.

Pistepilven käyttämisen sellaisenaan PDMS-järjestelmässä havaittiin olevan kustannustehokkain vaihtoehto. Pistepilven tuottaminen ja käsittely kannattaa tilata alihankkijalta. Mikäli laserkeilauksen tuloksena halutaan piirustukset, täytyy pistepilvi mallintaa kolmiulotteiseksi malliksi. Myös tällöin on kustannustehokkaampaa tilata palvelu alihankkijalta.

Avainsanat laserkeilaus, laitosmittaus, laitossuunnittelu

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ABSTRACT

The objective of this thesis was to study three-dimensional laser scanning and how it can be integrated to Aveva PDMS plant design system. The intent of this thesis was also to research what kind of costs does laser scanning produce. In addition, this thesis focused on which laser scanning option would be the most cost-effective for Metso Power.

The main research methods in this thesis were literature surveys, interviews and inquiries. Part of the cost data was retrieved from old projects.

The first part of this thesis studies three-dimensional laser scanning technology and accuracy. At the same time, it studies how laser scanning can be integrated to Aveva PDMS.

The second part of this thesis focuses on comparing laser scanner models from four manufacturers whose software cooperates with Aveva PDMS. Research on four laser scanning service providers is also conducted in the second part.

As a result, it was found that laser scanning is a measurement method that Metso Power can utilize to digitize three-dimensional environments. The point clouds that laser scanning produces can be integrated to PDMS in three ways. First, the point cloud can be modelled and then brought to PDMS. Secondly, the point cloud can be brought to PDMS as such, and then used as a modelling guide in PDMS. The point cloud does not necessarily have to be modelled, so the third option is to use it as such for clash detection etc.

Bringing the unmodelled point cloud to PDMS needs two specified programs. The PDMS system needs a module called Aveva Laser Model Interface. In addition, third party point cloud software is needed.

Using the point cloud as such in PDMS was found to be the most cost-effective method. The generation of the point cloud should be outsourced to a subcontractor. If the wanted result of the three-dimensional laser scanning is drawings, then the point cloud must be modelled. In this case, it is also the most cost-effective method to outsource the actual scanning to a subcontractor.

Keywords laser scanning, plant surveys, plant design

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Foreword

3D laser scanning and plant engineering are a little bit away from the main focus area of mechanical engineering studies in Tampere University of Applied Sciences. However, the topics proved to be very interesting.

3D laser scanning is a new and exciting technology. There are a lot of articles and research papers to be found about this subject, so a lot of information can be found.

I would like to thank my thesis supervisors, senior lecturer Harri Laaksonen, development engineer Teemu Toivo and engineering manager Timo Haapala.

I also express my thanks to all the companies that cooperated with me for my thesis. The companies are Metso Oyj, Elomatic Oy, Geotrim Oy, Geostar Oy, Leica Nilomark Oy, Mitta Oy, Neopoint Oy and Pöyry Environmental Oy

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Symbols and special vocabulary

c	speed of light in vacuum, m/s
d	distance, m
n	number of full wavelengths
t	time, s
S	spherical radius, m
λ	wavelength, m
Φ	phase shift, rad. Two frequencies that do not oscillate at the same time have a measurable shift between them.
α	angle in the vertical plane
β	angle in the horizontal plane
π	mathematical constant pi
3D	three-dimensional
AS-BUILT data	data of actually built construction, not just planned
Aveva LMI	Aveva laser model interface
CAD	computer aided design
Common sight	target specified for point cloud unification
Divergence	the angle in which the laser beam scatters, mrad
FWHH	full-width half-height, method for determining laser beam diameter
Gaussian-based	another method for laser beam diameter determination
Laser class	laser safety classification, categories I-IV, class I is the safest and class IV is the most dangerous
Laser emitter	laser light source
Noise	in laser scanning: Points that are false measurements.
PDA	personal digital assistant, a small, hand held computer
PDMS	plant design management system, software for plant engineering by Aveva
Point cloud	large collection of three-dimensional points
Resolution	the amount of points in a certain area
Tachymeter	surveying measurement tool, used for coordinate finding
TDC	time-to-digital converter

Time-of-flight	the time that light takes to travel a certain distance, also refers to the technology that a laser scanner uses to calculate distance
Triangulation	mathematical method for distance calculation
Tribrach	Instrument attachment device for tripod. Consists of two triangular plates and three thumbscrews at the corners. Instruments can be levelled by the thumbscrews.
WLAN	wireless local area network, networks that operate in radio waves

1 Introduction

Three-dimensional laser scanning is a new technology. The first commercial laser scanners were seen at a fare in Germany in 1999. The first laser scanner was imported to Finland in 2001. A terrestrial 3D laser scanner measures points in a three dimensional space. The point is defined by three measurements. The measurements are the distance to the object, the angle in horizontal plane and the angle in vertical plane. When these three measurements are taken, the laser scanner calculates the three-dimensional coordinates of the point. Hundreds of thousands or millions of points are measured. The outcome is a so-called point cloud. It contains the spatial coordinates of all the measured points. The point cloud can be processed to produce a three-dimensional computer model.

Laser scanning has the potential to be a major cost and time saver, especially when refurbishing old plants and factories. It is usually very difficult to upgrade or refurbish old plants and factories, because there is limited as-built data available. With laser scanning, accurate as-built data can be obtained and new components and pipes can be added easily. Laser scanning can also reduce or prevent collisions between old structures and new planned structures.

The first objective of this thesis is to introduce terrestrial three-dimensional laser scanning. The second objective is to find out how 3D laser scanning can be integrated to Aveva Plant Design Management System and what kind of costs it introduces.

This thesis will introduce laser scanning technology and its accuracy. Further, it will reveal what end products can be obtained from 3D laser scanning. Many laser scanners are used today in Finland. However, so far laser scanning has been a special knowledge of companies whose focus is surveying. Because of this, this thesis will also research whether it is more cost-effective for Metso Power to acquire its own laser scanner, or to outsource the scanning service to a subcontractor. In addition, post processing of the point cloud will also be studied in this thesis. Laser scanning can be utilized in a large distance scale, but this thesis focuses on distances less than 200 meters.

A lot of research papers can be found on laser scanning. In addition, many companies provide laser scanners or laser scanning services. Therefore, the research methods used in this thesis are literature surveys, interviews and inquiries.

2 Metso Power Oy

2.1 The structure of Metso Corporation

Metso Power is part of the global technology group Metso. Metso has operations all over the world and it has over 27000 employees. Metso Corporation is divided in three segments. The segments are Energy and Environmental technology, Mining and Construction technology, and Paper and Fiber technology.

Metso Power Oy is part of the Energy and Environmental technology segment. Metso Power operates globally. Metso Power designs and manufactures systems for power production, chemical recovery and environmental protection. Its customers are power producers and pulp and paper industry. (Tervetuloa Metso Poweriin! 2008, 1-3; Paper and Fibre Technology- One Metso: questions and answers 2008, 1)

2.2 Units within Metso Power and their products

Metso Power is divided in three units. Capital projects unit is responsible for large boiler and evaporation plant projects. They have three boiler products. HYBEX is a bubbling fluidized bed boiler, CYMIC is a circulating fluidized bed boiler and RECOX is a recovery boiler. TUBEL and REVAP are evaporation plant products.

Service unit is responsible for boiler upgrades, boiler maintenance and spare parts. It also provides training and process study services. Third unit of Metso Power is Heat and Power. The sales of Heat and Power are usually project sales in smaller scale.

Environmental Systems is part of Capital projects, but it has its own product families. Their product families are GASCON, ODOCON and BALCON. GASCON products are for flue gas cleaning and heat recovery in power boilers and pulp and paper plants. ODOCON products are meant for odour control in pulp and paper plants. BALCON products aim for enhancing the operation of pulp and paper plants, or reducing their chemical usage. (Tervetuloa Metso Poweriin! 2008, 3-9)

2.4 The Service unit and Environmental Systems department

The service unit does many boiler upgrades. Parts of the sales of Environmental Systems department are also plant upgrades or refurbishments. Pulp and paper plants and power plants are very complex constructions. In addition, numerous upgrades and changes have been made in the plants. Therefore, it is sometimes very difficult to find accurate as-built data.

It is very time consuming and costly to find and verify as-built data, when dealing with old plants. As-built data has to be found before designing and the layout of new equipment can begin. This takes a lot of time and money, because everything has to be measured on site. Moreover, this kind of as-built data gathering is prone to errors. Figure 1 illustrates the usability of laser scanned as-built data in plant and piping design. (Haapala 2008, 1)

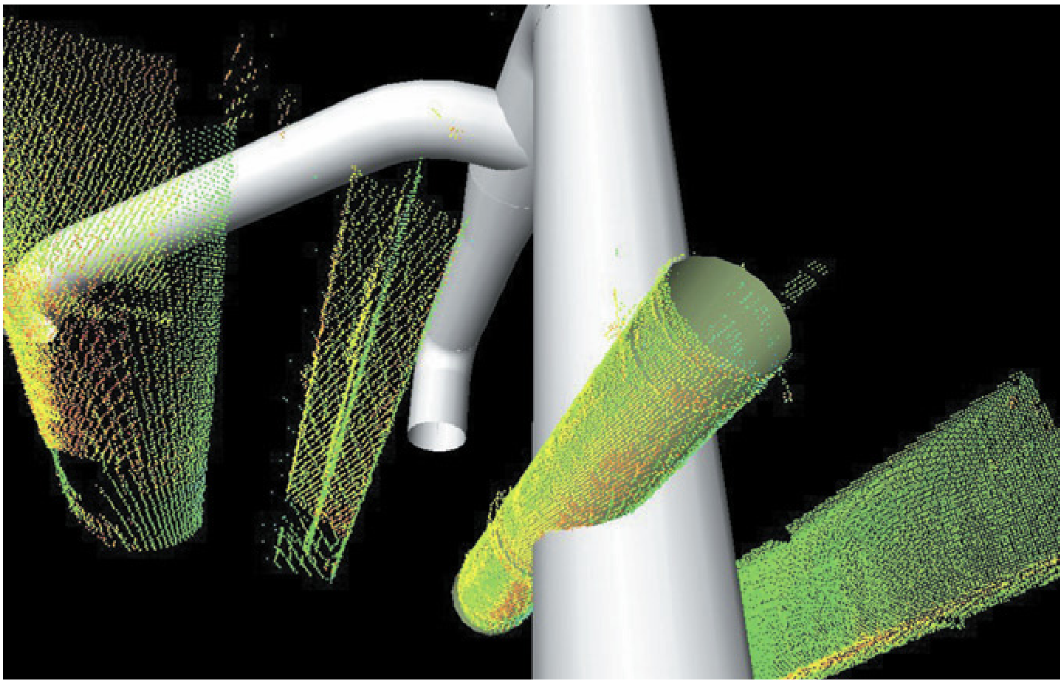

Figure 1. Collision of pipes. Points are laser scanned structures and pipes. The light grey pipe is the intended new pipe. (Jacobs 2006, 2)

As illustrated in figure 1, collisions of old and new structures can be avoided in early design state by using 3D laser scanning. In figure 1, the scanned point cloud is used as such, or very lightly modelled.

