A comparison of scans

Laser scanners and photogrammetry for heritage institutions

by

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Abstract

This project compares different laser scanners and photogrammetry in relation to scan quality, cost and speed. The target group is heritage buildings and large objects. Two rooms at the open air museum Skansen was chosen for their level of detail and reflective surfaces. Noise and deviation was compared. The main result of the study shows that quality follows price and that you can obtain good scan results without reference markers.

These are the scanners used:

- FARO Fokus s70
- Leica BLK360
- Leica RTC360
- Leica BLK2GO
- Trimble X7
- Photogrammetry with Nikon D800, prime lens.
- Photogrammetry with Olympus Mk10, zoom lens.

Table of content

Introduction

Laser scanning of buildings is a big field with many companies on the market, but is in general directed towards the industry, construction and mining etc. Very few are specialized in heritage projects, where small details and high resolution as well as good textures are essential. As the equipment is very costly and resources are low in the cultural field, it is also of utmost importance to choose the right tool from start to get the details required. In order to facilitate cost effective and high-quality scanning solutions, I wanted to compare different laser scanners and photogrammetry, as well as the time for processing and the cost of hardware and software. A good quality documentation in the heritage sector demands not only a good-looking result, but also one where you, for example, can extract the profile of the floor moulding under the table.

Purpose and questions

The aim of this paper is to present an objective view of different brands and models of scanners for the purpose of documenting heritage buildings primarily, but also other larger objects. The parameters being noise levels, deviation, ease of use and cost. Is there a method to make these comparisons? I also hoping to compare the laser scans with photogrammetry and to compare the difference between using a prime lens with manual focus (recommended) and a zoom lens with autofocus (not recommended[1]).

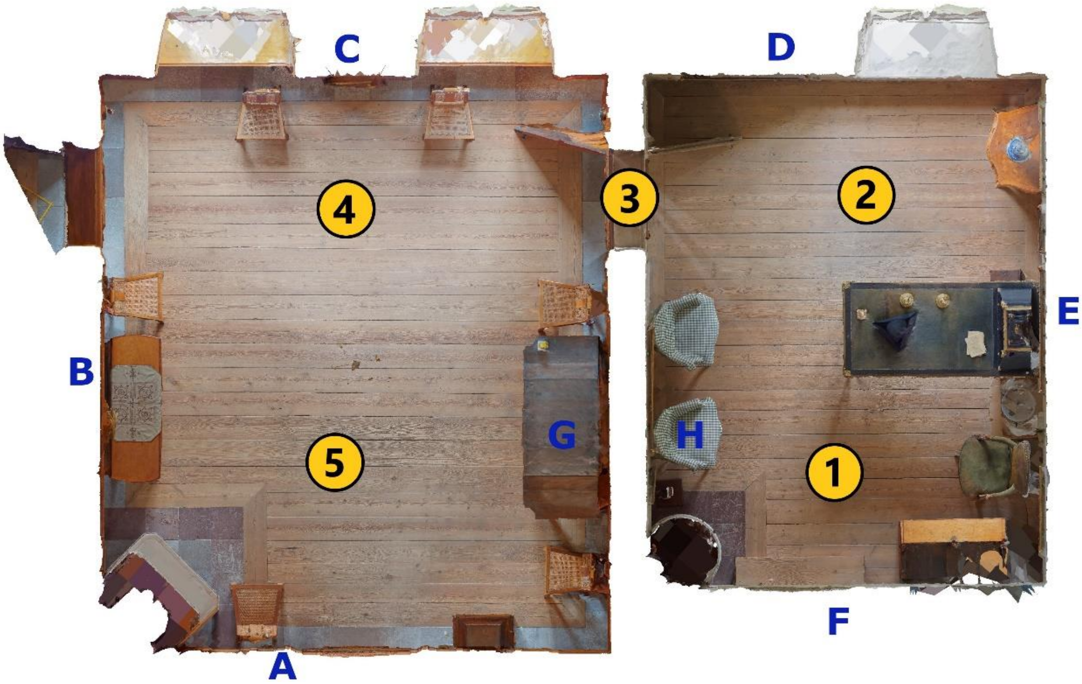
Method

Location

As an example building I chose the small dining room and the office at Tottieska malmgården at Skansen open air museum. The choice of location was based on its accessibility since Skansen is a member of Digisam where I did my internship and I have previously worked there with restorations. The reason for choosing these specific two rooms, is because they form a horseshoe shape, which is a bit challenging for registration. Further the wood panels are quite reflective which makes it harder to get a good return signal and they are full of details that needs to be captured in great detail. A too simple object would give a good result with even bad scanners and with a too complicated one might get no measurable result with some scanners. I was hoping this would be a good middle ground.

The walls of these rooms have been litterated A-F in the plan below, for ease of describing a position.

[1] Michael Fergusson, Viospatia



Scanning

I limited the capture to five scan positions (1-5 in the image above) even though this will not capture everything. The reason being to keep the data amount down so I could process it on my not very powerful computer and to keep scan time down. If I were to document these rooms for real, I would use at least 15 positions at different heights from the floor to high under the ceiling. I made sure the conditions were as equal as possible at all scans with the approximate same positions used and curtains being up. To eliminate the factor of poor handling and knowledge, all scanning and registration was done by the reseller/representative of each brand. These are the scanners used:

- FARO Fokus s70
- Leica BLK360
- Leica RTC360
- Leica BLK2GO
- Trimble X7

Photogrammetry

All photos are taken with a tripod except the ones high under the ceiling. For these a camera mast was used. Camera settings were: Aperture priority, fixed ISO and whitebalance but variable shutter speed. Only natural light was available.

- Nikon D800 with AF-S Nikkor 50 mm f/1.4G (not intended). Captured at ISO 200, F13, 0 EV, variable shutterspeed, AF.
- Olympus E-M10 Mk II with M.Zuiko 14-42 mm f/3.55-5.6 EZ. Captured at ISO 200, F7.1, 0 EV, variable shutterspeed, AF, 14 mm (equals to 28mm full frame).

Images taken in RAW and processed in DxO Photolab 3 to remove shadows and highlights. Converted to lossless jpg and then processed in Reality Capture.

Analysis

The initial plan was to analyse noise and deviation of the pointclouds in CloudCompare. However, in the end another approach by comparing meshes was chosen.

When I posted the e57 clouds on Laserscanningforum.com[2], in hope to get feedback from people having more experience and better software to experiment with, I received some renderings of the pointclouds with regards to the picture quality and a lot of suggestions of other scanners to try. That was very good as well and gave me some contacts but did not answer my main questions. Chao Han, founder of VirtualGrid[3] meshed the pointclouds with their software VRmesh and shared them. That seemed like a promising approach to explore. The meshing in VRmesh was done with "maximal amount of triangles", typically 15 million, and no filtering. This presented a very clear representation of the noise, enabling me to skip doing that in CloudCompare. Instead I aligned the meshes in Artec Studio 11, for which I have a student licence, so I could capture a screenshot of all the meshes from the same angle. Since Artec Studio also have a surface distance measure tool, and they were already imported and aligned I also checked the deviation there instead of in CloudCompare. As a reference, the FARO mesh was used as it was scanned with the ATS reference spheres and with a deviation report by Marko Matilainen from ATS, and therefore should be the most correct one.

Limitations

The project was limited to scanners available in the Stockholm area. The outbreak of the pandemic limited the possibility to try scanners that were located elsewhere and the possibility to collaborate more closely with other experts due to restrictions. The FARO scan and the Leica scans were done just before the close down, so I had to wait a long time for some of the data. Degree project started on the 4:th of May, Trimble scan was made the 12:th of May and report handed in the 19:th.

I got contacted around the 12:th of May by Maskin och Laserteknik AB in Gothenburg who wanted me to try the Z+F 5016 and by FARO who wanted me to try their new Plus series. Unfortunately, there was no time to include them in the project. I would also have liked to try the Artec Ray but the closest one is in Germany. Surphaser and Riegl were also left out due to practical reasons. My hope is to continue with these comparisons and make a second report with more scanners included.

Regarding the photogrammetry, I borrowed a Nikon D800 from Wilund Arkitekter och antikvarier and a 28 mm lens from the National Heritage board. Unfortunately, the lens did not function, and a 50 mm lens had to be used instead.

Previous research

I have not found any published studies on comparisons between scanners done before, although there might be some that I could not find during these two weeks. There are some comparisons of scan times and I could find some pictures of surface distance analysis, but not the report itself. Both the RTC360 and the Trimble X7 are fairly new to the market as well.

[2] https://www.laserscanningforum.com/forum/viewtopic.php?f=20&t=16272&sid=e0c980bbe4157412dd58b68a17d88dcc

[3] Chao Han, VirtualGrid

Result

Software

All scanners have their proprietary fileformat that can only be read by their own software. Thus when renting a scanner, you probably also have to rent the software. Without it the scanner is useless. The basic software for most scanners are very simple, but still bear a premium pricetag. Most also demand a yearly update at an extra fee. There is often the possibility to rent the software instead of buying a perpetual license, but at a higher longterm cost. Working with the proprietary fileformat with the intended software is always faster and more efficient but it may lack functions you want or have a user interface that does not suit you. The only manufacturer, of the scanners in this study, who has choosen to include a free software is Trimble, enabling you to register your scans in their included field app. You can then export it in an open format so you are free to choose whatever software to use for further processing. There are workarounds[4] for getting the info out of FARO scanners, but according to my reference it is not for the novice.

Leica and Trimbles basic software do registration and export, plus some simple measurements. Leica then have different modules you can add on for visualisation, meshing and so on[5]. Trimbles field app is very simple and if you want to continue working in their fileformat they have paid software for the office[6]. FARO Scene is a more complete solution but also come in different versions[7].

