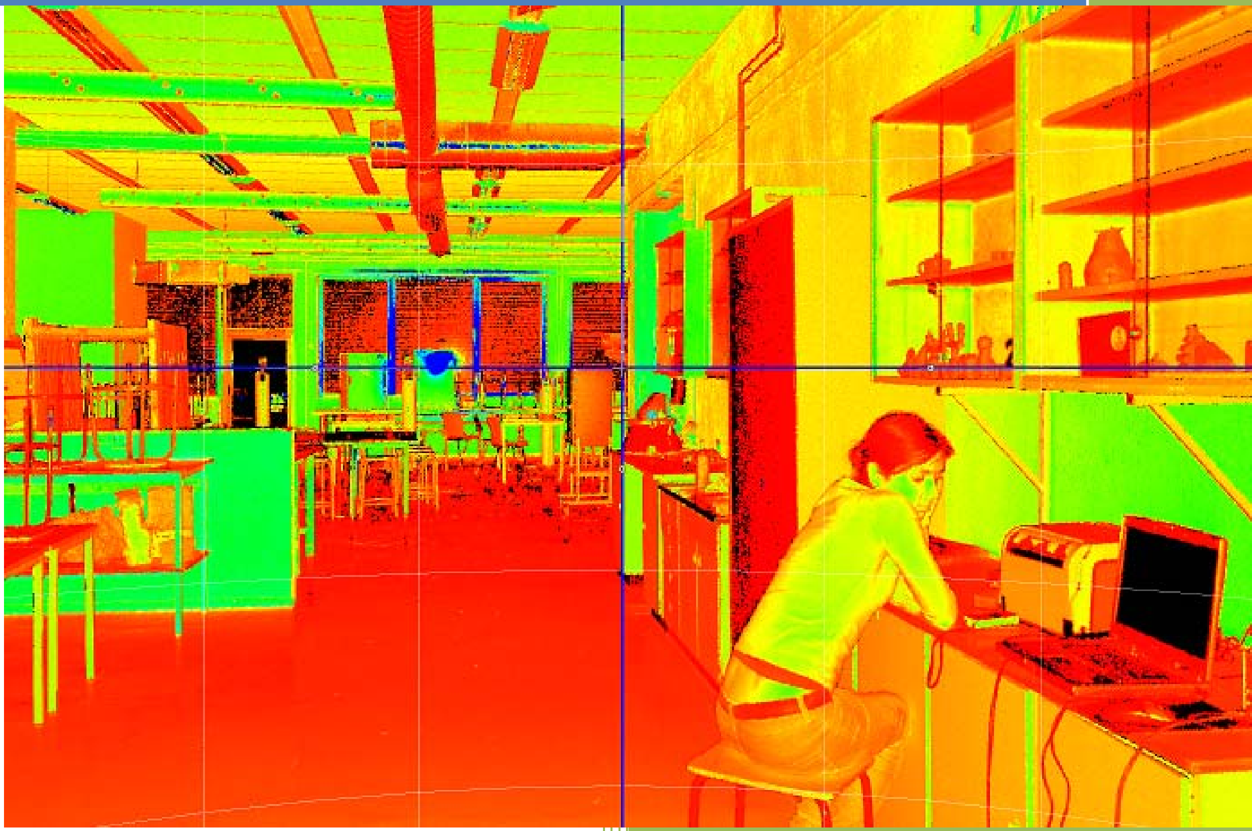
Bachelor Project 2010

Comparison of Short Range and Long Range Laser Scanner's Accuracy Differences



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1. Introduction

This Bachelor thesis is a final task of Geodesy study programme. The topic of my thesis is Comparison of Short Range and Long Range Laser Scanner's Accuracy Differences.

Laser Scanning is a technology which is used to gather data about an object or surface which can be used to create a 3D model or for detailed reconstruction. There are many applications for laser scanning: architecture, archaeology, geography, geodesy, geology, constructions, civil and transport engineering sectors, extraction of petroleum and gas and other scientific areas. Laser Scanner measures the distance to the first object on its path and find three dimensional coordinates of that point. Therefore like all other Electronic Distance Measurement (EDM) instruments it has to be calibrated before doing all measurements, because only then we can choose suitable method of measurement and guarantee precision results.

1.2. Aim of the Project

The aim of this Bachelor thesis is to compare an accuracy of two different types Laser Scanners.

1.3. Task

The task is to create a set of calibration methods to verify an accuracy of distances and angles measured by Short Range Laser Scanner *Leica HDS4500* and Long Range Laser Scanner *Leica HDS3000 (ScanStation 2)* and to compare those results.

2. Laser Scanning

Laser Scanning is a new surveying method which is used to get the 3D model of objects or surfaces in various applications, such as land surveying, archaeology, architecture, bridge and tunnels structures, highway surveys.

The principle of work is that Laser Scanner sends out a huge number of rays to scanned area and measures the distance of the first object on its path. After this procedure we get 3D view of scanned area (point cloud) and we can check information about an each point (distance, three dimensional coordinates (x, y, z), time) with a surface accuracy up to 1 mm, depending on the selected frequency point, resolution, lightning and other factors.

The raw data from laser scanning can be run through the software which will establish a 3D model from point clouds which it got. If we want to get complete image of all angles and sides we have to move the scanner around the object or to rotate the object which we want to model during laser scanning process, because the instrument can only see what is visible. These different scans are connected after the scanning procedure in computer program.

Very important advantage of Laser Scanning method is high speed. A scan can be completed in minutes, and when you get a point cloud that provides a complete picture of an object. Every point in point cloud has measured coordinates and distance, so it is rarely necessary to have more data.

There are three main principles of Laser Scanning:

- Scanning over 100 meters;
- Scanning up to 100 meters;
- Scanning only few meters away with high precision.

Naturally, the accuracy decreases as the distances get longer.

There are also three main types of laser scanners to scan different size of areas:

- Terrestrial phase-based laser scanner (Short Range);
- Terrestrial time-of-flight laser scanner (Long Range);
- Very Long Range laser scanners.

Laser scanning as a surveying method can be used almost everywhere where we need a true picture of reality.

3. Equipment and Resources

I used different equipment in my work:

- Total Station *Leica TPS1200+*;
- Short Range Laser Scanner *Leica HDS4500*;
- Long Range Laser Scanner *Leica HDS3000* (ScanStation 2).

Software I used:

- *Leica Cyclone 7.0*;
- *Leica Geo Office*;
- *Microsoft Word, Excel, PowerPoint 2007*;
- *Adobe Dreamweaver*.

3.1. Total Station *Leica TPS1200+*

Total Station is an electronic/optical instrument to measure distances, angles, coordinates. It is an electronic theodolite integrated with an electronic distance meter (EDM) to read distances from instrument to a particular point. It is widely used by land surveyors for different tasks. I was using this instrument as a standard in calibration procedures.

Figure 1
Leica TPS1200+ is highly accuracy measuring instrument. It can measure the distance with 2mm accuracy, angles with 3’’ accuracy. More information you can find in **Appendix A**.

