Terrestrischer Laserscanner RIEGL LMS-Z620

Extra Long Range & High Accuracy 3D Terrestrial Laser Scanner

LMS-Z620

The terrestrial laser scanner system *RIEGL*® LMS-Z620 consists of a high performance long-range 3D scanner, the accompanying operating and processing software RiSCAN PRO, and a calibrated and accurately orientated and mounted high-resolution digital camera.

The system provides data which lends itself to automatic or semi-automatic processing of scan- and image data to generate products such as textured triangulated surfaces and high resolution panorama images as a basis for e.g., geotechnical analysis and mining assessment.

The *RIEGL* LMS-Z620 is a rugged and fully portable sensor especially designed for the rapid acquisition of high-quality three dimensional images even under highly demanding environmental conditions, providing a unique and unrivalled combination of a wide field-of-view, high maximum range, and fast data acquisition.

A standard Windows notebook and the bundled software package RiSCAN PRO enable the user to instantly acquire high-quality 3D data in the field and provide a variety of registration, post processing and export functions.

- *Topography & Mining*
- *Monitoring & Civil Engineering*
- *Archaeology & Cultural Heritage Documentation*
- *Architecture & Facade Measurement*

RIEGL® LASER MEASUREMENT SYSTEMS

http://www.riegl.com/

System Key Performance Data

Scanner Hardware LMS-Z620

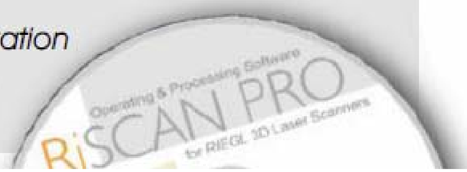
allows high-speed, high resolution and accurate 3D measurements

- *Range up to 2000 m @ Laser Class 1*
- *Repeatability up to 5 mm*
- *Measurement rate up to 11000 pts/sec*
- *Field of View up to 80° x 360°*
- *TCP/IP data interface, allowing easy wireless data transmission*
- *Operable with any standard PC or Notebook*
- *Fully portable, rugged & robust*

Software RiSCAN PRO

RIEGL software package for scanner operation and data processing

- *Data archiving using a well-documented tree structure in the XML file format*
- *Object VIEW / INSPECTOR for intelligent data viewing and feature extraction*
- *Straightforward Global Registration*
- *Interfacing to Post Processing Software*



Camera (optional)
provides high resolution calibrated color images

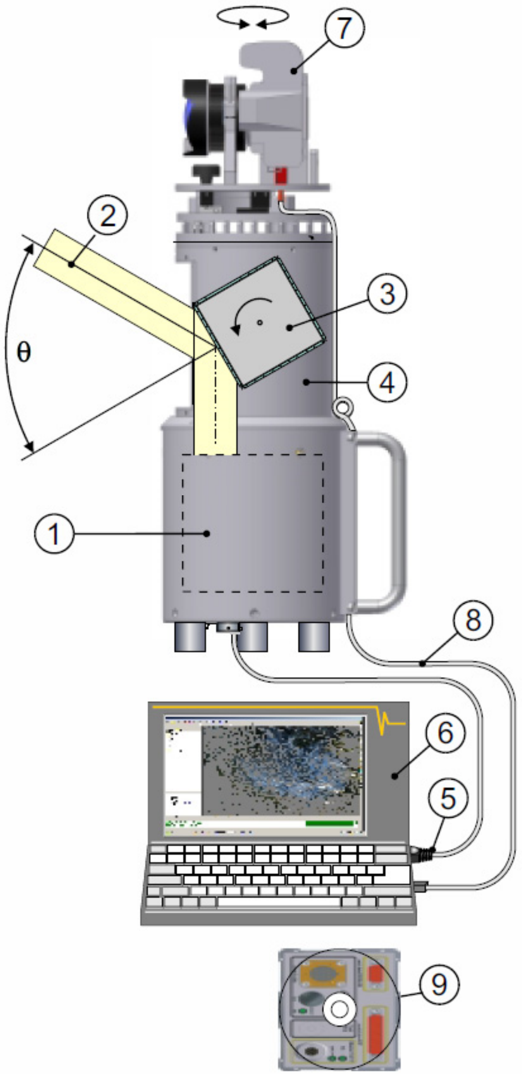
NIKON D700 / NIKON D300(s) / NIKON D200:

- *D300(s): 12.3 Megapixel*
- *D700: 12.1 Megapixel, Nikon FX format*
- *D200: 10.2 Megapixel*
- *USB interface*

The combination of the key components <u>Scanner</u>, <u>Software</u> and <u>Camera</u> results in