The Service unit has previously made one laser-scanning project. The scanning and the point cloud modelling was done by Neopoint Oy. The project consisted of 3D surface model, point clouds and grey scale raster images. (Haapala 2008, 1)

3 Terrestrial three dimensional laser scanning and PDMS

3.1 Introduction of 3D laser scanning

Terrestrial 3D laser scanning is the measurement of three-dimensional structures with a laser beam. As a product, a dense point cloud is obtained in the specified coordinate system. The point cloud can be processed to produce a continuous digital 3D model.

Laser scanning is expected to have an as profound effect on the field of surveying as GPS technology had in its time. Laser scanning is not limited to three-dimensional measurements only; it can be used to produce three dimensional computer models out of real world environments. It also makes reverse engineering of industrial plants and factories easy. However, laser scanning is a new technology. While the measurement itself is fast and easy, post processing the point cloud is still very time consuming.

Laser scanners were first presented in Germany in 1999. A Finnish company called Terrasolid Oy imported the first laser scanner to Finland in 2001. It was meant to scan construction sites. Many companies and various sectors in society are interested in 3D laser scanning. In Finland for example, Road Administration has studied its uses in bridge building.

Laser scanner is basically a laser range finder. There are many techniques for range finding, but most laser scanners use two different technologies, of which the first is so called time-of-flight method. The second technique is based on phase shift between outgoing and returning beams. Figure 2 represents Leica HDS6100 and Leica Scanstation 2 laser scanners. Scanstation 2 is a time-of-flight based and HDS6100 is a phase shift based laser scanner. (Heikkilä etc. 2004, 3; Ruohonen 2007, 7; Roe 2007, 1-3)

Figure 2. Leica HDS6100 (left) and Scantation 2 (right) laser scanners. (Leica HDS6100 2009, 1; Leica Scanstation 2 2009, 1)

3.2 Measurement techniques of 3D laser scanners

3.2.1 Time-of-flight method

The time-of-flight method takes advantage of the speed of light constant. The distance to the target is calculated by measuring the time it takes for a laser pulse to travel to the target and back. The principle of this measurement is illustrated in figure 3.

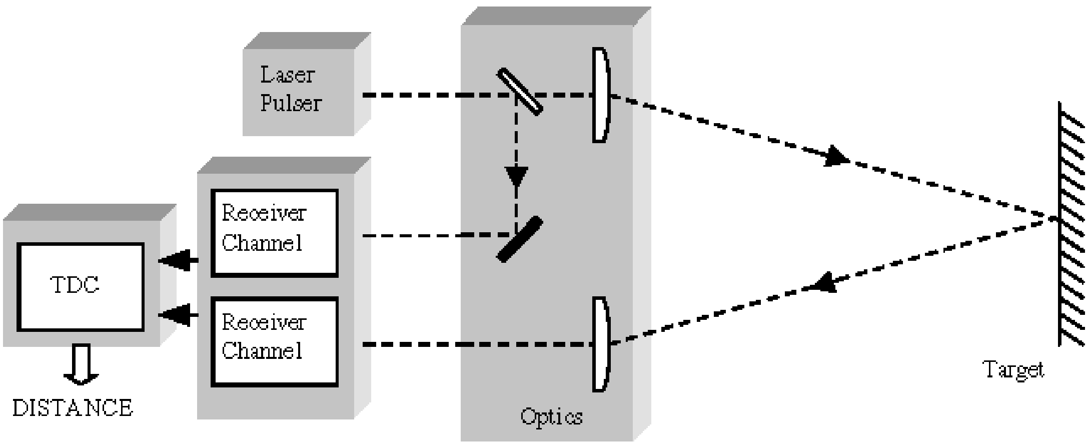

Figure 3. Principle of the time-of-flight method. (Palojärvi 2003, 17)

The laser pulse transmitter in figure 2 sends a short laser light pulse to the target. The outgoing pulse also goes to the time-to-digital converter (TDC). Timing is started in the TDC. The laser pulse is reflected from the target back to the TDC. The returning laser pulse stops the timing. With the help of the measured time, distance to the target is calculated by equation 1.

In uniform motion distance (d) is given by

$$d = \frac{c \cdot t}{2} \qquad (1)$$

where c is the speed of light constant and t is the measured time-of-flight.

The product of the speed of light and the time of flight must be divided by 2, because the measured time of flight is the time that the laser pulse takes to travel the distance twice.

For example, the distance between earth and sun can be calculated from the equation 1. Assuming that, it takes 8 minutes for light to travel the distance between sun and earth, so the time twice that is 16 minutes. Speed of light is approximately 300000km/s.

The distance between earth and sun, according to equation 1 is

$$\frac{300000 \cdot (16 \cdot 60)}{2} \cdot \frac{\text{km}}{\text{s}} \cdot \text{s} = 144000000\text{km}$$

The mean distance between earth and sun is around 150000000km, thus proving the equation 1. Error is introduced to the example above by approximate values of travel time and the speed of light.

Because the speed of light is so high, an accurate time measurement is required for an accurate distance measurement. For example, one nanosecond corresponds to the distance of 300mm, or 150mm of true distance. This technique requires very accurate time measurement electronics to reach millimetre scale accuracy. (Palojärvi 2003, 17; El-Omari & Moselhi 2008, 1-9)

One common feature in time-of-light laser scanners is their low amount of measurements per second. The low measurement speed is a result of the technique used. Typical amount of points measured in one second is below 10000.

The distance measurement alone is not enough to calculate the x, y and z coordinates of the point. The angles in horizontal and vertical plane are also required. Values that need to be measured are represented in figure 4. (El-Omari & Moselhi 2008, 1-9)

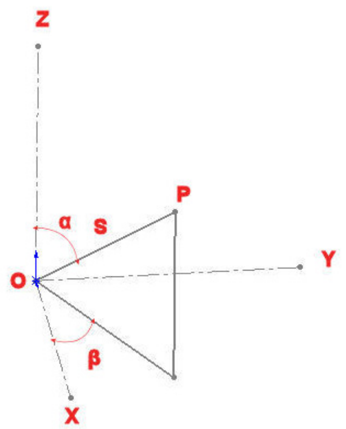

Figure 4. Values that need to be measured to calculate x, y and z coordinates.

Distance S, angles α, and β are the spherical coordinates of the point P. X, y, and z coordinates can be calculated from the spherical coordinates with equations 2, 3, and 4. (3D coordinate systems 2008, 3)

Spherical coordinates can be converted to x, y and z coordinates with equations

$$x = S \cdot \sin(\alpha) \cdot \cos(\beta) \tag{2}$$

$$y = S \cdot \sin(\alpha) \cdot \sin(\beta) \tag{3}$$

$$z = S \cdot \cos(\alpha) \tag{4}$$

where S is the radius of the sphere, α is the angle between vertical axis and the radius and β is the angle between x axis and projection of the radius on xy-plane.

The laser scanner calculates the x, y and z coordinates of the point automatically. Because thousands of measurements are made every second, a cloud of points is formed.

The point cloud represents the x, y and z coordinates of every point in the specified coordinate system.

In time-of-flight type laser scanners, the intensity of the laser pulse and the amount of light reflected off the target determines the maximum distance that can be measured. Many manufacturers give the maximum distance in the form of reflectance. For example, maximum range is 300 meters with 90 % reflectance, but only 50 meters with 10 % reflectance.

3.2.2 Phase shift method

Phase shift method uses continuous waves in different frequencies, as opposed to a single frequency pulse. Continuous wave of laser light is transmitted to the target. The wave is then reflected back to the scanner. Because it takes a certain amount of time to travel the distance between the scanner and the target, the outgoing wave and the returning wave are not in the same phase. This phase difference can be measured; which in return can be used to calculate the distance between the scanner and the target. (Bannister, Baker & Raymond 1998, 134-140)

Phase shift will be zero, if the distance between the target and the scanner is exactly the wavelength of the frequency used, or its multiple. Because of this, the only two measurements needed are the number of full wavelengths and the phase shift between the returning and the outgoing signal. The returning signal is always needed to measure the phase shift. This means that twice the distance between scanner and target is calculated. Distance between the target and the scanner in phase shift method is given by equation 5.

Distance (d) is given by

$$d = n \cdot \lambda + \frac{\Phi \cdot \lambda}{2 \cdot \pi} \qquad (5)$$

where n is the amount of full wavelengths, λ is the wavelength and Φ is the measured phase shift.

Usually, three different frequencies are used in laser scanners as illustrated in figure 5. In figure 5, d is the distance being measured and A and E are two different frequencies that have corresponding wavelengths of 40m and 50m. Third, the lowest frequency is the difference of frequencies A and E. The phase shift of the third frequency is also the difference of phase shifts of A and E. Frequencies A and E are selected so, that the third frequency has a wavelength suitable for the specified measurement range. (Bannister etc. 1998, 134-140; Kukko 2005, 7-8)

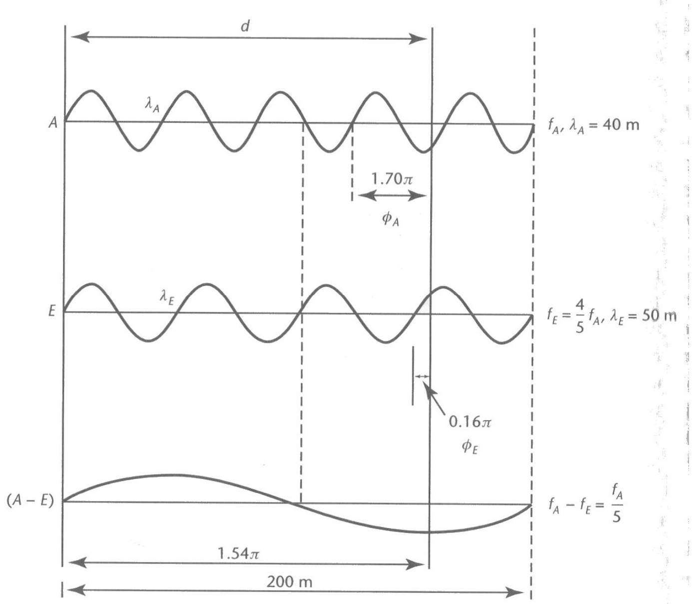

Figure 5. Three distinct frequencies of phase shift method. (Bannister etc. 1998, 138)

In figure 4, the phase shift of the frequency A is 1.70π. Frequency E has a phase shift of 0.16π. Their difference is 1.54π, which is the phase shift of the third frequency. From the given values it is known, that one wavelength of the third frequency is 200 meters. This corresponds to a phase shift of 2π. Now, the distance d can be calculated from the equation 5.

