On the Calibration of a Ground-based Laser Scanner

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SUMMARY

This paper deals with the calibration of the ground-based laser scanner the Cyrax 2500. The aim of the present work was to determine the accuracy and the uncertainty of the Cyrax 2500 system in measuring the 3D-coordinates (x,y,z) of the object points. The reference coordinates were measured with the 3D-theodolite measuring system the accuracy of which is 0.05 mm. The number of the object points was 36, and they were measured at the different distances: 3 m, 10 m, 25 m and 50 m. For determining the 3D-coordinate measuring accuracy of the Cyrax 2500 system the 3D-coordinates of the measured object points were compared to the corresponding coordinates determined with the reference measuring system, i.e. the 3D-theodolite measuring system. For obtaining all coordinates to the same reference system the seven parameter Helmert's transformation was used.

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1. 3D LASER SCANNERS

1.1. Types of the 3D laser scanners

There are a lot of ways to capture reality. One of the newest of them is 3D-laserscanning, which changes surveying in different ways. First of all it adds dramatically number of details in surveying data, gives more accuracy trough modeling and gives new tools for designers of the plants, architects and mining companies. It is very strong tool for quality analysis for example for bridge building projects.

3D-laserscanners are classified in different ways. There are scanners to make scanning from the earth, from the ground and there are also hand-held scanners. First type of scanners has point accuracy in centimeters, second ones have accuracy of measured points in millimeters and there are also scanners with sub millimeter accuracy for industrial measurements.

3D scanning instruments are very similar to the reflectorless total stations. They are measure two angles and slope distance to the object. Up to now there is now way to point exactly to the object details, but using very dense point cloud as result of the capturing makes possible to model objects very accurately.

Three different types of laser scanners are used for ground-based laser scanners.

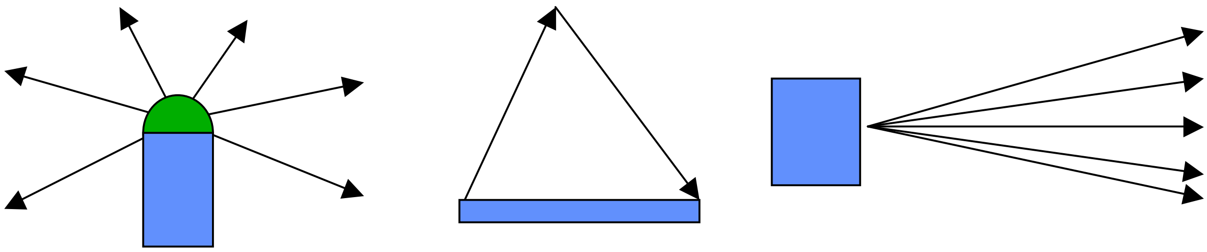

Figure 1. Different types of ground-based 3D laser scanners.

First of them, “dome-like scanner”, is not easily calibrated because it is almost impossible to focus to the measured object (density of the scanned point cloud is the function of the distant from instrument to the object. Second method is very rare, used only by one producer, where measured point accuracy seems to be good, but using for different kind of objects is limited, because construction of the scanner is not designed for measurements of narrow corridors and long distances (more than 50 m). Third method, fan-shaped method, is most interested because it is most used in plant applications, where accuracy and density of the measured point cloud is very important. One of them, Cyrax 2500 laser scanner from Cyra Technology Inc. (owned by Leica Geosystems, Switzerland), was used to create calibration methodology.

1.2. Cyrax 2500 laser scanner

The Cyrax 2500 is the world's most popular 3D ground-based laser scanner for engineering, surveying, construction and related applications. This 3D-scanner is successfully used in hundreds of projects in different countries for last two years, when production of this instrument was started (March 2001).

Figure 2. Cyrax 2500 3D laser scanner

The portable Cyrax 2500 3D laser scanner consists of the scan head, Cyclone-SCAN software that runs on a PC, plus a power supply and accessories. Popularity of Cyrax 2500 scanners is based on the system's optimal combination of accuracy at range; highly adjustable scans density; high scanning speed; adjustable field of view and ease of use.

Technical specs of Cyrax 2500:

Single point accuracy:	
Position	±6 mm @ 1.5 m – 50 m range, 1 Sigma
Distance	±4 mm, 1 Sigma
Angle	±60 micro-radians
Modeled surface precision	±2 mm
Spot size	≤ 6 mm from 0 - 50 m
Range	Maximum up to 100 m
Scan rate	1000 points/sec
Scan density	Independently selectable vertical and horizontal point-to-point measurement spacing, 0.25 mm minimum point-to-point spacing (at 50 m) in both direction.
Field of view	40º vertical and 40º horizontal
Number of measured points	1000x1000 points/scan

Distance measururing of Cyrax 2500 is based on time of flight method, which makes also possible very accurate measurements on the edges of the objects. Additionally to measuring of the coordinates of the points, intensity of the returned signal is measured, which makes captured data more informative and easier to use in modelling.