- Automatic generation of high resolution textured meshes
- Online position and distance measurements
- Photorealistic 3D reconstruction
- Online setting of any virtual point of view
- Exact identification of details

Principle of Scanner Operation



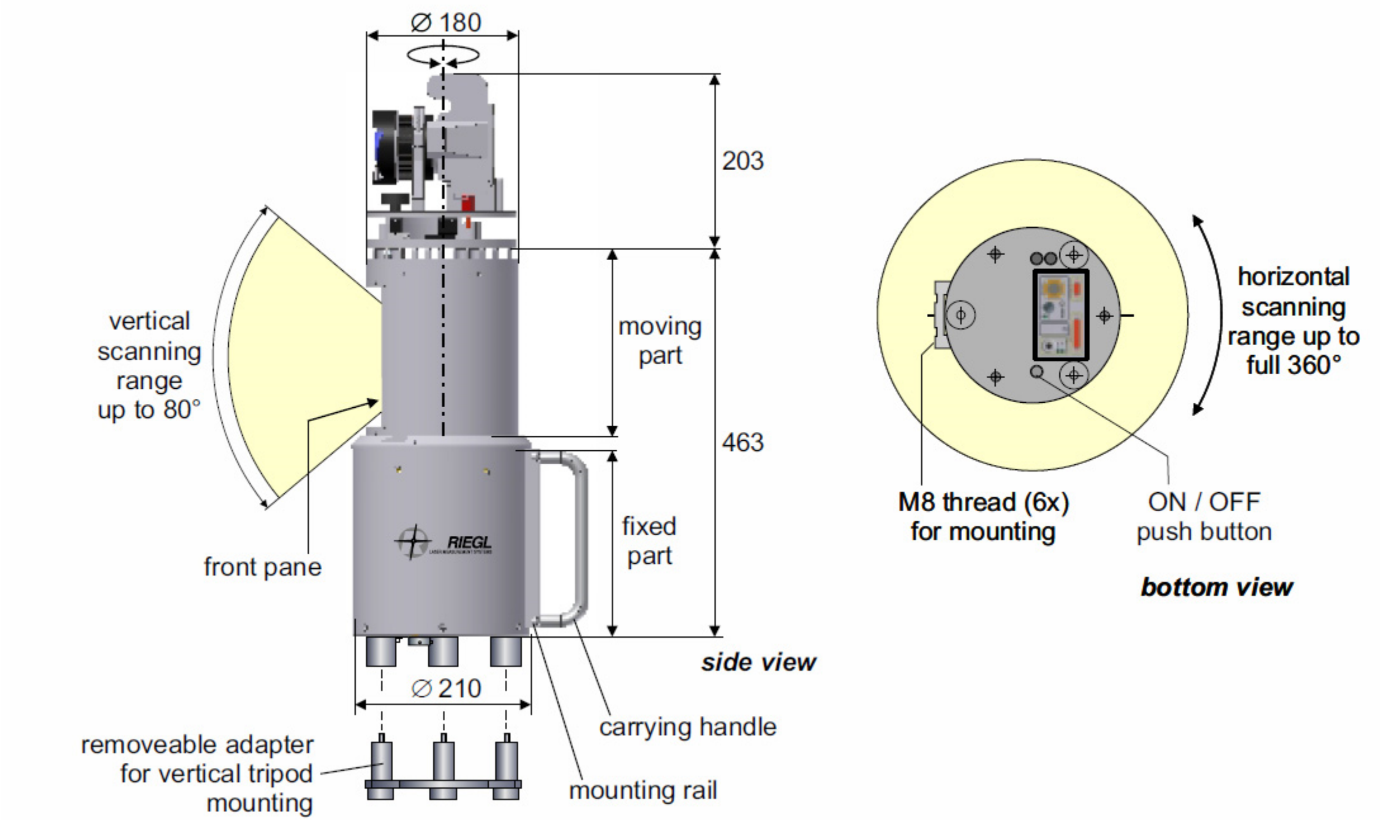
The **range finder electronics (1)** of the 3D scanner *RIEGL* LMS-620 are optimized in order to meet the requirements of high speed scanning (high laser repetition rate, fast signal processing, and high speed data interface).

The *vertical deflection* ("line scan") of the **laser beam (2)** is realized by a **polygon (3)** with a number of reflective surfaces. For high scanning rates and/or a vertical scan angle of θ up to 80°, the polygonal mirror continuously rotates at an adjustable speed. For slow scanning rates and/or small scanning angles, it linearly oscillates up and down. The *horizontal scan* ("frame scan") is realized by rotating the complete **optical head (4)** up to 360°.