Approximate prices in Euro.

Scanner	**FARO Focus s70**	**Leica BLK360**	**Leica RTC360**	**Leica BLK2GO**	**Trimble X7**
Price hardware	39000	16714	48442	45609	33050
rent hardware/day	?	157	364	------	283
Price software	5744	1794	3777	1794	Included
update software/year	1105	348	774	348	included
rent software/year	2299	897	1747	897	Included
service	?	250	1284	1190	?

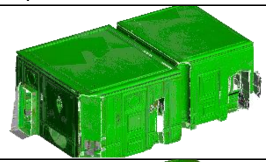
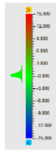
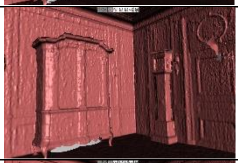
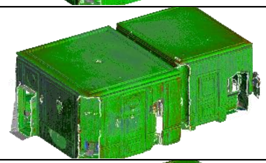
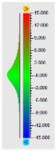
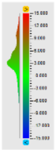
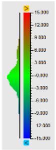
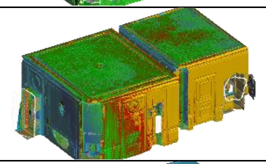
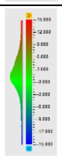
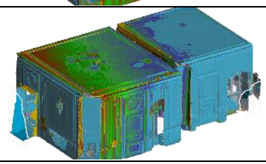
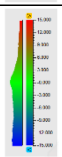
Time

The scan time is the small part of the job, but I did not have the possibility to compare the time required for processing the data. In the table below are the minimum and maximum scan times presented in the manufacturers specifications and the setting we used for the scans in this project.

[4] Jonathan Westin, Centre for Digital Humanities, University of Gothenburg.
[5] Mattias Bornholm, Leica.
[6] Magnus Åberg, Trimtec.
[7] Marko Matilainen, ATS.

Scanner	FARO Focus s70	Leica BLK360	Leica RTC360	Leica BLK2GO	Trimble X7
Scantime min	2 min	3 min	26 sec	-------	2 min
Scantime max	2 h	3 min	3 min	40 min	7 min
Scantime used	7 min	3 min	3 min	~8 min	4 min
Setting name	1/5, 4X	high	high	-------	4 min

Noise and deviation summary

Scanner	Noise	Deviation	Graph	comments
FARO s70	N/A	N/A	N/A	This was used as reference
RTC360				Low noise and perfectly placed within a millimetre.
BLK2GO				Very noisy but within 8 millimetres. Mostly the noise that deviates.
BLK360				Quite noisy and wall A and F has shifted 10 mm.
Trimble X7				Medium noise and some registration error in wall D and F.
Zoom lens				Noise is varied depending of capture and light reflections. Deviations up to 15 mm
Prime lens				Same problem with noise as in zoom lens, but at lower levels. Scaling and deviation problems.

Noise

Normally one would clean up the pointcloud before meshing it. However for this study the meshing was performed without cleaning in order to visualize the noise in each scan. The smoothness of the mesh reflects the noisyness of the cloud. Most registration software have some kind of cleaning of extreme points when doing the registration and hopefullt they are equally gentle. The following images is in order from least to most noisy.

Faro Focus s70

The FARO mesh was accidentally made from a cleaned up pointcloud and therefore does not qualify for a comparison. This will be fixed for version two of this report.

Leica RTC360

A very fine and distinct mesh with minimal noise. It struggles on some difficult areas such as the side of the pendulum clock, the doorway in wall B and the lower part of the door in wall G.

Trimble x7

We did not run the highest resolution on the Trimble but choose the 4 minute scan, and it is possible that the mesh would have been less noisy if we had chosen a higher resolution. The accuracy was the same on all settings. The result is 0k, but not perfect.

Leica BLK360

Here we begin to see some serious noise. It is a budget alternative so that is expected.

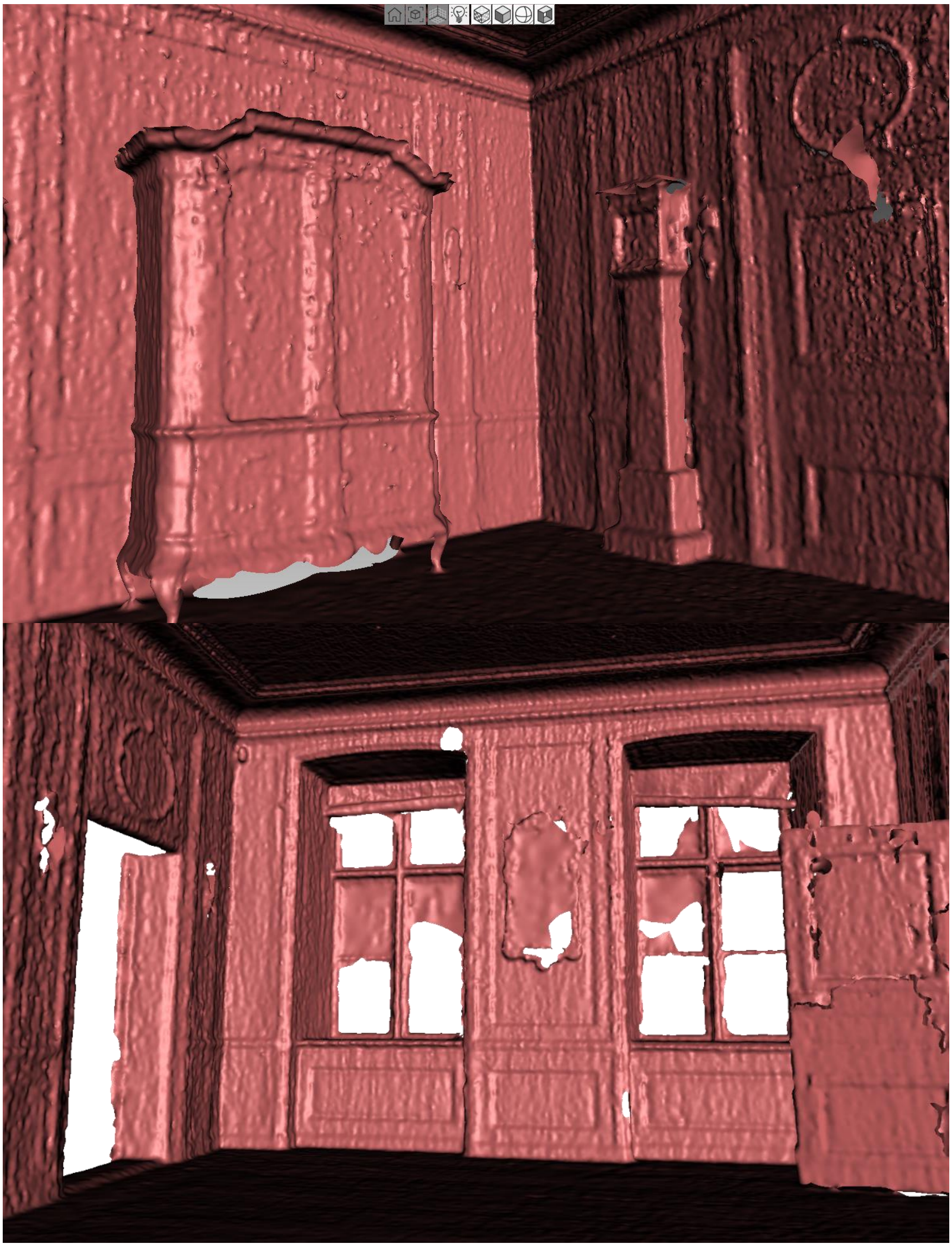
Photogrammetric mesh, prime lens

The photogrammetric mesh has a very uneven quality. Photographing towards the very bright windows on wall C, as well as the reflections on wall A creates huge noise. B and G on the other hand looks fairly good.

Photogrammetric mesh, zoom lens

The zoom lens show the same problems as the prime lens, only worse as it had a wider lens and less pixels.

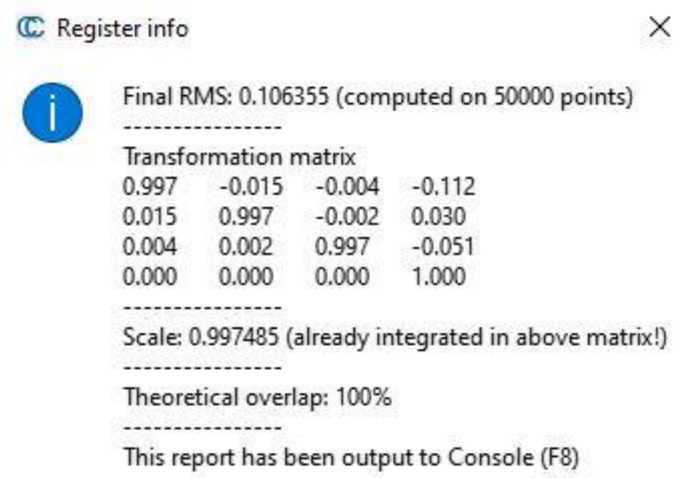
Leica BLK2GO



Very noisy data as expected from a handheld scanner. Also, some floating blobs. The strength of a handheld is its speed and not its precision. It can reach all those places that are in shadow of an areascanner.

Deviation

To check the deviation, I used the FARO as reference. It is therefore not part of the analysis. The meshes are all within 10 mm except for the photogrammetric meshes that are only scaled after a folding rule that was out of focus. In CloudCompare, the photogrammetric meshes were aligned with scale to the FARO cloud. This scaling was applied in Artec Studio and a new surface distance measure was made as to get a result of the deviation.


