



Western Norway  
University of  
Applied Sciences

# BACHELOR'S THESIS

Laser scanning of power lines

**Dieter Dens**

**Tuur Peeters**

Bachelor in construction

A project in cooperation with Statnett

Department of Civil Engineering

Advisors: Loftur Thor Jonsson/ Trond Nordvik/ Stig Frode Samnøy

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I confirm that the work is self-prepared and that references/source references to all sources used in the work are provided, cf. Regulation relating to academic studies and examinations at the Western Norway University of Applied Sciences (HVL), § 10.

## Preface

This Bachelor thesis was written at Western Norway University of Applied Sciences Bergen, Department of Civil Engineering, Spring 2019 for the company Statnett. In this thesis you can find 3D models of electricity pylons and their surrounding terrain with the use of laser scanning technology.

This thesis was written by Dieter Dens and Tuur Peeters, 2 construction engineering exchange students from Belgium with Loftur Thor Jonsson, Trond Nordvik and Stig Frode Samnøy as internal supervisors and Frode Kutschera as Statnett's employer. The task was assigned to us 5 days after we arrived in Bergen 6.02.2019 by Loftur Thor Jonsson. 2 days after this meeting we met Trond Nordvik and Stig Frode Samnøy both teachers at HVL. Together with them, we have further developed the assignment for laser scanning. Stig Frode Samnøy contacted the company Statnett, which had given us the following assignment about the powerlines. In the beginning the thesis was not very clear and very detailed so we attended the lessons LEI110-1 19V Industrilandmåling og laserskanning to learn more about the operation and the theory of the laser scanner.

The tasks around the assignment were interesting, exciting and very challenging. This was the first time that we learned to work with a laser scanner and also that we used various land surveying equipment in such a unique location.

We would like to thank Loftur Thor Jonsson for searching together with us for a land surveying assignment. We also want to thank Trond Nordvik and Stig Frode Samnøy for their help with the questions we had about laser scanning. Certainly Trond Nordvik because he made a lot of time for us.



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*Dieter Dens*



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*Tuur Peeters*

*Bergen, May 2019*

## Abstract

In this thesis we will talk about a terrestrial laser scan of an electricity pylon that we have performed for the company Statnett. The aim of this research is to get an idea of which method is most efficient for measuring electricity pylons and what technique should be used. We will also look at the advantages that are not necessarily related to the scanning itself.

We will compare these results with photogrammetry data from a drone. Both scans have been converted into a 3D model in order to be able to compare them with each other. We will also compare the data with the data from Høydedata.no. This is a database where you can find detailed altitude data generally collected using airborne LIDAR of all Norway.

A general conclusion is that the laser scanner is better for measuring the pylon than the drone scanner, but the drone is better for measuring the surrounding terrain. The drone is also easier to transport than the laser scanner, which can be an advantage in some areas. For larger areas and difficult terrain, it is better to use a drone because the range is much bigger. The laser scanner scans much more in detail with difficult shapes because it scans from different positions and has a higher accuracy.

To place the obtained point cloud in the world coordinate system it is best to use total station, GNSS and targets that you place around the object and the terrain to be scanned. This method is the most accurate to use and causes the least errors.

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## List of abbreviations

Euref	Reference Frame Sub Commission for Europe
UTM	The Universal Transvers Mercator
GNSS	Global Navigation Satellite Systems
GPS	Global Positioning System
WGS84	The World Geodetic System 1984
ppm	Parts per million
ICP	Iterative closest point
GLONASS	Global Navigation Satellite System
ITRS	International Terrestrial Reference System

# 1 Introduction

As part of the management and maintenance of the electricity pylons, there is a need to check the condition of the pylons. Due to the large spans and heavy snow and ice loads on the cables, there are large forces on the electricity pylons. In some places these forces are too great, and an extra pylon must be placed to prevent the cables or pylon from collapsing.

Statnett is the system operator in the Norwegian energy system, owning and operating the transmission grid and maintaining the balance between consumption and production. Statnett is a state enterprise owned by the Norwegian state through the Ministry of Petroleum & Energy. They operate about 11 000 km of high-voltage power lines and 150 transformer stations.

The device we used to perform our measurements is the Leica P20, it is a relatively new device that we had at our disposal by HVL.

## 1.1 Subject/ Research question

We have measured the terrain in a period with snow and a period without snow and compared these 2 different models with each other. We will search for the differences between the methods of measuring. Which method is the best for measuring electricity pylons and their surrounding terrain?

We have measured electricity pylons and their surrounding terrain with a laser scanner with an emphasis on detail, accuracy, coverage and efficiency. We have converted this measured data into 3D drawings and compared it with data from Høydedata.no and with photogrammetry data from a drone. Høydedata is a database where you can find detailed altitude data of all Norway. The data of the drone is obtained by another group.

## 1.2 Information about the area

Location (Figure 1): 5226 Bergen  
Hordaland  
Norway

Coordinates Pylon (Figure 2): Tower 1  
60.324689, 5.443699  
Euref89 UTM32

You can find more pictures of the location in Appendix A.

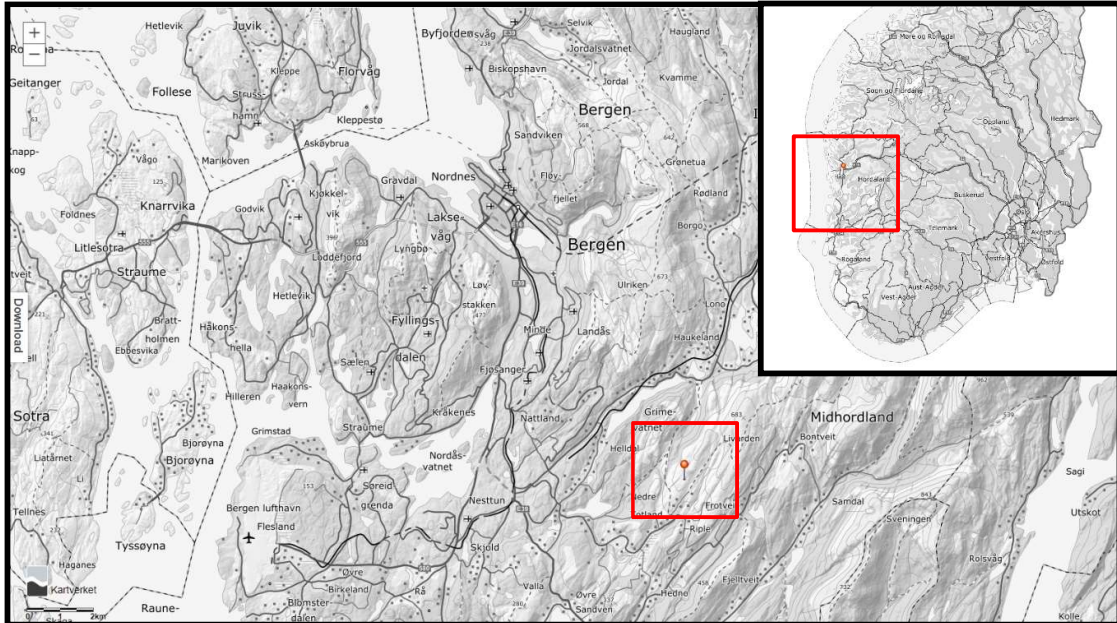


Figure 1: Location in Norway, Bergen (Høydedata)

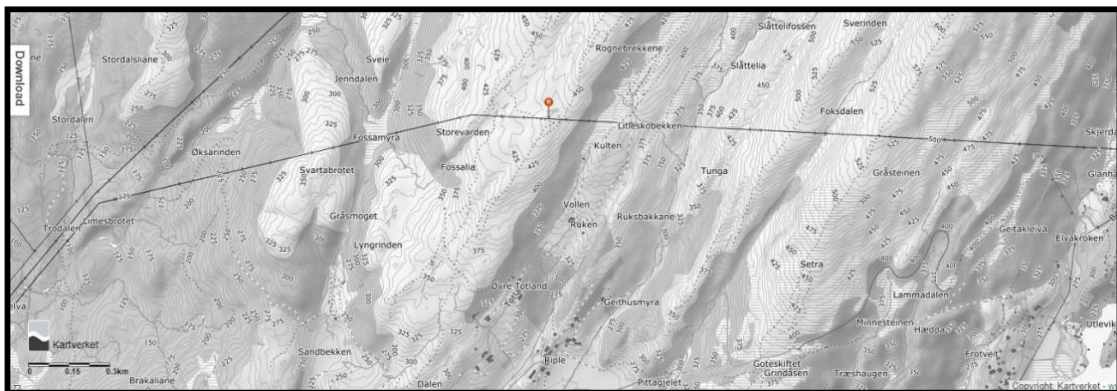


Figure 2: Location area, Pylon (Høydedata)

## 2 Theory

### 2.1 Georeferencing

In order to be able to compare our data with other data, we must first assign coordinates to certain points and place the different point clouds in the same coordinate system. In this way we can compare the point clouds correctly.

This means that the scanner's coordinate system can be related to a ground system of geographical coordinates (world coordinate system). It means connecting to locations in real world. This is what we will need in order to place our models in real world. Which means you need to search for coordinates by using a GPS. These coordinates will then be added to Cyclone or Cloudcompare so that the model can be orientated correctly. The correct orientation is necessary to be able to compare different models.

#### 2.1.1 Type of coordinates systems

Many different coordinate systems are used in different countries. Therefore, it is important to know them well, to make sure that you are not using the wrong one when setting up the device.

- UTM (Universal Transverse Mercator): It's a 2-dimensional Cartesian coordinate system that is implanted on Earth. It has a horizontal position view. It is used to indicate locations independent of height on earth. The UTM system is not a single map projection. The system divides the earth into 60 zones, each being a six-degree band of longitude as you can see in the picture (Figure 3), the western part of Norway is located in zone 32. (Wikipedia, 2019)

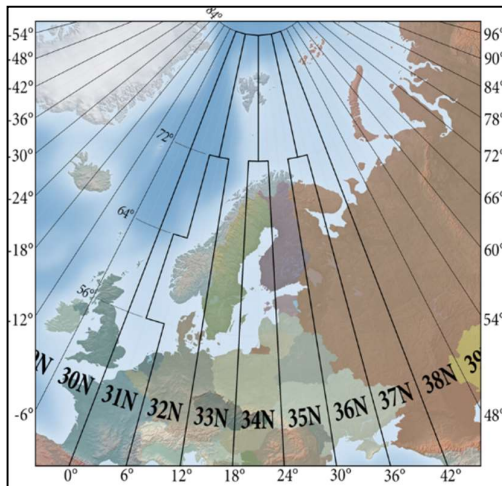


Figure 3: Modified UTM Zones (Wikipedia)



Figure 4: EUREF89 coordinate system (Wikipedia)

- WGS84 (World Geodetic System 1984): This is the Earth's coordinate reference system. It has a variation of a few centimeters at the International Terrestrial Reference System (ITRS). It is designed for GPS so, it is used in the Leica GPS that we have used. (Wikipedia, 2018)
- EUREF89: This is a two-dimensional coordinate system for representing positions on the ground surface. Norway is situated in zone 31 up to zone 36 (Figure 4). This grid is more detailed than the UTM. (Wikipedia, 2018)

## 2.2 Laser scanning

3D Laser scanning is a measurement method in which an object or surface is scanned by laser technology. A laser scanner is a device that sends light pulses at high speed up to a certain distance. By constantly changing the angle, both vertically and horizontally, it is possible to get a full 360° image. For each light pulse, the distance between the scanner and the measured object is calculated by the elapsed time between the sent and received pulse. Each scanned point will be converted to a pixel with known x, y and z coordinates and reflection value or intensity. The result is a point cloud of millions of points.



*Figuur 5: Leica P20 Laser Scanner (Scanable)*

There are two types of situations in laser scanning: static laser scanning on the one hand and dynamic laser scanning on the other. Static laser scanning is done from a fixed position, which ensures the highest accuracy and point density. Static laser scanners can be divided according to their usable scanning range. Dynamic laser scanning is not relevant for this study and is therefore not described further in the thesis.

In order to get the best results, it is recommended to measure in perfect weather conditions. By this we mean dry weather. The device is equipped to measure in bad weather and can resist water, but precipitation can disturb the results of the measurements and create noise.

The device is easy to use due to the simple graphical menu. The data is automatically saved on the device which is very useful when you need to scan large projects. Afterwards you can easily export the files to an external USB stick.

The Leica P20 (Figure 5) laser scanner is a time-of-flight based optical 3D measurement system. This system uses a laser source to scan a surface in order to obtain dense range data. Time-of-flight is the measured time taken by an object, particle or wave to travel a distance through a medium. With this information we can measure the velocity or path length to the object. (Vosselman & Maas, 2010) (Wikipedia, 2019)

### 2.2.1 Accuracy

Before the measurement, it is important to adjust the tribrach correctly so that the instrument is levelled and the deviations are as small as possible. Circular levels of Leica geosystems tribrachs are specified with 8'/2mm which means that a tilt of the horizontal plane of 8' moves the bubble for 2mm. The bubble can be moved by turning the 3 adjusting screws.