Scandata: RANGE, ANGLE, SIGNAL AMPLITUDE, and optional TIMESTAMP are transmitted to a **laptop (6)** via **TCP/IP Ethernet Interface (5)**. **Camera (7)** data is fed into the same laptop via **USB/firewire interface (8)**.

The RiSCAN PRO software (9) allows the operator to perform a large number of tasks including sensor configuration, data acquisition, data visualization, data manipulation, and data archiving. RiSCAN PRO runs on the platforms WINDOWS XP or 2000 SP2.

Dimensional Drawings



Technical Data 3D Scanner Hardware *RIEGL* LMS-Z620

Rangefinder performance [1]

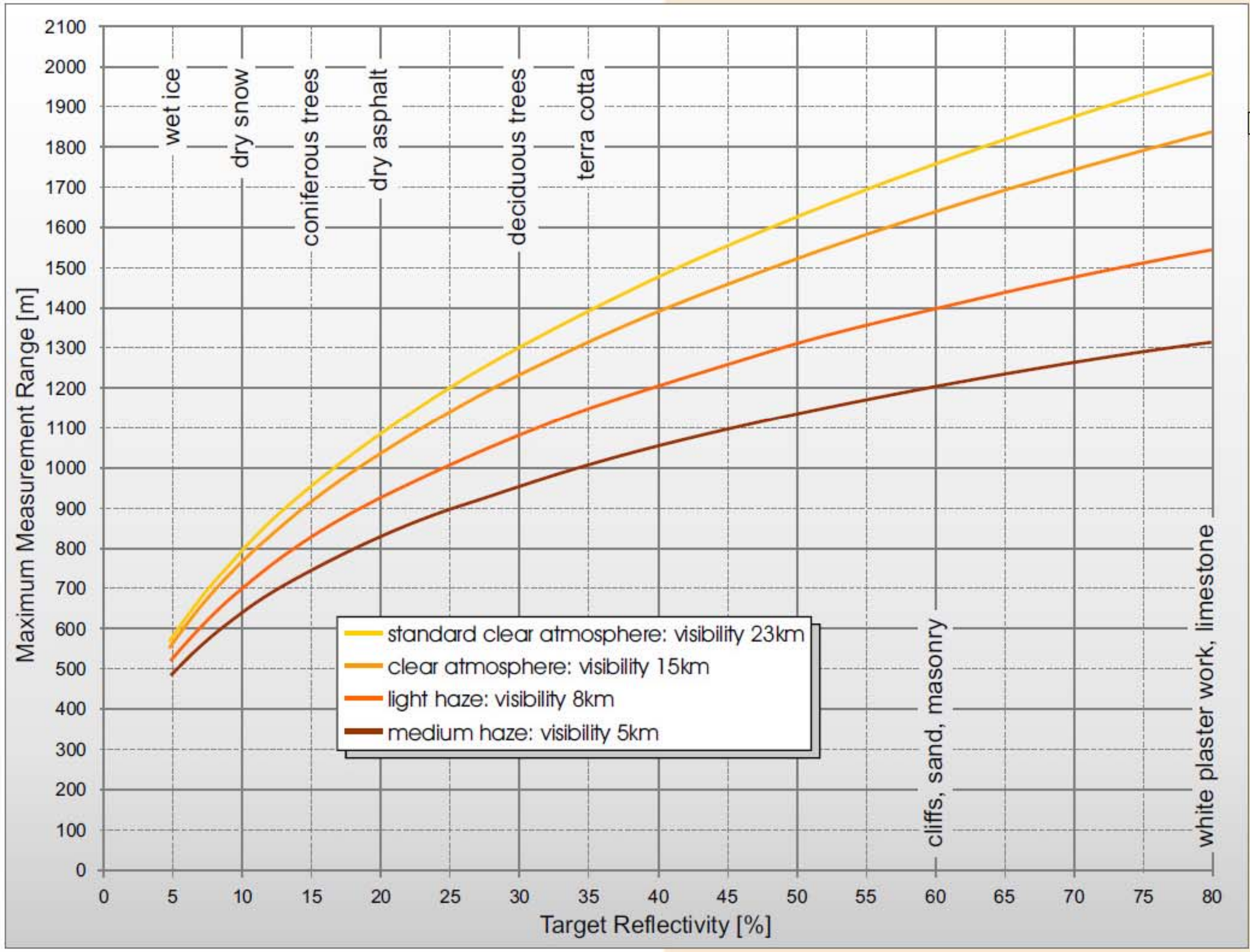
Eye safety class	CLASS 1 LASER PRODUCT according to IEC60825-1:1993+A1:1997+A2:2001 The following clause applies for instruments delivered into the United States: Complies with 21 CFR 1040.10 and 1040.11 except for deviations pursuant to Laser Notice No. 50, dated July 26, 2001.
Max. Measurement range [2]	
for natural targets, $\rho \geq 80$ %	up to 2000 m
for natural targets, $\rho \geq 10$ %	up to 650 m
Minimum range	2 m
Accuracy [3) 5)]	10 mm
Repeatability [4) 5)]	10 mm (single shot), 5 mm (averaged)
Measurement rate	up to 11000 pts/sec @ low scanning rate (oscillating mirror) up to 8000 pts/sec @ high scanning rate (rotating mirror)
Laser wavelength	near infrared / 1550 nm
Beam divergence [6]	0.15 mrad