Distance d in the figure 4 is,

$$\frac{1{,}54 \cdot \pi \cdot 200}{2 \cdot \pi} \cdot \mathrm{m} = 154\mathrm{m} \qquad (6)$$

One of the most important features of this method is that a large part of the distance can be calculated without any error. That part is within full wavelengths. The only error producing measurement is the part that is the residual part between full wavelengths and the target. For example, in the case of frequency A, distance d is

$$3 \cdot 40 + \frac{1.70 \cdot \pi \cdot 40}{2 \cdot \pi} \cdot \mathrm{m} = 154\mathrm{m} \qquad (7)$$

While only one frequency could be used to determine distance d, three or more are used to calculate the number of wavelengths accurately. Phase shift method also has one important constraint. The number of wavelengths beyond one wavelength of the lowest frequency cannot be calculated accurately. Because of this constraint, the largest wavelength is also the maximum distance that can be measured.

The spherical coordinates of the point are measured like in time-of-flight method. The laser scanner then calculates the x, y and z coordinates of the point.

Because of phase shift method, these kinds of laser scanners can reach very fast measurement speeds. Most expensive models can measure up to 500000 points in one second. Generally, the measurement speed of a phase shift laser scanners is over 10 times the speed of a time-of-flight type scanner. (Bannister etc. 1998, 134-140)

3.2.3 Other measurement methods

Some 3D laser scanners use triangulation to find the distance to the target. In triangulation, laser emitter shines a laser dot on the target. A camera is then used to look for the location of the laser dot. Depending on the distance, the laser dot appears in different places in the field of view of the camera. The laser emitter, the camera and the laser dot on the target, form a triangle. Using geometry, distance to the target can be calculated.

Triangulation is not very widely used in laser scanners. One reason for this is the accuracy of these kinds of laser scanners. In triangulation laser scanners, the accuracy of acquired distances diminishes with the square of the distance. (Boehler & Marbs 2005, 2)

3.3 Measurement accuracy of 3D laser scanners

3.3.1 Angular increment and angular accuracy

Angular increment is the angle between two measurement beams. Angular accuracy determines how accurately the angles in horizontal and vertical planes are measured. Laser beam is usually deflected to the target by rotating mirror or prism. The second angle, perpendicular to the first, can be changed with mechanical axis or another rotating mirror or prism. Angular increment can be different in horizontal and vertical planes. (Kukko 2005, 11-12; Boehler & Marbs 2005, 3)

The angle between the two measurement beams determines the distance between the points on the target being measured. The distance between the points changes with the range of measurement. The longer the range is, the larger is the distance between the points. The distance between the points on target determines the smallest size of feature that can be scanned. This is sometimes called the resolution of the laser scanner. The angular increment and angular accuracy are illustrated in figure 6.

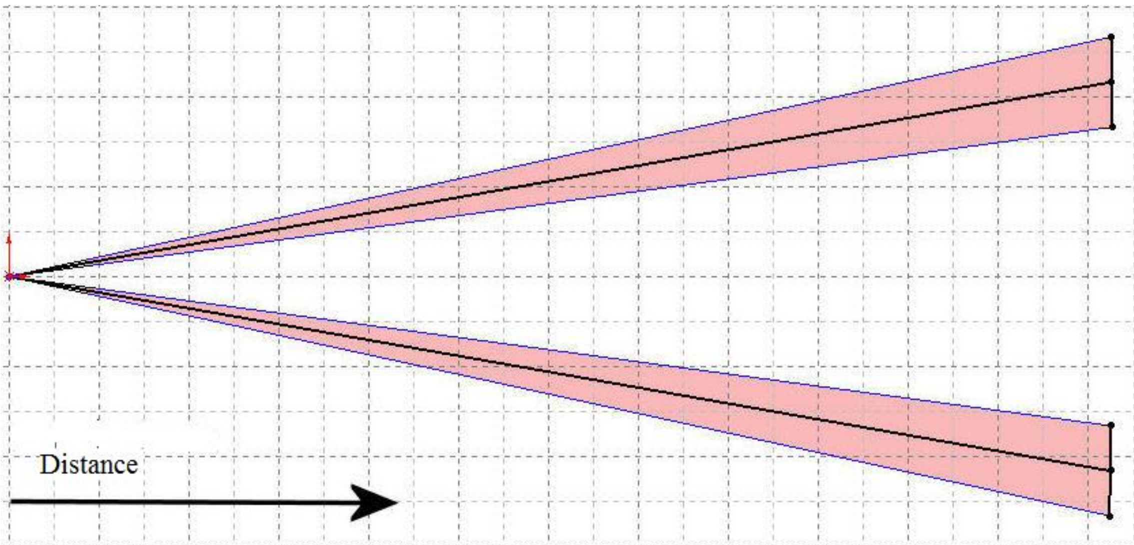

Figure 6. The black lines represent the measurement beams and red areas are the angular accuracy ranges.

The angular accuracy determines the accuracy of the point’s location. As angular increment, the angular accuracy also diminishes when distance becomes larger. Angular accuracy is determined by the mechanical properties of the beam-deflecting device and by the angle measurement electronics.

Boehler and Marbs (2005) have studied angular accuracy in laser scanners. Rather than comparing manufacturer specifications, which never tell the true performance of the laser scanner, they did measurement test. Their study involved 13 laser scanners. Because the error of a single point is very hard to determine, Boehler and Marbs used two small spherical objects that were scanned. The two spheres were then modelled from the point cloud and the distance between them was compared to the real distance of the spheres. In table 1, there are the results that Boehler and Marbs gathered. Results are mean errors that have been calculated from 12 individual scans.

Boehler and Marbs observed that there were large differences in accuracy between different manufacturers. A large error was usually resulting from the large angular increment and poor angular accuracy. The second factor that had an effect on the results was the beam diameter. They also pointed out, that not all scanners had been calibrated. (Kukko 2005, 9; Boehler & Marbs 2005, 1-17)

Table 1. Errors in horizontal and vertical directions and the absolute error. The number behind the scanner name means another scanner of the same model. (Boehler & Marbs 2005, 12)

Laser scanner/error	Vertical error/mm	Horizontal error/mm	Absolute error/mm
Callidus Precision Systems 1	5.6	4.3	12.2
Callidus Precision Systems 2	9.9	2.5	18.3
Leica HDS2500 1	0.8	0.8	1.6
Leica HDS2500 2	0.5	0.5	1.1
Leica HDS3000 1	1.3	1.1	2.9
Leica HDS3000 2	1.1	1.8	2.8
Mensi S25	3.8	3.4	9.2
Mensi GS100	1.9	2.3	3.3
Mensi GS200	4.7	2.2	8.3
Riegl LMS-Z210	10.2	16.8	27.1
Riegl LMS-Z420i	1.7	2.1	4.1
Riegl LPM-25HA	2.5	3.9	65
Zoller+Froehlich imager 5003	2.9	7.5	11.1

3.3.2 Laser beam diameter

The energy of the laser beam scatters in a specific angle. This angle is called divergence. Because of the divergence, the diameter of the beam tends to become larger as the distance becomes longer. At the same time, the energy of the laser beam is divided on larger area, so points are no longer exact points. The beam diameter with the angular increment and accuracy influences the ability of the laser scanner to measure small and sharp features.

Although all manufacturers give the beam diameter, the techniques used to measure the diameter can differ. The most common techniques are based on Gaussian profile of intensity. The intensity of a laser beam usually follows Gaussian profile. Figure 7 illustrates two techniques used to determine beam diameter.

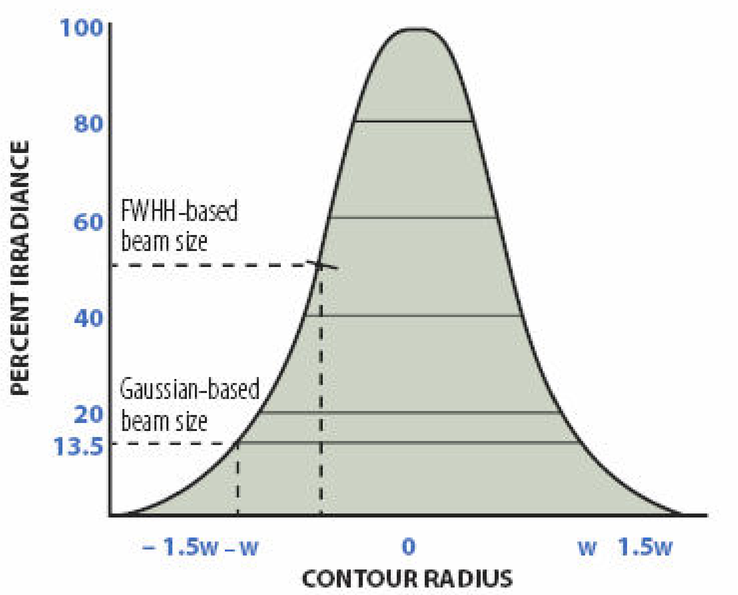

Figure 7. Intensity according to Gaussian profile and the two beam diameter definitions. (Jacobs 2006, 2)

Horizontal axis on figure 7 is the radius of the beam. On vertical axis is the intensity compared to the intensity in the middle of the beam. FWHH means a beam diameter where the intensity is 50 % of the intensity in the middle. (Kukko 2005, 13; Jacobs 2006, 1-3)

Gaussian-based means a beam diameter where the intensity is 13.5 % of the intensity in the middle. FWHH of course gives the smaller beam diameter, but at the same time, the beam intensity is still 50 %.

Manufacturers usually give the beam diameter at the scanner and then the divergence of the beam. For example, a 3mrad divergence gives a beam diameter of 160mm at the distance of 50m, when the beam diameter is 10mm at the scanner.

Beam diameter can be controlled with lenses. In this case, the beam diameter shrinks up towards the half distance and then starts to grow again. The result is that the beam diameter is the same at the full distance, as at the start.

The beam diameter influences measurement accuracy in two ways. It determines with the angular increment and accuracy the smallest features that can be scanned. Secondly, it causes false readings, as the beam is too wide to determine point exactly. This is why sharp edges and inclined surfaces are difficult to scan. (Jacobs 2006, 1-3)

3.3.3 Resolution

Resolution signifies the scanner's ability to distinguish features on the target being scanned. Angular increment, angular accuracy and beam diameter influence resolution. The smaller these values are, the smaller are the features that the scanner can distinguish. Because the distance between the points grows when the range becomes larger, the resolution reduces.

Figure 8 represents a statue of a parrot that has been laser scanned. On the left and in the middle, there are models made from the scanned point clouds. On the right is the picture of the statue. Point distance in the left model is about 1mm. The middle one has a point distance of 0.3mm.