The accuracy of the laser scanner is an important point for the quality of the data. The Leica P20 has a 3D position accuracy of 3mm at 50m and 6mm at 100m. In terms of angular accuracy, the device is accurate to 8", horizontally and vertically.

After we registered the point clouds an average error of 0.004 m at each point was added. This is because the point clouds have to adapt to each other. At this moment we had an accuracy of 7mm at 50m and 10mm at 100m. When the point cloud was finally placed in the correct coordinate system, the error in accuracy became even bigger. Because we didn't use the most accurate method, we now had to add an error of 18mm at each point. Finally, the accuracy of the measured points is 25mm at 50m and 28mm at 100m.

Detailed information about the Leica P20 can be found in the product specifications in the Appendix. (Appendix B)

## 2.3 GNSS

Global Navigation Satellite System (GNSS) (Figure 6) is a type of receiver for determining a location. The position of the GNSS is determined by the satellites, which send radio waves to the GNSS and the device knows where it is located. There are various satellite systems (GPS, GLONASS, Galileo or BeiDou) that can receive the GNSS. In Europe we use the Galileo GNSS system. (Novatel, n.d.)



Figure 6: Leica Viva CS10 & GS14 (Scssurvey)

The GNSS can be used in 2 different ways. Kinematic mode & Static mode. We have used the Kinematic mode so our thesis will not discuss the Static mode. More information about the Kinematic mode can be found in the next section.

The electricity pylon can't interfere with the GPS signal either because we have placed the GPS points at a safe distance. (Alsalmán, 2013)

To determine the coordinates of certain points, we used the Leica Viva GS14 - GNSS Smart antenna and the Leica Viva CS10 Field Manual (Figure 6).

### 2.3.1 Kinematic mode

Also called Real-time Kinematic Positioning (RTK). It uses the live location of the available satellites at that moment, which are in range of the GNSS receiver. Within a few seconds the receiver can obtain the coordinates. The accuracy of the device is up to several centimetres. There are a lot of other factors to get the device more accurate. (Novatel, n.d.)

### 2.3.2 Accuracy

The accuracy after Post Processing at the Kinematic mode is at the horizontal 8mm + 1ppm and at the vertical 15mm + 1ppm this usually depends on certain factors such as the number of satellites, obstructions, observation time, .... It is also quite important to keep the GNSS poles straight above the point when you are measuring with the GNSS in order to get an accurate result (Appendix C).



## 2.4 Total station

The total station is an electronic/optical measuring instrument in which a theodolite is integrated. The instrument measures the horizontal and vertical angles and distances from the device to a certain point. It can be controlled remotely with a remote control. The device we have used is the Leica TS13 (Figure 7) (Appendix D). The error in range on this device is 5cm by 100m. (Wikipedia, 2019)



Figure 7: Leica TS13 Total Station (Leica)

### 2.4.1 Accuracy

Before the measurement, it is important to adjust the tribrach correctly so that the instrument is levelled and the deviations are as small as possible. Circular levels of Leica geosystems tribrachs are specified with  $8'/2\text{mm}$  which means that a tilt of the horizontal plane of  $8'$  moves the bubble for 2mm. The bubble can be moved by turning the 3 adjusting screws.

The distance that can be achieved for distance measurements is from 1.5 to 1000m with an accuracy of  $2\text{mm} + 2\text{ppm}$  and if we would use a prism this would be up to 3500m with an accuracy of  $1\text{mm} + 1.5\text{ppm}$  (Appendix D).

### 2.4.2 Prism

A prism is used as a target for the total station. Prisms comes in various shapes. The specific prism used in the project was the  $360^\circ$  prism GRZ4 (Figure 8). This prism is screwed on an adaptable pole so that you can adjust the height as you want.



Figure 8: Prism GRZ4 (Leica)



## 2.5 Registration

The purpose of the registration is to combine all the scans taken on the field. After we registered all the scans, we can merge them together into one model and create a 3D point cloud model.

There are several possibilities to register but we have used the point-related registration for which exact point correspondences between coordinate systems exist. This is achieved by placing targets in the scanner's scanning field. The targets are oversampled and the strongly overlapping set of points is used to estimate the 3D coordinates of the target in the sensor frame. These coordinates are then used as observations for parameter estimation. The common feature of the targets is that they have a high contrast between the target components to enable a high accuracy center determination by some form of signal or feature based approach. Retro-reflective targets (Figure 9) are best avoided because they can cause artifacts, we used the Leica HDS P20 6" tilt & turn black & white (grey) target (Figure 10).

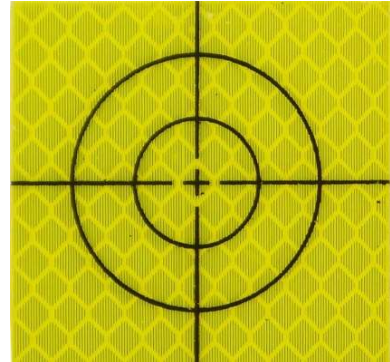


Figure 9: Retro-reflective target (Surveyequipment)



Figure 10: Black & white target (Survey.crkennedy)

First we need to import the scans that we want to combine into the registration window. We do this through the option 'scan world' and 'add scan world'. Now all the targets and common targets needs to get imported through constraint and add constraint with identified targets only. After this there should be made a registration. On Constraint list we can see the deviation between the common targets. Depending on the maximum aberration of the project, targets with the most aberration can be removed or disabled if this doesn't affect the drawing. If we remove too much targets the registration will fail and the result is useful.

After we add the constraints, we can make an optimization through cloud constraint and auto add cloud constraints. This means that the program will try to align the scans as close as possible to each other to minimize the aberrations. Now we have to freeze our obtained results and create a model out of it through the option registration.

It's also possible to make a 3D-model without using targets but this outcome is less accurate than with targets. The steps are the same until registration. We can make a cloud to cloud registration, in this case a large number of points (from the overlap region) are used by an ICP algorithm to obtain transformation parameters. (Vosselman & Maas, 2010)

## 2.6 Software

### 2.6.1 Leica Cyclone

Leica Cyclone is a processing software program to place laser scan data to a common coordinate system and to register different clouds. All the data obtained during the measurement can be imported into this program. For us is this a very important program because there are no other programs in which we can read out our data directly.

The bigger the file, the longer it will take to import the data into cyclone. If we later import it into Cloudcompare, it is very difficult to work with heavy files because our computers can't handle it. As a result, the model is faltering and the program gets stuck. To prevent this we have used SubSampling, here we can adjust what percentage of the point cloud density we want to import. We used 1/25 of the points out of the model (Figure 11).

The file you import is a raw data file, if you have measured from multiple points, you will see multiple scan stations in the file. Below you can find several terms that we have been working with. (Leica, 2015)

- Modelspace: The modelspace is used to edit (cut, delete) in the cloud. It can also be used to measure. In the modelspace we get an overview of the point cloud (Figure 12) and we can see the position of the scanstations.
- Truspace: This is a function in the Modelspace. In this model we can see everything from the position of the stations themselves (Figure 13).
- Image: We took pictures during the scanning process, this is a useful function within the model space. We can display these photos at the same time as the point cloud to get a more realistic view of the model.
- Scanstation: These are the different files from each measured point. For example, if 4 scans have been scanned in 4 different places, you should obtain 4 scan stations in the program.
- Scanworld: Each position of a scan is also called a scanworld, which creates the modelspace.

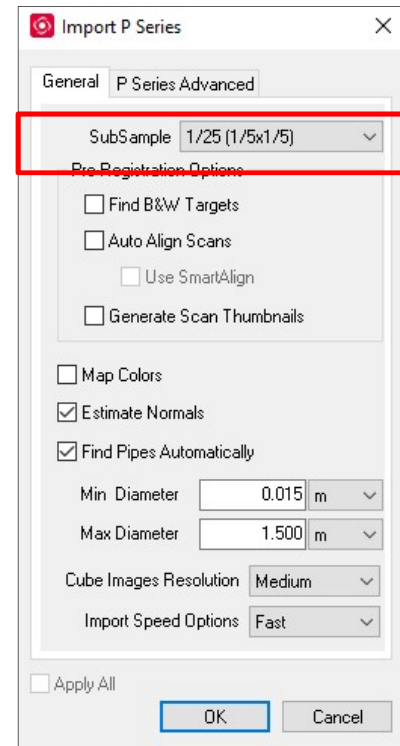


Figure 11: SubSample settings (Cyclone)



Figure 13: Truspace view (Cyclone)

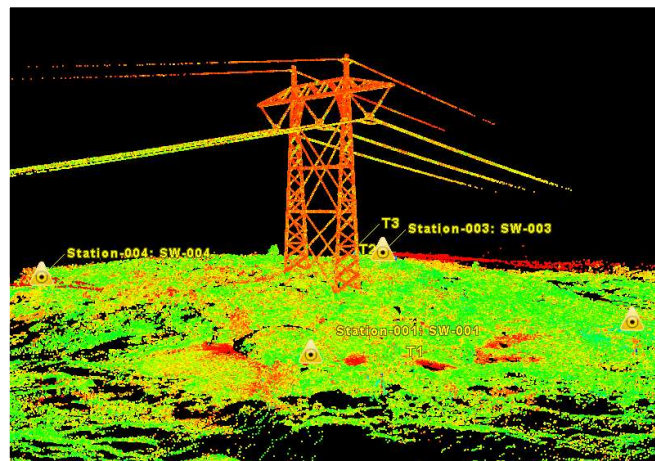


Figure 12: Modelspace view (Cyclone)

### 2.6.2 CloudCompare

CloudCompare is a 3D point cloud editing and processing software. It is designed to perform a direct comparison between 3D point clouds. It is based on a specific octree structure that allows performance in performing these types of tasks. We have mainly used CloudCompare to compare our point clouds with those of the drone or Høydedata.no.

In CloudCompare we filtered our data. During the filtering process, we removed all data that is not relevant for the project (vegetation, devices, people, etc.). By filtering the project, we can also look at certain things in the drawing separately, such as the electricity pylon. We can compare the electricity pylon and the surrounding terrain (Figure 14) with other data or only the pylon itself (Figure 15).



Figure 15: Electricity pylon with the surrounding terrain (Cloudcompare)

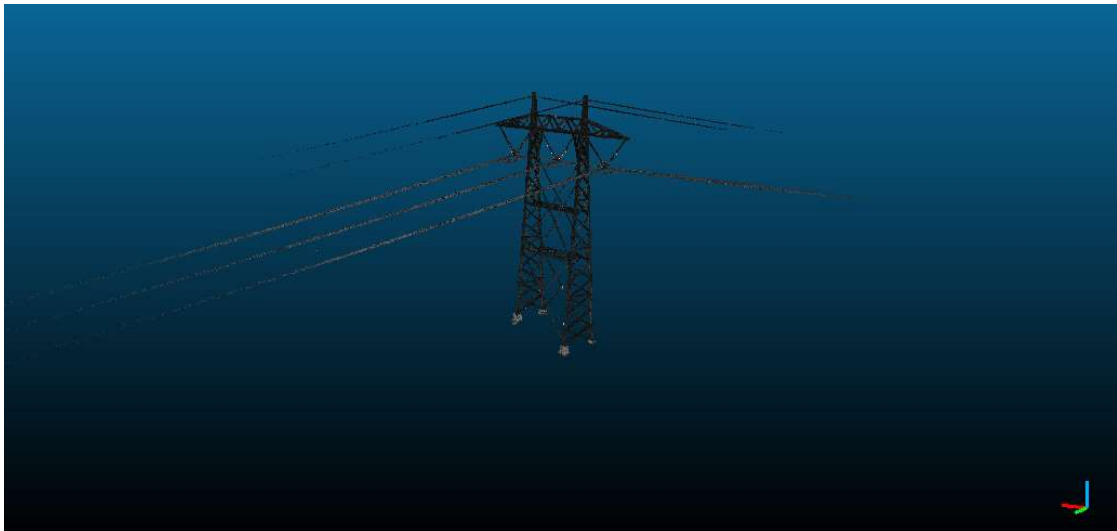


Figure 14: Electricity pylon separated (Cloudcompare)

One of the many useful features of CloudCompare is the scalar field that we can modify. A scalar field is a group of values (one per point). Each point or vertex has a certain value and we can give this value a color, apply a filter to it or perform some elementary mathematical operations. We can also divide the cloud with respect to these values. (Cloudcompare, 2016)



### 3 Method

Before we started scanning, we did some preparatory works. With this we mean drawing up a scan plan (Appendix E) so we know what we have to do when we arrive on the mountain. We also made a safety and risk evaluation plan (Appendix F). This is a plan that shows what the dangers on the site can be and how we can prevent them. The persons present on the site at that moment are also mentioned in the document and have to agree with the plan before they enter the site.