3.2. Laser Scanner *Leica HDS4500*

Leica HDS4500 is a Short Range Laser Scanner which is working by phase-based laser scanning technology which is used when distances are not long, high accuracy and detail are the most important factors, such as intricate interior work including automotive, manufacturing, nuclear, process and power plants, tunnels, and other industrial facilities as well as architectural heritage and restoration projects.

Figure 2
Leica *HDS4500* Laser Scanner is ultra high-speed phase-based laser scanner. It can measure from 100 000 to 50 000 point per second. More information you can find in **Appendix B**.

3.2.1. Terrestrial phase-based Laser Scanning (Short Range)

Phase-based Laser Scanning method is used for shorter distances, when we need high accuracy and precision model of object or surface. The phase difference is measured between sent and received beam. The target distance is proportional to phase difference and the wave length of the amplitude modulated signal. This is a basic principle of phase-based technology.

Figure 3. Phase-based laser scanner's working principle.

Short-range laser scanning provides better accuracy than time-of-flight method. It has frequency of between 100 000 and 500 000 points per second. The result is huge amount of data collected in a short time. The accuracy of the point position is about 1-2mm at distances up to 25 meters.

Short-range scanner works better for shorter distances than long range scanner, and it is also much better to describe the details of distances up to approximately 30 meters. The scanner used to scan buildings, indoor, and generally in projects where accuracy and detail are the most important factors.

3.3. Laser Scanner *Leica HDS3000 (ScanStation 2)*

Leica *HDS3000 (ScanStation 2)* is a Long Range Pulsed Laser Scanner. It very high speed, very high accuracy, capable of single point surveying. It also has integrated high-resolution camera and dual-axis level compensator. It is working by time-of-flight laser scanning technology.

Figure 4. *Leica HDS3000 (ScanStation 2)*. More information you can find in **Appendix C**.

3.3.1. Terrestrial Time-of-flight Laser Scanning (Long Range)

Time-of-flight Laser Scanning method is also known as LIDAR (Light Detection and Ranging). It is used more for long distances but also can measure short distances. Time-of-flight laser scanner uses laser light to probe the subject. The laser rangefinder finds the distance till object or surface by timing the round-trip time of a pulse of light. The laser rangefinder only detects distance of one point in its direction of view, so it is possible to scan different points, not only full visible area like with phase-based laser scanner.

Time-of-flight Laser Scanning technology is similar to that which is used in Total Stations, but the speed of measurement is totally different. The average of number of measured distances per second with typical Total Station is eight when with Laser Scanner 50 000.

The working principle of time-of-flight laser scanning technology is based upon the principle of sending out the laser pulse and observing a time taken for round-trip of laser pulse from instrument to an object or surface and then compute to the range to the target. The accuracy of results depends on how precisely laser scanner can measure the time.

Figure 5. Time-of-flight laser scanner's working principle.

3.4. Software

For Total Station data processing I used *Leica Geo Office* program, which is very easy to import raw data from Total Station and after to *Microsoft Office Excel*.

For both Laser Scanners data processing I used *Leica Cyclone 7.0* computer program, where *Cyclone SURVEY*, *Cyclone REGISTER*, *Cyclone MODEL* are included. Point clouds which are result of Laser Scanning process take a huge place in computer's hard disk, so there are special requirements for free space in hard disk, working speed and other criterions.

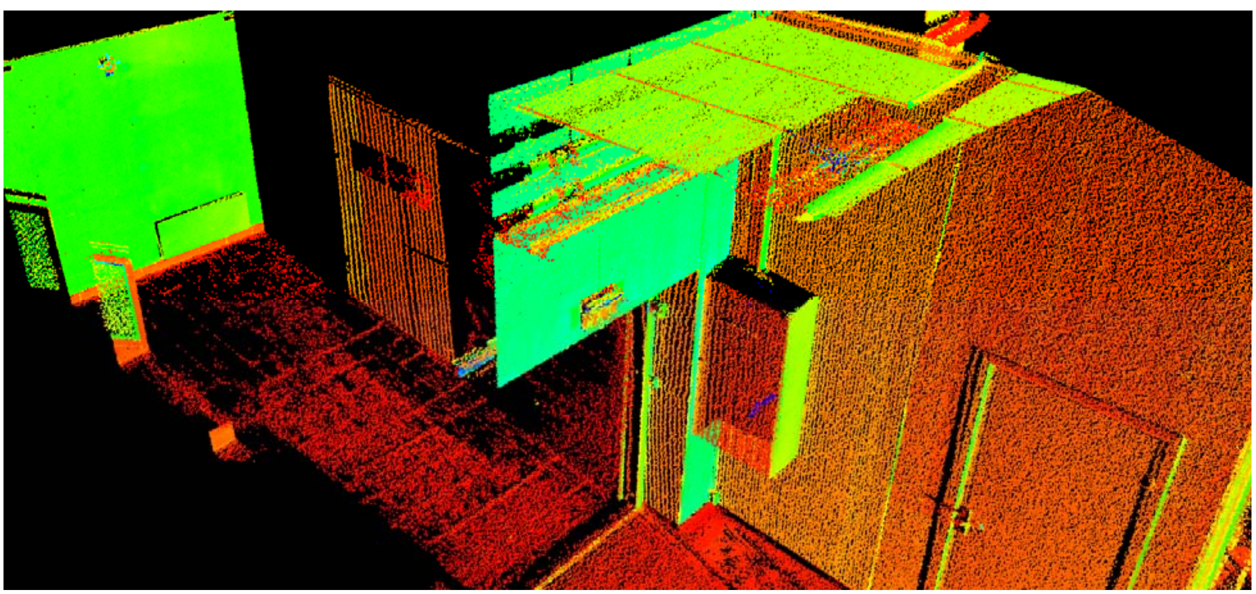


Figure 6. Point cloud in *Cyclone MODEL* which is got from *HDS4500* Laser Scanning procedure.

More information about *Leica Cyclone 7.0* you can find in **Appendix D.**

4. Calibration of Electronic Distance Measurement Instruments

Calibration is very important procedure which determines quality of measurements' results of EDM instruments. It has to be done periodically for all EDM equipment. Calibration is a comparison of measurements between known magnitude which is made with one device with another measurement which is made in as similar way as possible with a second device. There are number of error's sources in surveying equipment and Calibration of EDM instruments concentrates only on those which influence quality of results of this equipment.

Three main systematic errors usually found in EDM instruments are:

- Index error or zero constant;
- Scale error;
- Cyclic or short periodic error.

4.1. Index Error

Index error or zero constant means difference between real place of zero point of measured object and that zero from which EDM instrument measure the distance.