Register info

Final RMS: 0.106355 (computed on 50000 points)

Transformation matrix

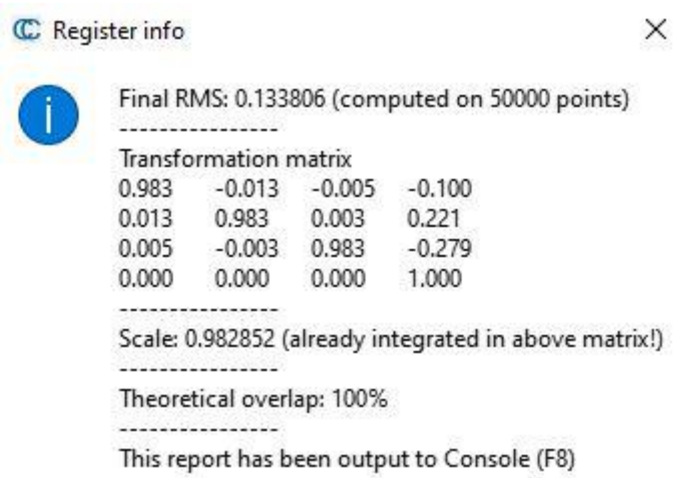
0.997	-0.015	-0.004	-0.112
0.015	0.997	-0.002	0.030
0.004	0.002	0.997	-0.051
0.000	0.000	0.000	1.000

Scale: 0.997485 (already integrated in above matrix!)

Theoretical overlap: 100%

This report has been output to Console (F8)

The zoom lens mesh scaling.


Register info

Final RMS: 0.133806 (computed on 50000 points)

Transformation matrix

0.983	-0.013	-0.005	-0.100
0.013	0.983	0.003	0.221
0.005	-0.003	0.983	-0.279
0.000	0.000	0.000	1.000

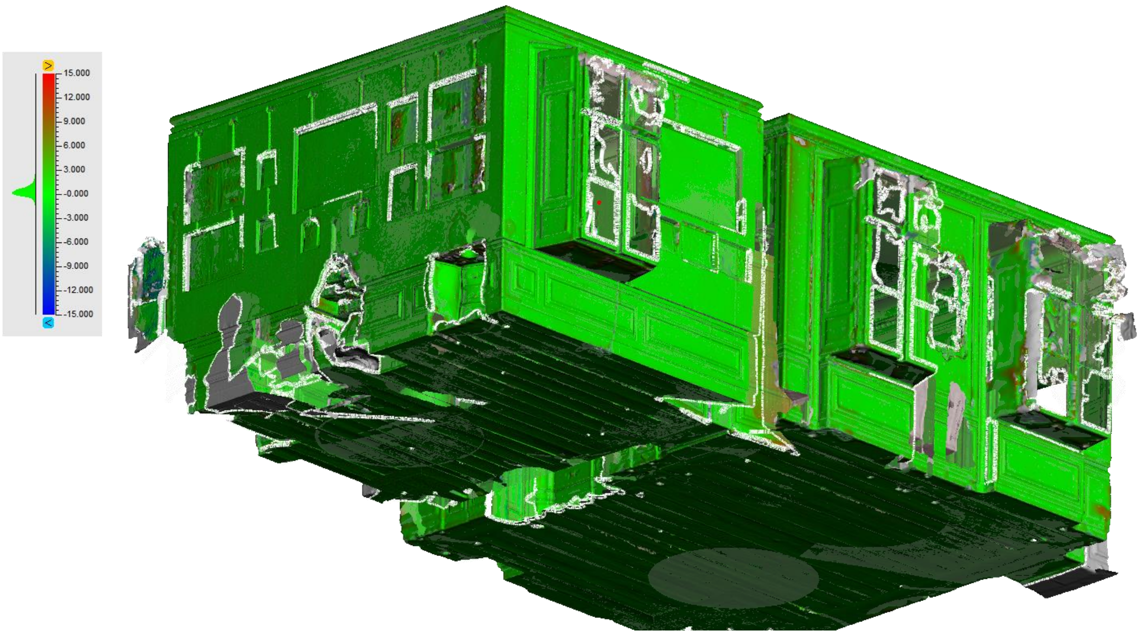
Scale: 0.982852 (already integrated in above matrix!)

Theoretical overlap: 100%

This report has been output to Console (F8)

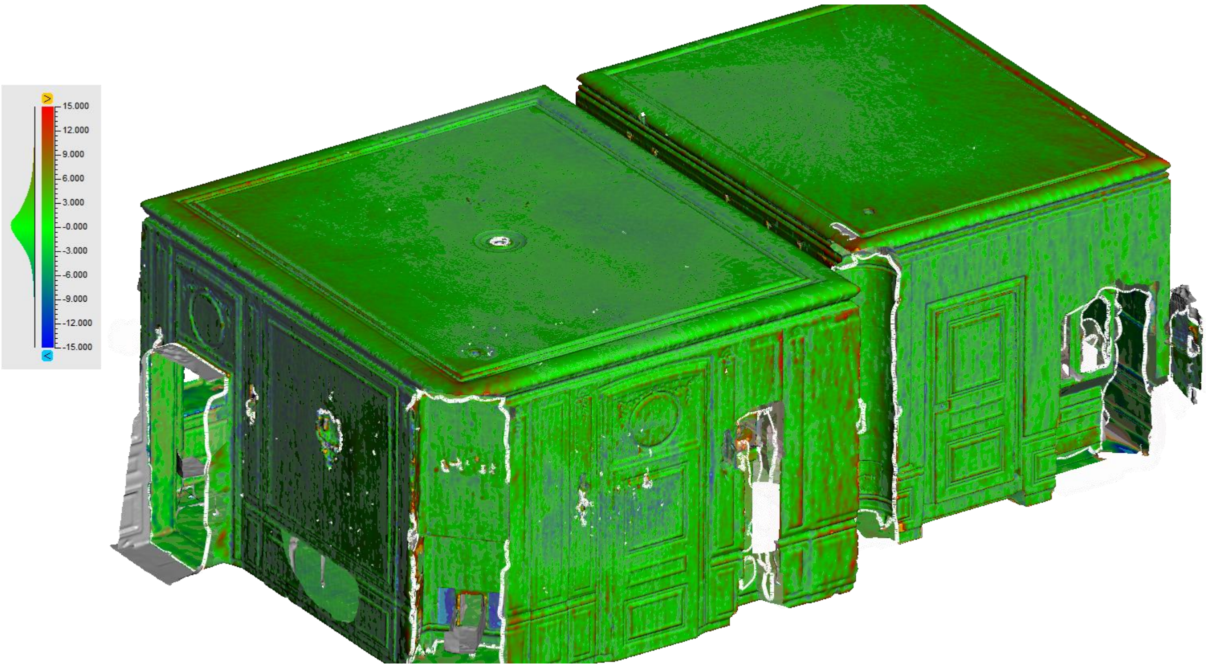
The prime lens mesh scaling.

Leica RTC360



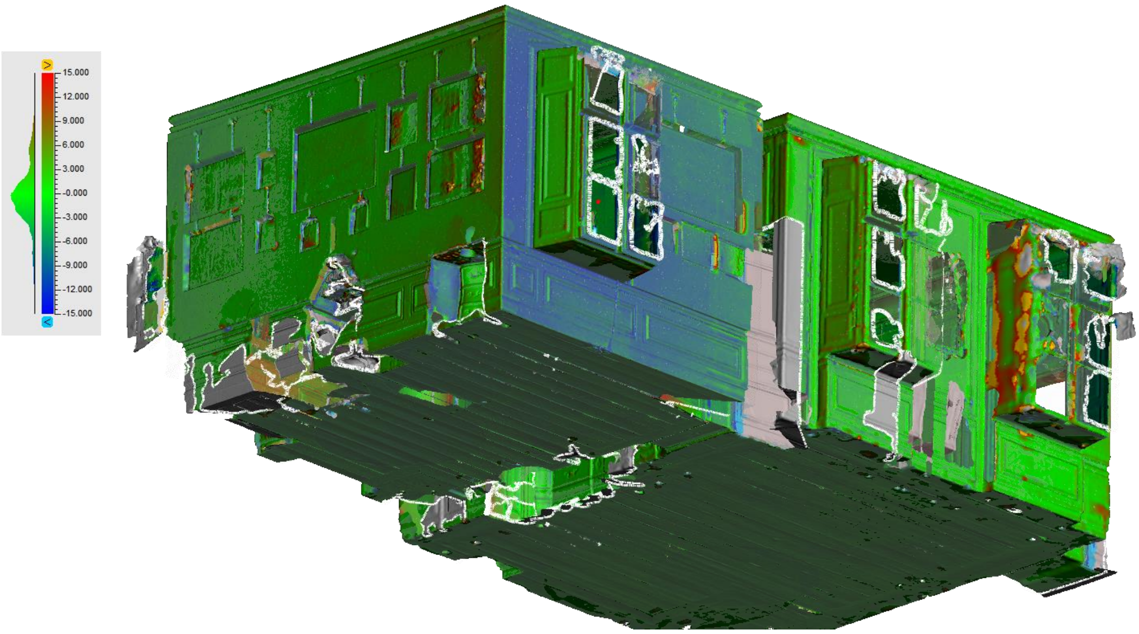
A very precise fit within the millimetre.