#### 3.1 Laser scanner

The device and the targets are set according to the scan plan. There are 4 scanning stations to make sure every side of the electricity pylon has been properly scanned. 2 scans have been made in each station, the first scan is important to have data from the terrain around the pylon and to cover the entire area. The second scan is specifically for the pylon and will be adjusted so we don't get a 360° scan. We did this by setting up a field of view (Figure 16) to spare some scanning time. A field of view is a way to reduce the scan image from the laser scanner to a smaller image by setting degrees where the device should stay between with the scan. The second scan has a higher resolution to make sure we have the pylon in good quality.



Figure 16: Field of view (own picture)

After we scanned the pylon and the surrounding area, we fine scanned the targets. This is important in order to easily find the targets in Cyclone when we want to register the different point clouds. We have done this task again in every scan station (Figure 17).

We store all our data on a USB stick so we can easily import it into Cyclone.

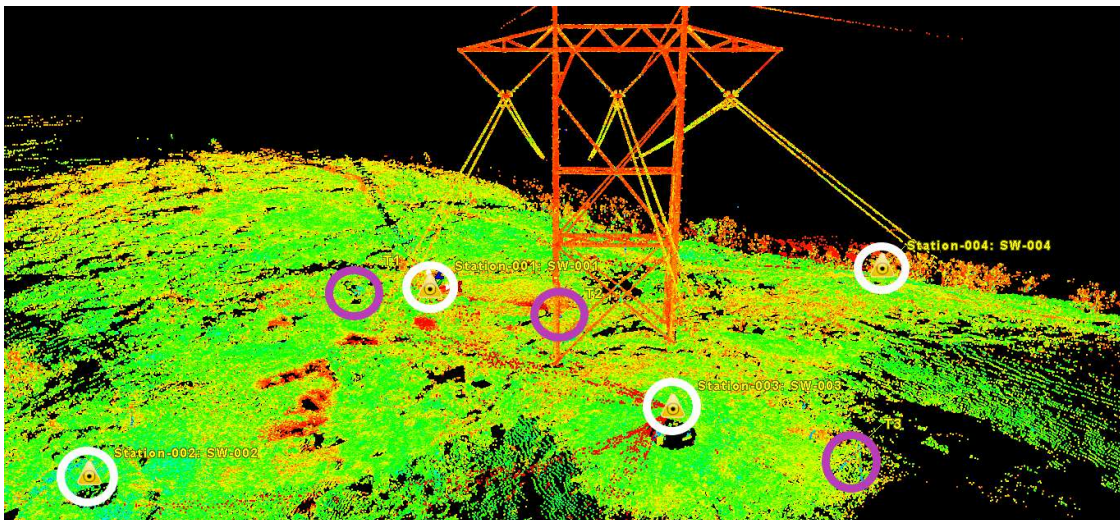


Figure 17: Purple circles are the targets. White circles are the scanning stations. (Cyclone)

### 3.2 Georeferencing with totalstation

The total station we have used was the Leica TS13 (Figure 18).

After measuring with the laser scanner, we have determined the coordinates of the targets by using the total station. This was not done correctly the first time, so we had to return to our scanning area at another time. The second measurement we used a different technique as the first time because there were no more targets at the area that we could scan. This technique is called 'known station coordinates and backsight to a known point'. We determined coordinates of points on the electricity pylon that we then later linked to the same points in the point Cloud.

It is important to check that the device is set to the correct coordinate system. In our case this is Euref89 UTM32.

We have set up the total station at a position where all the points to be measured are clearly visible. It's best to set it at a far enough distance to keep the accuracy as low as possible (Figure 18).



Figure 18: Leica TS13, distance to the pylon

We positioned the arbitrary point in relation to the total station by placing the arbitrary point further away than the distance between the total station and the points to be measured on the pylon (Figure 19). We did this to keep the fault as small as possible. The jual pole that is used to indicate the arbitrary point must also be placed perpendicular to the marked point, this can be done by using a jual pole tripod. The position of the arbitrary point must be clearly marked so that it can be measured with the GPS afterwards (Figure 20).



Figure 19: Position arbitrary chosen point used for orientation



Figure 20: Marked point, jual pole



We also measured two angles of two known points 'extra reference point', for this we used the pylon on Ulriken & Lovstakken.

While measuring the points on the electricity pylon, we took the best possible points that can easily be found in the point cloud in cloudcompare such as corner points of the foundation. We measured at least 10 points to get the best possible result.

### 3.3 GNSS

We used Leica Viva GS14 - GNSS Smart antenna and Leica Viva CS10 Fieldbook (Figure 21) to determine the coordinates of the arbitrary point and the position of the total station. It was important here that we had sufficient connection with the satellites so that we did not get the wrong coordinates. This can be controlled by the symbol in the upper left corner of the field book, the symbol must be a small circle around the center of a cross (Figure 22).

It was also important that we determined the position of the total station and the arbitrary point used for orientation in advance so that they were not positioned below the high-voltage lines. This is because the high-voltage lines can cause possible disturbances due to their electromagnetic field. We are not sure about this subject because we have not found a clear source of information about it, so we have taken the precaution and placed the device far enough away from the tower.

To determine the coordinates of the position of the total station and the arbitrary point used for orientation, we placed the Leica Viva GS14 perpendicular to the position of the total station and after that above the arbitrary point and measured it with the device.



Figure 21: measuring of a point



Figure 22: Symbol for fix solution (obtained using CPOS) on the Leica Viva CS10

### 3.3.1 Coordinates integration in model

After we registered the models, we placed the point clouds in the UTM coordinate system by linking the measured points to the corresponding points in Cyclone. At least 3 points are needed, 2 to get the correct orientation in the coordinate system and 1 to check if the point cloud is correctly oriented.

The 2 points to determine the orientation can be located at a distance from each other so that the orientation can be more accurately determined (Figure 23).

Cyclone works with a right-handed system, so north and east have to be exchanged to get the right system. That's why we had to switch the X and Y values in our calculation to calculate the angle. In the table you can find the coordinates that we got from the program of the total station (Appendix G), so they are still in the wrong system. In the sketch, the coordinates are already in the right-handed system (Appendix G).

To determine the Azimuth point, we have to calculate the angle between a reference point (point 1) and the other point (point 2) of which we have the coordinates already available. So we will rotate point 2 against point 1. This angle is then filled in at azimuth point. The calculation behind this can be found in Appendix G.

The other points are used in Cyclone to check whether the georeferencing of the cloud has been successfully completed.

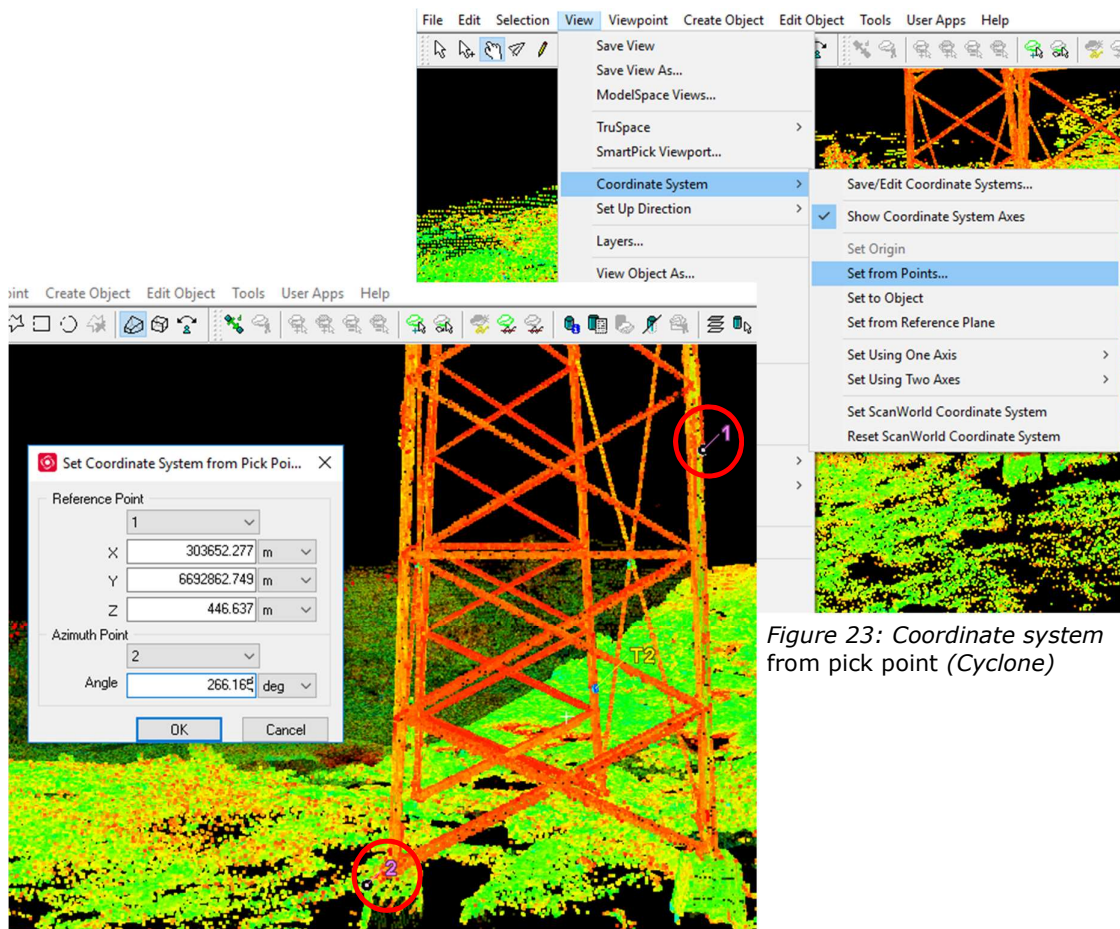


Figure 23: Coordinate system from pick point (Cyclone)

Figure 24: 1 reference point & 2 Azimuth point (Cyclone)

### 3.4 Cloud to cloud comparison

After we have registered our data and placed them in the correct coordinate system, we started to compare them with each other. We did this with the help of CloudCompare. By selecting two different point clouds and using the 'compute cloud/cloud distance' function, we can easily overlay the clouds. One point cloud is set as 'reference' while the other one is set as 'compared'. The point cloud with the most size, the largest, is used as a reference. The compared point cloud is the cloud that we have used to make the comparison with (Figure 25). It is important to find the correct maximum distance between the points (Figure 26). Next, the differences in the point clouds are made very clear by color differences between each other.

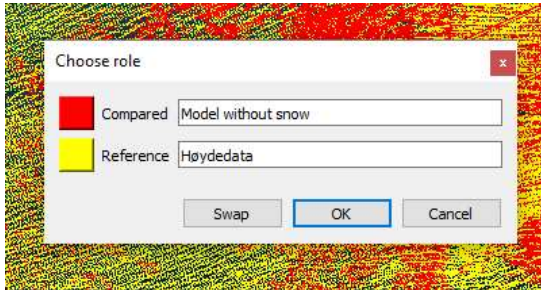


Figure 25: Compared, Reference section (Cyclone)

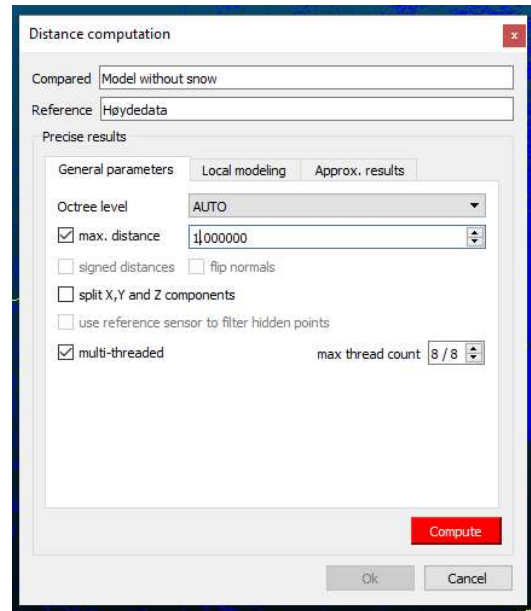


Figure 26: Settings menu (Cyclone)



## 4 Results

In this chapter you can find the results obtained by scanning as well as the comparisons between certain techniques. We will compare the different data we obtained with the laser scanner with each other and also with data from Høydedata and a photogrammetric data collected using drones.

### 4.1 Accuracy of the models

Registering the model and placing it in the correct coordinate system had important consequences for the accuracy of the point cloud. After the registration of the data without snow from the laser scanner there was an error of 0,004m, the data with snow had an error of 0.008m (Appendix H). The data with snow is less accurate because we only used two scan stations in comparison with the two scanning stations we used to measure without snow. On this point the laser scanner was really accurate but after we georeferenced the point cloud we recalculated the error. By calculating the average error of six known points we found that the error was 0.018m (Table 1). The reason of this larger error is the way of georeferencing we used, if we had used a better technique (e.g. with using the targets) the error would have been smaller.

The error on the laser scanner itself is 3mm at 50m & 6mm at 100m, so if we add all these errors together we have a total error of 0.025m at 50m or 0.028m at 100m.