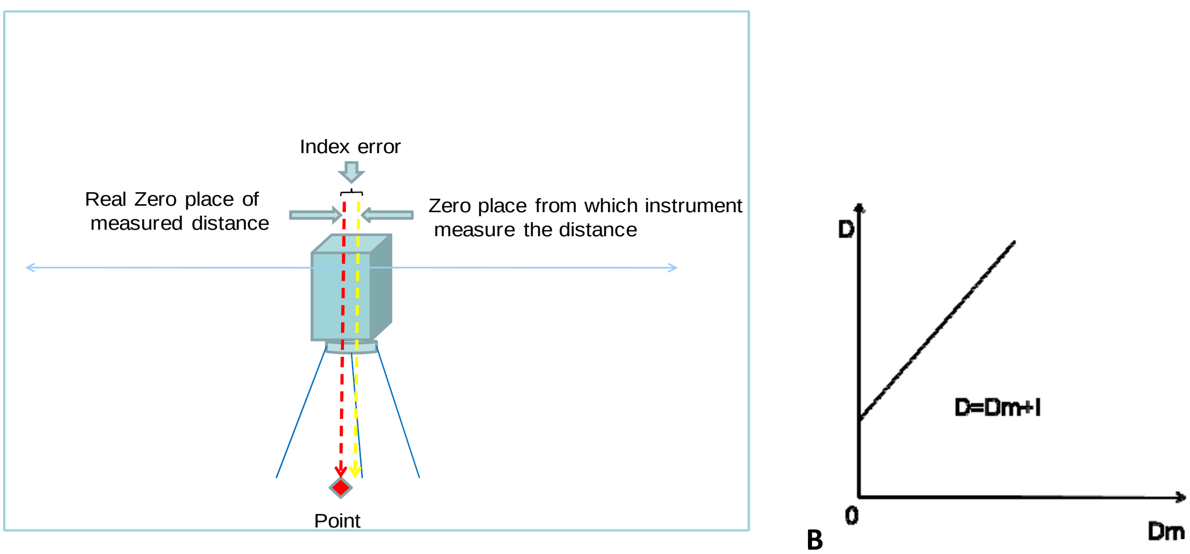
A  B

Figure 7. **A**: Index error in practical. **B**: Index error. D-true distance, Dm-measured distance, I-index error.

Eccentricities in the instrument, geometrical detours, electrical delays, differences between the electronic and mechanical centres of the instrument are the main reasons why index error exists almost in all distances measured by a particular EDM instrument.

4.2. Scale Error

Scale error or scale uncertainty means not accurate graduation of rule, limb when distances between graduations are not equal. This error is proportional to the length of the line measured. It caused by errors of temperature, pressure, humidity, internal frequency errors, also non-homogeneous emissions and reception patterns from the emitting and receiving diodes, which called phase inhomogeneity.

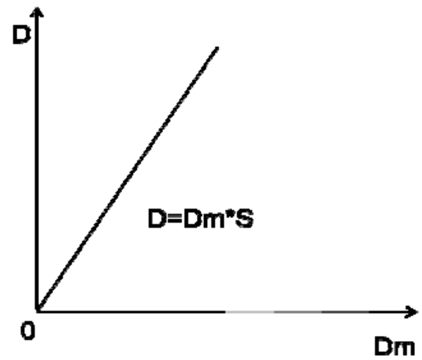


Figure 8. Scale Error. Dm-measured distance, D-true distance, S-scale error.

4.3. Cyclic Error

The precision of an Electronic Distance Measurement instrument is dependent on the internal phase measurement's precision. Cyclic error exists when multi-path effects of the transmitted signal onto the received signal. It is sinusoidal with a wavelength equal to the unit length of the EDM instrument. The unit length is scale on which instrument measures the distance. The magnitude of the cyclic error can be from 5 to 10 millimetres, but it is varying depending on the actual length measurement.

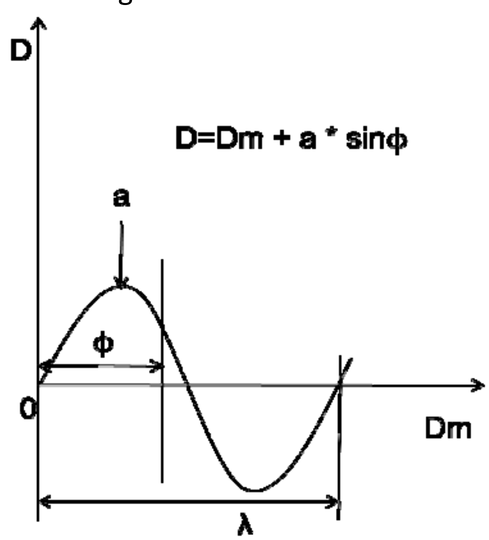


Figure 9. Cyclic error. D-true distance, Dm-measured distance, a-amplitude, -phase, λ-wavelenght.

5. Distance Calibration Method for Laser Scanner

In my project known or standard instrument is Total Station and calibrated instruments are two types of Laser Scanners: Short Range and Long Range. Known magnitudes (distances and angles) were measured with Total Station and got results were compared with Laser Scanners' results.

I placed two Black and White targets on the wall in approximately 34 meters corridor in one line and marked four points on the ground in this line. Then I measured distances from each point to both targets five times with Total Station. This EDM instrument is designed especially for precision distances and angles measurements and with Reflector-less mode it is easy to measure the distance from instrument to the centre of target. To collimate to exact centre of target is impossible, that is why it is necessary to measure more times and to calculate the average of measured distance.

Figure 10. Black and White target.

After Total Station measurements I repeated the same procedure with both Laser Scanners *Leica HDS4500* and *Leica HDS3000*.

Figure 11. Procedure of measuring distances with two targets and four stations.

5.1. Calibration procedure with *Leica HDS4500*

I scanned only small area where the target is, because of speed of work and big amounts of data. I was interested only in measured distance, so I did not do registration procedure which is common in laser data processing.

I decided to scan only once from each point to both targets and to check distances five times in *Cyclone MODEL,* because of hardly difficult centring and levelling procedure which I will describe in following chapters.

5.1.1. Centring

The most difficult task while I was working with *Leica HDS4500* was centring. It is very important operation to preclude the index error. In my project centring is very important, because I wanted to get as precision horizontal distances as possible from each centre of station to the centre of target. This instrument does not have this function, because usually laser scanning is used not for particular distance measurements but for 3D modelling. Also this type of Laser Scanner is not designed for single point measuring. We can get accurate results only after requiring targets and registration, when few scans from different stations are connected to one. Therefore, I would do this task in different way now.

Figure 12. Solution for centring (plummet) and centred point.

5.1.2. Levelling

Levelling procedure with Laser Scanner *Leica HDS4500* is also not easy and unfortunately not accurate enough. This is because an instrument does not have precision electronic level, it only has simple one which is not reliable.

Moreover, level of this Laser Scanner is only on instrument, what means that levelling procedure can only be doing with an instrument on the tripod. It takes long time, because scanner does not have tribrach which is common and easy to use in all surveying equipment.

I was trying to solve this difficulty with double-sided level which I put on tripod, levelled it, then placed an instrument on the tripod and levelled again. Actually this procedure is not very easy to do and the result is still unreliable.