Leica BLK2GO



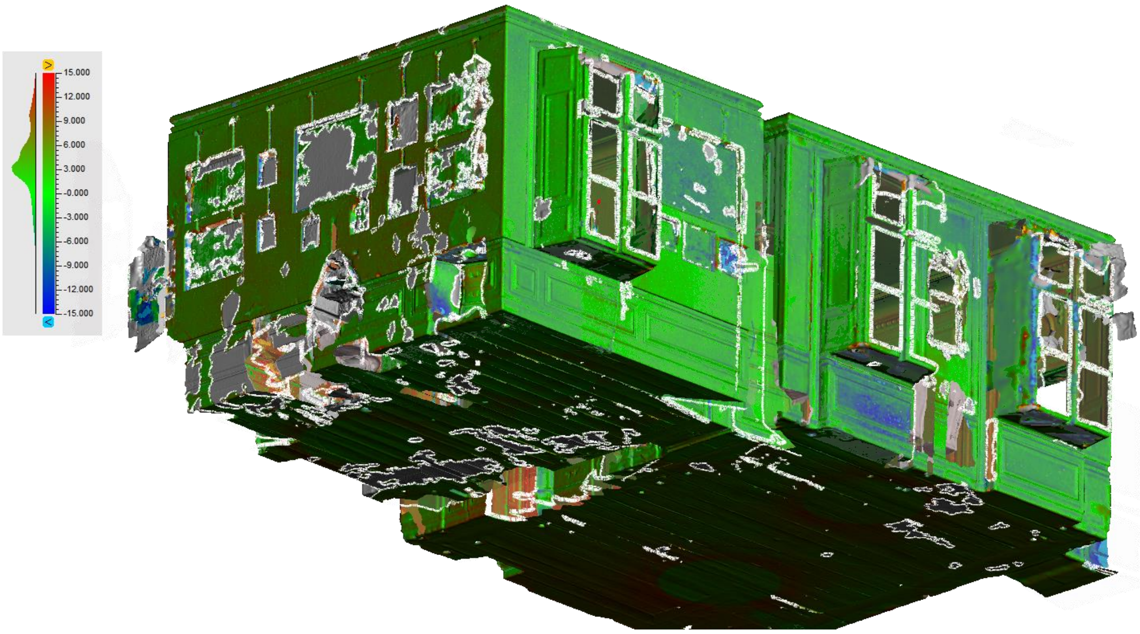
Although this scan has the most noice of them all, it is also very correct when it comes to geometry. Within a few millimeters.

Trimble X7



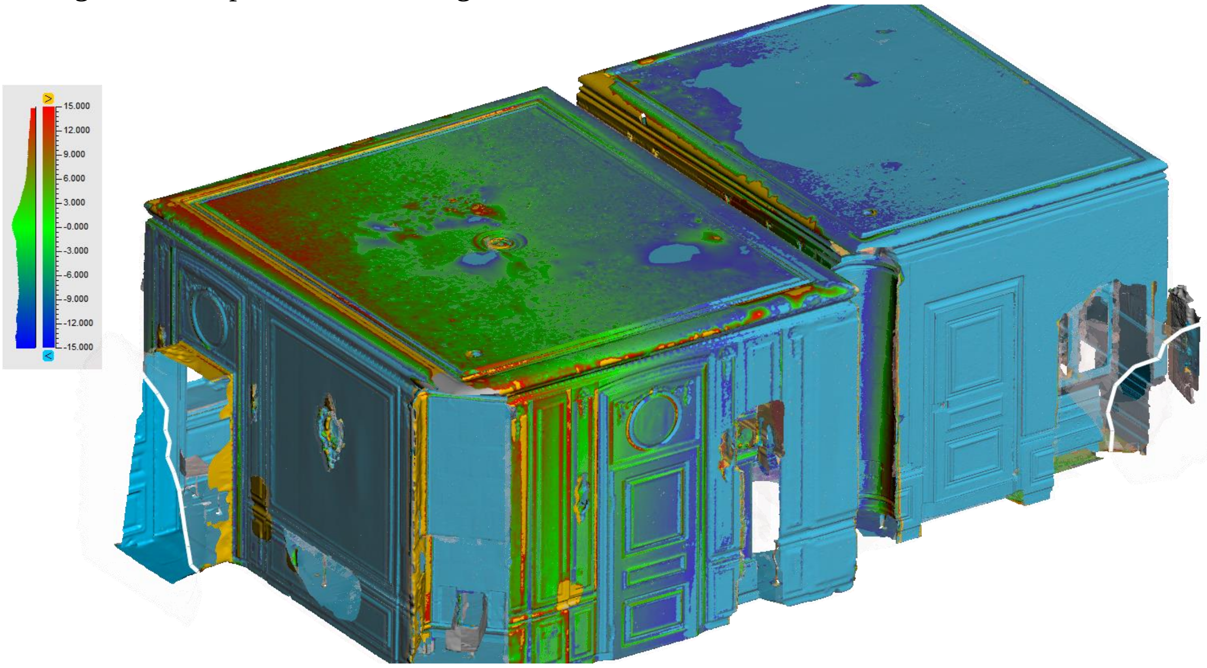
One step down from the previous ones with 8-9 mm deviation in two corners. 90% is still within the millimetre. It seems as if wall E has moved slightly along its axis and caused the shift in wall D and F. If it was a pure registration error between the rooms, it would probably have rotated and caused deviation in wall E as well.

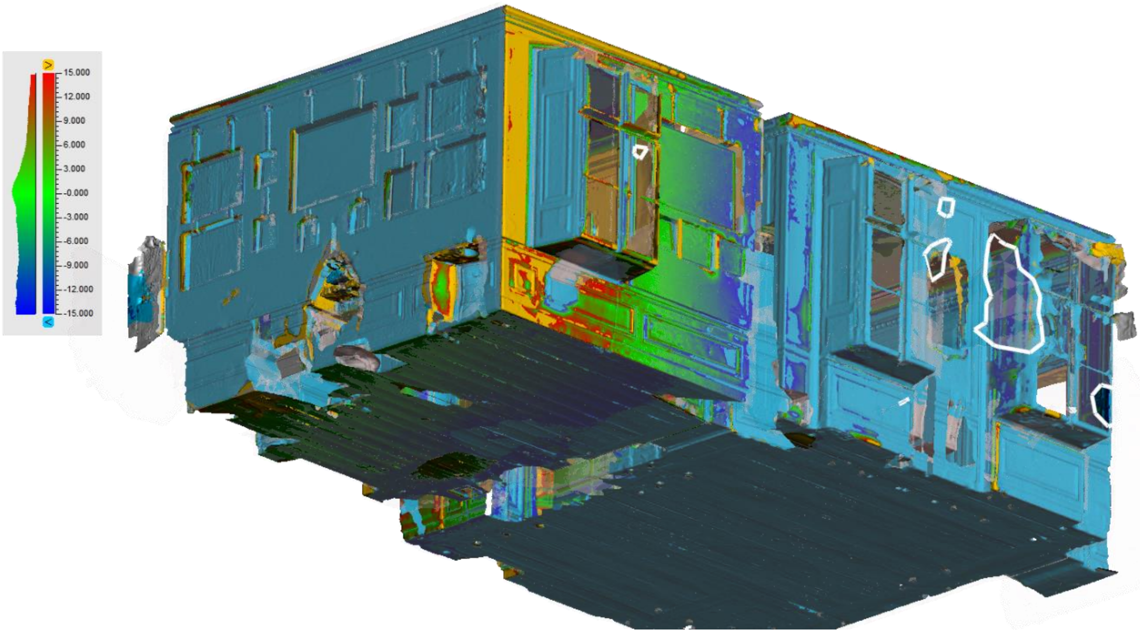
Leica BLK360



The geometry is good except we can see that the whole walls A and F are pushed away, which means the scaling in one axis is off by 10 mm while the other two axis are good.

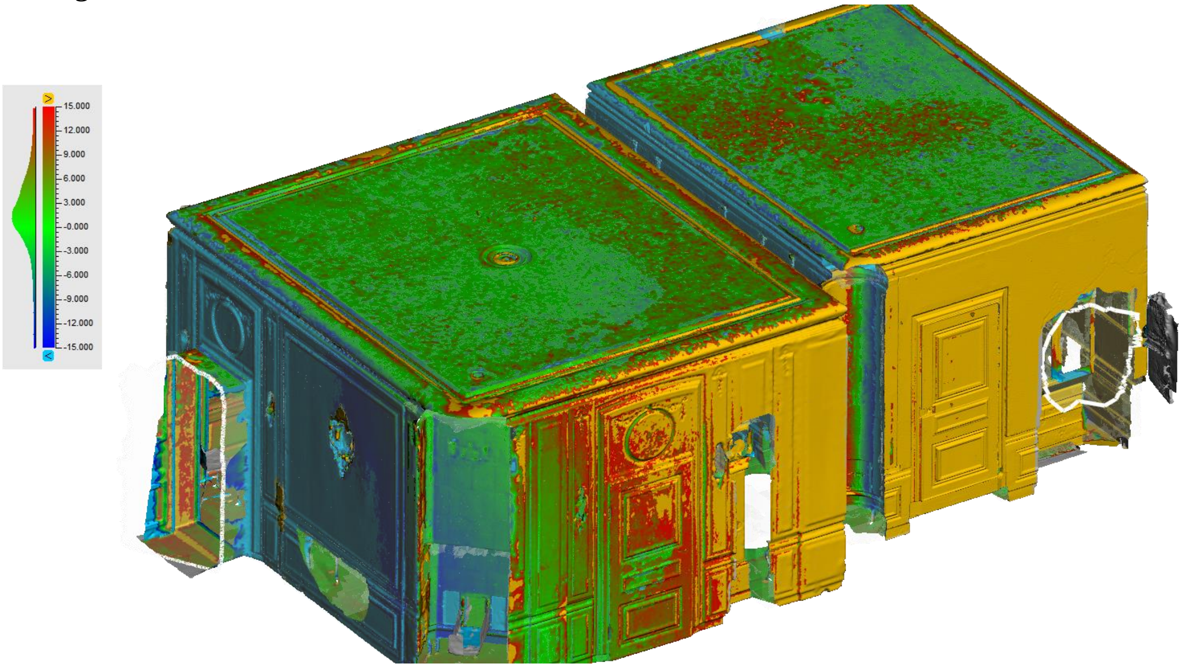
Photogrammetric prime lens, folding rule