	X	Y	Z
Point 1	0,040	0,001	0,014
Point 2	0,001	0,022	0,023
Point 3	0,030	0,028	0,007
Point 4	0,005	0,010	0,027
Point 5	0,000	0,000	0,000
Point 6	0,016	0,091	0,014
Average =			0,018

Table 1: Error on certain points

### 4.2 3D model

#### 4.2.1 Comparison snow

In the figure below we can see a comparison between two point clouds scanned when there was snow and when there was no snow (Figure 27).

In the diagram (Figure 28) we get an overview of how many points there are which have a certain distance between them. The blue parts of the drawing indicate points that appear in both drawings and are very close to each other. Here we see that both scans measured the electricity pylon accurately.

The green color shows you where the different point clouds have matching points but with a distance of about 6-30cm between the points. This can be distinguished as the points where snow was still on the ground during the measurements.

The red color shows parts of the data that we did not receive during the measurement without snow. The black/grey part is the part where we didn't scan with the first measurement because we only had 2 stations installed. This is because of the hilly terrain so the laser did not hit every part of the terrain. That is why it is important to have multiple scanning stations, in order to be able to cover as much terrain as possible.

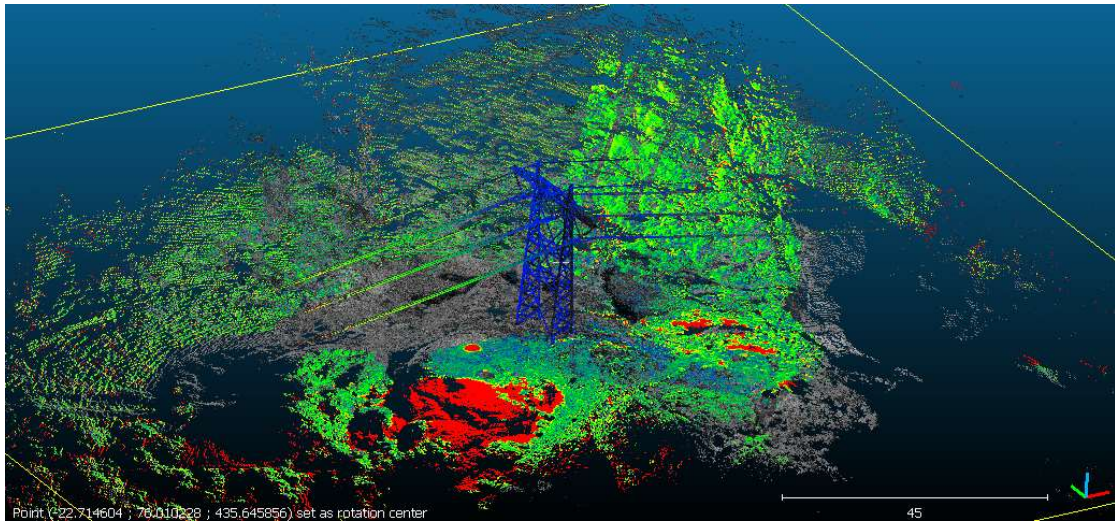


Figure 27: Comparison between measurement with & without snow (CloudCompare)

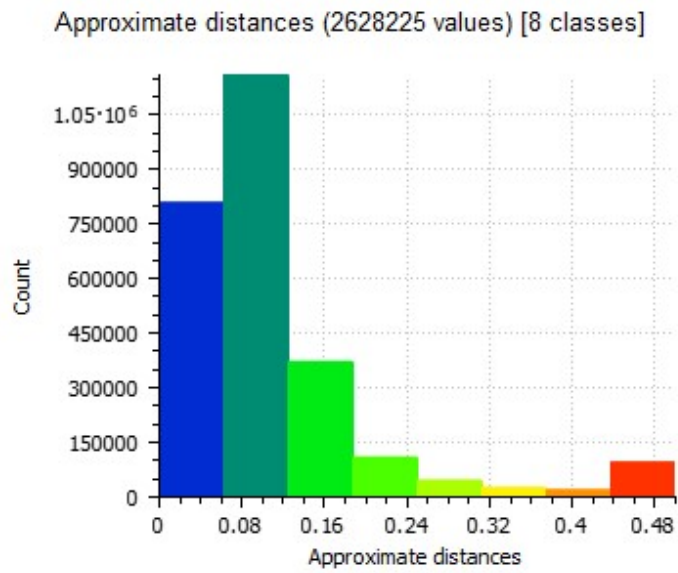


Figure 28: Diagram overview points of comparison between the 2 clouds

### 4.3 Comparison of Høydedata

The two biggest differences between these point clouds are the pylon and the terrain (Figure 30,31). As you can see, the pylon is much clearer on the point cloud scanned with the laser scanner than on the point cloud of Høydedata (scanned with a helicopter or airplane). The terrain in Høydedata is much clearer than the terrain we scanned with the laser scanner. This is because the measuring device (Figure 29) has a better range from above and the laser scanner cannot reach every point through the hilly area with the laser. The helicopter or airplane that's been used to scan the area scans perpendicular to the ground, which why the electricity pylon is scanned so badly.

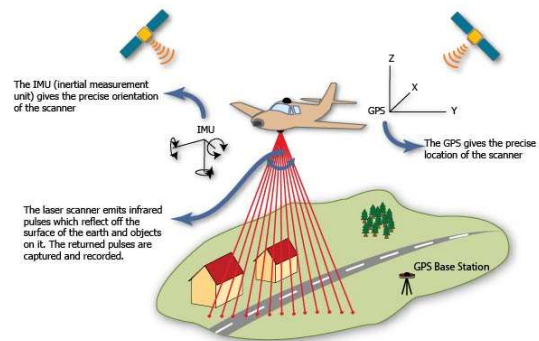


Figure 29: Way of scanning with a plane (<http://gmv.cast.uark.edu>)



Figure 31: Point cloud own measurement with a terrestrial laser scan data (Cloudcompare)

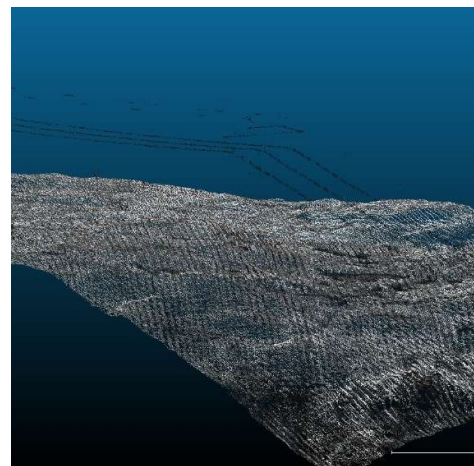


Figure 30: Point cloud Høydedata (Cloudcompare)

Below you can find a comparison of cloud to cloud-distance between the cloud of the laser scanner and the cloud of Høydedata (Figure 32). The red color in the figure means that it is not visible in either point clouds. In the point cloud of Høydedata the tower is not visible and you can clearly see this in the figure.

The blue and green parts show the points that are visible in both point clouds. The blue color are the points that are not very far apart from each other, between 0-12 cm. The green color is for points that have been scanned but where there is a larger distance between the different point clouds, this is from 12-50cm.

The black and grey color in the point cloud is the part that we didn't scan with the laser scanner but that is visible on Høydedata.

It is therefore clear that with a helicopter a much better scan can be made of the terrain and with the laser scanner a more detailed scan of the pylon.

In this diagram (Figure 33) we can clearly see the amount of points that match and the amount that do not match at all.

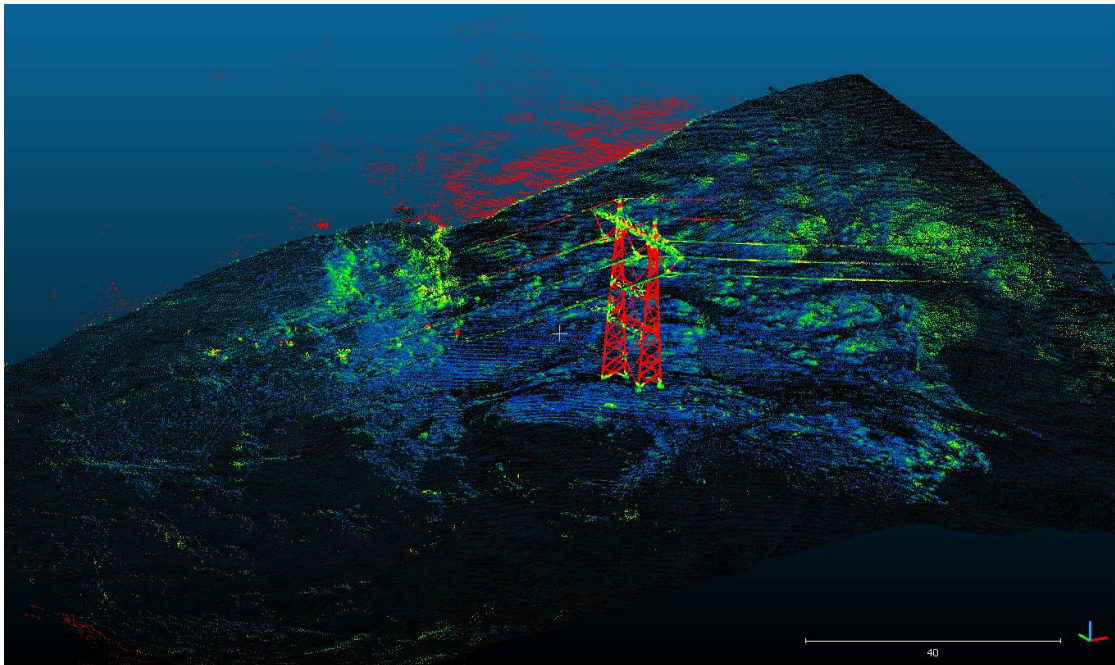


Figure 32: Comparison between own measurement with terrestrial laser scan data & Høydedata (CloudCompare)

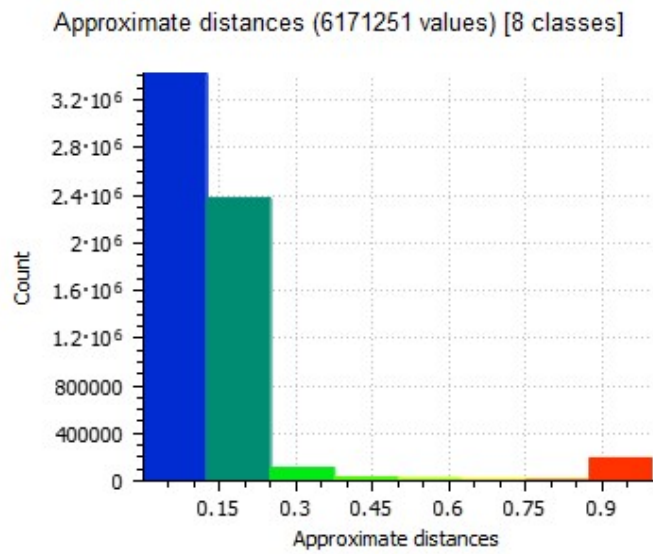


Figure 33: Diagram overview points Høydedata & own measurement with terrestrial laser scan data

## 4.4 Comparison drone scanning

In this section you can find a comparison between the laser scanner and the drone in terms of usability, technical specifications and the data scanned with both devices.

### 4.4.1 Practical experiences

There are not only differences between the drone and the laser scanner in terms of scanning and the data you get, there are also some practical differences. The laser scanner takes a lot more time to scan an area than the drone scanner. When we look at the equipment that we need to measure (Table 2), the drone scanner is far more easier to handle than the laser scanner. Especially in an area like the one where we have been measuring, it is not that easy to get all the materials from the laser scanner on site. If you make a mistake with the drone, it is not that difficult to go back, but with the laser scanner it takes more effort.

Drone scanner	Laser scanner
1 drone scanner	1 laser scanner
1 RTK station	5 tripods
3 gcp's	1 totalstation
	3 targets
	1 GNSS system
	1 prisma
	1 jual pole tripod
	1 jual pole

Table 2: Comparison of list of materials

### 4.4.2 Comparison devices

There are some technical differences between the laser scanner and the drone. After the registration of the data without snow from the laser scanner there was an error of 0,004m. On this point the laser scanner was really accurate but after we georeferenced the point cloud we recalculated the error. By calculating the average error of six known points we found that the error was 0.018m. The reason of this larger error is the way of georeferencing we used, if we had used a better technique (e.g. with using the targets) the error would have been smaller. For the drone, it is recommended to fly higher and to use larger overlaps. A frontal overlap of 85% and a side overlap of 70% is recommended. Camera settings should be adjusted to get the highest possible contrast. The error produced is highly dependent on the settings of the drone, and the used software. The error of the drone after georeferencing is approximately 0.063 m. This error stems from a combination of the georeferencing technique and the process of generating the pointcloud. (This comparison is made in collaboration with Andreas Verheyden, Thomas Jonckheere and Sil Gevaert)



#### 4.4.3 Comparison data

If we compare the 3D model of the drone with the one of the laser scanner, there is a clear difference between the both point clouds. The total scan of the laser scanner (Figure 34) has a much smaller area than the scan of the drone. The drone also has a much better scan (Figure 35) of the terrain than the laser scanner because the drone can see everything clearly from above and the laser scanner cannot see certain parts due to the hilly landscape. But if we look at the electricity pylon there is also a clear difference here, but this time the laser scanner comes out as the better one. On the point cloud of the laser scanner the electricity pylon is clearly visible (Figure 36), even parts of the electricity cables are visible. If we look at the point cloud (Figure 37) of the drone, we have to make an effort to get a picture of the electricity pylon because there are very few points visible.