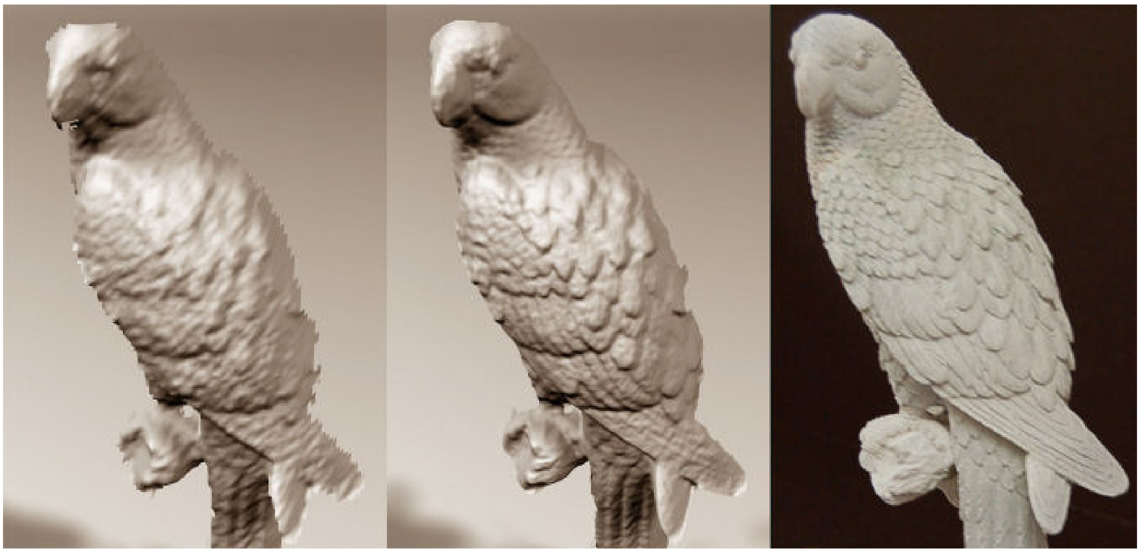

Figure 8. Parrot statue (right) and scanned models. (Joo Kil, Mederos & Amenta 2006, 2)

Figure 8 clearly proves that smaller resolution looses features. Another evident effect is the amount of noise at the edge of the statue (the unclear edges of the model).

Boehler and Marbs also conducted scanner resolution tests. They used a test box represented in figure 9. The size of the box is 300mm x 300mm x 55mm. With high resolution, points should be found at the surface of the box and at the back plane of the box between the slits. With a very high resolution, points should also be found towards the middle of the box. (Boehler & Marbs 2005, 8; Joo Kil, Mederos & Amenta 2006, 2)

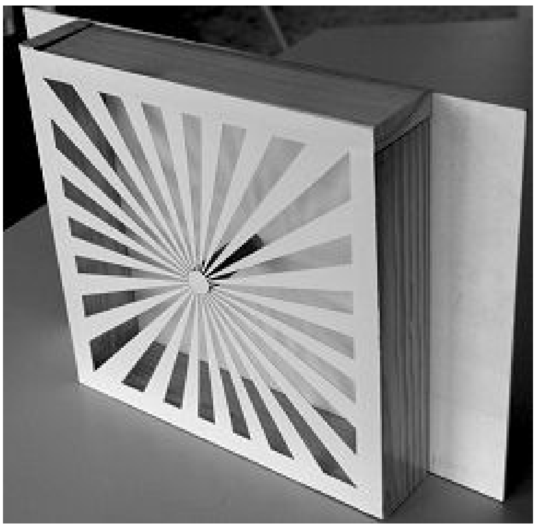

Figure 9. Test box used by Boehler and Marbs for resolutions test. (Boehler & Marbs 2005, 8)

The results of the resolution tests are represented in figure 10. In the middle of the figure 10 are the horizontal cuts of the point clouds scanned from the box. On the right are the scanned point clouds viewed from the front of the box. There should be two lines of points visible in the horizontally cut point clouds. All other points apart from the points on the two lines are false readings. They are points that did not actually exist in the real world, but because of scanner's accuracy, they have been measured.

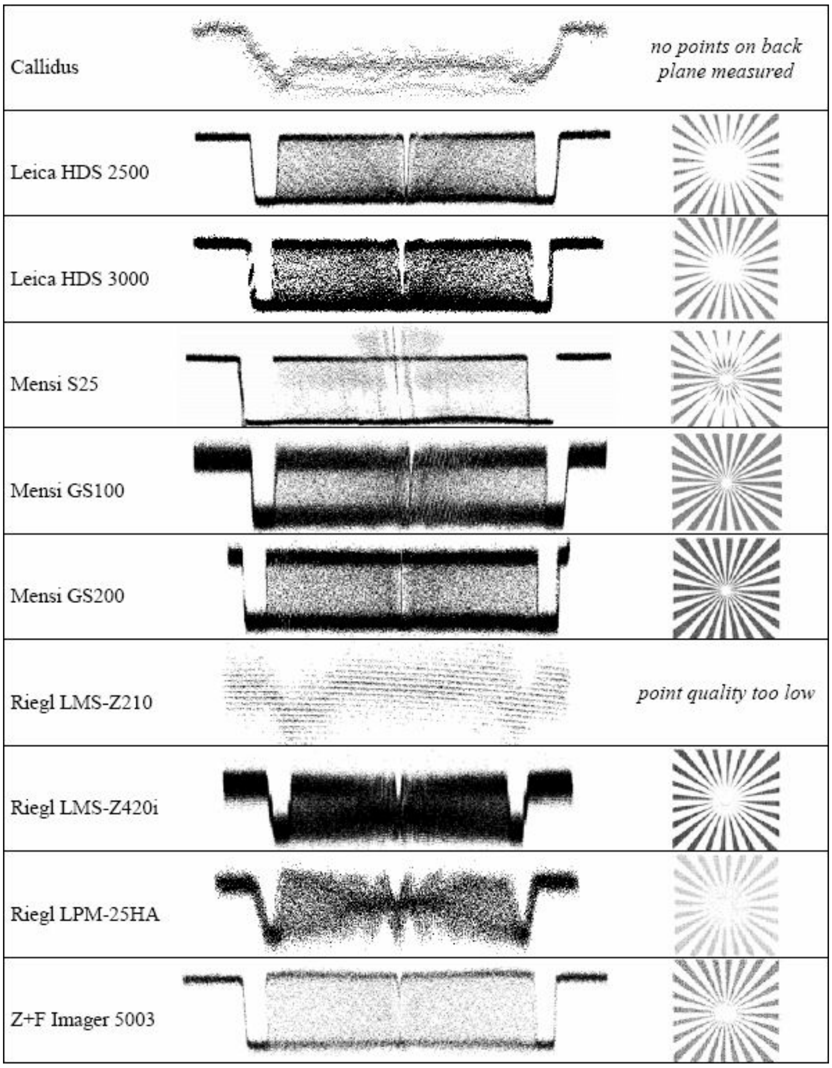

Figure 10. Results of the resolution test conducted by Boehler and Marbs. Scanning distance was 6m. (Boehler & Marbs 2005, 14)

The results clearly state that some laser scanners cannot distinguish features on the test box. Moreover, all scanners had measured points that did not really exist. These false points are called noise. The beam diameter being too large is one reason for noise. With adequate beam diameter and angular increment, difficult objects like the test box can be scanned.

All laser scanners produce noise to the scanned point clouds. The noise must be reduced somehow. The noise is usually partially removed by the scanner or with the point cloud software. However, it must be pointed out that Boehler and Marbs deliberately used a difficult and small test object. Noise effect is not as dramatic on actual structure scans. (Boehler & Marbs 2005, 1-17)

Resolution also influences the scanning time. The better the resolution is, the longer it takes to scan. El-Omari and Moselhi (2008) have studied the effect of resolution on scanning time. They used a time-of-flight type laser scanner. A couple of cardboard boxes were scanned at the distance of 4.3m. The angle scanned in the horizontal plane was 20 degrees and 17 degrees in the vertical plane. Results of their scanning time test are illustrated in figure 11.

It can be seen from figure 11 that resolution clearly affects scanning time. When it is pointed out that very small angles were scanned, resolution has a huge effect on scanning time. On the other hand, if a smaller resolution is adequate, the scanning time decreases very fast. (El-Omari & Moselhi 2008, 1-9)

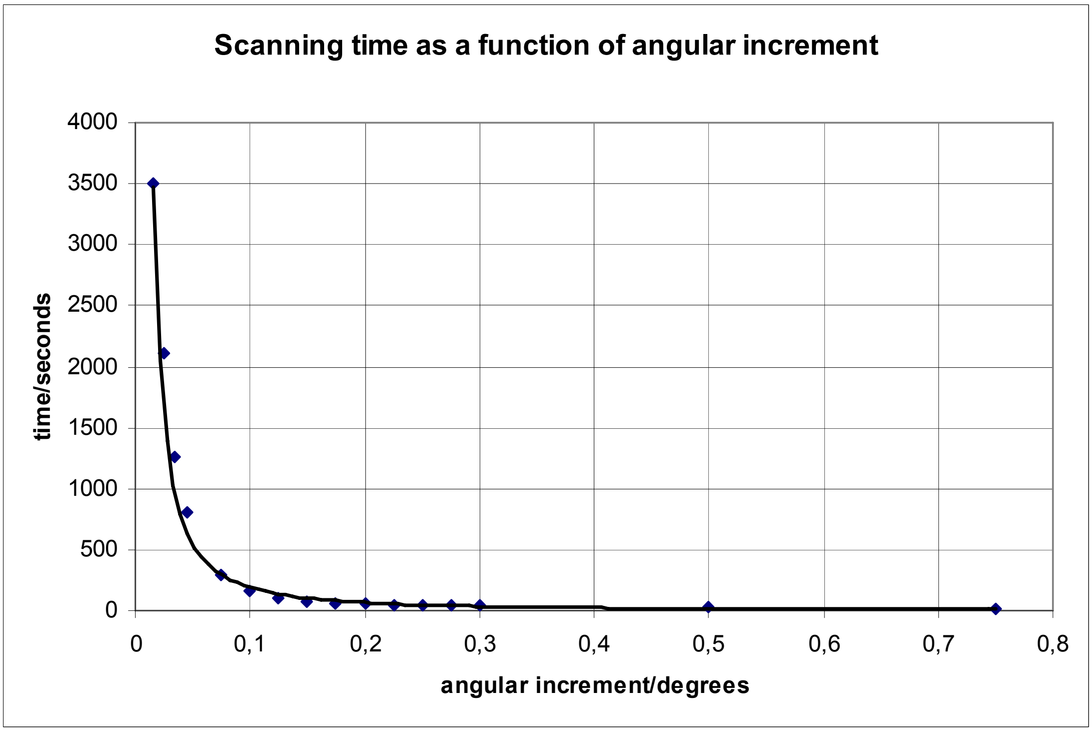

Figure 11. Results from the scanning time test done by El-Omari and Moselhi. (El-Omari & Moselhi 2008, 1-9)

3.3.4 Accuracy of the distance measurement

The accuracy in the distance measurements has two main sources of error. First is the error by the distance measurement itself. In time-of-flight type scanners, error is introduced by incorrect measurement of time. In phase shift scanners, error comes from the incorrect phase shift measurement. Second source of error is linked to the target being measured. The surface reflectivity has a large effect on accuracy. Some surfaces cannot be scanned at all.