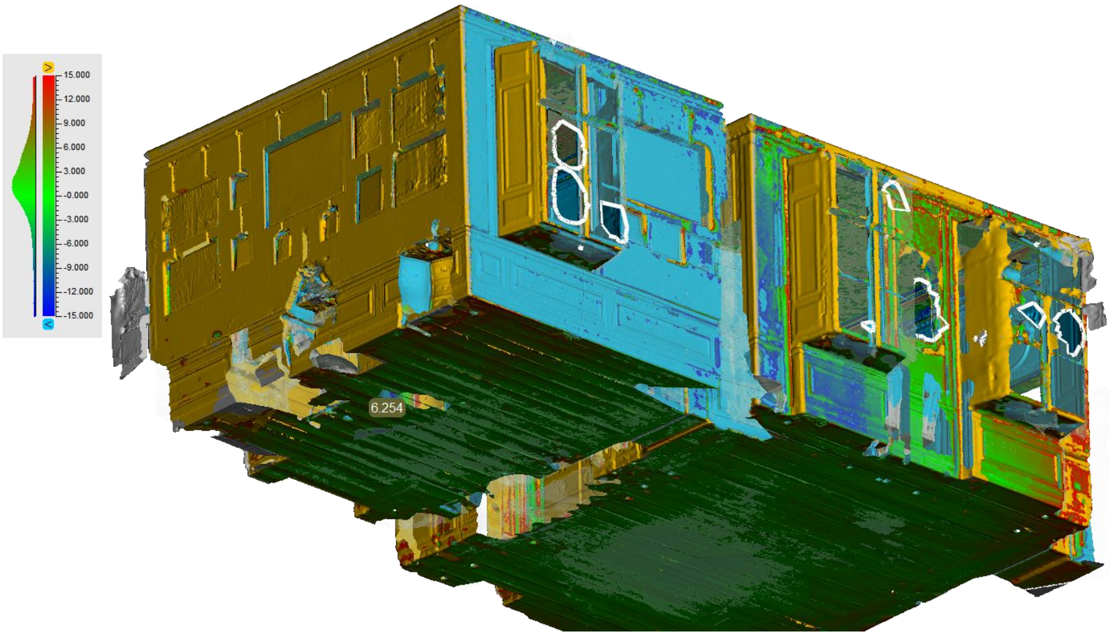




Scaling is off so there is no result to have. It shows that just using a folding rule is not very exact. I will scale it and analyse if there is any warp.

Photogrammetric zoom lens, scaled





After scaling, the floor and the ceiling are well aligned within a few millimetres. The walls however are still out of scale.

Discussion

Noise

This study suggests that noise levels follow price levels with the exception of BLK2GO since it is handheld.

The involuntary use of a 50 mm lens for prime lens photogrammetry caused many problems. I needed to get as much distance as possible to my target to cover the biggest possible area. That made it unreasonable to use manual focus as the distance constantly varied. With small area covered, a lot of images was needed to get a good overlap. My licence for Reality Capture is limited to 1000 pictures and I had 1060 when being economic about them. After sorting away 60 images the alignment failed some places and only 868 made it in the model. Therefore, some parts are bad and should not be evaluated.

Deviation

RTC360 and BLK2GO are exactly matching the referenced FARO focus s70 scan. This seems to confirm that the referenced FARO scan is correct as these three are identical. Also, regarding deviation, quality of scans follow the cost of the scanner.

Photogrammetry and hand scanner both have the advantage of more easily covering those spaces that are hidden from area scanners. Photogrammetry however relies heavily on the skill and knowledge of the photographer to get a reliable result. It is also very hard to validate unless you have a pointcloud like I do here. Simply using a folding ruler, or any ruler, is not enough for scaling over larger areas. Ground control points of some sort is needed to properly scale and anchor the model. They can be made with RTK, laser scanner or total station. The model made with zoom lens and autofocus does not align well even after scaling. Laser scanners on the other hand can be pretty reliable but will also need georeferencing if to be put in a larger context. Using targets is no problem for exteriors, but for interiors it can be difficult to place them without blocking part of the object to be scanned.

Time

For a small room with a few scans the difference in scan time is neglectable. Especially when considering that a day of scanning can need weeks in the office for processing depending on the character of your project. If going to a remote area and scanning a large object however, or scanning a site that is open to visitors, scan time can be the difference between one or three days on site.

Cost

Being expensive hardware and software, you need to scan a lot to justify buying one. Especially the subscription based software that makes it a cost even when you do not scan. Heritage institutions often can only get funding for projects, and not for long term expenses. Even renting a scanner can be more expensive than have someone come scan for you, since you also have to go pick it up and return it and rent the software. We can only hope that manufacturers will change their business models so that it will be beneficial to buy a scanner even if you do not constantly use it. Because once you have one, there are always places to put it to good use.

Part two of report

This degree project was only scheduled for two weeks and even though I started much earlier with scanning, the time limit was noticeably short. Having a pandemic further limited the possibilities. These are the things I would like to complement with for a part two in the future.

- Pick points from the FARO cloud to get ground control points in Reality Capture and then compare again, but my license does not allow it.
- Photograph with manual focus and better lighting with my newly acquired Nikkor 28 mm F2.8 Ai-s lens that should have almost no distortion[8].
- To get sharp images even high up, a higher tripod is needed or a good light source for shorter shutterspeed.
- A good light source for less reflection and glare.
- Combine laser scan and photos in Reality Capture if I can get a sponsor for the software.
- Clean the pointclouds before meshing to compare the results.
- Scan with FARO plus-series and M-series without markers to make a fair comparison.
- Remesh the uncleaned FARO cloud to compare the noise.
- Rescan with the Trimble at highest resolution to see if it lowers the noise.
- Scan with the Z+F 5016, Surphaser, Riegl and Artec Ray in combination with Leo when possible.

References

Chao Han, VirtualGrid www.vrmesh.com

Jonathan Westin, Centre for Digital Humanities, University of Gothenburg.

Laserscanningforum
https://www.laserscanningforum.com/forum/viewtopic.php?f=20&t=16272&sid=e0c980bbe4157412dd58b68a17d88dcc

Magnus Åberg, Trimtec, reseller of Trimble. https://www.trimtec.se/

Marko Matilainen, ATS, maker of ATS reference system and reseller of FARO. https://ats.se/

Mattias Bornholm, Leica. https://leica-geosystems.com/sv-se

Michael Fergusson, High end photogrammetry. https://viospatia.com/

Appendix

[8] Michael Fergusson, Viospatia

Alignment report from Reality Capture for zoom lens.

Selected component(s)	
Name	Component 0 (1)
Component ID	{6CCB065B-C1E8-44C...
Reconstruction ID	{501E5A88-A572-437...
Camera count	669
Point count	2 367 118
Control point count used	0
Constraint count used	0
Alignment report	
Total projections	7 055 979
Average track length	2.979138
Maximal error [pixels]	1.999996
Median error [pixels]	0.582646
Mean error [pixels]	0.693328
Geo-referenced	No
Metric	No
Alignment time	00h:10m:49s
Alignment settings	
Alignment engine	RealityCapture
Alignment mode	High
Max features per mpx	40 000
Max features per image	160 000
Detector sensitivity	High
Preselector features	80 000
Image downscale factor	1
Max feature reprojection error	2.000000
Use camera positions	No
Lens distortion model	Brown3
Final optimization	Yes

Alignment report from Reality Capture for Prime lens.

Selected component(s)	
Name	Component 1
Component ID	{4010360D-45BF-4A65-BE80-3535543...
Reconstruction ID	{3406BC7B-FF68-43C4-9128-4971B0A...
Camera count	884
Point count	4 081 821
Control point count used	0
Constraint count used	0
Alignment report	
Total projections	12 588 464
Average track length	3.083787
Maximal error [pixels]	1.999998
Median error [pixels]	0.446894
Mean error [pixels]	0.572970
Geo-referenced	No
Metric	No
Alignment time	00h:29m:16s
Alignment settings	
Alignment engine	RealityCapture
Alignment mode	High
Max features per mpx	40 000
Max features per image	160 000
Detector sensitivity	High
Preselector features	80 000
Image downscale factor	1
Max feature reprojection error	2.000000
Use camera positions	No
Lens distortion model	Brown3
Final optimization	Yes