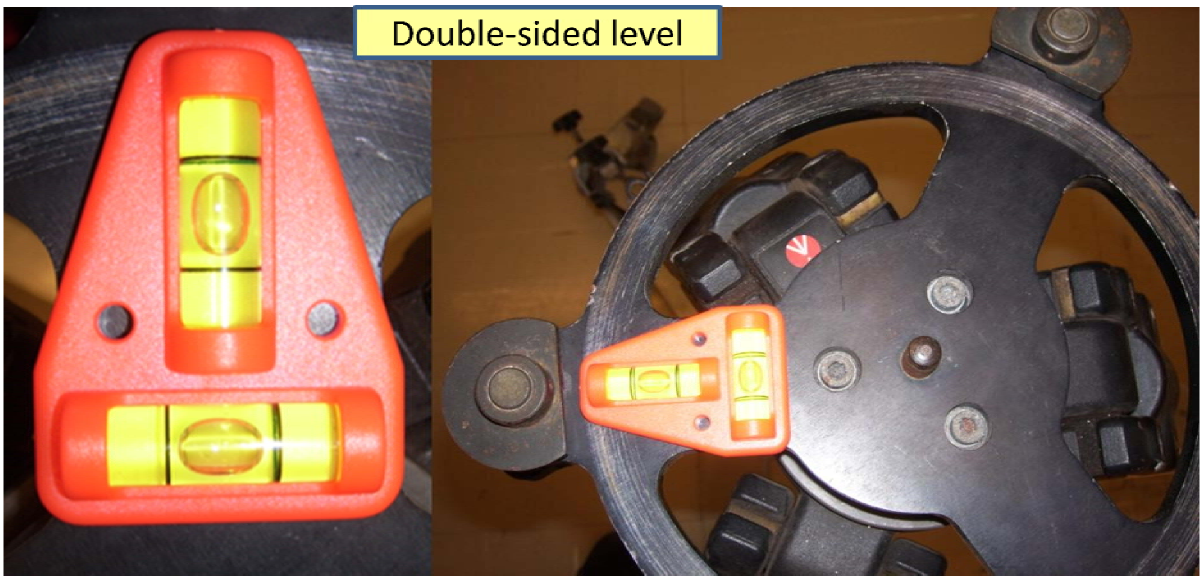


Figure 13. Double-sided level on the tripod.

5.1.3. Marking the centre of target

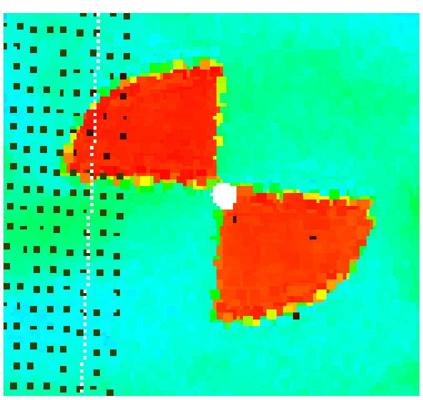


Figure 14. Marked centre of target.

When I did calibration procedure of *Leica HDS4500* distance measuring accuracy, to get as accurate result as possible I decided not to move the instrument, but to check the distance in *Cyclone 7.0* five times, as I mentioned before. However, to mark an exact centre of target on the point cloud was quite complicated. This could also be a reason why results which I got with this scanner where different from Total Station results. I will describe those results in chapter 5.3.

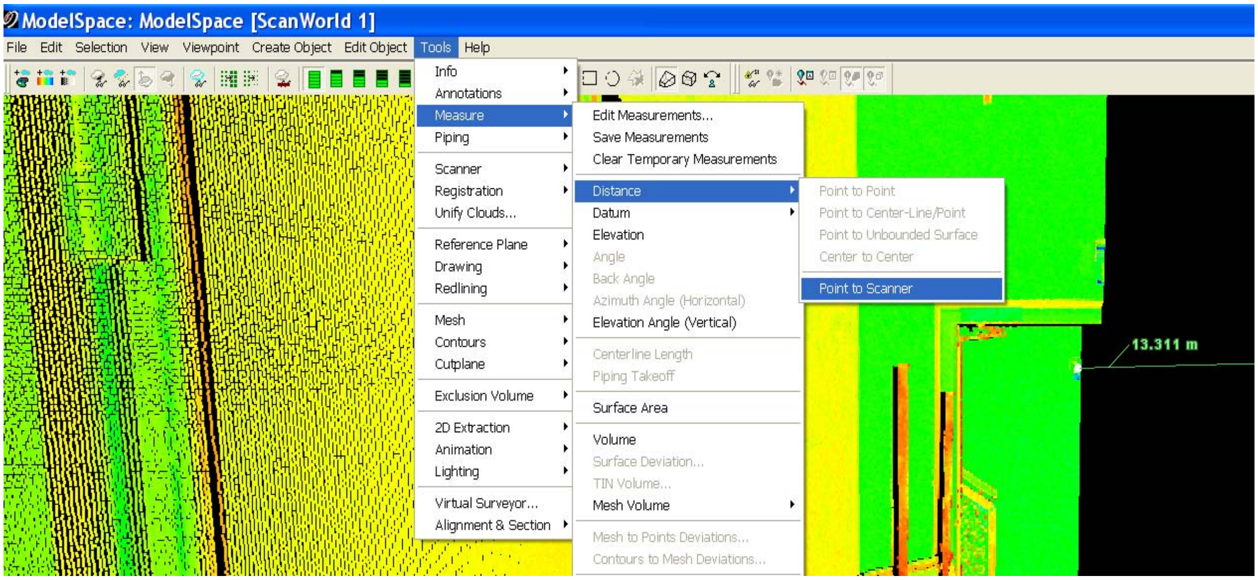


Figure 15. Distance measuring in *Cyclone ModelSpace*.

5.1.4. Connection between scanner and computer

Laser Scanner has to be connected with computer while measuring and when working in *True Space*, not in *Model Space*. So it is very important to have this connection all the time, otherwise it is possible to miss data or must repeat scanning procedure.

Leica HDS4500 has very unstable connector, which is really impeding work process.

It was even necessary to change the computer for *Cyclone* programme. After changing connection situation became better but not as good as we expected.


Figure 16. *Leica HDS4500* plug for connection between scanner and computer.

5.2. Calibration Procedure with *Leica HDS3000 (ScanStation 2*

As I mentioned before, *Leica HDS3000 (ScanStation 2*) is working by time-of-light Laser Scanning method which is similar to Total Station working principle. That is why work process with this scanner was incomparably easier and faster. Especially when I already knew how to use software and I had better conception of Laser Scanning technology at all.

5.2.1. Centring

Figure 17. *Leica HDS3000* tribrach.

This type of Laser Scanner is placed not directly on tripod like *Leica HDS4500*, but also has a tribrach with optical plummet. Because of that it is possible to centre an instrument over an exact point.

5.2.2. Levelling

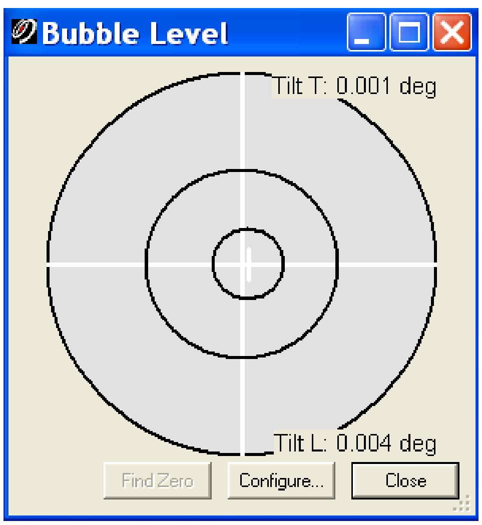


Figure 18. Precision level of *Leica HDS3000* in *Cyclone*.