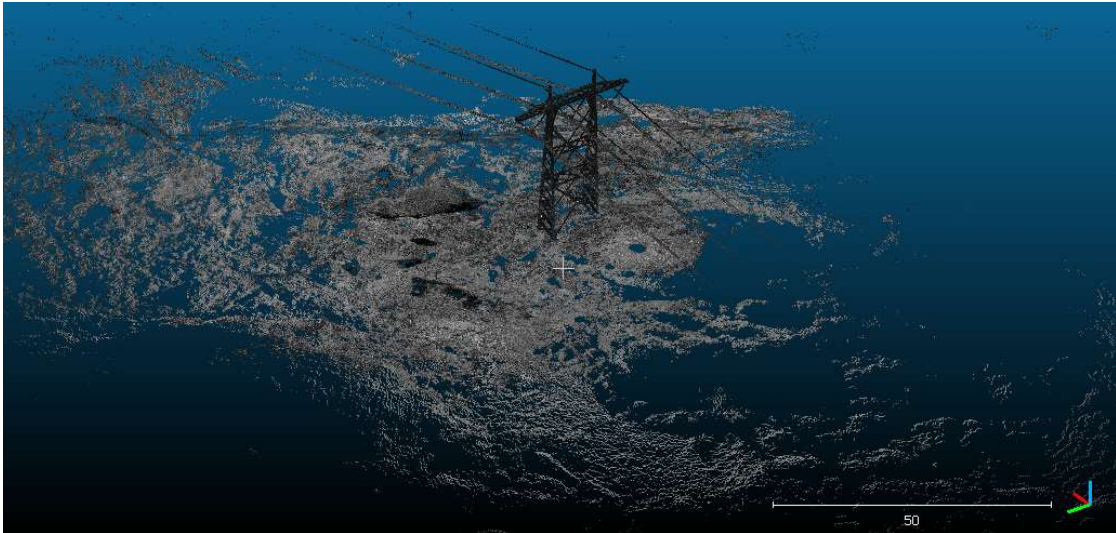


Figure 34: Total scan laser scanner without snow (Cloudcompare)

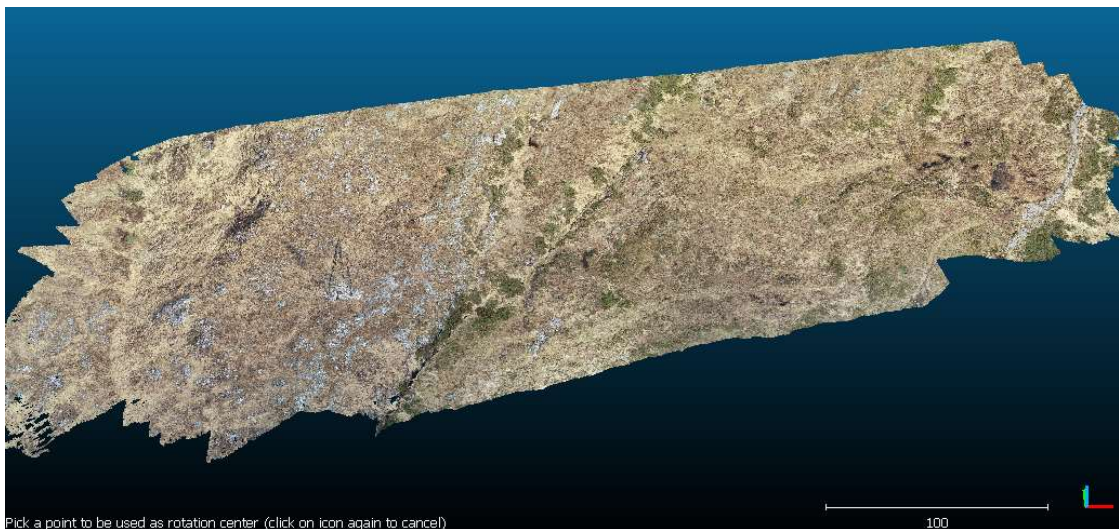


Figure 35: Total scan drone without snow (Cloudcompare)



Figure 36: Zoomed in picture of the electricity pylon from the laser scanner (Cloudcompare)



Figure 37: Zoomed in picture of the electricity pylon from the drone (Cloudcompare)

## 5 Discussions

### 5.1 Georeferencing

The georeferencing can be carried out on different methods, we have tried out two of them.

- GPS on the position of the targets and in this way determine the coordinates, it is important that the target is mounted on a tripod where afterwards the GNSS can be screwed on.
- The second method is to determine the coordinates based on a total station and GNSS. This is clearly explained in the method but instead of the arbitrary point on the pylon, we take the targets as points. This method is most accurate because it takes the targets as known points after they are measured accurately with the laser scanner.

By facing some problems during the execution of these methods, we have not been able to execute them correctly. As a result, we had to look for another technique in order to determine the coordinates of the electricity pylon.

The scans with the laser scanner were quite successful, so it was not necessary to take back all the equipment a third time. We went back with only the total station and the GNSS. The problem with this technique is that this georeferencing is less accurate than the way you do it with the targets. It is difficult to indicate the perfect point in Cyclone so there is often a difference here. In total we had an error of 25mm on 50m and 28mm on 100m, of which 18mm is due to georeferencing. If we had used the method with the targets and the total station, this would have been less. This is important to know so that next time we can use the correct method and get a more accurate result.

### 5.2 Laserscanner vs drone

The photogrammetry scan from the drone is better to scan a hilly terrain than a terrestrial laser scanner because the drone scans from above and can get a clear picture of everything while the laser scanner scans from a certain point and thus misses a large part of it. A laser scanner is a lot better to scan an object in great detail based on certain settings. In order to scan the pylon, we have chosen to fine scan it for a better quality of the point cloud. In order to get a complete picture of the tower, it is necessary to scan from several scanning stations.

The drone is less good when it comes to scanning the tower because it scans downwards in a straight line and therefore does not touch all corners of the tower. The group that writes the thesis about the drone tried to get a better picture by flying around the tower with the drone, but this still didn't give an accurate picture.

If people are more interested in terrain with a large surface area, it would be better to choose the drone because it has a much larger range than the laser scanner. If you need a more detailed scan of an object, it is better to go for a laser scanner.



## 6 Conclusion

For Statnett, we went to see which method is the most efficient for measuring high-voltage pylons. We compared 3 different techniques: a terrestrial laser scanner, a drone using photogrammetry and a Norwegian website, Høydedata, using the Lidar in the air. We have paid attention to detail, accuracy, coverage and efficiency.

For scanning objects it is good to use a laser scanner because it can scan difficult shapes in much more detail than a drone since you can make a fine scan from multiple positions. For a hilly terrain or a large area it is better to use a drone because it has a larger range and thus creates a better image.

If we compare measurements of the laser scanner with those of Høydedata, we can conclude that the laser scanner is better for mapping the electricity pylon and that Høydedata gives a better picture of the terrain. This is due to the fact that Høydedata only gets an image from the air and the laser scanner can scan the pylon from different positions.

It is also important to scan from multiple stations to keep the accuracy as low as possible, because when we were scanning with snow we only scanned from 2 stations and the error is much bigger than without snow because there we scanned from 4 stations. The difference on this error is 4mm.

To orientate the point cloud in the world coordinate system it is best to use the total station and the GNSS because the accuracy is much higher than just using the GNSS. To get the accuracy of this even higher than we did in our results. It is important to make measurements at the same time as laser scanning so that the same target is used.

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Appendix D: Leica TS13 datasheet

Appendix E: Scan plan

Appendix F: Safety and risk evaluation plan

Appendix G: Calculation Azimuth point & coordinates

Appendix H: Error registration

## Appendix A: Photos from the test site



# Appendix B: Leica P20 datasheet

## Leica ScanStation P20 Product Specifications

General	
Instrument type	Compact, ultra-high speed pulsed laser scanner with survey grade accuracy, range and field-of-view; integrated camera and laser plummet
User interface	Onboard control, notebook or tablet PC, PDA
Data storage	Integrated solid-state drive (SSD) or external USB flash drive
Camera	Auto-adjusting, integrated high-resolution digital camera with zoom video

System Performance	
Accuracy of single measurement	3 mm at 50 m; 6 mm at 100 m
3D Position Accuracy	≤ 1 mm
Linearity error	8" horizontal; 8" vertical
Angular accuracy	2 mm standard deviation up to 50 m
Target acquisition*	Selectable on/off, resolution 1", dynamic range +/- 5', accuracy 1.5"
Dual-axis compensator	

Laser Scanning and Imaging System																																													
Type	Ultra-high speed time-of-flight enhanced by Waveform Digitising (WFD) technology																																												
Wavelength	808 nm (invisible) / 658 (visible)																																												
Laser class	1 (in accordance with IEC60825:2014)																																												
Beam divergence	0.2mrad																																												
Beam diameter at front window	≤ 2.8 mm																																												
Range	Up to 120 m; 18% reflectivity (minimum range 0.4 m)																																												
Scan rate	Up to 1'000'000 points/s																																												
Range noise**	<table border="1"> <thead> <tr> <th>Range</th> <th>Black (10%)</th> <th>Gray (28%)</th> <th>White (100%)</th> </tr> </thead> <tbody> <tr> <td>10 m</td> <td>0.8 mm rms</td> <td>0.5 mm rms</td> <td>0.4 mm rms</td> </tr> <tr> <td>25 m</td> <td>1.0 mm rms</td> <td>0.6 mm rms</td> <td>0.5 mm rms</td> </tr> <tr> <td>50 m</td> <td>2.8 mm rms</td> <td>1.1 mm rms</td> <td>0.7 mm rms</td> </tr> <tr> <td>100 m</td> <td>9.0 mm rms</td> <td>4.3 mm rms</td> <td>1.5 mm rms</td> </tr> </tbody> </table>	Range	Black (10%)	Gray (28%)	White (100%)	10 m	0.8 mm rms	0.5 mm rms	0.4 mm rms	25 m	1.0 mm rms	0.6 mm rms	0.5 mm rms	50 m	2.8 mm rms	1.1 mm rms	0.7 mm rms	100 m	9.0 mm rms	4.3 mm rms	1.5 mm rms																								
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0.8	54:07	1:48:13	----	----																																									
Field-of-View																																													
Horizontal	360°																																												
Vertical	270°																																												
Aiming/Sighting	Parallax-free, integrated zoom video																																												
Scanning optics	Vertically rotating mirror on horizontally rotating base Up to 50 Hz with internal battery Up to 100 Hz with external power supply																																												
Data storage capacity	256 GB onboard solid-state drive (SSD) or external USB device																																												
Communications	Gigabit Ethernet or integrated Wireless LAN																																												
Imaging	5 megapixels per each 17" x 17" colour image; streaming video with zoom; auto-adjusts to ambient lighting																																												
Onboard display	Touchscreen control with stylus, full colour VGA graphic display (640 x 480 pixels)																																												
Level indicator	External bubble, electronic bubble in onboard software																																												
Data transfer	Ethernet, WLAN or USB 2.0 device																																												
Laser plummet	Laser class 1 (IEC60825:2014) Centering accuracy: 1.5 mm at 1.5 m Laser dot diameter: 2.5 mm at 1.5 m Selectable ON/OFF																																												

Electrical	
Power supply	24 V DC, 100 – 240 V AC
Power consumption	40 W typical
Battery type	Internal: Li-Ion; External: Li-Ion
Power ports	Internal: 2, External: 1 (simultaneous use, hot swappable)
Duration	Internal > 7 h (2 batteries), External > 8.5 h (room temp.)