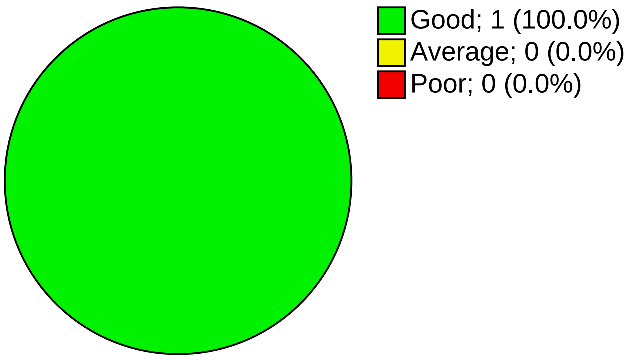
Point Cloud Registration Quality Report

ATS_MMA_Demo_Tottie

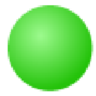
2020-01-21

Summary

Quality of clusters



Project overall quality

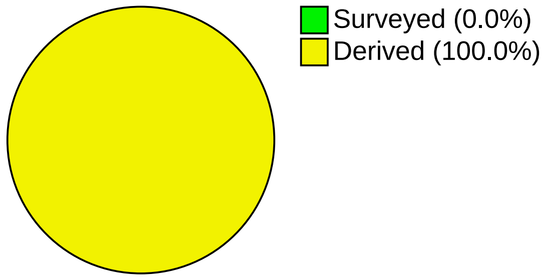


Good

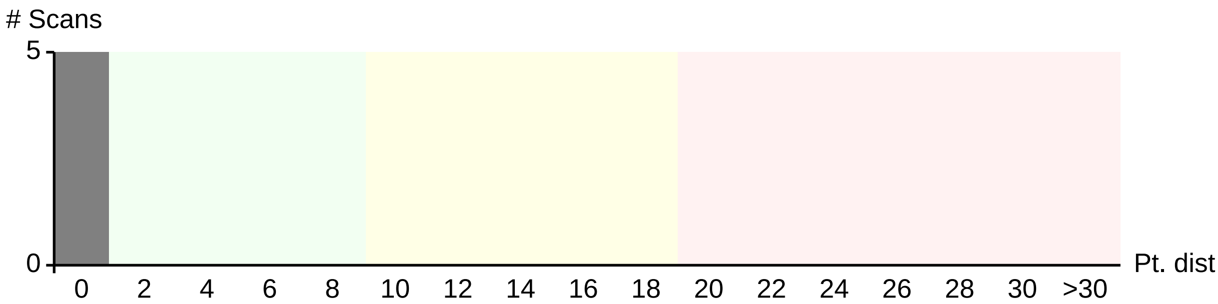
(avg pt. dist: 1.0 mm)

Quality of scans

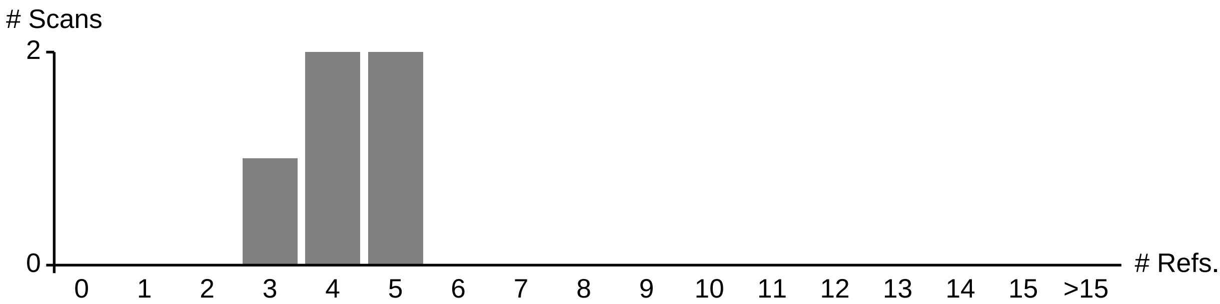
References used for fitting



Scans grouped by point distance



Scans grouped by number of references used



Average scan point distance:	1.0 mm
Total number of scans:	5
Total number of references:	6 (0 surveyed and 6 derived)
Based on workspace:	ATS_MMA_Demo_Tottie (2020-01-21 13:20:13)

Quality intervals

Quality thresholds based on template:

FARO Normal

Name	High threshold	Low threshold
Quality of scans		
Point distance quality (spheres) [mm]	10	20
Chain depth quality	2	3
Absolute longitudinal mismatch quality [mm]	10	20
Longitudinal mismatch quality [mm]	10	20
Orthogonal mismatch quality [mm]	10	20
Inclinometer mismatch quality [deg]	1	5
Quality of references		
Point distance quality (spheres) [mm]	5	10
Point distance quality (checkerboards) [mm]	5	10
Total mismatch quality [mm]	10	20
Longitudinal mismatch quality [mm]	10	20
Orthogonal mismatch quality [mm]	10	20
Num points quality	80	20
Quality of clusters		
References per square quality	0.5	0.25

Good Average Poor

Good >= [High threshold] > Average >= [Low threshold] > Poor

Scanners

1) LLS081813297

Clusters

Name	Pt. dist	Refs.*	Num scans	Ref. ratio	Quadrants	Scanners
Scans	0.98	0	5	N/A	N/A	LLS081813297

* Surveyed references only

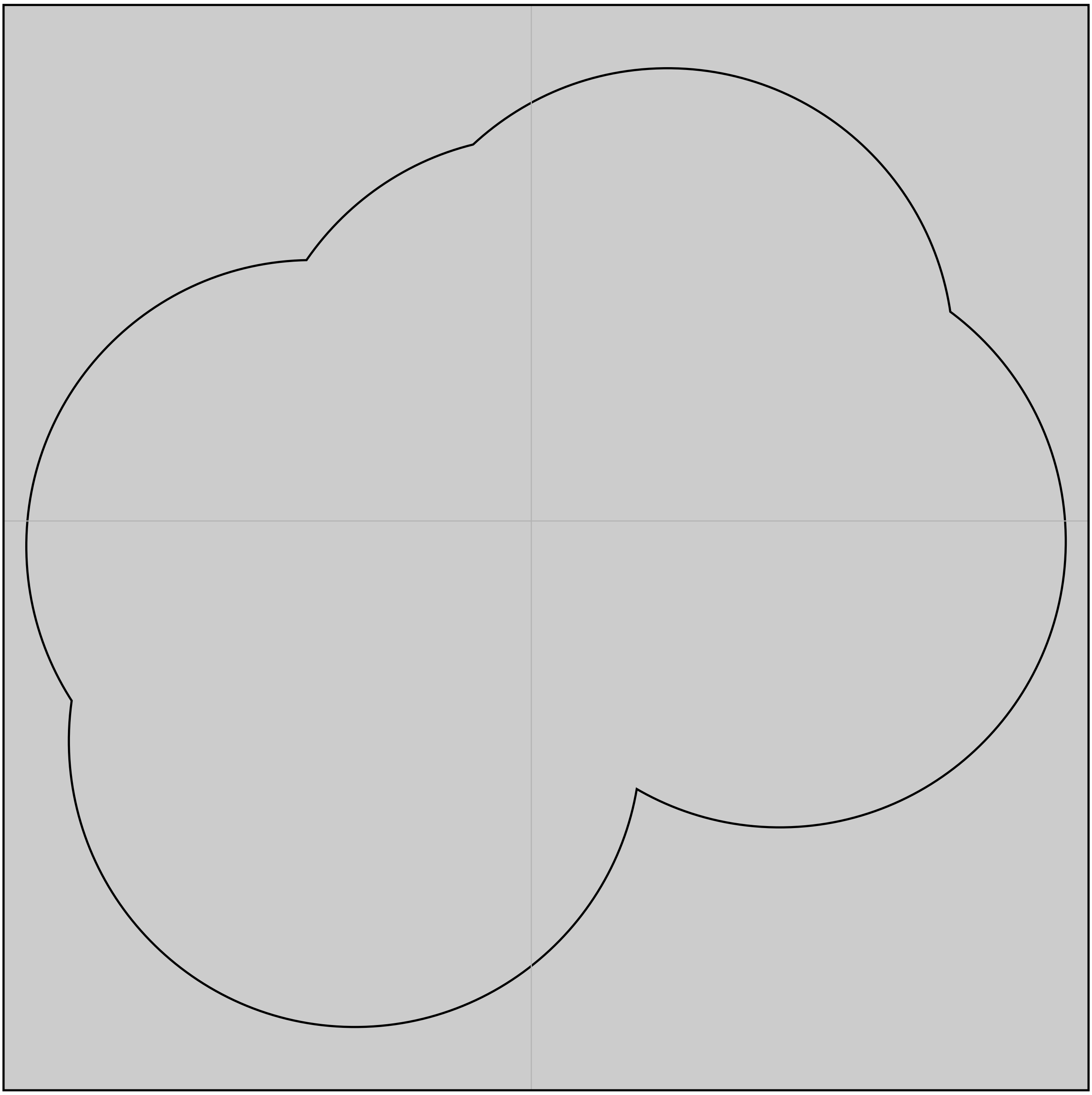
Scans

Name	Pt. dist	Refs.	Inclin.	X	Y	Z
Scans	0.98					
ATS_MMA_DEMO_Skansen_001	0.29	3	YES	2.597	-1.302	-16.889
ATS_MMA_DEMO_Skansen_003	1.07	5	YES	1.370	0.741	-16.890
ATS_MMA_DEMO_Skansen_004	0.75	4	YES	0.000	0.000	-16.887
ATS_MMA_DEMO_Skansen_005	1.49	5	YES	-2.511	-1.354	-16.900
ATS_MMA_DEMO_Skansen_006	1.29	4	YES	-2.046	-3.482	-16.900

References

Name	Type	Size	X	Y	Z
Sphere	*Sphere*	*69.5*	*0.792*	*-3.746*	*-17.769*
Sphere1	*Sphere*	*69.5*	*-3.627*	*-3.584*	*-17.488*
Sphere2	*Sphere*	*69.5*	*2.943*	*1.884*	*-17.385*
Sphere4	*Sphere*	*69.5*	*4.287*	*-1.772*	*-16.230*
Sphere5	*Sphere*	*69.5*	*-0.076*	*0.020*	*-18.189*
Sphere7	*Sphere*	*69.5*	*-4.467*	*-1.124*	*-17.772*

[<<] /Scans



1 square equals 20 x 20 m

Surveyed references in use: -

Total number of scans: 5

Average scan point distance (mm): 0.98

Scanners

LLS081813297

Reference ratio: -

Occupied quadrants: -

Scan list for this cluster

<< ATS_MMA_DEMO_Skansen_001

/Scans LLS081813297

Position (m): 2.597, -1.302, -16.889

Orientation: -0.00051, 0.00851, -0.99996

Angle (°): 134.32603

Point distance (mm): 0.29

Chain depth 1

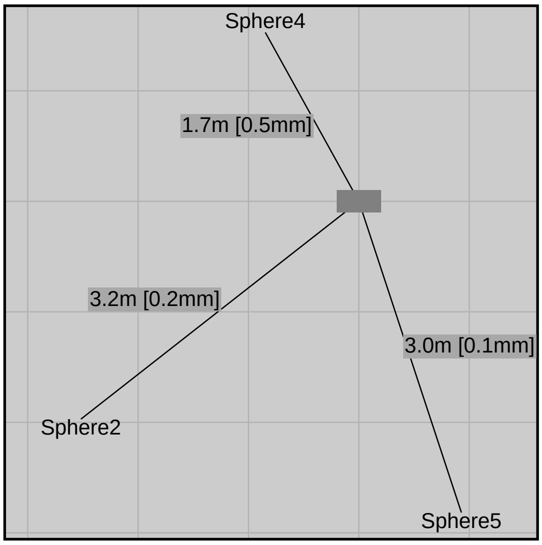
Longitudinal mismatch (mm): -0.12 (abs. 0.12)

Orthogonal mismatch (mm): 0.27

Angular mismatch (°): 0.006729

Inclinometer mismatch (°): 0.000000

Inclinometer used in match: YES



Num distinct references: 3 + inclin.