Leica HDS3000 has very accurate levelling system. First of all, it has tribrach which is used to level only tripod without an instrument. Second, when laser scanner is placed on the tribrach you can level again. And finally, this instrument has precision electronic level which you can see in *Cyclone*. As a result you have precisely levelled instrument placed on exact point.

5.2.3. Finding the centre of target

Because of very accurate centring and levelling system of *Leica HDS3000* I moved the instrument a little bit before an each measurement, centred and levelled again. As a result I got five slightly different distances from each point to both targets. That is why I did not mark the centre of target in Cyclone how I did with *Leica HDS4500*, but I used automatic finding of target function. Even if I would like to mark the centre of Black and White target it would be impossible, because colour contrast between target and wall was weak.

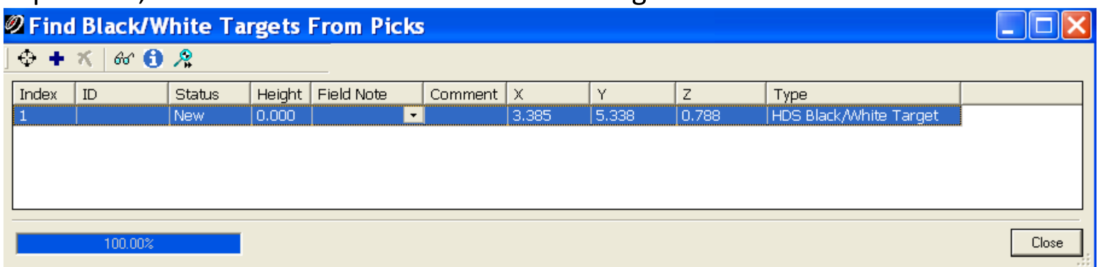


Figure 19. Table in *Cyclone* for finding the target.

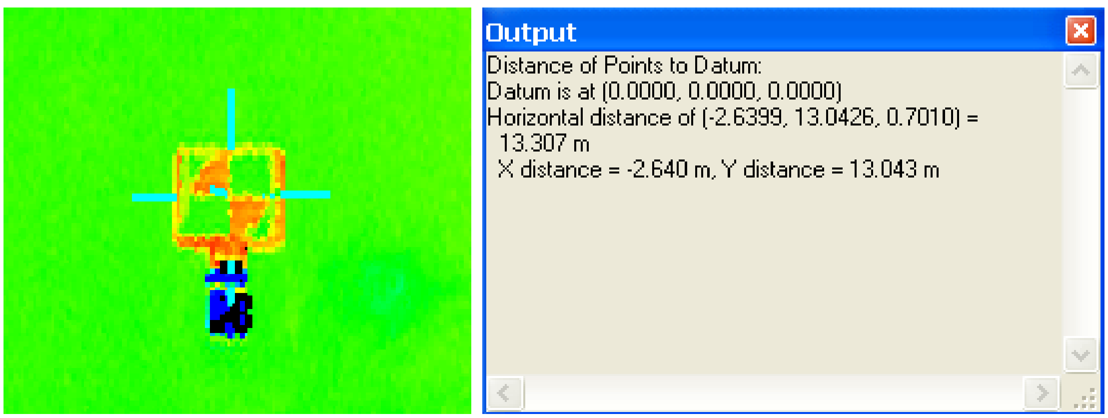


Figure 20. Already found the centre of target and its data.

For *Leica HDS3000* it is more common to use other type of targets:

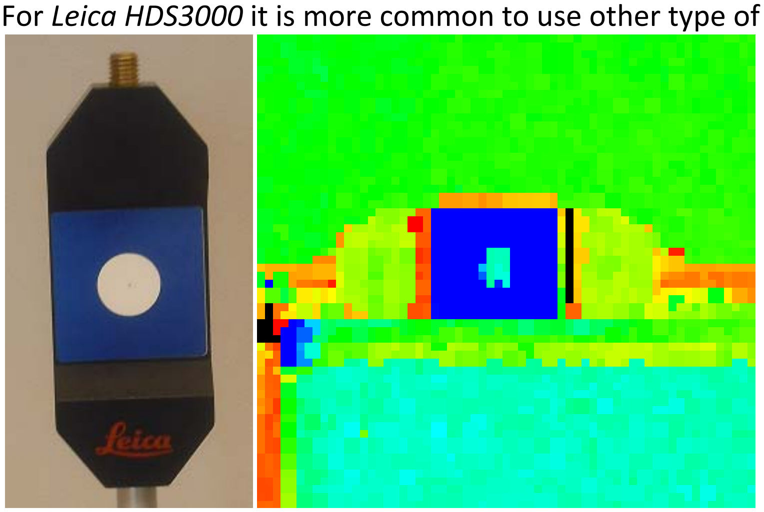


Figure 21. *Leica* target in reality and *Cyclone*.

5.2.4. Connection between scanner and computer

Laser Scanner *Leica HDS3000* uses USB (Universal Serial Bus) connection, which is much more stable and safe then connection which *Leica HDS4500* uses. If there is not extraneous power, good connection is guarantee all scanning time. Because of that speed of work is high and working process simpler.

5.2.5. Integrated camera

Leica *HDS3000 (ScanStation 2)* has one more advantage – integrated camera. I am not doing any modelling in my project so I only tried that because of curiosity. However, in my opinion this function is very useful and interesting, because you can work with scan which looks like real and you can make not only accurate 3D model of object but also with the same colours and etc. I think this function is very important especially for cultural heritage and museums exhibits scanning.

Figure 22. Image and point cloud got from *Leica HDS3000*.

5.3. Results and Comparison of Accuracy

Results which I have got from *Leica HDS4500* measurements as I expected were not similar to Total Station's results, because of the reasons which I mentioned in chapter 5.1. [**Appendix E**]

Average of distances' differences from the Total Station is 4.8 mm when with *Leica HDS3000* only 0.8 mm. I have got sometimes longer, sometimes shorter distances with *Leica HDS4500*, so it is hard to say where from exactly it measures the distances. *Leica HDS3000* laser scanner's measured distances were very close to Total Station results.

However, as results show the biggest difference *Leica HDS4500* got when the distance was longest. When the instrument scanned 27 m distance the difference between scanner and Total Station was approximately 6 mm, but in 6 m distance – 4mm. I think it is because of marking of target's centre in Cyclone: when distances were longer it was harder to mark it. Zoom function is limited in Cyclone Model and to see big enough view of target was not possible.