1) First, Last, or Alternating Target Mode selectable.
2) Typical values under average conditions. Maximum range is specified for flat targets with size in excess of the laser beam diameter and near perpendicular incidence of the laser beam and atmospheric visibility in excess of 23 km. In bright sunlight, the operational range is considerably shorter than under an overcast sky.
3) Accurcy is the degree of conformity of a measured quantity to its actual (true) value.
4) Precision, also called reproducibility or repeatability, is the degree to which further measurements show the same result.
5) One sigma @ 100 m range under *RIEGL* test conditions.
6) 0.15 mrad correspond to 15 mm increase of beamwidth per 100 m of range.

Maximum Measurement Range *RIEGL* LMS-Z620

The following conditions are assumed:

Flat target larger than footprint of laser beam, perpendicular angle of incidence, average brightness



Scanner performance

Vertical (line) scan

Scanning range	0° to 80°
Scanning mechanism	rotating / oscillating mirror
Scanning rate	1 scan/sec to 20 scans/sec @ 80° scanning range
Angle stepwidth $\Delta\vartheta$ 7) between consecutive laser shots	$0.004° \leq \Delta\vartheta \leq 0.2°$
Angular resolution	0.002°

Horizontal (frame) scan

Scanning range	0° to 360°
Scanning mechanism	rotating optical head
Scanning rate 8)	0.01 °/sec to 15 °/sec
Angle stepwidth $\Delta\varphi$ 7) between consecutive scan lines	$0.004° \leq \Delta\varphi \leq 0.75°$
Angular resolution	0.0025°
Inclination Sensors	integrated, for vertical scanner setup position (specifications to be found in separate datasheet)
Internal Sync Timer	Option for GPS-synchronized time stamping of scan data (specifications to be found in separate datasheet)

7) Selectable via Ethernet Interface or RS232.

8) Horizontal scan can be disabled, providing 2D-scanner operation.

Terrestrischer Laserscanner RIEGL LMS-Z620
Technische Daten

General technical data

Interface:	for configuration & data output	TCP/IP Ethernet, 10/100 MBit/sec
	for configuration	RS 232, 19.2 kBd
	for data output	ECP standard (enhanced capability port) parallel

Power supply input voltage	12 - 28 V DC
Power consumption	typ. 75 W, max 85 W
Current consumption	typ. 6.25 A, max 7.1 A @ 12 V DC; typ. 3.13 A, max 3.54 A @ 24 V DC
Main dimensions	463 mm x 210 mm (length x diameter)
Weight	16 kg
Temperature range	0°C to +40°C (operation), -10°C to +50°C (storage)
Protection class	IP64, dust and splash-water proof

Data sheet, LMS-Z620, 13/08/2008

RIEGL
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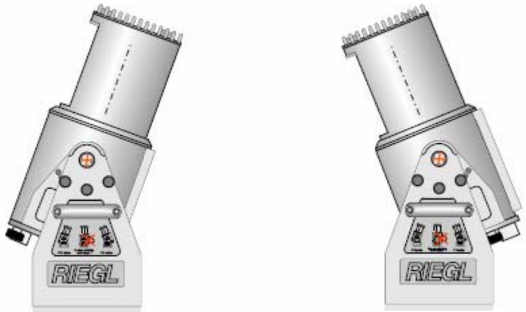
Scanner Mount for Manual Tilt

The *RIEGL* Scanner Mount for Manual Tilt serves to setup the scanner to a determined tilted position for comfortable covering the desired field of view.