Generally, metal surfaces and metal paints are difficult to scan accurately. Some scanners have difficulties to scan black surfaces. Environmental conditions can also create errors in distance measurement. As a clear view to the target is required, foggy or dusty environments can be difficult. Figure 12 represent the noise in distance measurement of the scanners tested by Boehler and Marbs in different ranges. The test was conducted on grey surface. (Boehler & Marbs 2005, 5-17)

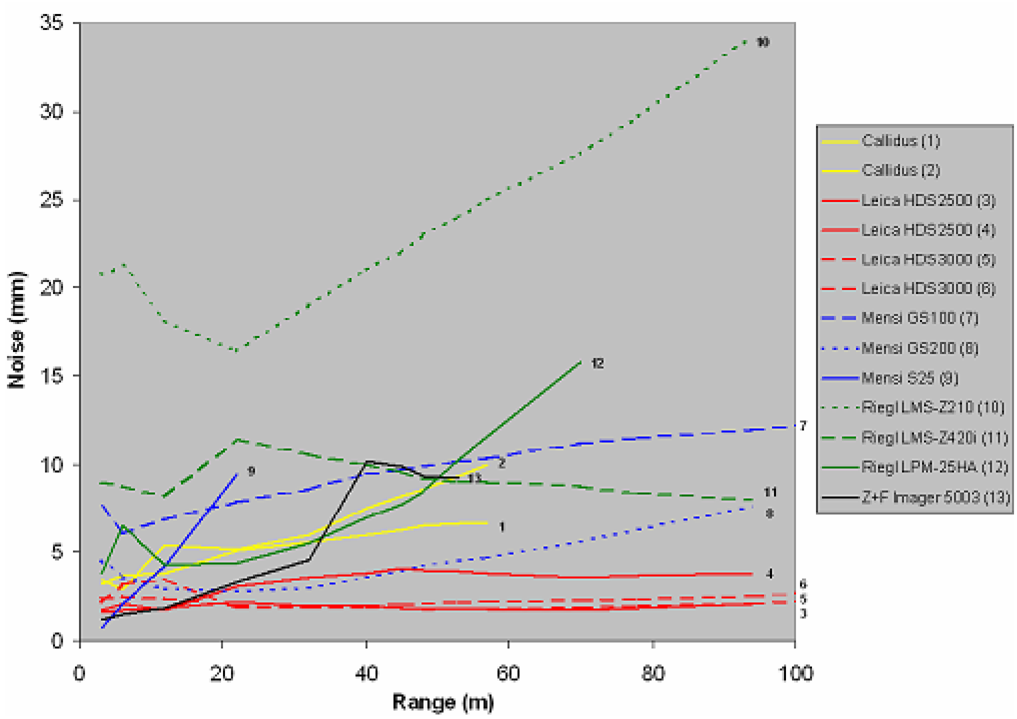

Figure 12. Noise of the laser scanners in different ranges on gray surface tested by Boehler and Marbs (standard deviation for a single point). (Boehler & Marbs 2005, 11)

It is evident from the figure 12 that some laser scanners have great difficulty in scanning gray surfaces even in small ranges. Moreover, their noise grows larger with range. On some scanners, noise is kept very low throughout the whole range.

3.3.5 Accuracy of scanner positions and joined point clouds

Since one scan cannot represent a 3D environment very well, several scans have to be made from different positions. All of those scanned point clouds must be integrated to the same coordinate system. In addition, often the point clouds must be in a certain co-ordinate system related to the real world.

If the point clouds must be in a real world coordinate system, GPS or similar surveying method must be used to find a reference point. Accuracy of laser scanning is usually lower than traditional coordinate finding methods, so surveying the scanner positions does not influence accuracy of the scan substantially.

There are several methods to unite point clouds. The most accurate of them is the use of common sights. Each point cloud must have at least three sights common to another point cloud. Centre points of the sights can be surveyed by tachymeter. Centres of sights are automatically determined from the point clouds. An accuracy of 1-3mm can be achieved by this method. Figure 13 shows two common sights (white spheres) for Faro laser scanner.

Common features can also be modelled from the point clouds. The common features then unites two point clouds or more. This method is not as accurate as the use of common sights. (Vahur 2003, 1-3)

Figure 13. Two common sights and a Faro laser scanner (indicated by the black arrows). (Ruohonen 2007, 26)

The third and latest method is to measure point clouds that overlap each other. At least one third of the point cloud must overlap another point cloud. Three common points are selected from both of the point clouds. Those points are then united together. This method can achieve an accuracy of 10mm. (Vahur 2003, 1-3)

3.4 PDMS basics

PDMS is an acronym for Plant Design Management System. As the name states, it is used for the design and design management of process plants. PDMS is a tool, which allows the user to model the whole plant into a computer 3D model. However, the system is not only for 3D model creation. Reports, drawings and other documents can be extracted from the system.

The PDMS model includes the accurate position and orientation of every component of the plant. It also includes detailed information about the components used in the plant.

Unlike conventional mechanical 3D CAD software, PDMS is arranged in hierarchical databases. Different disciplines of plant engineering use different databases. A single database also has a hierarchical construct. The figure 14 represents the simplified hierarchical structure of the Design database. (Aveva: Getting started with PDMS 2005, 1-37)

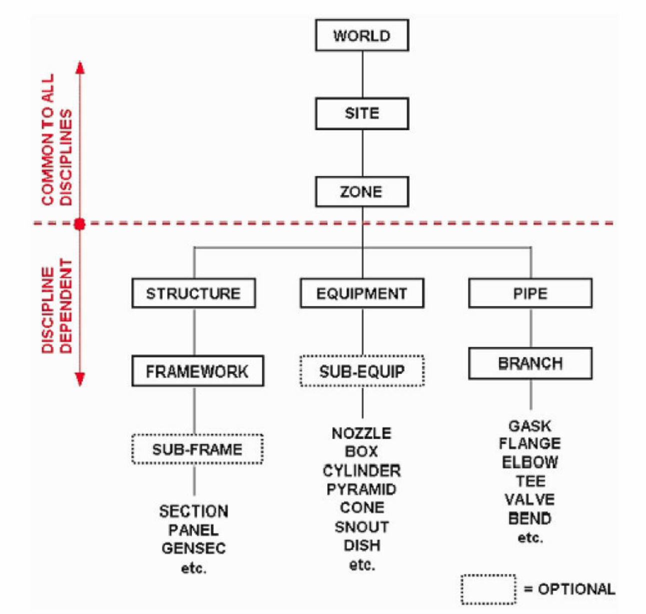

Figure 14. Simplified structure of the Design database in Aveva Vantage PDMS. (Aveva Getting started with PDMS 2005, 37)

The part below zone in the Design database is divided to different disciplines of plant engineering. These disciplines are then broken down to smaller parts. The lowest level of PDMS model is the primitive level. Primitives are basic shapes, cylinders, cones, boxes etc. All higher-level models are constructed with primitives of various sizes and shapes.

Every component of a PDMS model has a name, either given by the user or assigned by the system. Every component also has an owner. The owner of the component is the element one level above of the component in question.

Aveva supplies the PDMS system. Current versions in use are 11.5 and 11.6. Versions of 11.6, 11.6 SP3 and above support a module called Aveva Laser Model Interface. The Laser Model Interface can import point clouds scanned by 3D laser scanners. Point cloud can then be integrated to PDMS 3D model. The Laser Model Interface is discussed further in chapter 4.3. (Aveva: Getting started with PDMS 2005, 1-37; Aveva Solutions Product Support Site 2008, 1)

3.5 Models and drawings from the point clouds

A 3D model is much easier to comprehend and visualise than a point cloud. Therefore, if any way possible, modelling the point cloud to 3D model is preferred. Traditionally modelling takes a lot of time so time and cost considerations must be made when thinking of point cloud modelling.

Modelling from point cloud is mostly done by hand. Some automated modelling features are included in several software packages. These features include fitting algorithms and basic component libraries. Fitting algorithm can fit basic mathematical features to point clouds.

Like any modelling job, point cloud modelling takes a lot of time. Typical time spent for modelling work is 5…15 times the time spend scanning. This is an important feature to remember when dealing with point clouds.

Getting fully intelligent PDMS models out of point clouds is difficult. Usually models created from point clouds are “dummy” surface models. Meaning that they represent the surfaces of the real, scanned geometry accurately, but they do not include any additional information. PDMS models can be modelled from point cloud, but then the modelling has to be made in PDMS with Aveva LMI or the modelling software must have an ability to use PDMS component catalogues.

Drawings can be obtained from the point cloud, but this requires a 3D model. Slices and volumes can be selected from the point cloud and printed but they are not drawings. If the point cloud is thinned, then sections from the point cloud can be taken and printed. These sections can be very informative but they are not at all like 2D drawings.
(Boehler, Heinz, Marbs & Siebold 2002, 3)

3.6 Other deliverables from the point clouds

Some scanners can record the colour of the point being measured. This usually requires an optional digital camera mounted to the scanner. The scanned point cloud can then be overlaid with the colour image.

Panoramic grey scale images can also be processed from the point cloud. These are ordinary digital images that are viewed from the scanners position. The images can be viewed with a special spherical viewer, so it seems that the user is standing in the picture.

These grey scale panoramic images can be very useful. They are very light, and the program for spherical viewing is small. The images only include the points that were scanned, so there is very little of useless information in them. (Boehler etc. 2002, 3)

4 PDMS in Metso Power and laser scanning integration to it

4.1 General remarks

There are many ways to design a plant and different companies develop different techniques for it. There for it is useful to know the basics how plant design is carried out in Metso Power. The best way to learn was to interview experienced PDMS designers.

Companies usually are well informed about the software they use. Especially larger companies have a CAD master user, who follows the development of the software they use. There for it was natural to interview him to gain knowledge about Aveva Laser Model Interface.

4.2 PDMS design philosophy in Metso Power

When a new project is started, equipments and structures are usually copied from an older project. The old, copied 3D models are then cleaned and changed to suit the new project. Pipelines are usually not copied because they vary so much between different projects.

If the project in question is an old plant, then old structures are modelled when needed. Usually this is done in points where new structures are fastened to the old ones. Measurements for old structures are done by tape measurer on site. Photographs are also taken.

In old plant projects, collisions between old and new structures do happen. The two most common colliding structures are pipes and support structures for new equipment. The most difficult stage in PDMS design is pipe and duct routing, when considering old plants. (Maanoja 2008, 1)

A full 3D model of the old plant would be preferred but it takes a lot of time to model and that is not necessarily very cost effective. Same kind of time considerations have to be taken if laser scanning is applied to old plant as-built data retrieval. The point cloud can be used alone with PDMS design but then it comes down to performance issues of the system. If the point cloud impairs PDMS software performance, then it may not be the best course of action. (Maanoja 2008, 1)

4.3 Point cloud interfacing options for PDMS

Laser Model Interface can integrate point clouds to the PDMS 3D model. This PDMS module needs a third party program to work. Usually the third party program is the point cloud software for a specific laser scanner. To date, Laser Model Interface supports software from Faro, Leica Geosystems, Quantapoint, Trimple Dimensions and Z+F.