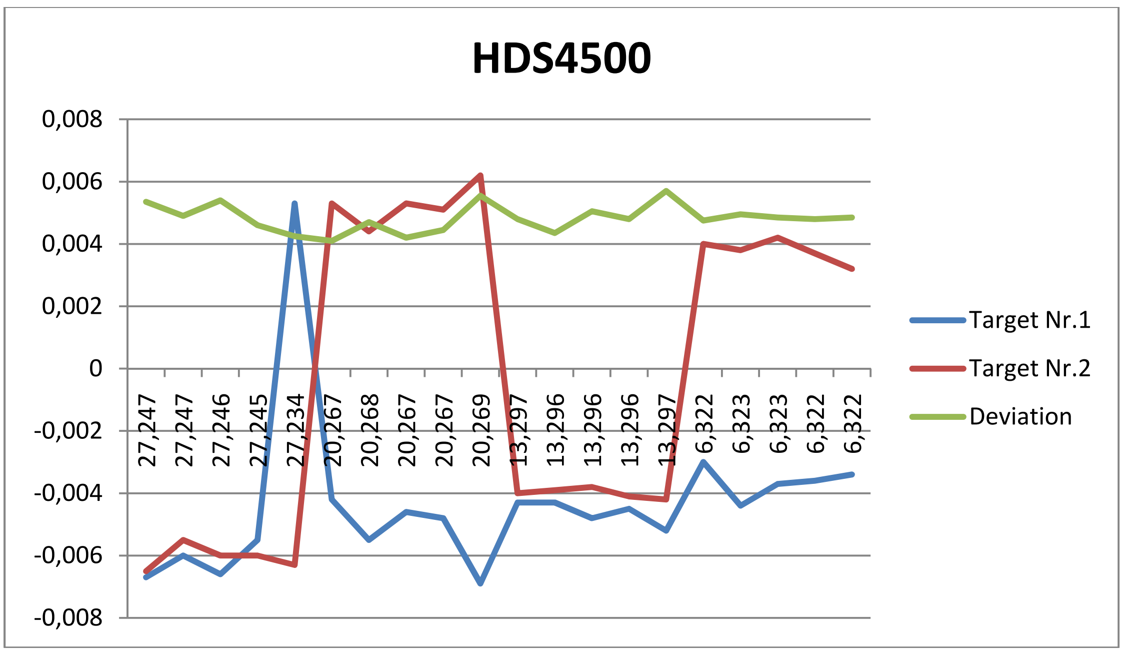


Figure 22. *Leica HDS4500* errors depending on distances.

Errors of Target Nr. 2 measurements vary from Target Nr. 1. Results show that Laser Scanner sometimes measures longer distance, sometimes shorter. Actually, as you can see in **Figure 23**, *Leica HDS3000* also fixes distances as little bit longer and sometimes conversely but differences are too small to worry about them.

So with reference to both Laser Scanners' results I can summarize that there are some eccentricities in *Leica HDS4500*, probably because of long time after last calibration.

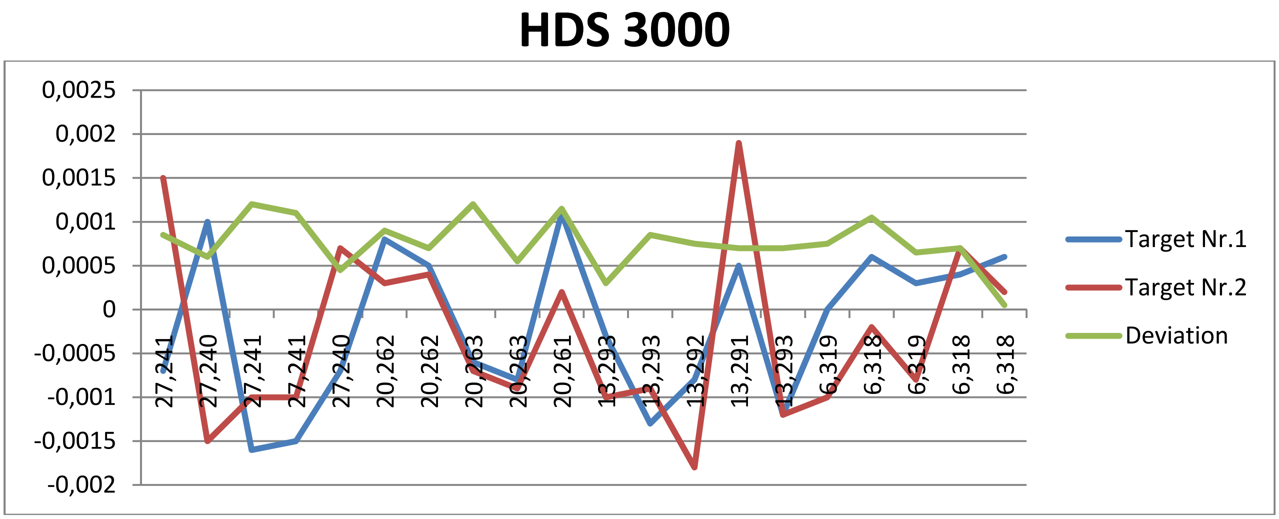


Figure 23. Leica HDS3000 errors depending on distances.

Leica HDS3000 differences from Total Station are very little, so these variations do not influence results of measurements. Errors are not depending on measured distances. Perhaps to see how distance affects the value of error we should measure much longer ranges.

After this data processing I was computed Index Error and Scale Error. [**Appendix F**].

To find an index error I used these formulas:

TSleft + TSright = (Sleft + I) + (Sright + I) = Sleft + Sright + 2I

I = (TS – S)/2

Where TSleft – distance measured with Total Station to Target Nr. 1, TSright – distance measured with Total Station to Target Nr. 2, I – index error.

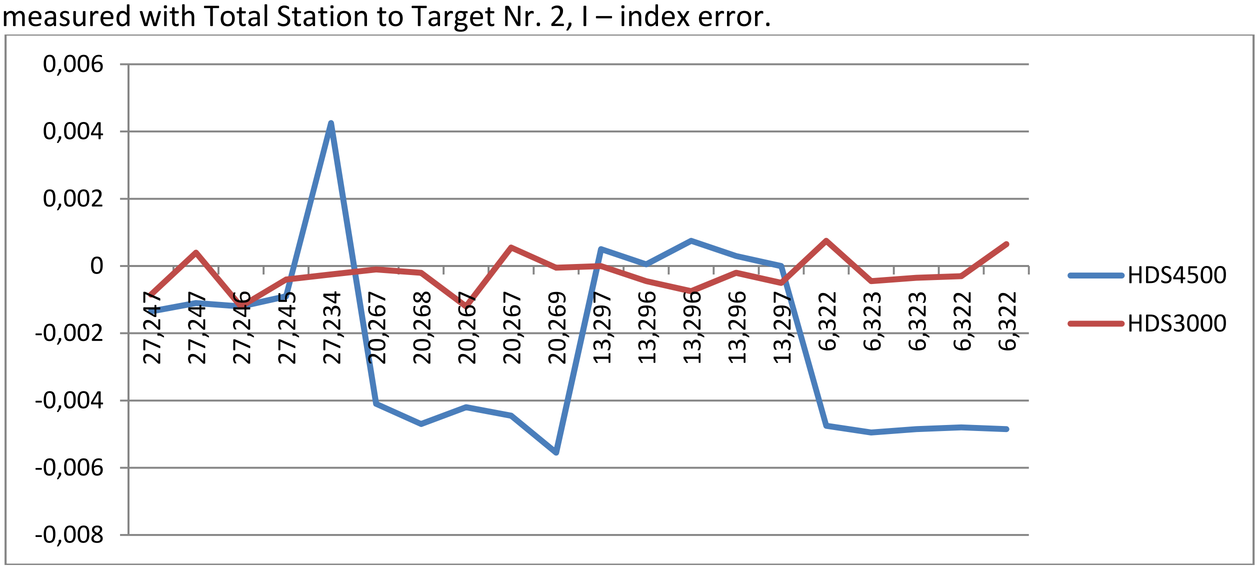


Figure 24. Both Laser Scanner's index errors.