Num quadrants occupied: 2 + inclin.

Matched references

				Mismatch					
Name	**Surveyed**	**Type**	**Size**	**Tot.**	**Long.**	**Orth.**	**dX**	**dY**	**dZ**
Sphere2	-	Sphere	69.5	0.2	-0.1	0.2	-0.1	0.1	0.1
Sphere4	-	Sphere	69.5	0.5	-0.2	0.5	0.2	-0.2	-0.2
Sphere5	-	Sphere	69.5	0.1	-0.0	0.1	-0.0	0.1	0.1

<< ATS_MMA_DEMO_Skansen_003

/Scans LLS081813297

Position (m): 1.370, 0.741, -16.890

Orientation: 0.00631, -0.00311, 0.99998

Angle (°): 96.53052

Point distance (mm): 1.07

Chain depth 1

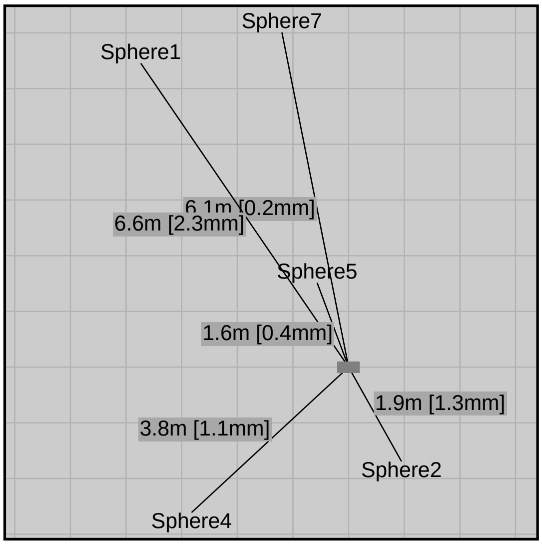
Longitudinal mismatch (mm): 0.01 (abs. 0.31)

Orthogonal mismatch (mm): 1.02

Angular mismatch (°): 0.016487

Inclinometer mismatch (°): 0.000002

Inclinometer used in match: YES



Num distinct references: 4 + inclin.

Num quadrants occupied: 2 + inclin.

Matched references

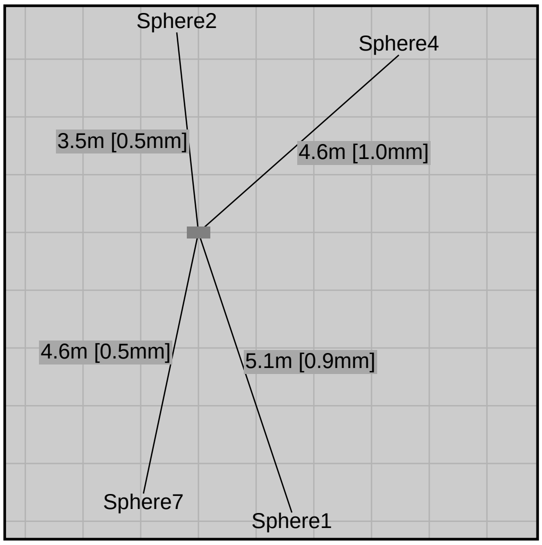
Name	Surveyed	Type	Size	Mismatch Tot.	Long.	Orth.	dX	dY	dZ
Sphere1	-	Sphere	69.5	2.3	-0.5	2.2	-0.3	-0.0	-1.7
Sphere2	-	Sphere	69.5	1.3	0.6	1.2	-0.1	-0.2	1.0
Sphere4	-	Sphere	69.5	1.1	-0.2	1.0	0.5	0.4	0.4
Sphere5	-	Sphere	69.5	0.4	0.1	0.4	-0.0	-0.2	0.3
Sphere7	-	Sphere	69.5	0.2	0.1	0.2	0.0	0.1	0.1

<< ATS_MMA_DEMO_Skansen_004

/Scans

LLS081813297

Position (m):	0.000, 0.000, -16.887	
Orientation:	0.02590, 0.00709, -0.99964	
Angle (°):	63.73614	
Point distance (mm):	0.75	
Chain depth	0	
Longitudinal mismatch (mm):	0.10	(abs. 0.59)
Orthogonal mismatch (mm):	0.42	
Angular mismatch (°):	0.005087	
Inclinometer mismatch (°):	0.000000	
Inclinometer used in match:	YES	



Num distinct references:	4 + inclin.
Num quadrants occupied:	2 + inclin.

Matched references

				Mismatch					
Name	**Surveyed**	**Type**	**Size**	**Tot.**	**Long.**	**Orth.**	**dX**	**dY**	**dZ**
Sphere1	-	Sphere	69.5	0.9	0.5	0.7	0.4	0.0	0.5
Sphere2	-	Sphere	69.5	0.5	-0.5	0.1	0.3	0.2	-0.1
Sphere4	-	Sphere	69.5	1.0	0.8	0.6	-0.6	-0.1	-0.2
Sphere7	-	Sphere	69.5	0.5	-0.5	0.3	-0.3	-0.1	-0.3

<< ATS_MMA_DEMO_Skansen_005

/Scans LLS081813297

Position (m): -2.511, -1.354, -16.900

Orientation: -0.00108, 0.00353, -0.99999

Angle (°): 159.80678

Point distance (mm): 1.49

Chain depth 1

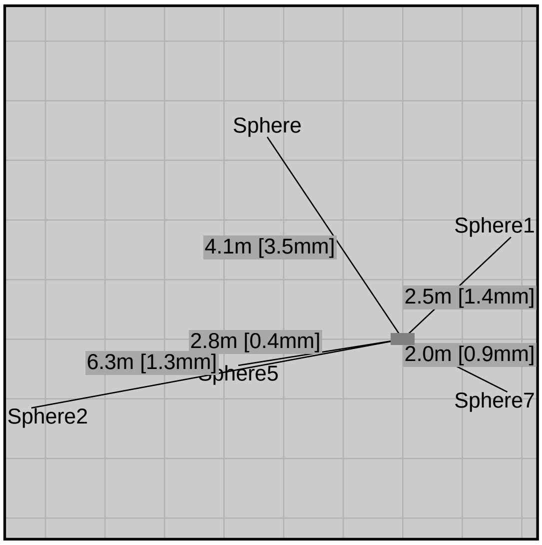
Longitudinal mismatch (mm): -0.15 (abs. 0.37)

Orthogonal mismatch (mm): 1.43

Angular mismatch (°): 0.023313

Inclinometer mismatch (°): 0.000001

Inclinometer used in match: YES



Num distinct references: 4 + inclin.

Num quadrants occupied: 3 + inclin.

Matched references

Name	Surveyed	Type	Size	Mismatch Tot.	Long.	Orth.	dX	dY	dZ
Sphere	-	Sphere	69.5	3.5	-1.0	3.3	0.3	0.1	-1.7
Sphere1	-	Sphere	69.5	1.4	0.3	1.4	-0.2	0.0	1.1
Sphere2	-	Sphere	69.5	1.3	0.1	1.3	-0.1	-0.1	-0.9
Sphere5	-	Sphere	69.5	0.4	-0.2	0.3	0.3	0.0	0.1
Sphere7	-	Sphere	69.5	0.9	0.2	0.8	-0.1	-0.1	0.6

<< ATS_MMA_DEMO_Skansen_006

/Scans LLS081813297

Position (m): -2.046, -3.482, -16.900

Orientation: -0.00341, -0.00467, 0.99998

Angle (°): 116.21762

Point distance (mm): 1.29

Chain depth 1

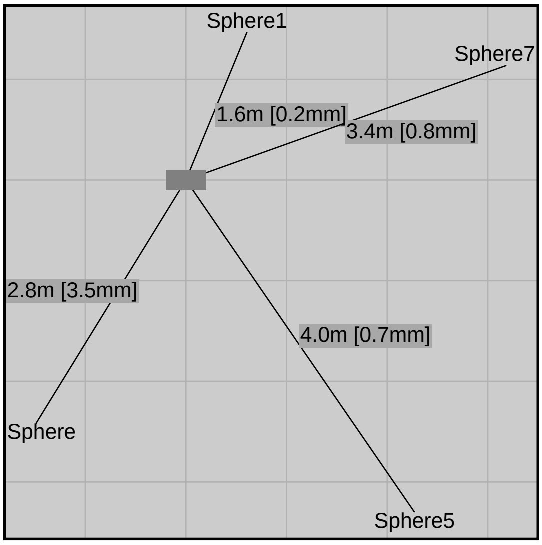
Longitudinal mismatch (mm): 0.41 (abs. 0.48)

Orthogonal mismatch (mm): 1.19

Angular mismatch (°): 0.021875

Inclinometer mismatch (°): 0.000000

Inclinometer used in match: YES



Num distinct references: 4 + inclin.