Environmental	
Operating temperature	-20° C to +50° C / -4° F to 122° F
Storage temperature	-40° C to +70° C / -40° F to 158° F
Lighting	Fully operational between bright sunlight and complete darkness
Humidity	Non-condensing
Dust/Humidity	IP54 (IEC 60529)

Physical	
Scanner	
Dimensions (D x W x H)	238 mm x 358 mm x 395 mm / 9.4" x 14.1" x 15.6"
Weight	11.9 kg / 26.2 lbs, nominal (w/o batteries)
Battery (internal)	
Dimensions (D x W x H)	40 mm x 72 mm x 77 mm / 1.6" x 2.8" x 3.0"
Weight	0.4 kg / 0.9 lbs
Battery (external)	
Dimensions (D x W x H)	95 mm x 248 mm x 60 mm / 3.7" x 9.8" x 2.4"
Weight	1.9 kg / 4.2 lbs
AC Power Supply	
Dimensions (D x W x H)	170 mm x 85 mm x 42.5 mm / 6.6" x 3.3" x 1.6"
Weight	0.86 kg / 1.9 lbs
Mounting	Upright or upside down

Standard Accessories Included	
Scanner transport case	
Tribrach (Leica Geosystems Professional Series)	
4 x Internal batteries	
Battery charger / AC power cable, car adapter, daisy chain cable	
Data cable	
Height metre and distance holder for height metre	
1 year CCP Basic support contract	

Additional Accessories & Services	
B&W scan targets and target accessories	
Range of Customer Care Products (CCPs) that include Support, Hardware & Software maintenance and Extended warranty.	
External battery with charging station, AC power supply and power cable	
Professional charger for internal batteries	
AC power supply for scanner	
Tripod and tripod star	
Upside down mounting adapter	

Control Options	
Full colour touchscreen for onboard scan control.	
Remote control: Leica CS10/CS15 controller or any other remote desktop capable device, including iPad, iPhone and other Smartphones.	

Ordering Information	
Contact your local Leica Geosystems representative or an authorised Leica Geosystems dealer.	

All specifications are subject to change without notice.  
All accuracy specifications are one sigma unless otherwise noted.  
\* Algorithmic fit to planar B&W targets  
\*\* Detailed explanation on request

Scanner: Laser class 1 in accordance with IEC60825:2014  
Laser plummet: Laser class 1 in accordance with IEC60825:2014

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Heerbrugg, Switzerland  
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# Appendix C: Leica Viva GS14 - GNSS Smart antenna datasheet

## Leica Viva GS14

GNSS PERFORMANCE		
GNSS technology	Leica SmartTrack	Advanced four constellation tracking
Leica SmartCheck	Continuous check of RTK solution	Reliability 99.99%
Signal tracking		GPS (L1, L2, L2C), Glonass (L1, L2), BeiDou (B1, B2), Galileo (E1, E5b), SBAS (WAAS, EGNOS, MSAS, GAGAN)
Number of channels		120 (up to 60 satellites simultaneously on two frequencies)
MEASUREMENT PERFORMANCE & ACCURACY <sup>1</sup>		
Time for initialisation		Typically 4 s
Real-time kinematic	Single baseline Network RTK	Hr 8 mm + 1 ppm / V 15 mm + 1 ppm Hr 8 mm + 0.5 ppm / V 15 mm + 0.5 ppm
Post processing	Static (phase) with long observations Static and rapid static (phase)	Hr 3 mm + 0.1 ppm / V 3.5 mm + 0.4 ppm Hr 3 mm + 0.5 ppm / V 5 mm + 0.5 ppm
Code differential	DGPS / RTCM	Typically 25 cm
COMMUNICATIONS		
Communication ports	Lemo Bluetooth®	USB and RS232 serial Bluetooth® v2.00 + EDR, class 2
Communication protocols	RTK data protocols NMEA output Network RTK	Leica, Leica 4G, CMR, CMR+, RTCM 2.2, 2.3, 3.0, 3.1, 3.2 MSM NMEA 0183 V 4.00 and Leica proprietary VRS, FKP, IMAX, MAC, RTCM SC 104)
Built-in data links	3.75 G GSM / UMTS / CDMA phone modem Radio modem	Fully integrated, internal antenna Fully integrated, receive and transmit, external antenna 403 - 470 MHz, 1 W output power
External data links		GSM / GPRS / UMTS / CDMA and UHF / VHF modem
GENERAL		
Field controller and software	Leica SmartWorX Viva software	Leica CS10 and CS15 field controller
User interface	Buttons and LEDs Web server	On / Off and Function button, 7 status LEDs Full status information and configuration options
Data recording	Storage Data type and recording rate	Removable microSD card, 8 GB Leica GNSS raw data and RINEX data at up to 20 Hz
Power management	Internal power supply External power supply Operation time <sup>2</sup>	Exchangeable Li-ion battery (2.6 Ah / 7.4 V) Nominal 12 V DC, range 10.5 - 28 V DC 7 h receiving (Rx) data with internal radio, 5 h transmitting (Tx) data with internal radio, 6 h Rx/Tx data with internal modem
Weight and Dimensions	Weight Diameter x Height	0.9 kg (CS14) / 2.90 kg standard RTK rover setup on pole 190 mm x 90 mm
Environmental	Temperature Drop Proof against water, sand and dust Vibration Humidity Functional shock	-40 to 65°C operating, -40 to 80°C storage Withstands topple over from a 2 m survey pole onto hard surfaces IP68 (IEC60529 / MIL STD 810G 506.5 I / MIL STD 810G 510.5 I / MIL STD 810G 512.5 I) Withstands strong vibration (ISO9022-36-08 / MIL STD 810G 514.6 Cat.24) 100% (ISO9022-13-06 / ISO9022-12-04 / MIL STD 810G 507.5 I) 40 g / 15 to 23 msec (MIL STD 810G 516.6 I)

LEICA VIVA GS14 - GNSS SMART ANTENNA	Performance	Professional
<b>SUPPORTED GNSS SYSTEMS</b>		
Dual frequency	✓	✓
GPS / GLONASS / Galileo / BeiDou	✓ / ✓ / ✓ / ✓	✓ / ✓ / ✓ / ✓
<b>RTK PERFORMANCE</b>		
DGPS/RTCM, RTK Unlimited, Network RTK	✓	✓
<b>POSITION UPDATE &amp; DATA RECORDING</b>		
5 Hz / 20 Hz positioning	✓ / ✓	✓ / ✓
Raw data / RINEX data logging	✓ / ✓	✓ / ✓
NMEA out	•	✓
<b>ADDITIONAL FEATURES</b>		
RTK reference station functionality	✓	✓
3.75G or CDMA Phone / UHF Radio (receive & transmit) modem	✓ / •	✓ / •
		✓ Standard      • Optional

<sup>1</sup> Measurement precision, accuracy, reliability and time for initialisation are dependent upon various factors including number of satellites, observation time, atmospheric conditions, multipath etc. Figures quoted assume normal to favourable conditions. A full BeiDou and Galileo constellation will further increase measurement performance and accuracy.

<sup>2</sup> Might vary with temperature, age of battery, transmit power of data link device.

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# Appendix D: Leica TS13 datasheet

## Leica TS13 Total Station

Basic variant			
	<b>ANGULAR MEASUREMENT</b>		
	Accuracy Hz and V	Absolute, continuous, diametrical	1" (0.3 mgon), 2" (0.6 mgon) 3" (1 mgon), 5" (1.5 mgon)
	<b>DISTANCE MEASUREMENT</b>		
	Range <sup>2</sup>	Prism (GPR1, GPH1P) <sup>3</sup> Non-Prism / Any surface <sup>4</sup>	1.5 m to 3500 m R500: 1.5 m to >500 m, R1000: 1.5 m to >1000 m
	Accuracy / Measurement time	Single (prism) <sup>2,5</sup> Single (any surface) <sup>2,4,5,6</sup>	1 mm + 1.5 ppm / Typically 2.4 s 2 mm + 2 ppm / Typically 3 s
	Laser dot size	At 50 m	8 mm x 20 mm
	Measurement technology	System analyser	Coaxial, visible red laser
	<b>AUTOMATIC AIMING - ATR</b>		
	Target aiming range <sup>2</sup>	Circular prism (GPR1, GPH1P) 360° prism (GRZ4, GRZ122)	1000 m 800 m
	Accuracy <sup>1,2</sup> / Measurement time	ATR angle accuracy Hz, V	1" (0.3 mgon), 2" (0.6 mgon), 3" (1 mgon), 5" (1.5 mgon) / Typically 3-4 s
<b>GUIDE LIGHT (EGL)</b>			
Working range / Accuracy		5 - 150 m / Typically 5 cm @ 100 m	
<b>GENERAL</b>			
Processor	TI OMAP4430 1GHz Dual-core ARM <sup>®</sup> Cortex™ A9 MPCore™	Operating system – Windows <sup>®</sup> EC7	
Power management	Exchangeable Lithium-Ion battery	Operating time 8 - 10 h	
Field software	Leica Captivate incl. apps	Running on field controller (Leica CS20)	
Data storage	Internal memory 2 GB SD card 1 GB or 8 GB	On field controller (Leica CS20)	
Interfaces	RS232, USB, Bluetooth <sup>®</sup> , WLAN		
Weight	Total station including battery	5.0 kg	
Environmental specifications	Working temperature range Dust / Water (IEC 60529) / Humidity	-20°C to +50°C IP55 / 95%, non-condensing	
Keyboard	Face I standard	4 button keyboard with status LEDs	
<b>Upgrades<sup>7</sup></b>			
	<b>KEYBOARD DISPLAY UNIT (Optional)</b>		
	Keyboard with display	Face I and face II optional	5" (inch), WVGA, colour, touch 25 keys, illumination
	Power management	Exchangeable Lithium-Ion battery	Operating time 6 - 8 h
	Field software	Leica Captivate including apps	Running on TS13 instrument
	Data storage	Internal memory 2 GB SD card 1 GB or 8 GB	On TS13 instrument
	Weight	Total station including battery	5.3 kg
	<b>TARGET LOCK (Optional)</b>		
	Target locking range <sup>2</sup>	Circular prism (GPR1, GPH1P) 360° prism (GRZ4, GRZ122)	800 m 600 m
	<b>ROBOTIC SURVEYING including PRISM FAST SEARCH (Optional)</b>		
	SpeedSearch range / Search time	360° prism (GRZ4, GRZ122)	300 m / Typically 7 s
Robotic range with long-range Bluetooth <sup>®</sup> s	To CS20 internal long-range Bluetooth <sup>®</sup> s To CTR20 expansion pack	500 m 1000 m	

<sup>1</sup> Standard deviation ISO 17123-3

<sup>2</sup> Overcast, no haze, visibility about 40 km, no heat shimmer

<sup>3</sup> 1.5 m to 2000 m for 360° prisms (GRZ4, GRZ122)

<sup>4</sup> Object in shade, sky overcast, Kodak Gray Card (90% reflective)

<sup>5</sup> Standard deviation ISO 17123-4

<sup>6</sup> Distance > 500 m; Accuracy 4 mm + 2 ppm; Measurement time typically 6 s

<sup>7</sup> Initial or after sales, independent from each other

<sup>8</sup> Under good radio conditions

The Bluetooth<sup>®</sup> trademarks are owned by Bluetooth SIG, Inc.  
Laser radiation, avoid direct eye exposure. Class 3R laser product in accordance with IEC 60825-1:2014.



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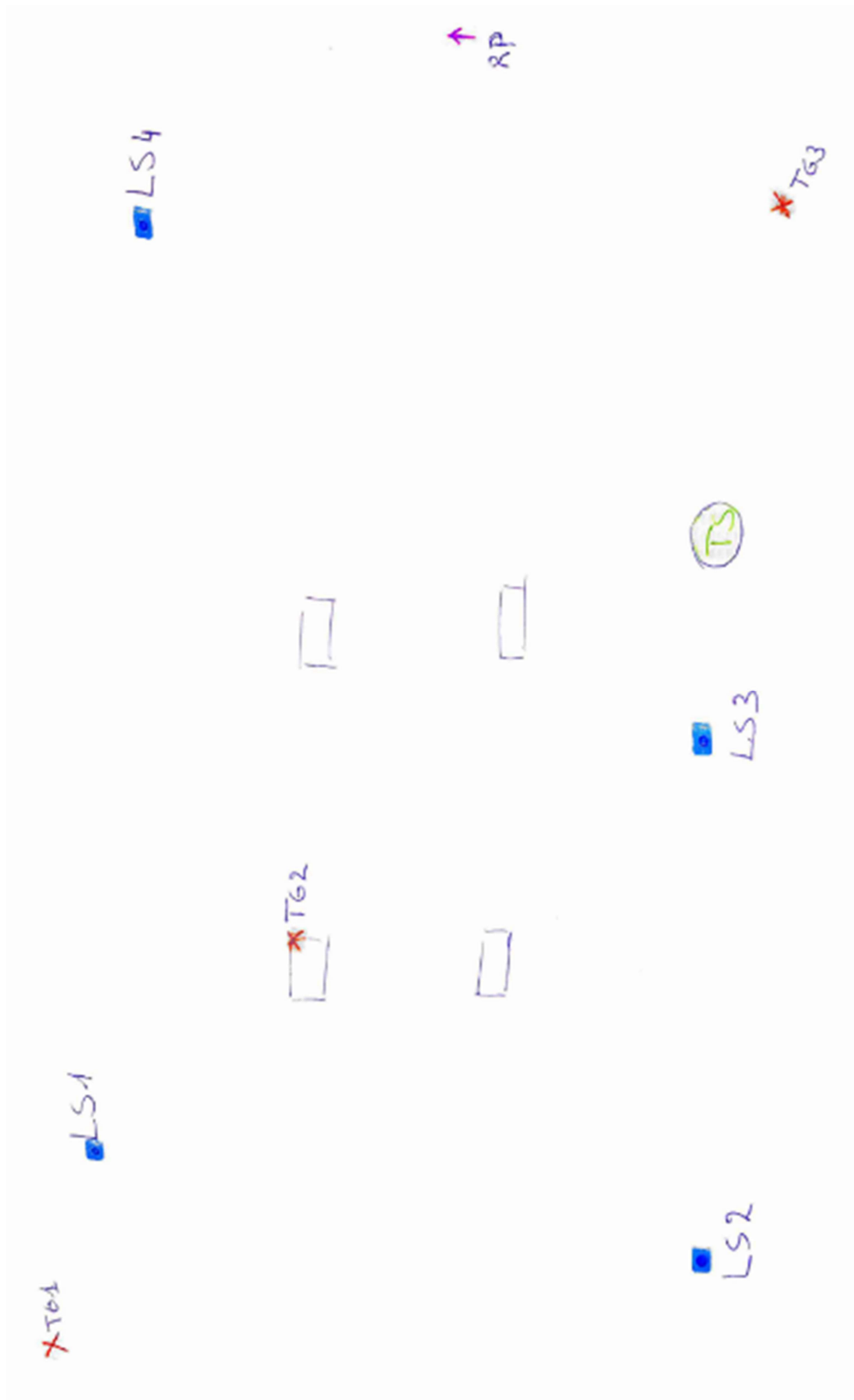
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**Leica Geosystems AG**  
Heinrich-Wild-Strasse  
9435 Heerbrugg, Switzerland  
+41 71 727 31 31