Tilting range:
± 90° adjustable in steps of 5° and 10°



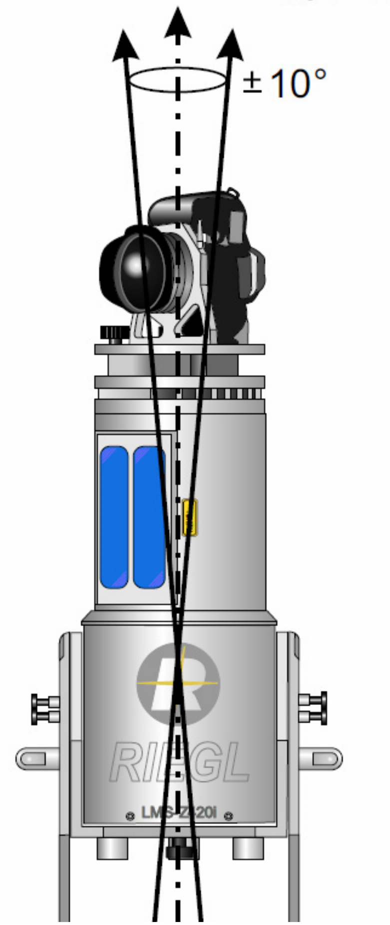
"+" Position "-" Position

Tilted positions of the mounted scanner can be calibrated for straight forward registration of the scanner position.

NOTE:
In case the scanner is taken off from the tilt mount, the calibration is lost.

Terrestrischer Laserscanner RIEGL LMS-Z620
Technische Daten

Integrated
Inclination Sensors
for *RIEGL* Terrestrial Laser Scanners



For straightforward and efficient registration of large data sets, *RIEGL* Terrestrial Laser Scanners are / can be optionally[1)] equipped with integrated INCLINATION SENSORS for vertical scanner setup position.

RiSCAN PRO makes complete use of the additional sensor data within its backsighting functions.

- ***utilization of inclination data by RiSCAN PRO's backsighting functions***
- ***angular correction applicable for vertical scanner setup position***
- ***angular tilt range ± 10 deg***
- ***accuracy typ. ± 0.008 deg*** [2)]

Reflector Targets

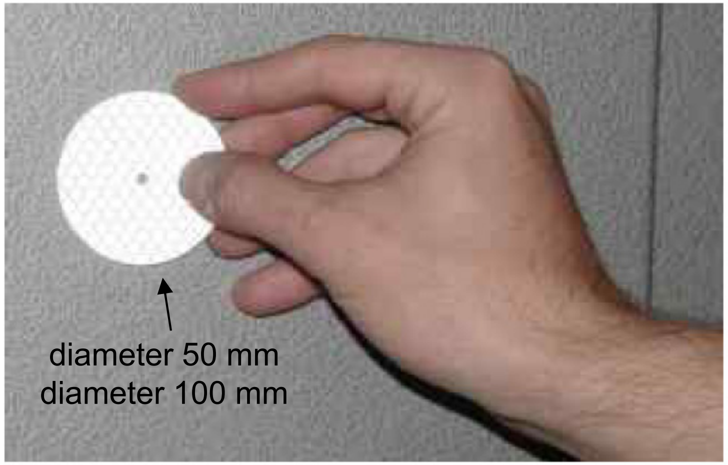
for Local/Global Scan Data Registration

RIEGL Retroreflector Targets are intended to be used as control points or tiepoints for scan data registration.

self-adhesive

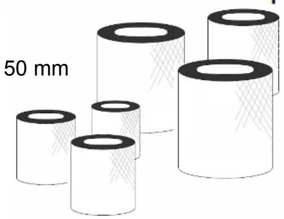
Flat Circular Retroreflectors can be used with totalstations as control points in RiSCAN PRO and RiPROFILE projects. To meet road traffic regulations, these reflectors are available in red and white color.

Biaxial Bireflex Flat Circular Retroreflectors mounted on universal joints offer the additional advantage of pivoting the reflector for setting the optimal angle of incidence to the laser measurement system.



Cylindrical Retroreflectors are primarily used for prior surveying by DGPS.

height 50 mm x diameter 50 mm



height 100 mm x diameter 100 mm

Always follow BASIC SAFETY PRECAUTIONS when working with retroreflectors!

- **Without owner's allowance retroreflectors must not be affixed to facades or buildings.**
- **When affixing retroreflectors on or nearby streets, roads, or other traffic areas, relevant road traffic regulations must be observed.**
- **Ensure that retroreflectors are properly mounted to avoid potential hazards, like personal injury, material damage, or delays in traffic.**
- **To avoid irritations retroreflectors must not be left on roads or traffic facilities at darkness.**
- **Relevant to the scanner types LMS-Z420i, LMS-Z390, LMS-Q280i and LMS-Q560:**

  Never use glass retroreflectors (so-called corner cube reflectors or prisms) as a target with the instrument.