Num quadrants occupied: 3 + inclin.

Matched references

Name	Surveyed	Type	Size	Mismatch Tot.	Long.	Orth.	dX	dY	dZ
Sphere	-	Sphere	69.5	3.5	1.6	3.1	-0.3	-0.1	1.7
Sphere1	-	Sphere	69.5	0.2	0.1	0.1	0.0	-0.1	0.1
Sphere5	-	Sphere	69.5	0.7	-0.1	0.7	-0.3	0.1	-0.4
Sphere7	-	Sphere	69.5	0.8	0.2	0.8	0.4	0.0	-0.5

Thomas
konsult
Hagaeus Bygghantverk AB
Company Website

Registration Report

Skansen

den 12 maj 2020

5 Stations

1 Reg. Set

Project Summary

Stations

5

Reg. Sets

1

Average Error

0.9 mm

Average Overlap

63 %

Average Consistency

100 %

Registration Summary

Reg. Set 1	5 Stations	0.9 mm Avg. Error	63 % Avg. Overlap	100 % Avg. Consistency

Station Name	Links	Avg. Error (mm)	Avg. Overlap (%)	Avg. Consistency (%)
1	2	1.0 mm	64 %	100 %
2	2	1.0 mm	67 %	100 %
3	4	0.9 mm	54 %	100 %
4	2	0.9 mm	67 %	100 %
5	2	0.9 mm	65 %	100 %

Detailed Summary

Reg. Set 1	5 Stations	0.9 mm Avg. Error	63 % Avg. Overlap	100 % Avg. Consistency

1	2 Links	1.0 mm Avg. Error	64 % Avg. Overlap	100 % Avg. Consistency

Linked Station	Error (mm)	Overlap (%)	Consistency (%)
2	1.1 mm	77 %	100 %
3	0.9 mm	51 %	100 %

2	2 Links	1.0 mm Avg. Error	67 % Avg. Overlap	100 % Avg. Consistency

Linked Station	Error (mm)	Overlap (%)	Consistency (%)
1	1.1 mm	77 %	100 %
3	0.9 mm	56 %	100 %

3	4 Links	0.9 mm Avg. Error	54 % Avg. Overlap	100 % Avg. Consistency

Linked Station	Error (mm)	Overlap (%)	Consistency (%)
1	0.9 mm	51 %	100 %
2	0.9 mm	56 %	100 %
4	0.8 mm	57 %	100 %
5	0.9 mm	52 %	100 %

4	2 Links	0.9 mm Avg. Error	67 % Avg. Overlap	100 % Avg. Consistency

Linked Station	Error (mm)	Overlap (%)	Consistency (%)
3	0.8 mm	57 %	100 %
5	0.9 mm	78 %	100 %

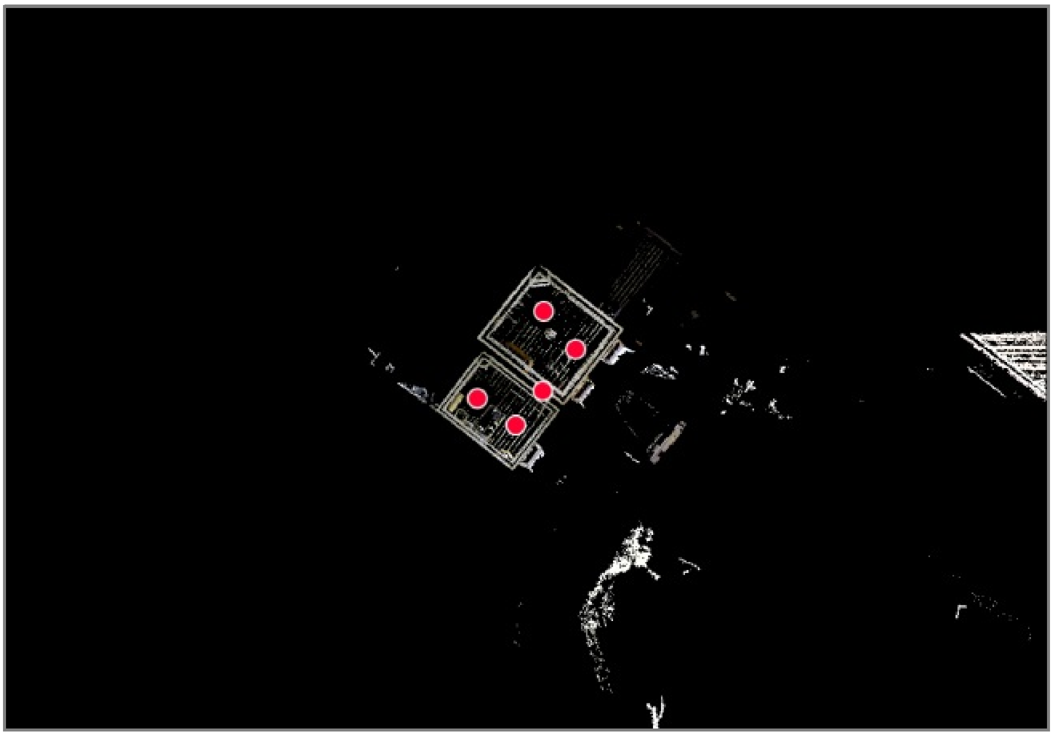
5	2 Links	0.9 mm Avg. Error	65 % Avg. Overlap	100 % Avg. Consistency

Linked Station	Error (mm)	Overlap (%)	Consistency (%)
3	0.9 mm	52 %	100 %
4	0.9 mm	78 %	100 %

Cyclone REGISTER 360
Registration Report

maj 30, 2020

Certified by:
Rikard Evertsson



Tottie1-1

Overall Quality

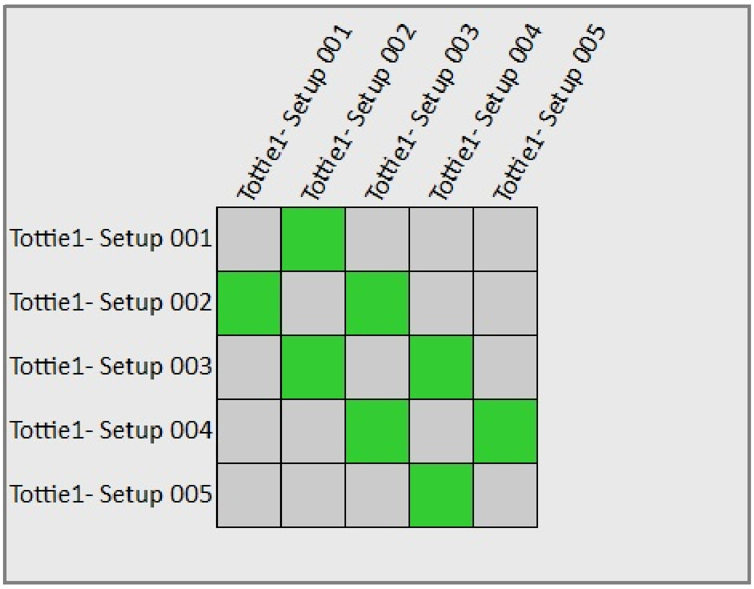
Error Results for Bundle 1

Setup Count:	5
Link Count:	4
Strength:	84 %
Overlap:	68 %

Bundle Error 0.001 m ✓	
Overlap 68 % ✓	Strength 84 % ✓
Cloud-to-Cloud 0.001 m ✓	Target Error --

Max error of 0.015 m. Max error of 0.020 m. Error greater than 0.020 m.

Link-Quality Matrix (1 of 1) -



Link Error Results

1 Overview

Link Name	Setup 1	Setup 2	Overlap	Abs. Mean Error
Link 1	Tottie1- Setup 001	Tottie1- Setup 002	69 %	**0.000 m**
Link 2	Tottie1- Setup 002	Tottie1- Setup 003	64 %	**0.001 m**
Link 3	Tottie1- Setup 003	Tottie1- Setup 004	53 %	**0.001 m**
Link 4	Tottie1- Setup 004	Tottie1- Setup 005	88 %	**0.001 m**

2 Details

Link Name	Setup 1	Setup 2	Overlap	Abs. Mean Error
Link 1	Tottie1- Setup 001	Tottie1- Setup 002	69 %	**0.000 m**
		Cloud to Cloud		**0.000 m**
		Target	Mean Target Error:	--

Link Name	Setup 1	Setup 2	Overlap	Abs. Mean Error
Link 2	Tottie1- Setup 002	Tottie1- Setup 003	64 %	**0.001 m**
		Cloud to Cloud		**0.001 m**
		Target	Mean Target Error:	--

Link Name	Setup 1	Setup 2	Overlap	Abs. Mean Error
Link 3	Tottie1- Setup 003	Tottie1- Setup 004	53 %	**0.001 m**
		Cloud to Cloud		**0.001 m**
		Target	Mean Target Error:	--

Link Name	Setup 1	Setup 2	Overlap	Abs. Mean Error
Link 4	Tottie1- Setup 004	Tottie1- Setup 005	88 %	**0.001 m**
		Cloud to Cloud		**0.001 m**
		Target	Mean Target Error:	--

Graphics

Tottie1-1