As we can see in this diagram above, *HDS3000* index errors' various are very tiny. *Leica HDS4500* index errors' differences are quite big and they are not depending on distances.
Scale errors I calculated by these formulas:

TSdist = (Sleft + Sright) * Scale error

Scale error = TSdist/ (Sleft+Sright)

Where: TSdist – distance measured with Total Station, Sleft – scanned distance to Target Nr. 1, Sright – scanned distance to Target Nr. 2.

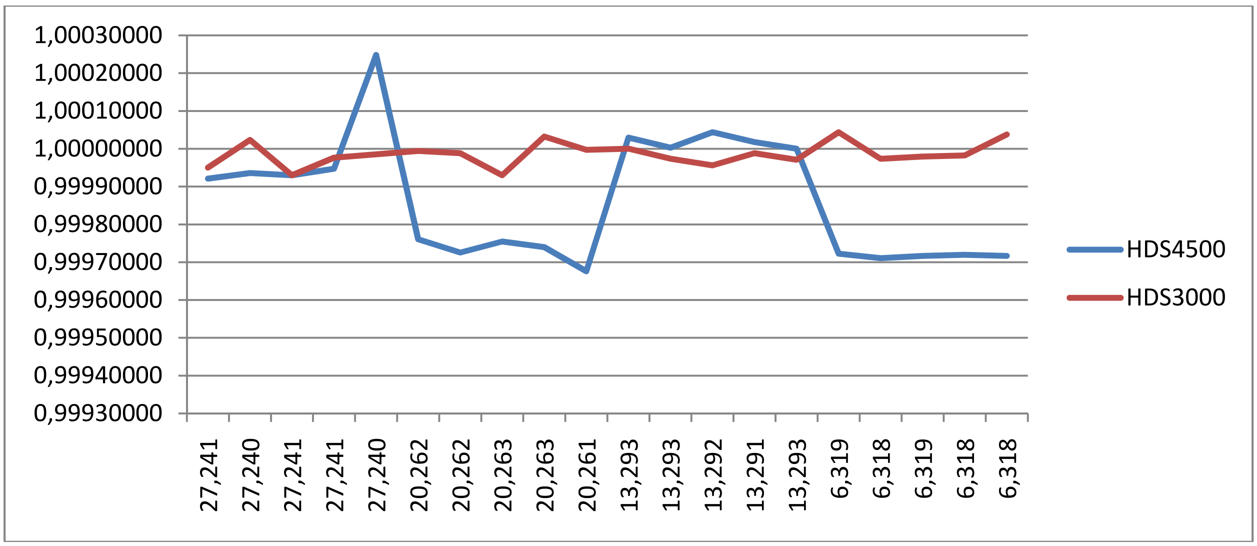


Figure 25. Both Laser Scanners' Scale Errors.

Leica HDS3000 scale errors are almost equal to 1, but *Leica HDS4500* these errors vary.

I could not find Cyclic Error because scatter of errors does not compose sinusoid:

Figure 26. Both Laser Scanners' scatters of results of errors.

6. Angles Calibration Method for Laser Scanner

To find out how accurate both Laser Scanners can measure the angle I create angles calibration method. As a standard I used Total Station measurements too. I placed two Black and White targets approximately 17 meters away from Total Station. After measurements with Total Station I scanned those targets with both Laser Scanners from the same point. Laser Scanner does not measure angles, so I computed them by Law of Cosines or Cosines Rule. I have got two distances in the same way as I described in chapter 5, and the third side of triangle I measured in *Cyclone*.

Figure 26. Measuring of angles procedure.

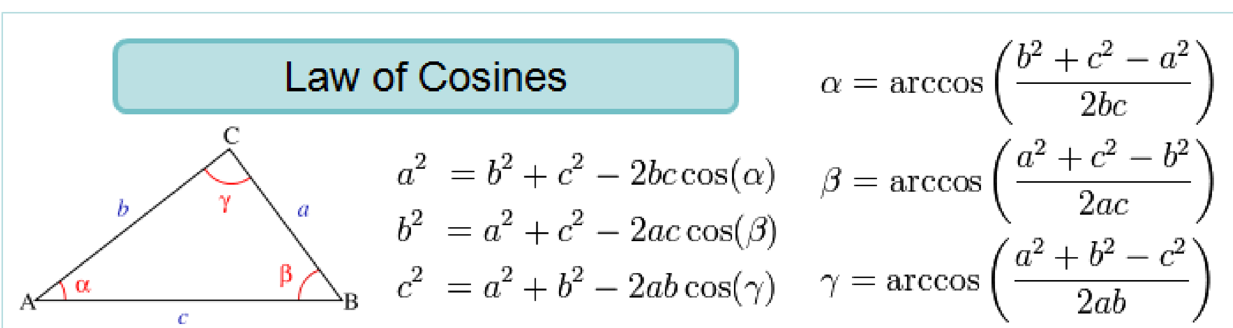


Figure 27. Law of Cosines or Cosines Rule.

For measuring distances of the third side of triangle I used Finding of targets function with both *Leica HDS4500* and *Leica HDS3000*.

Figure 28. Acquiring targets and measuring distance in *Cyclone*.

6.1. Calibration Procedure with Leica HDS4500 and Leica HDS3000

Laser Scanner *Leica HDS4500* measures distances different from Total Station, there are not reliable centring and levelling too, as I mentioned in previous chapters. That means computed angle is also 'wrong', different from the Total Station.

Situation of angles measurement with *Leica HDS3000* was really better. The reason is already known: working principle is similar to Total Station, accurate centring and levelling. That is all what it is necessary for precision surveying.

Moreover, very important thing which I must to mention – *Leica HDS3000 (ScanStation 2)* arrived just three weeks before my work with it from Switzerland Leica Calibration Laboratory and for Leica HDS4500 last calibration was done approximately 700 days ago.

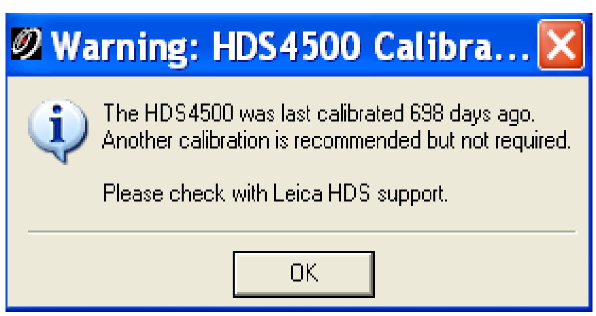


Figure 29. Warning of *HDS4500* calibration.