1.3. Errors in 3D laser scanning

There are a lot of parameters influencing to the quality of the result model made using point clouds measured with 3D laser scanners. In the calibration process of the scanners should be consider to the following:

- Accuracy of the single point (distance and angle measurements)
- Uncertainty of measurement of the one point (deviations on the plain, etc.)
- Scale factor changing on the edges of the scan areas

As separately scanned point clouds are connected together and result is geo-referenced using common targets (registration operation), accuracy of determine of the center points of the targets is very important. For this purpose targets can be scanned by Cyrax scanner using very high density of the point cloud and be surveyed by traditional surveying instruments. Method used in this research is based on determine of the targets centers using scanner. It also includes calculations for scale factor errors.

2. THE CALIBRATION OF THE CYRAX 2500

2.1 The calibration frame and method

For determining the precision and the accuracy of the laser scanner Cyrax 2500 the calibration measurements were made at the laboratory. The temperature value was about 20 degrees and the air pressure 760 mmHg.

For creating the calibration frame the object points, i.e. laser targets of the Cyrax 2500 were fixed with a magnetic system on the round aluminium table, the diameter of which was about 3 m (Fig. 3). The number of targets points was 9. The aluminium table can be rotated around the horizontal and vertical axis. We used the azimuths of 300, 270 and 240 degrees - the azimuth of the laser scanner beam was 0 degrees (Fig. 4). Correspondingly the rotations around the horizontal axis were 0 (vertically up), 90, 180 and 270 degrees. So 36 object points formed the whole calibration frame. The 3D-coordinates (x, y, z) of the object points were measured with the laser scanner at the different distances: 3 m, 10 m, 25 m and 50 m.

Figure 3. The determination of the reference coordinates of the object points by using the theodolite measuring system.

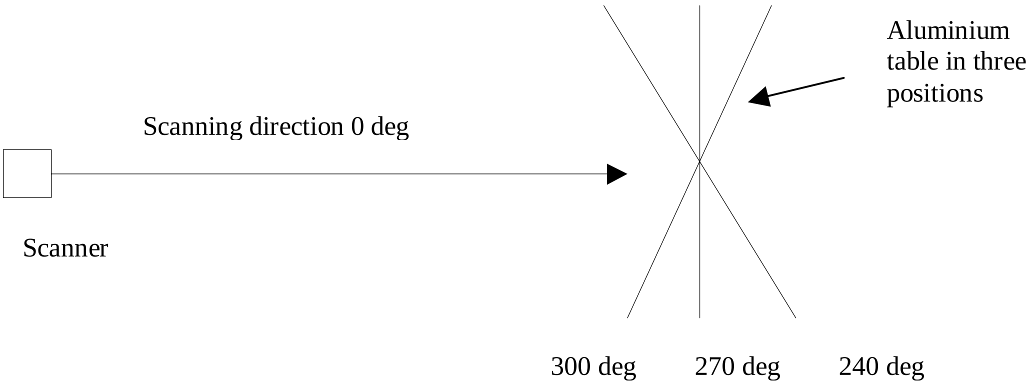

Figure 4. Targeting azimuths from scanner to the targets (view from the top).

At every measuring distance the 3D-reference coordinates of the object points were determined with the theodolite measuring system (Tms), (two Wild T2000 theodolites). The distance between theodolites was about 4 m, and the relative position between the theodolites and the object points was such that the spatial intersection angle was the best possible, i.e. about 110 degrees (Fig. 3 and 5). So the determination accuracy of the reference coordinates was very high 0.05 mm.

Figure 5. The operator controls functions of the Cyrax 2500 system.

At every measuring distance first the reference coordinates were determined by using the Tms and after that the same object points were measured with the Cyrax 2500. The coordinates measured with the Cyrax 2500 were transformed to the coordinate system of the Tms by using the seven parameter Helmert's transformation. After that the value of the scale factor and the RMS of the differences between the 3D-coordinates determined by the Cyrax 2500 and the 3D-reference coordinates were calculated.

2.2 The results

At every measuring distance and to the different azimuths, the scale factor and the RMS value are collected in the Table 1.

Table 1. The scale factor and the RMS value at every measuring distances and to the different azimuths.

Measuring distance (m)	Azimuth (degrees)	Scale factor	RMS (mm)
3	300	0.99931715	4.26
3	240	0.99954980	4.23
10	300	1.00233566	18.29 *
10	270	0.99964254	4.19
10	240	0.99971347	4.19
25	300	0.99966873	4.32
25	270	0.99972678	4.09
25	240	0.99983798	4.13
50	300	0.99988770	4.08
50	270	1.00018201	4.59
	mean *	0.99998618	5.64
	sdev *	8,556610 e-4	4.45
	mean	0.99972513	4.23
	sdev	2.385457 e-4	0.16

* Cross error (18.29 mm) is influenced by very bright light on the target, which was reflected to the scanner. Mean value (mean*) and standard deviation (sdev*) are calculated using cross error. Other results mean and sdev are obtained without using cross error.

Results show that scanner used in this calibration fulfill specs given by producer in range of distance 0-50 m. There wasn't determined influence of the targeting angle to the scanned targets at azimuth range ±30 deg.

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