Metso Power has an option for Aveva Laser Model Interface licence and it can be brought online very fast. However, it also needs a second program as discussed earlier. This must be taken into account if Metso Power orders the point cloud from another company. The subcontractor that does the scanning must have a laser scanner, or more accurately, the laser scanner software, that can be integrated to PDMS via Laser Model Interface. Figure 15 represents the procedure of point cloud integration to PDMS.

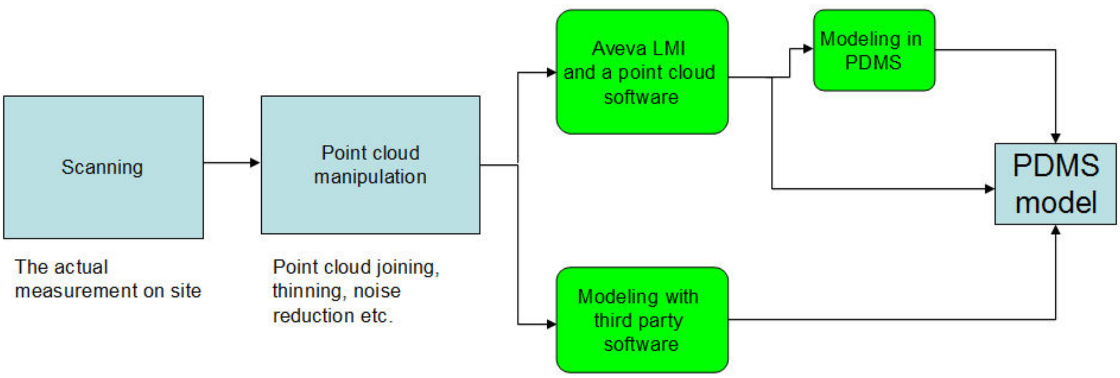

Figure 15. Procedure of laser scanning integration to PDMS.

Laser Model Interface cannot manipulate the point cloud. All point manipulation must be made with the point cloud software in question. The point cloud cannot be modelled directly from the Laser Model Interface. Old structures can be modelled to the PDMS using the Laser Model Interface and the point cloud as a surveying tool. The measured points act like a guide for modelling. In figure 16, point cloud is being used as a modelling guide. (Aveva Laser Model Interface 12.0 2007, 1-3; Ilomäki 2008, 1)

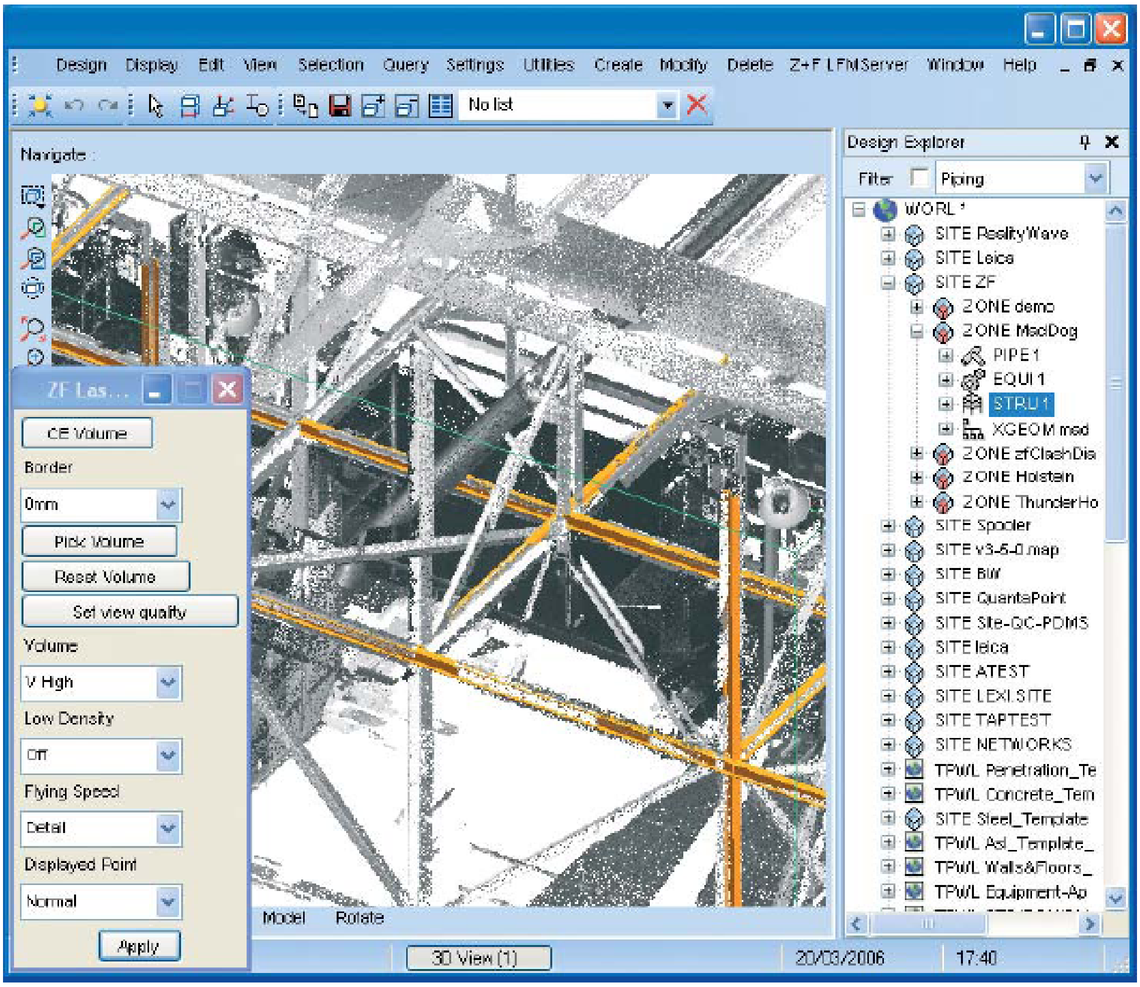

Figure 16. Point cloud used as a modelling guide. (Aveva Laser Model Interface 12.0 2007, 2)

Aveva clash manager can identify clashes between the point cloud and the PDMS model. Measurements between the point cloud and the PDMS model can also be made. Even without modelling, accurate position and clash check can be made with the new plant components.

5 Laser scanners and scanning services

5.1 General remarks

One of the objectives of this thesis was to find out what kind of costs laser scanning introduces. This chapter focuses on two separate ways to obtain the point cloud or the 3D model. Chapter 5.2 describes costs involving laser scanners equipment and software. Chapter 5.3 describes the cost of laser scanning services. Since costs are competitive edge of companies, they will not be showed here. Instead, all costs will be compared to the cost of Trimble GX.

The research was conducted by interviewing laser scanner distributors and making inquiries. Technical specifications for laser scanners were obtained from product brochures and by interviewing distributors. Laser scanning service providers were interviewed and asked to send a cost example.

Today, 11 manufacturers offer 20 different 3D laser scanner models. There is no common standard for technical specification data format, so some specifications cannot be directly compared. Manufacturers have their own specific ways to describe technical data. Some scanners did not have data available. Technical data given by manufacturer does not necessarily represent the actual performance of the scanner. Some kind of verification test would be ideal when thinking of a laser scanner investment. However, a rough comparison can be done with given data.

This study focuses on four manufacturers because other scanners do not support integration with Aveva PDMS. The compared laser scanners are from Trimble, Leica, Faro and Z+F.

3D laser scanning has made a breakthrough in surveying business. Today many companies provide laser-scanning service. Some companies are more focused on land surveys, some for mining industry. Four companies that provide laser-scanning service for plants were selected for interviews. The companies included are Pöyry Environment Oy, Elomatic Oy, Neopoint Oy and Mitta Oy.

5.2 Terrestrial 3D laser scanners

5.2.1 Trimble laser scanners

Trimble laser scanners are sold by Geotrim Oy in Finland. Trimble currently has two scanner models, GX and FX. Both scanners have a warranty period of one year. The warranty can be extended by making an annual payment. Geotrim Oy has Trimble service centre in Finland where faster services can be made. Services that are more complex must be made in Trimble European service centre. Manufacturer calibrates Trimble laser scanners before they are delivered to the customer. Field calibration can be made by user semi automatically. Technical specifications of Trimble laser scanners are represented in table 2. Trimble has not released technical specifications for FX scanner. However, it is basically the same instrument as Surphaser 25HSX. Geotrim Oy provides training for Trimble products.

Table 2. Trimble laser scanner specifications. (Trimble GX 3D scanner datasheet 2008, 1-3; Surphaser 25HSX specification 2008, 1-2; Immonen 2008a, 1-2)

Trimble			
		GX	FX
Scanner type		time of flight	phase shift
Max range	m	350	38
Max speed	points/s	5000	175000
Laser	nm	532	690
Laser class		3R	3R
Field of view(HxV)	°	360x60	360x270
Position accuracy	mm	12 /100m	1/15m
Distance accuracy	mm	7 /100m	1/15m
Weight in transport	kg	14.1	10
Operating temp	°C	0…40	5…45
Spot size	mm	3 / 50m	2.3/ 5m
Cost	units	1.00	0.88

Three optional point cloud softwares are available. Real works survey is high end point cloud software. It is better suited for surveying and geospatial industry. 3Dipsos is a 3D modelling software. It can export models to Aveva PDMS. LaserGen software suite is a point cloud software that can interface with Aveva Laser Model Interface. (Trimble Real works survey software technical notes 2007, 1-4; 3Dipsos 2008, 1; Trimble LASERGen Suite 2008, 1)

A basic scanner package includes scanner, transport case, power cables, tripod and scanning software. A field PC is needed for scanning; an ordinary laptop with scanning software will be sufficient. There are also two options for batteries, 4h battery and 8h battery. Trimble laser scanners align point clouds automatically, so no common sights are needed.

Trimble GX is more suited for surveying purposes because it has low scanning speed and small field of view in vertical direction. Moreover, it has a long range that is not really needed in plant applications. The FX scanner is clearly more suitable for plant engineering applications. High scanning speed and large field of view minimises the time spend scanning.

For plant engineering purposes, Realworks survey is oversized. 3Dipsos and LASER-Gen suites would be more suitable. They provide 3D modelling capabilities and an interface with Aveva PDMS. Since LASERGen can integrate point clouds with Aveva Laser model Interface, 3D modelling of the point cloud can be done in PDMS. Therefore, 3Dipsos is not necessary. LASERGen for PDMS can select volumes from point clouds so large point clouds can be handled easily. Table 3 represents costs for Real-Works survey and LASERGen for PDMS. (Immonen 2008b, 1)

Table 3. RealWorks Survey and LaserGen costs. (Immonen 2008a, 2)

Software	Cost
RealWorks Survey	0.22
LASERGen for PDMS	0.11

5.2.2 Leica laser scanners

Leica offers two laser scanner models. The Scanstation 2 is a time-of-flight based laser scanner. HDS6000 is phase shift based. Both scanners have a warranty period of one year. The warranty can be extended to three years, but then regular service is required. The extended warranty is bought by annual payments. Table 4 describes technical data for Scanstation 2 and HDS6000.