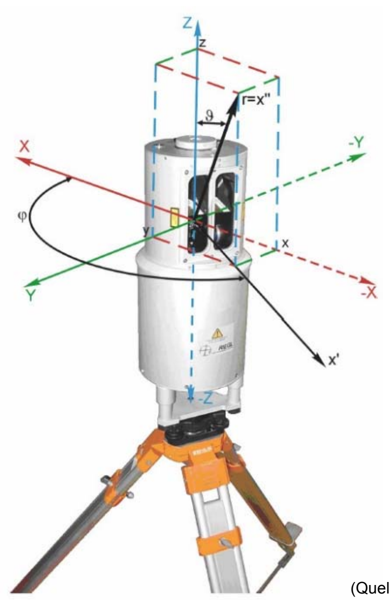
  Measuring to optical-grade retroreflectors at ranges below 100 m can permanently damage the instrument and must therefore be avoided under all circumstances.

Aula der TU Graz
Photo: V. Kaufmann, 22.01.2010

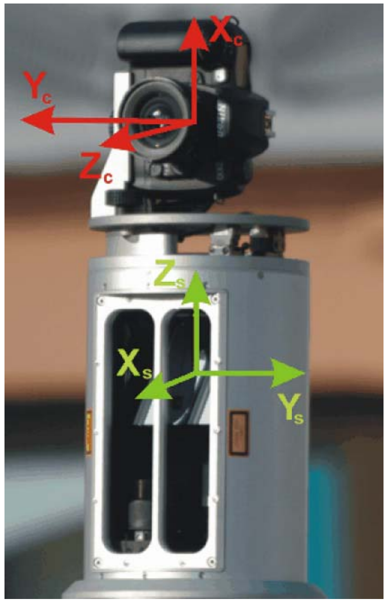
Terrestrischer Laserscanner RIEGL LMS-Z620
Koordinatensysteme

Alle Scandaten und Bilddaten stehen über hierarchisch strukturierte Koordinatensysteme in Wechselwirkung.

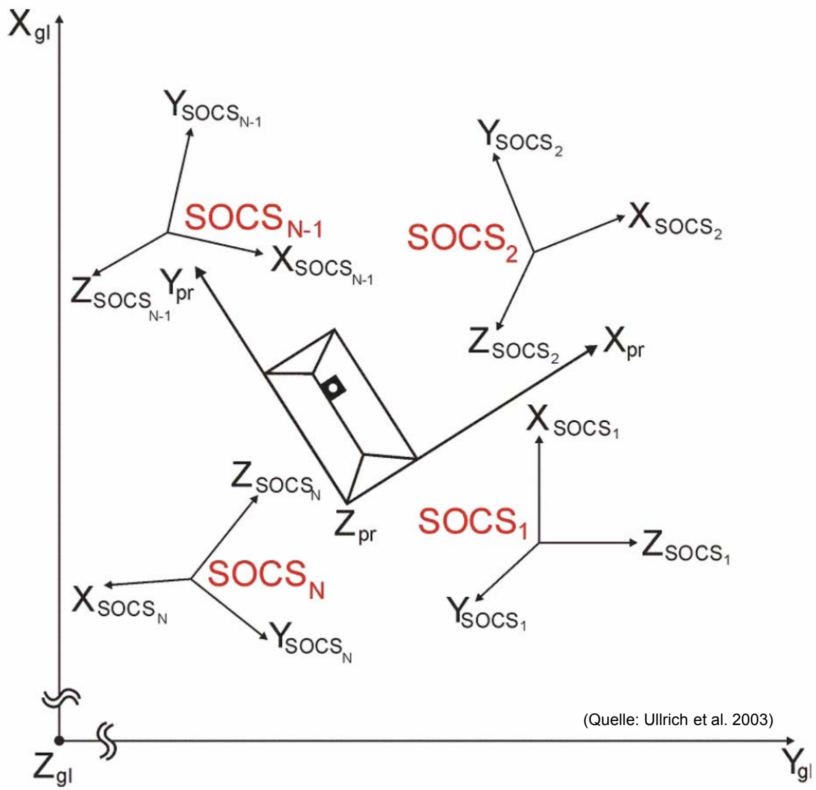
- Scanner‘s Own Coordinate System (SOCS) – das scannereigene Koordinatensystem
- Project Coordinate System (PRCS) – das Projektkoordinatensystem (→ Koordinatenverspeicherung: 7 signifikante Ziffern)
- Global Coordinate System (GLCS) – das globale Koordinatensystem (z.B. Landeskoordinatensystem)
- Camera Coordinate System (CMCS) – das Kamerakoordinatensystem



(Quelle: Ullrich et al. 2003)



Definition des scannereigenen Koordinatensystems SOCS bei einem RIEGL LMS-Z-Seriengerät (links) und bei einem RIEGL LMS-Z360 mit aufgesetzter Digitalkamera (rechts).