6.2. Results and Comparison

Results of angles measurements with *Leica HDS3000* were very similar to Total Station. Laser Scanner measures distances to targets, the third side of triangle I measured in *Cyclone*. As I described in previous chapters *Leica HDS3000 (ScanStation 2)* measures the distances almost the same like Total Station, that is why I got almost the same angles too.

	Hz	***Horiz. Dist.***	***Scan. Dist.***	***Hz deg***	***Hz rad***
A	261° 35' 55.9"	17.3426	17.341	261.5988611	4.565761446
	261° 36' 24.8"	17.3402	17.342	261.6068889	4.565901557
	261° 36' 39.3"	17.3408	17.341	261.6109167	4.565971855
	261° 36' 34.2"	17.3405	17.342	261.6095000	4.565947129
	261° 36' 36.8"	17.3404	17.340	261.6102222	4.565959735
Average	261° 36' 26.2"	17.3409	17.341	261.6072778	4.565908344
B	275° 13' 40.1"	17.2257	17.224	275.2278056	4.803631400
	275° 14' 15.6"	17.2237	17.226	275.2376667	4.803803509
	275° 14' 23.2"	17.2242	17.223	275.2397778	4.803840355
	275° 14' 27.5"	17.2245	17.224	275.2409722	4.803861202
	275° 14' 25.3"	17.2244	17.224	275.2403611	4.803850536
Average	275° 14' 14.3"	17.2245	17.224	275.2373167	4.803797400
C measured	13° 37' 44.2''	4.103335948	4.103	13.62894444	0.237869954
	13° 37' 50.8''	4.103351709	4.104	13.63077778	0.237901952
	13° 37' 43.9''	4.102911179	4.103	13.62886111	0.237868500
	13° 37' 53.3''	4.103676135	4.104	13.63147222	0.237914072
	13° 37' 48.5''	4.103253233	4.103	13.63013889	0.237890801
Average	13° 37' 48.1''	4.103305641	4.1034	13.63003889	0.237889056
C scanned	***C scanned (rad)***		***C scanned (deg)***	***Difference***	
	0.237873023	13.62912029	13° 37' 44.8''	0.00017585	0° 00' 00.6''
	0.237912205	13.63136526	13° 37' 52.9''	0.00058748	0° 00' 02.1''
	0.237878292	13.62942217	13° 37' 45.9''	0.00056106	0° 00' 02.0''
	0.237922759	13.63196996	13° 37' 55.1''	0.00049774	0° 00' 01.8''
	0.237881570	13.62960999	13° 37' 46.6''	-0.00052890	0° 00' 01.9''
Average	0.237893570	13.63029754	13° 37' 49.6''	0.00025865	0° 00' 00.9''
St. deviation				0.00047006	0° 00' 01.7''

Table 1. Differences of angles' measurements between Total Station and *Leica HDS3000*.

As you can see in the table above the difference from Total Station measurements is about 0.9" and standard deviation 1.7". So we can trust this type of Laser Scanner when we need to measure the angles.

Situation with *Leica HDS3000* was truly complicated. The difference of measured angle and computed one is particularly big, what means that this method is absolutely unreliable to find an angle. It happened also because of wrong distances. The average of angles' differences is even 24.7" and standard deviation 7.9".

	Hz	***Horiz. Dist.***	***Scan. Dist.***	***Hz (deg)***	***Hz (rad)***
A	261° 36' 38.9"	17.3472	17.343	261.6108056	4.56596992
	261° 36' 29.4"	17.3477	17.344	261.6081667	4.56592386
	261° 36' 33.5"	17.3478	17.343	261.6093056	4.56594374
	261° 36' 30.0"	17.3478	17.344	261.6083333	4.56592677
	261° 36' 24.3"	17.3482	17.344	261.6067500	4.56589913
Average	261° 36' 31.2"	17.34774	17.344	261.6086722	4.565932682
B	275° 13' 39.0"	17.2259	17.220	275.2275000	4.80362607
	275° 13' 30.8"	17.2259	17.221	275.2252222	4.80358631
	275° 13' 32.5"	17.2258	17.221	275.2256944	4.80359455
	275° 13' 23.0"	17.2256	17.220	275.2230556	4.80354850
	275° 13' 24.0"	17.2257	17.222	275.2233333	4.80355334
Average	275° 13' 29.9"	17.22578	17.221	275.2249611	4.803581755
C measured	13° 37' 00.1''	4.10036296	4.097	13.61669444	0.23765615
	13° 37' 01.4''	4.10054495	4.098	13.61705556	0.23766245
	13° 36' 59.0''	4.10035118	4.098	13.61638889	0.23765082
	13° 36' 53.0''	4.09983428	4.096	13.61472222	0.23762173
	13° 37' 00.0''	4.10045965	4.097	13.61658333	0.23765421
Average	13° 36' 58.6''	4.10031060	4.0972	13.61628889	0.23764907
C scanned	***C scanned (rad)***		***C scanned (deg)***	***Difference***	
	0.237526948	13.6092916	13° 36' 33.4''	-0.00740280	0° 00' 26.7''
	0.237571438	13.6118407	13° 36' 42.6''	-0.00521481	0° 00' 18.7''
	0.237580062	13.6123349	13° 36' 44.4''	-0.00405401	0° 00' 14.6''
	0.237460009	13.6054563	13° 36' 19.6''	-0.00926588	0° 00' 33.4''
	0.237507435	13.6081736	13° 36' 29.4''	-0.00840973	0° 00' 30.3''
Average	0.237529179	13.6094194	13° 36' 33.9''	-0.00686945	0° 00' 24.7''
St. deviation				0.00218314	0° 00' 07.9''

Table 2. Differences of angles' measurements between Total Station and Leica *HDS4500*.

7. Conclusions

The aim of my Bachelor thesis is to compare an accuracy of Short Range and Long Range Laser Scanners. Calibration is the only one method to verify Electronic Distance Measurement instrument's errors and to find out which instrument is suitable for precision geodesic surveying and which one is not.

EDM instruments' calibration procedure requires high accuracy of baseline, standard instrument, placement of targets, temperature, humidity and lighting verification. Calibration procedure is doing in special laboratories to get precision results. My task was to create as accurate as possible laboratory in university conditions and to verify an accuracy of two different types of Laser Scanners: *Leica HDS4500* and *Leica HDS3000*.

Results which I got show that *Leica HDS4500* is not suitable for accurate distances and angles measurements as much as *Leica HDS3000*. Anyways, it does not mean that *Leica HDS4500* Laser Scanner is not suitable for precision 3D models, just the way how they are creating is different from the way which I used in my experiments. Furthermore, this instrument is not designed for single point measurements.

A big challenge for me was to learn how to use an equipment and software, especially when Laser Scanning is a new technology and there is not enough information about that. However, practice is the best way to understand how this technology works and I am grateful for opportunity to have it.

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9. Appendixes