Table 4. Leica Scanstation 2 and HDS6000 technical data. (Leica Scanstation 2 2007, 1-2; Leica HDS6000 2008, 1-2; Vahur 2008a, 1-2)

Leica			
		Scanstation 2	HDS6000
Scanner type		time of flight	phase shift
Max range	m	300	79
Max speed	points/s	50000	500000
Laser class		3R	3R
Field of view(HxV)	°	360x270	360x310
Position accuracy	mm	6 /50m	10 /50m
Distance accuracy	mm	4 /50m	6 /50m
Weight in transport	kg	30 (¹	16.5 (¹
Operating temp	°C	0…40	0…40
Spot size	mm	6 /50m (²	14 /50m (²
Cost	units	1.03	0.94

(¹ with power supply unit
(² Gaussian based

Leica Nilomark Oy imports Leica products in Finland. They also offer professional training to all laser scanner buyers. Training is subject to a charge of around 3000 euros. Service is done in Leica Nilomark Oy in Espoo, Finland.

The Scanstation 2 package includes scanner, transport case, tripod, tribrach, Ethernet cable, user manual, cleaning kit and Cyclone-SCAN software. The package also includes two power supply cases each containing power supply, power supply charger and power cable for battery/scanner connection. For point cloud joining, Scanstation 2 needs common sights. Leica offers various models of common sights. A PC is needed for scanning. The Scanstation 2 can be mounted upside down if needed.

HDS6000 package includes scanner, transport case, Ethernet cable, two integrated batteries, charging/power cable, A/C cable, charging cradle, cleaning kit and Cyclone-SCAN software. Common sights can be printed on A4 paper sheets. The package does not include tripod or tribrach, so they must be bought separately.

HDS6000 can be mounted upside down. It can also be used as a moving scanner. For example, tunnels can be scanned by moving the scanner along the long axis of the tunnel. The HDS6000 does not need a computer for scanning control and it has an internal hard drive of 60GB for point cloud storage. (Vahur 2008b, 1)

Cyclone software suite is a collection of modules for point cloud manipulation. Cyclone-REGISTER is for point cloud joining operations. Cyclone-SCAN, which is included in both scanner packages, can register Leica common sights automatically. Cyclone-MODEL is a point cloud modelling software. It has a feature that semi automatically models pipelines from point cloud.

Leica CloudWorx for PDMS is a point cloud software that can interface with Aveva Laser Model Interface. The point cloud can be shown together with the PDMS 3D models. PDMS clash detection also works with CloudWorx. CloudWorx for PDMS has a feature that can detect pipe centre points. Volumes can be selected in CloudWorx so that working with large amount of point cloud data is easy. (Leica Cyclone 6.0 technical specifications 2008, 1-8; Leica CloudWorx 1.1 for PDMS 2008, 1-2)

Scanstation 2 has an oversized range for plant applications but it also is more accurate than HDS6000. HDS6000 has a lot better scanning speed. HDS6000 also has much higher transportability than Scanstation 2. This is an important factor when considering scannings abroad. HDS6000 has slightly larger field of view than Scanstation 2. Because of speed, weight and field of view, HDS6000 would be the better choice for plant as-built data gathering purposes. (Leica Scanstation 2 2007, 1-2; Leica HDS6000 2007, 1-2)

Cyclone-MODEL software would be the best choice for point cloud modelling, because it has important automated features that can reduce modelling time. CloudWorx for PDMS can interface with Aveva Laser model module, so modelling can be done in PDMS. This would make Cyclone-MODEL unnecessary. Cyclone-REGISTER is a clearly necessary software to have. In plant scannings one cannot always use common sights, so point clouds must be joined by some other method. In table 5 there are costs for MODEL, REGISTER and CloudWorx for PDMS softwares. (Vahur 2008b, 1)

Table 5. Leica software costs. (Vahur 2008a, 2)

Software	Cost	License
Cyclone-MODEL	0.20	1 PC
Cyclone-REGISTER	0.12	1 PC
CloudWorx for PDMS	0.07	1 PC
licenses include 1 year free updates		

5.2.3 Faro laser scanners

Faro has two 3D laser scanner models. Both models are phase-based scanners. The two Faro laser scanners are very similar. Actually, only the range changes between the two models. Technical data for Faro laser scanners are given in table 6. These laser scanners are modular. Their laser, mirror, laptop and base modules are individually changeable. Geostar Oy represents Faro in Finland.

Table 6. Faro laser scanner technical data. (Faro Photon 20/80 2008, 1-2; Jäppinen 2008, 1-2)

Faro			
		Photon 20	Photon 80
Scanner type		phase shift	phase shift
Max range	m	20	76
Max speed	points/s	120000	120000
Laser class		3R	3R
Field of view(HxV)	°	360x320	360x320
Distance accuracy	mm	2 /25m	2 /25m
Vertical resolution	°	0.009	0.009
Horizontal resolution	°	0.00076	0.00076
Weigth	kg	14.5	14.5
Operating temp	°C	5-40	5-40
Spot size ([1]	mm	3.3	3.3
Beam divergence	mrad	0.16	0.16
Cost	units	0.79	0.98

([1] at exit from the scanner

Faro offers several options for warranty. Standard warranty for laser scanners is one year. It includes service parts, labour and shipment back to customer. Faro laser scanners should be calibrated annually and the first calibration is included in standard warranty. Warranty can be extended to three years. It can also be upgraded to premium warranty. (Faro Photon 80/20 2008, 1-2; Faro LS catalog 2008, 1-42)

With premium warranty, the owner receives a loaned scanner during service. The loaned scanner is shipped next business day if there are scanners available. Premium warranty is available for one year and three year periods.

Standard accessories for Faro Photon scanner include a transport case, Ethernet cable, 24V power supply, two pairs of laser safety classes and a user manual. The power supply can be connected to A/C ranging from 90V to 285V. Both laser scanner packages have Faro record and Faro Scene softwares, one license each.

Both Faro scanners need common sights to join multiple point clouds. Faro offers white spherical targets for common sights. Tripod and tribrach are also needed. Faro laser scanners can be controlled via PC or PDA using Ethernet or WLAN connection, although they can be used without external control. In this case, data is recorded to internal 80GB hard drive.

Faro record is point cloud viewing software. It can also control Faro laser scanners. It has basic analysis tools for point clouds, for example distance measurement. Faro scene is also point cloud analysis software but it is more sophisticated than Faro Record. For integration to Aveva PDMS, INOVX RealityLINx software is required. (Photon - Process, Power & Piping Package 2008, 1-2)

5.2.4 Z+F laser scanners

Z+F (Zoller+Froehlich) laser scanners are represented by Mitta Oy in Finland. Z+F currently has two laser scanner models, IMAGER 5006i and IMAGER 5006EX. Both scanners are phase based. The IMAGER 5006i and 5006EX are based on the same instrument, but the 5006EX is approved against hazardous areas. 5006EX can be used in explosive areas. Technical specifications of Z+F IMAGER 5006i are represented in table 7.

Basic package includes a tripod, two batteries, A/C power cable, Ethernet cable, battery recharger and a Lasercontrol software. The battery life is about 1.5 hours. Common sights are needed for point cloud joining and they can be printed on A4 paper. Spherical sights are also available.

IMAGER 5006i can be controlled individually, or with PC or PDA. Ethernet or WLAN establishes connection to PDA or PC.

Standard warranty period is one year. It includes one scanner calibration. The calibration must be done after 130 days or certain amount of scans. The manufacturer in Germany conducts the calibration. (Technical data Z+F Imager 5006i 2008, 1-2)

Table 7. Z+F laser scanner technical specifications. (Technical data Z+F imager 5006i 2008, 1-2; Lappi 2008a, 1-2)

Z+F		
		5006i
Scanner type		phase shift
Max range	m	79
Max speed	points/s	500000
Laser class		3R
Field of view(HxV)	°	360x310
Linearity error	mm	1 ([1]
Vertical resolution	°	0.0018
Horizontal resolution	°	0.0018
Weigth	kg	23
Operating temp	°C	-10…45
Spot size ([2]	mm	3
Beam divergence	mrad	0.22
Cost	units	1.11

([1] up to 50m
([2] at 1m distance

The Lasercontrol software is used to join point clouds or to control the laser scanner. The program can visualize scans, either as 2D grey scale images or as 3D point clouds. Measurements from point clouds can also be made with this software. ProjectView software is a server-based tool. Scans can be stored in central server and accessed by any relevant person by Internet explorer. With ProjectView scans can be redlined.

Light From Modeller is a selection of software modules intended for point cloud manipulation. Different modules provide support for modelling, point cloud registering and viewing. LFM Server PDMS link module can be interfaced with Aveva Laser Model Interface. It has a feature that can detect clashes between the point cloud and the PDMS model. The LFM Server can handle unlimited amount of point clouds, and the user can select a volume of interest.

The IMAGER 5006i is almost the same equipment as Leica HDS6000. Being a phase based scanner, IMAGER 5006i would be ideal for as-built data gathering. The speed and accuracy of the scanner are at least adequate for plant scanning purposes. Battery life of 1.5 hours is not ideal since scanning large plants will take more time. To counteract this, the scanner comes with two batteries, so that when one battery is used, one is being recharged. (LFM Family Overview n.d., 1-4; Mikkonen 2008a, 1)

LFM Server application with PDMS link is of course needed when interfacing with Aveva PDMS. No other additional software would be needed, although LFM Register could be useful. The Register module can join scans in multiple ways. The cost of the LFM server and PDMS link is 0.073 units. (Mikkonen 2008a, 1)

5.3 Laser scanning service providers

5.3.1 Pöyry Environment Oy

Pöyry Environment offers laser-scanning services for industrial and general applications. They use scanning systems supplied by Leica. The company currently has two laser scanners, Leica HDS3000 and HDS6000. They have previously made 50 industrial scans.

Pöyry uses Leica Cyclone and CloudWorx softwares, so exporting models to Aveva PDMS is not a problem.

Pöyry Environment sent two cost example cases. First case was a point cloud model from a volume of 30x90x20m. The point cloud was united and tied to a coordinate system. The project also included documented photographs and a raster model of the area. The cost of the project was 0.08 units+ project expenses.

The second example project was modelled into 3D surface model. The volume scanned and modelled was slightly smaller than the first. The budgeted cost for the project was 0.188 units + project expenses.

Cost of a laser-scanning project depends heavily on the end product and the size of the project. Modelling the point cloud raises costs. (Mäkelä 2008a, 1; Mäkelä 2008b, 1-8; Mäkelä 2008c, 1-3)

5.3.2 Elomatic Oy

Elomatic Oy does not own laser scanners; instead, they have several cooperating companies that provide the actual scanning. Since projects are all different and new laser scanner models are introduced very frequently, they use a laser scanner that is best suited for the task.