Koordinatensysteme PRCS, GLCS und einige lokale Systeme SOCS am Beispiel der Datenaufnahme an einem Gebäude.

Anmerkung: Das PRCS muss stets ein rechtshändiges Koordinatensystem sein.

SOP … Sensor's orientation and Position within PRCS
POP … Orientation and Position of PRCS within GLCS
COP … Camera's Orientation and Position

Transformation PRCS → GLCS

$$\mathbf{X}_{\mathrm{GLCS}} = \mathbf{M}_{\mathrm{POP}}\mathbf{M}_{\mathrm{SOP_N}}\mathbf{X}_{\mathrm{SOCS_N}}$$

Transformation CMCS → GLCS

$$\mathbf{X}_{\mathrm{GLCS}} = \mathbf{M}_{\mathrm{POP}}\mathbf{M}_{\mathrm{SOP_N}}\mathbf{M}_{\mathrm{COP_{N,M}}}\mathbf{M}_{\mathrm{CMCS}}^{-1}\mathbf{X}_{\mathrm{CMCS_{N,M}}}$$

Transformation CMCS → SOCS

$$\mathbf{X}_{\mathrm{SOCS_N}} = \mathbf{M}_{\mathrm{COP_{N,M}}}\mathbf{M}_{\mathrm{CM}CS}^{-1}\mathbf{X}_{\mathrm{CMCS_{N,M}}}$$

N steht für den N-ten Aufstellungsort.
M steht für das M-te Bild an diesem Aufstellungsort.
$\mathbf{M}_{\mathrm{CMCS}}$ ist die Kamera-Montage-Matrix, die als konstant während der gesamten Datenaufnahme angenommen werden kann.
Diese Matrix beinhaltet 6 Freiheitsgrade (6 DOF) der Montage: 3 Translationsparameter und 3 Rotationsparameter.
Die Matrix $\mathbf{M}_{\mathrm{COP_{N.M}}}$ beschreibt die bloße Rotation um die z-Achse des SOCS, unter welcher das Bild aufgenommen wurde, wobei der Drehwinkel als Messergebnis vom Scankopf geliefert wird. Die Montage-Matrix und die Rotationsmatrix zusammen beschreiben die Transformation zwischen CMCS und SOCS. Die Aufteilung in einen zeitlich unveränderlichen und kalibrierbaren Teil $\mathbf{M}_{\mathrm{CMCS}}$ und in einen veränderlichen Teil und messbaren Teil erlaubt ein einfaches Zusammenführen von Bilddaten und Scandaten.

Transformation GLCS → PRCS

$$\mathbf{X}_{\mathrm{SOCS_N}} = \mathbf{M}_{\mathrm{SOP_N}}^{-1}\mathbf{M}_{\mathrm{POP}}^{-1}\mathbf{X}_{\mathrm{GLCS}}$$

Transformation GLCS → CMCS

$$\mathbf{X}_{\mathrm{CMCS_{N,M}}} = \mathbf{M}_{\mathrm{CMCS}}\mathbf{M}_{\mathrm{COP_{N,M}}}^{-1}\mathbf{M}_{\mathrm{SOP_N}}^{-1}\mathbf{M}_{\mathrm{POP}}^{-1}\mathbf{X}_{\mathrm{GLCS}}$$

Transformation SOCS → CMCS

$$\mathbf{X}_{\mathrm{CMCS_{N,M}}} = \mathbf{M}_{\mathrm{CMCS}}\mathbf{M}_{\mathrm{COP_{N,M}}}^{-1}\mathbf{X}_{\mathrm{SOCS_N}}$$

Räumliche Drehstreckung (7 Freiheitsgrade)

$$\mathbf{X}_{\mathrm{G}} = \mu \mathbf{R} \mathbf{X}_{\mathrm{S}} + \mathbf{T}$$

μ … Skalierungsfaktor

$$\mathbf{R} = \begin{pmatrix} r_{11} & r_{12} & r_{13} \\ r_{21} & r_{22} & r_{23} \\ r_{31} & r_{32} & r_{33} \end{pmatrix} \text{ … Rotationsmatrix}$$

$$\mathbf{T} = \begin{pmatrix} t_1 \\ t_2 \\ t_3 \end{pmatrix} \text{ … Verschiebungsvektor}$$