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# Appendix E: Scan plan



## Appendix F: Safety and risk evaluation plan

<b>SJA MEETING PARTICIPANT</b>				
Attachment to Procedure for Safe Job Analysis, document number:		Page No: 1		
SJA title: First view of the site		Form Rev: 2		
Project No./Work Order No. (AO):				
SJA meeting		Date: 25/03/2019	Time: 8:30	
SJA-Responsible: /		Location: Litleskobekken		
Name (block letters)	Firma/Company	Role/Responsibility	Date	Signature
Tuur Peeters	HVL	Student Laserscanning	25/03/2019	
Dieter Dens	HVL	Student Laserscanning	25/03/2019	
Sil Gevaert	HVL	Student Dronescanning	25/03/2019	
Andreas Verheyden	HVL	Student Dronescanning	25/03/2019	
Thomas Jonckheere	HVL	Student Dronescanning	25/03/2019	
Trond Nordvik	HVL	Teacher	25/03/2019	
Stig Frode Samnøy	HVL	Teacher	25/03/2019	
Garret Day	HVL	Teacher	25/03/2019	
/	Statnett	Pilot drone	25/03/2019	
<p>Note: The signer of this document confirms that they have attended the SJA meeting, are familiar with the contents of the SJA form (sub-tasks, hazards and risk reduction measures) and in any procedures/instructions/guidelines that provide guidance To perform the work. They accept that the work will be carried out within the framework described in the SJA form for the assignment in question.</p>				

SJA-FORM							
Attachment to Procedure for Safe Job Analysis, document number:							
SJA title: First view of the site							
Project No./Work Order No. (AO):							
SJA meeting Date: 13/03/2019							
Description of the work: first scanning of the towers							
Assumptions:							
Time: 15:00							
Place: Lilleskobekken							
Page No:							
SJA Responsible:							
Form Rev.:							
Nr	Describe your work step by step	Risk element/Hazard torque	Possible consistency	Measures	Responsible for Action	Antall vedlegg:	
1	Transport to the area	Driving in general	Personal and material injuries	Drive carefully, use proper equipment	All	Drive carefully, use proper equipment	
2	Transport on the area	Risk of falling	Personal injuries	Walk carefully	All	Walk carefully	
3	Transport off the equipment	The equipment can fall and break	Personal and material injuries	Walk carefully, be careful with the equipment	All	Walk carefully	
4	Setting up the laserscanner	The equipment can fall and break	Material injuries	Be careful	Dieter Dens, Tuur Peeters	Be careful	
5	Dismount the laserscanner	The equipment can fall and break	Material injuries	Be careful	Dieter Dens, Tuur Peeters	Be careful	
6							
7							
8							
9							
10							
11							
Is the total risk acceptable: (Yes/No)?							
Yes	Recommendation/Approval Wear walking shoes					Date/Signature 19/03/2019	Experience Summary After the work is completed:
Conclusion/Comment:							
Responsible for the performance of the work							
Responsible for PROSJ./am./site. To be worked on							

NR	SJA Checklist for Project/AO Nr.: SJA title: First view of the site Page No:	Er ivaretatt			Skjema rev.:
		Yes	No	Not Applicable	20/05/2019 Comments
<b>A Documentation and experience data</b>					
1	Is this a well-known work operation for the working battle?		x		
2	Is there a comprehensive procedure/instruction/job package?	x			We were just going to inspectate the site.
3	Know the group of experiences/adverse events from the corresponding Jobs/SJA?	x			
<b>B Expertise</b>					
1	Do we have the necessary personnel and competence for the job?	x			
2	Are there others who should have participated in the SJA meeting?	x			
3	Have the personnel involved the certificates required to perform the job? Are these available?	x			
4	Does Everyone in the Work Safety card/Access card/ID card?	x			
<b>C Kommunikasjon og koordinering</b>					
1	Is there a job where several units / teams must be coordinated?		x		
2	Is good communication and suitable means of communication in place? (Both internally in the work team and towards others who will possibly work in the same area).	x			
3	Are there possible conflicts with simultaneous activities (the system / area / building / plant - eg work at height, work under tension etc.)?	x			
4	Is it clarified who is leading the work?		x		
5	Has enough time been set for the activities?	x			
6	Does the team have thoughtful handling of any alarm or emergency situation and informed emergency preparedness functions about possible measures that could affect them?		x		
7	Has it been designated Head of Security (LFS) for the job?	x			
8	Can LFS and Leader for Linking (LFK) communicate with the work team without the use of an interpreter?				
<b>D Emergency Preparedness Equipment</b>					
1	Are established barriers to reduce the likelihood of adverse events intact?				
2	Are and remain barriers to extinguish or limit the scope/dispersion of a fire/explosion intact (detection/warning, extinguishing system/equipment etc.)?				
3	Are and remain barriers that should contribute to a safe evacuation of personnel intact (emergency power/light, alarm, escape routes, etc.)?				
4	Is First Aid Kit available in close proximity to the work site?				



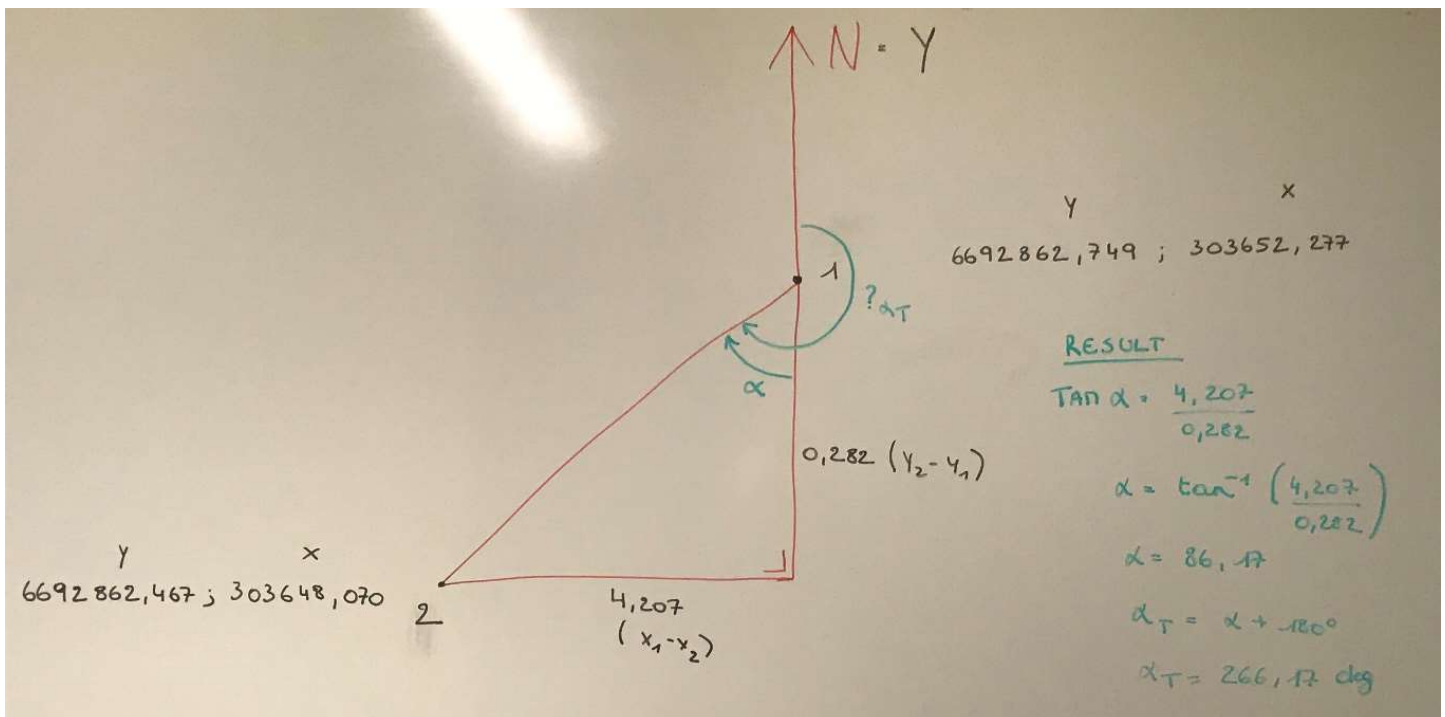
NR	SJA Checklist for Project/AO Nr.: SJA title: First view of the site Page No:	Er ivaretatt			Skjema rev.:
		Yes	No	Not Applicable	Comments
<b>E Equipment covered by the job</b>					
1	Are the necessary safeguards against energy-rich operations taken care of:		x		
2	Can high temperatures be a danger?	x			
3	Is there adequate machine protection/shielding?	x			
4	Are necessary safety measures carried out in relation to voltage set equipment (risk distance and safety distance defined, shielding of equipment, grounding etc.)?	x			
<b>F Equipment for the performance of the job</b>					
1	Are lifting gear, special tools, equipment/materials for the job known, available, checked and found in order?		x		
2	Do all the proper and adequate protective equipment?	x			
3	Is there a risk of uncontrolled movement/rotation of equipment/tools?		x		
4	Are the equipment to be used certified and according to the specifications for the job (size/dimension, safety level, quality etc.)?		x		
<b>G Area</b>					
1	Are inspection required to verify access, knowledge of the work area, working conditions, etc.	x			cold
2	Is it taken into account work in height/multiple levels over each other/falling objects?	x			ice form the towers
3	Is it taken into account the flammable gas/liquid/materials in the area?		x		

NR	SJA Checklist for Project/AO Nr.: SJA title: First view of the site Page No:	Er ivaretatt			Skjema rev.:
		Yes	No	Not Applicable	Comments
					20/05/2019
4	Is it taken into account the possible exposure to noise, vibration, toxic gas/liquids, smoke, dust, steam, chemicals, solvents or radioactivity?		x		
<b>H</b>	<b>Workplace</b>				
1	Is the workplace clean and tidy?	x			
2	Has it been taken into account the need for marking/signage/blocking?		x		
3	Is the transport relation to/from the work site taken into account?	x			
4	Is it taken into account the need for extra guard?		x		
5	Is it taken into account the lighting?		x		
6	Is it considered access/escape?		x		
7	Is the working position/risk of strain injuries taken into account?	x			
<b>I</b>	<b>Lifting operations</b>				
1	Work under or in the immediate vicinity of the machine's working area/hanging load?		x		
2	Has machine/Lifting equipment used for lifting cargo a device that prevents the cargo from accidentally falling into free fall. Hose Break Valves?		x		
3	Has it Been clarified where lifting troops are to be attached and is the approved/serfied lifting point (s) on the current load?		x		
4	Is the Hold/security zone assessed and established?		x		

NR	SJA Checklist for Project/AO Nr.: SJA title: First view of the site Page No:	Er ivaretatt			Skjema rev.:
		Yes	No	Not Applicable	Comments
5	Has the use of styreline been evaluated?		x		
6	Is the machine driver/crane Driver sure that the load's weight is within what the machine/lifting equipment can legally lift, jfr the lifting chart for the machine/lifting equipment?		x		
7	Is The weather/wind ratio assessed?		x		
8	Is there a risk of falling objects from current load (ice, tools, loose cargo etc.)?		x		
9	Is the machine/lifting equipment on a secure surface?		x		
10	Has a manager been designated for the lifting operation (e.g. the use of a signal man)?		x		
<b>J</b>	<b>Heating Works</b>				
1	Who will perform the work Certificate of execution of hot works?		x		
2	Flammable materials/liquids are removed or protected?		x		
3	Is the work site cleared and cleaned of dust and debris?		x		
4	Is the work site secured, eg. Are openings in the floor, wall, suspended ceilings sealed, hidden rooms are controlled?		x		
5	Are approved extinguitioned equipment deployed or readily available?		x		
6	Is the loop or detector disconnected through fire Center?		x		
7	Is the work equipment flawless?		x		
8	Is there a need for own fire guard during and after the work has ended?		x		
9	Is the Aftercheck after the work is completed completed?		x		
10	Is the loop or detector switched on through fire centre?		x		