The company started doing laser-scanning projects in 2001. Today they do laser scanning projects for plants, ships and smaller projects for single components. Elomatic does laser scanning projects roughly once per month.

The company has several point cloud modelling softwares. For plant engineering projects for Aveva PDMS, they use 3Dipsos or Cyclone. 3Dipsos is provided by Trimble software. Cyclone is a Leica product, and whenever needed, Elomatic rents the licence. They can supply 3D surface models to Aveva PDMS, or full PDMS models, if the customer wants it.

Rough cost estimate for a scanning of one day is 0.031 units. One-week (40 h) of modelling costs about 0.030 units. However, these costs are rough estimates and the real cost of laser scanning project varies considerably. (Sundberg 2008, 1)

5.3.3 Neopoint Oy

Neopoint Oy has done about 60 industrial laser-scanning projects. Mr Heikkinen, the company CEO, has done over 100 projects individually.

Neopoint owns two laser scanners, Surphaser 25HSX and Leica HDS2500. They use different scanners because different projects need different scanners. If a customer wants a specific scanner, they can rent one.

The company can supply 3D models to most commercial CAD systems, including Aveva PDMS. Models are surface models; they do not supply intelligent PDMS models.

Neopoint Oy has made one laser-scanning project for Metso Power Oy. The volume scanned was about 20x20x20 m and consisted of around 100 individual scans. Steel structures, cabling and parts of the piping were modelled. Cost for the project was 0.210 units. (Heikkinen 2008a, 1; Heikkinen 2008b, 1)

5.3.4 Mitta Oy

Mitta Oy has previously done four full plant-scanning projects and several projects where parts of a plant were scanned. For plant scanning projects, they use Z+F 5006 scanner, which is an older model of 5006i. If a longer range is needed, then they have Leica HDS3000.

The company can supply a 3D model to Aveva PDMS. For modelling purposes, they use RealWorks software. Currently Mitta Oy is searching for pilot project for LFM modeller/Server applications.

Cost for a sample project was asked from Mitta Oy. The project was only theoretical. Scanning time for the project was three days and modelling time after that was three weeks. The project was done in Finland. Mitta Oy sent a rough cost estimate for the project. The cost estimate is presented in table 8.

Table 8. Project cost estimate. (Lappi 2008b, 1)

Project part	Cost
Scanning	0.04
Modelling	0.08
Total	0.12

Costs above are rough estimates, and not for a real project. However, they do represent an obvious result. Modelling point clouds triple the costs. (Mikkonen 2008b, 2; Lappi 2008b, 1)

6 Summary

6.1 Interfacing point clouds with PDMS

There are three ways to get as-built data to PDMS using laser scanning. First, the point cloud can be modeled by external software and then transferred to PDMS. Second option is that the point cloud can be brought to the PDMS via Aveva LMI and used as such. Third option is to bring the point cloud to the PDMS via LMI and then model it in the PDMS.

The first option is preferred because it produces 3D model. 3D model is much easier to understand than large number points and collisions between old and new structures are more evident. Moreover, no additional software is needed if the scanning and modeling are bought from a sub contractor.

There are a couple of disadvantages, too, in the first option. Modeling takes a lot of time and that raises costs. Secondly, not all external programs produce intelligent PDMS models.

The option where point cloud is transferred to PDMS with Aveva LMI is more cost effective. In this case, modeling time and costs are eliminated. However, other costs are introduced because this option also requires software from laser scanner manufacturer.

Third option can produce an intelligent PDMS model, but lot of time is required for modeling. In addition, third party software from laser scanner manufacturer is required.

It is evident that software for point cloud modeling is much more expensive than the software required for Aveva LMI integration. This produces an interesting option. The actual scanning and point cloud joining can be bought from a sub contractor. Then the point cloud could be integrated to PDMS with Aveva LMI. Since PDMS can detect clashes with point clouds, no modeling of the old structures is needed. This way costs would be minimized and Metso Power would still have the as-built data.

6.2 Best case scenario for Metso Power Oy

A laser scanner is a big investment. With required software, the initial investment would be around 1.250 units. Some scanners require additional equipment, for example, tripod and common sights, but their costs are usually less than 1 % of the total cost of scanner and software. Training and up keeping the knowhow of personnel introduces further costs. Final comparison chart between the laser scanners researched in this thesis is provided in appendix 1.

There is also an additional risk involved when owning a laser scanner. The laser scanner equipment is quit heavy and large for transport by air. There is a risk that the scanner will just sit at the corner of the office. Moreover, the models become obsolete very fast.

Modeling the point cloud will increase costs fast, so it should be avoided. The point cloud alone provides enough information to make new designs to old plants.

If the scanning and the modeling are bought from a subcontractor, cost of a single project is from 0.125 to 0.250 units. This means that roughly five projects can be made with the cost of one laser scanner and software. There is also less risk involved. There are a lot of companies that provide laser scanning service so a healthy competition exists on the market. This will reduce the costs further.

Best option would be to buy software that can interface with Aveva LMI. That would mean a one-time cost of about 0.06…0.12 units. After that, the scanning should be outsourced to a subcontractor. The subcontractor would do the actual scanning and point cloud joining. Metso Power would still have the as-built information that could be used in Aveva PDMS but the costs would be minimized.

Buying software, that usually only works with a certain laser scanner is a risk. The risk is a small one because many laser scanning companies can provide the scanning with a laser scanner specified by buyer.

For example, if the software that interfaces with Aveva LMI were Leica CloudWorx for PDMS, the initial cost would be about 0.06 units. The scanning bought from a subcontractor costs about 0.05 units, so total project cost would be under 0.12 units for the first project. Of course, for the following projects, the cost would be about a half of that. This means that about 19 projects cloud be done with the cost of one laser scanner and software. Cost comparison between different ways to use laser scanning in a project is represented in the figure 17.

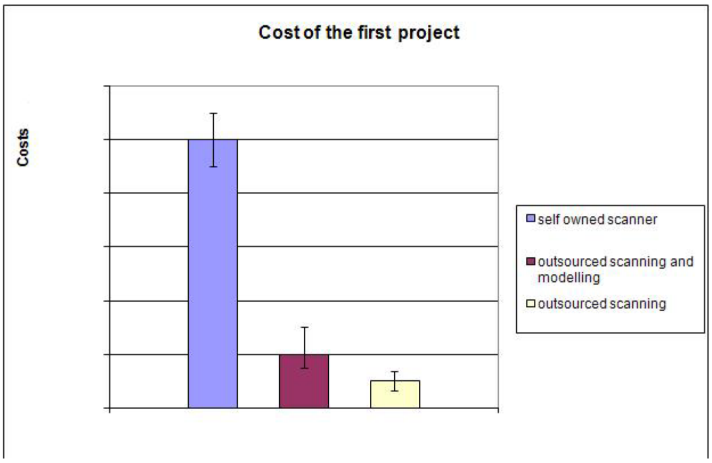

Figure 17. Costs of the first laser scanning project with different options. Error bars represent the difference between manufacturers or subcontractors.

The scanning is also very fast, so minimal time is required for it. This means that the as-built information is available very early in the project.

The cost of a laser scanning project varies with size of the project. The larger the project is, the higher the costs are. Before buying a laser scanning service, it should be considered which parts of the plant in question need to be scanned. There is no point to scan the whole plant; it just results to a large volume of data. However, if 2D drawings are the preferred output from lasers scanning, the situation becomes somewhat different. 2D drawings require a 3D model, so the point cloud must be modeled. Since modeling takes a lot of time, this raises cost. The modeling can be done in PDMS with Aveva LMI, or done by subcontractor.

In this case, there is no point to buy suitable link software to Aveva LMI for modeling; instead, the modeling should be bought from the subcontractor. That way, Metso Power does not need additional software or human resources for point cloud modeling.

7 Conclusions

The first objective of this thesis was to introduce 3D laser scanning. The second objective was to find out how 3D laser scanning can be integrated to PDMS what kind of costs it produces.

3D laser scanning is the measurement of structures with a laser beam. Laser scanning data is accurate enough for plant engineering purposes. The end product can be point clouds, surface models, drawing or images. Laser scanning can be used to digitize real world environments.

Point cloud modelling takes a lot of time and that raises costs. If anyway possible, modelling should be avoided. The PDMS can detect clashes between the point cloud and the new design. 3D model is not necessary.

The most cost effective method to use laser scanning in PDMS is to import the point cloud into it. The point cloud scanning and joining should be outsourced to a subcontractor. Software that can interface with Aveva LMI is needed.

If the as-built data is needed in the form of 2D drawings, then the most cost effective solution is to outsource the complete scanning project to a subcontractor.

There were no actual tests done during this thesis. It would have been interesting to test how the point cloud can be integrated to PDMS. It would have also provided feedback on PDMS performance with point clouds.

Some laser scanning project costs are rough estimates. When considering a laser-scanning project, real requests for quotation should be made. Projects also vary a lot, so it is difficult to establish a base line for laser scanning project cost.

There are more than four laser scanning service providers in Finland, but because they are smaller than the companies selected for review, they were not included to this thesis. In addition, foreign companies were not included. Since Metso Power operates around the world, it could be that local service provider would be cheaper.

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Appendix

Appendix 1: Final comparison chart of laser scanners

Final comparison chart								
Manufacturer		Faro	Faro	Leica	Leica	Trimble	Trimble	Z+F
Model		Photon 20	Photon 80	HDS600	Scanstation 2	GX	FX	Imager 5006i
Scanner type		phase shift	phase shift	phase shift	time-of-flight	time-of-flight	phase shift	phase shift
Max range	m	20	76	79	300	350	38	79
Max speed	points/s	120000	120000	500000	50000	5000	175000	500000
Field of view(HxV)	°	360x320	360x320	360x310	360x270	360x60	360x270	360x310
Equipment	x=included/ empty= not included							
Tripod					x	x		x
Tribrach					x			
Transport case		x	x	x	x	x		
Battery		x	x	x	x			x
Power cables		x	x	x	x	x		x
Ethernet cable		x	x	x	x			x
Battery recharger		x	x	x	x			x
Scanning software		x	x	x	x	x		x
Sights								
Warranty	years	1	1	1	1	1	1	1
Cost	units	0.788	0.981	0.938	1.031	1.000	0.875	1.113
Optional software		INOVX	INOVX	Cyclone	Cyclone	RealWorks Survey	RealWorks Survey	Project view
		RealityLINx	RealityLINx	CloudWorx	CloudWorx	3Dipsos	3Dipsos	Light From Modeller
						LaserGen	LaserGen	
PDMS link software		RealityLINx	Reality LINx	CloudWorx for PDMS	CloudWorx for PDMS	LaserGen for PDMS	LaserGen for PDMS	LFM server PDMS link
Cost	units			0.064	0.064	0.113	0.113	0.073
Notes		80 Gb	80 Gb	Sights can be printed		Laptop needed		Sights can be printed
		hard drive	hard drive	on A4		for scanner control		on A4