## Appendix G: Calculation Azimuth point & coordinates

ID	X	Y	Z
P1	6692863.012	303648.044	441.322
P2	6692862.467	303648.070	441.321
P3	6692862.463	303648.663	441.316
P4	6692863.223	303652.252	441.325
P5	6692862.749	303652.277	446.637
P6	6692872.758	303649.950	469.854



## Appendix H: Error registration with snow

### Registration Diagnostics

Status: VALID Registration

Mean Absolute Error:

for Enabled Constraints = 0.008 m

for Disabled Constraints = 0.000 m

Date: 2019.05.16 10:50:36

Database name : Thesis25.3

### ScanWorlds

Station-001: SW-001 (Leveled)

Station-002: SW-002 (Leveled)

### Constraints

Constraint ID	ScanWorld	Status	Weight	Error	ScanWorld	Error Vector	Type	H
orz	Vert							
T3	Station-001: SW-001 (Leveled)	On	1.0000	0.005 m	Station-002: SW-002 (Leveled)	(0.002 , 0.002, 0.004) m	Coincident:	0
Vertex - Vertex								
.002 m 0.004 m								
T2	Station-001: SW-001 (Leveled)	On	1.0000	0.004 m	Station-002: SW-002 (Leveled)	(0.002 , 0.002, 0.004) m	Coincident:	0
Vertex - Vertex								
.003 m 0.004 m								
T1	Station-001: SW-001 (Leveled)	On	1.0000	0.003 m	Station-002: SW-002 (Leveled)	(0.001 , -0.002, 0.001) m	Coincident:	0
Vertex - Vertex								
.003 m 0.001 m								
Cloud/Mesh 1	Station-001: SW-001 (Leveled)	On	1.0000	0.020 m	Station-002: SW-002 (Leveled)	aligned [0.014 m]	Cloud: Cloud	
loud/Mesh - Cloud/Mesh								

Cloud/Mesh 1 [Station-001: SW-001 (Leveled) : Station-002: SW-002 (Leveled)]

Objective Function Value: 0.000139682 sq m

Iterations: 71

Overlap Point Count: 443500

Overlap Error Statistics

RMS: 0.0144167 m

AVG: 0.0107575 m

MIN: 1.05204e-06 m

MAX: 0.0943721 m

Overlap Center: (-66.567, 17.700, -0.731) m

Error after global registration: 0.000205169 sq m

Translation: (-22.676, 41.408, -3.989) m

Rotation: (0.0000, -0.0002, -1.0000):-92.167 deg

### ScanWorld Transformations

Station-001: SW-001 (Leveled)

translation: (0.000, 0.000, 0.000) m

rotation: (0.0000, 1.0000, 0.0000):0.000 deg

Station-002: SW-002 (Leveled)

translation: (-22.694, 41.409, -3.983) m

rotation: (0.0000, 0.0000, 1.0000):92.189 deg

### Unused ControlSpace Objects

Station-001: SW-001 (Leveled):

Vertex : unlabeled

Station-002: SW-002 (Leveled):

Vertex : unlabeled



## Appendix H: Error registration without snow

### Registration Diagnostics

Status: VALID Registration

Mean Absolute Error:

for Enabled Constraints = 0.004 m

for Disabled Constraints = 0.000 m

Date: 2019.05.16 09:04:54

Database name : ThesisScan2

### ScanWorlds

Station-001: SW-001 (Leveled)

Station-002: SW-002 (Leveled)

Station-003: SW-003 (Leveled)

Station-004: SW-004 (Leveled)

### Constraints

Constraint ID	ScanWorld	Status	Weight	Error	ScanWorld	Error Vector	Type
	Horz	Vert					
T2	Station-001: SW-001	(Leveled)	1.0000	0.004 m	Station-002: SW-002	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.004 m	( 0.002 ,	0.003, -0.003) m		
0.003 m	-0.003 m						
T2	Station-001: SW-001	(Leveled)	1.0000	0.004 m	Station-003: SW-003	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.004 m	( 0.003 ,	0.003, 0.001) m		
0.004 m	0.001 m						
T2	Station-001: SW-001	(Leveled)	1.0000	0.004 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.004 m	(-0.001 ,	0.003, -0.003) m		
0.003 m	-0.003 m						
T1	Station-001: SW-001	(Leveled)	1.0000	0.003 m	Station-002: SW-002	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.003 m	(-0.002 ,	0.002, 0.001) m		
0.003 m	0.001 m						
T1	Station-001: SW-001	(Leveled)	1.0000	0.003 m	Station-003: SW-003	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.003 m	(-0.002 ,	-0.001, -0.002) m		
0.002 m	-0.002 m						
T1	Station-001: SW-001	(Leveled)	1.0000	0.002 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.002 m	( 0.000 ,	-0.002, -0.001) m		
0.002 m	-0.001 m						
T3	Station-001: SW-001	(Leveled)	1.0000	0.005 m	Station-002: SW-002	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.005 m	(-0.001 ,	-0.005, 0.002) m		
0.005 m	0.002 m						
T3	Station-001: SW-001	(Leveled)	1.0000	0.004 m	Station-003: SW-003	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.004 m	(-0.002 ,	-0.002, 0.003) m		
0.002 m	0.003 m						
T3	Station-001: SW-001	(Leveled)	1.0000	0.004 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.004 m	(-0.001 ,	0.000, 0.004) m		
0.001 m	0.004 m						
T2	Station-002: SW-002	(Leveled)	1.0000	0.003 m	Station-003: SW-003	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.003 m	( 0.001 ,	0.000, 0.003) m		
0.001 m	0.003 m						
T2	Station-002: SW-002	(Leveled)	1.0000	0.002 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.002 m	(-0.002 ,	0.000, 0.000) m		
0.002 m	0.000 m						
T3	Station-002: SW-002	(Leveled)	1.0000	0.003 m	Station-003: SW-003	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.003 m	(-0.001 ,	0.003, 0.001) m		
0.003 m	0.001 m						
T3	Station-002: SW-002	(Leveled)	1.0000	0.004 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.004 m	( 0.000 ,	0.004, 0.002) m		
0.004 m	0.002 m						
T1	Station-002: SW-002	(Leveled)	1.0000	0.005 m	Station-003: SW-003	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.005 m	( 0.000 ,	-0.004, -0.003) m		
0.004 m	-0.003 m						
T1	Station-002: SW-002	(Leveled)	1.0000	0.005 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.005 m	( 0.003 ,	-0.004, -0.002) m		
0.005 m	-0.002 m						
T1	Station-003: SW-003	(Leveled)	1.0000	0.003 m	Station-004: SW-004	(Leveled)	Coincident:
Vertex - Vertex	On	1.0000	0.003 m	( 0.002 ,	-0.001, 0.002) m		

## Registration Diagnostics

```

0.002 m 0.002 m
T2 Station-003: SW-003 (Leveled) Station-004: SW-004 (Leveled) Coincident:
Vertex - Vertex On 1.0000 0.005 m (-0.003 , 0.000, -0.003) m
0.003 m -0.003 m
T3 Station-003: SW-003 (Leveled) Station-004: SW-004 (Leveled) Coincident:
Vertex - Vertex On 1.0000 0.002 m ( 0.001 , 0.001, 0.001) m
0.002 m 0.001 m
Cloud/Mesh 1 Station-001: SW-001 (Leveled) Station-002: SW-002 (Leveled) Cloud: Cloud
loud/Mesh - Cloud/Mesh On 1.0000 0.006 m aligned [ 0.023 m]

Cloud/Mesh 2 Station-001: SW-001 (Leveled) Station-003: SW-003 (Leveled) Cloud: Cloud
loud/Mesh - Cloud/Mesh On 1.0000 0.004 m aligned [ 0.023 m]

Cloud/Mesh 3 Station-001: SW-001 (Leveled) Station-004: SW-004 (Leveled) Cloud: Cloud
loud/Mesh - Cloud/Mesh On 1.0000 0.002 m aligned [ 0.022 m]

Cloud/Mesh 4 Station-002: SW-002 (Leveled) Station-003: SW-003 (Leveled) Cloud: Cloud
loud/Mesh - Cloud/Mesh On 1.0000 0.004 m aligned [ 0.023 m]

Cloud/Mesh 5 Station-003: SW-003 (Leveled) Station-004: SW-004 (Leveled) Cloud: Cloud
loud/Mesh - Cloud/Mesh On 1.0000 0.007 m aligned [ 0.018 m]

Cloud/Mesh 1 [Station-001: SW-001 (Leveled) : Station-002: SW-002 (Leveled)]
Objective Function Value: 0.000251753 sq m
Iterations: 19
Overlap Point Count: 139800
Overlap Error Statistics
RMS: 0.0228839 m
AVG: 0.0159121 m
MIN: 2.26737e-06 m
MAX: 0.0986253 m
Overlap Center: (3.369, -25.318, 10.522) m
Error after global registration: 2.18885e-05 sq m
Translation: (-30.897, -26.152, -0.597) m
Rotation: (0.0000, -0.0002, -1.0000):-125.267 deg
Cloud/Mesh 2 [Station-001: SW-001 (Leveled) : Station-003: SW-003 (Leveled)]
Objective Function Value: 0.000307928 sq m
Iterations: 24
Overlap Point Count: 142800
Overlap Error Statistics
RMS: 0.0228946 m
AVG: 0.0165108 m
MIN: 3.33488e-07 m
MAX: 0.0951034 m
Overlap Center: (3.241, -15.175, 9.186) m
Error after global registration: 8.57826e-06 sq m
Translation: (3.890, -45.338, 5.659) m
Rotation: (0.0000, 0.0000, 1.0000):-71.430 deg
Cloud/Mesh 3 [Station-001: SW-001 (Leveled) : Station-004: SW-004 (Leveled)]
Objective Function Value: 0.000166826 sq m
Iterations: 10
Overlap Point Count: 87066
Overlap Error Statistics
RMS: 0.0219703 m
AVG: 0.0141744 m
MIN: 4.20452e-06 m
MAX: 0.0972051 m
Overlap Center: (8.873, -26.449, 17.790) m
Error after global registration: 2.46292e-06 sq m
Translation: (50.384, -25.057, 2.772) m
Rotation: (-0.0001, 0.0000, 1.0000):51.250 deg
Cloud/Mesh 4 [Station-002: SW-002 (Leveled) : Station-003: SW-003 (Leveled)]
Objective Function Value: 0.000241104 sq m
Iterations: 8
Overlap Point Count: 196500
Overlap Error Statistics
RMS: 0.0226488 m
AVG: 0.0159318 m
MIN: 3.16096e-06 m

```

**Registration Diagnostics**

```
MAX: 0.0957858 m
Overlap Center: (-14.497, -21.680, 10.311) m
Error after global registration: 9.72599e-06 sq m
Translation: (-35.756, -17.316, 6.263) m
Rotation: (0.0001, 0.0000, -1.0000):-163.300 deg
Cloud/Mesh 5 [Station-003: SW-003 (Leveled) : Station-004: SW-004 (Leveled)]
Objective Function Value: 0.000160789 sq m
Iterations: 28
Overlap Point Count: 57466
Overlap Error Statistics
RMS: 0.0182834 m
AVG: 0.0122549 m
MIN: 2.56076e-06 m
MAX: 0.0954895 m
Overlap Center: (-18.542, 8.941, 11.512) m
Error after global registration: 2.63688e-05 sq m
Translation: (-4.398, 50.519, -2.892) m
Rotation: (0.0001, 0.0000, -1.0000):-122.650 deg
```

**ScanWorld Transformations**

```
Station-001: SW-001 (Leveled)
translation: (0.000, 0.000, 0.000) m
rotation: (0.0000, 1.0000, 0.0000):0.000 deg

Station-002: SW-002 (Leveled)
translation: (-30.890, -26.150, -0.606) m
rotation: (0.0000, 0.0000, 1.0000):125.267 deg

Station-003: SW-003 (Leveled)
translation: (3.895, -45.342, 5.658) m
rotation: (-0.0000, -0.0000, -1.0000):71.428 deg

Station-004: SW-004 (Leveled)
translation: (50.386, -25.057, 2.770) m
rotation: (0.0000, 0.0000, 1.0000):51.251 deg
```

**Unused ControlSpace Objects**

```
Station-001: SW-001 (Leveled):
Vertex : unlabeled

Station-002: SW-002 (Leveled):
Vertex : unlabeled

Station-003: SW-003 (Leveled):
Vertex : unlabeled

Station-004: SW-004 (Leveled):
Vertex : unlabeled
```