Kompakte Schreibweise mit homogenen Koordinaten:

$$\mathbf{X}_{\mathrm{G},h} = \mathbf{M} \mathbf{X}_{\mathrm{S,h}}$$

$$\mathbf{X}_{\mathrm{G},h} = (X_G \;\; Y_G \;\; Z_G \;\; 1)^{\mathrm{T}}$$
$$\mathbf{X}_{\mathrm{S},h} = (X_S \;\; Y_S \;\; Z_S \;\; 1)^{\mathrm{T}}$$

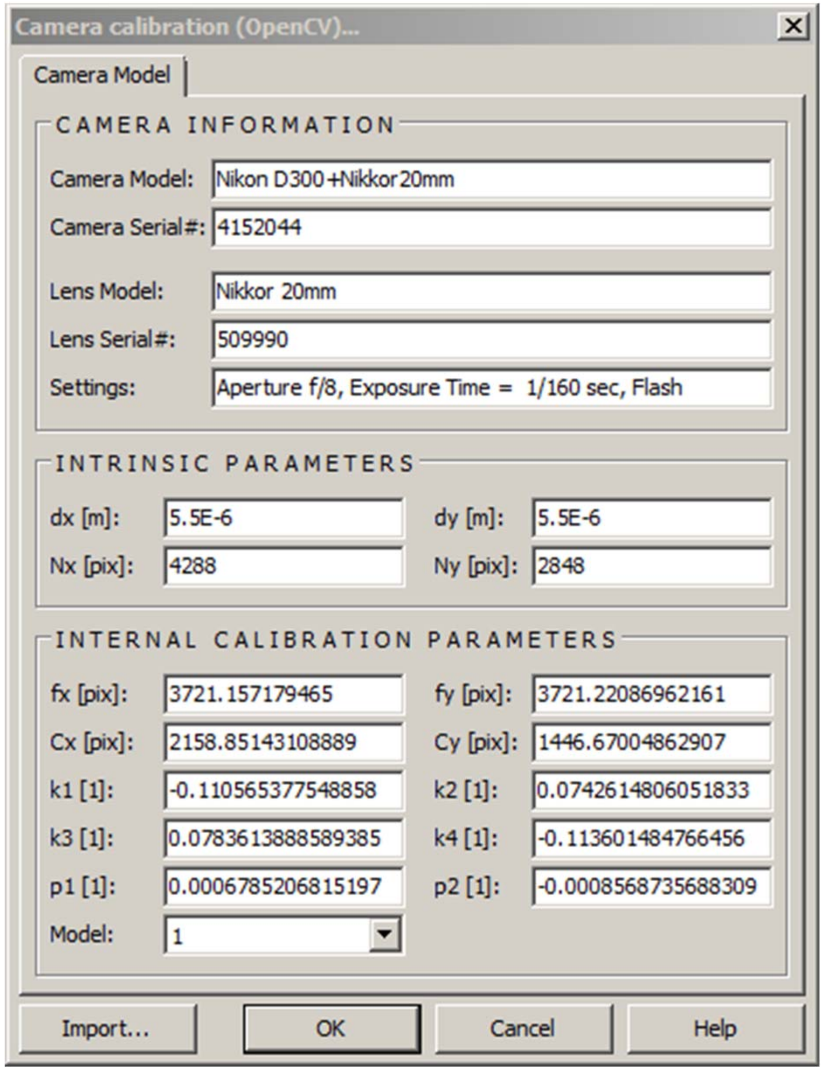
$$\mathbf{M} = \begin{pmatrix} \mu r_{11} & \mu r_{12} & \mu r_{13} & t_1 \\ \mu r_{21} & \mu r_{22} & \mu r_{23} & t_2 \\ \mu r_{31} & \mu r_{32} & \mu r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{pmatrix} \text{ … Transformationsmatrix}$$

mit $\mu = 1 \Rightarrow$

$$\mathbf{M} = \begin{pmatrix} r_{11} & r_{12} & r_{13} & t_1 \\ r_{21} & r_{22} & r_{23} & t_2 \\ r_{31} & r_{32} & r_{33} & t_3 \\ 0 & 0 & 0 & 1 \end{pmatrix} \text{ … Starrkörperbewegung (6 Freiheitsgrade)}$$

Terrestrischer Laserscanner RIEGL LMS-Z620
Koordinatensysteme

Kameraparameter (intrinsic parameters)



CMOS-Sensor
Bildelementgröße: 5.5 x 5.5 µm
Bildgröße: 4288 x 2848 (= 12.3 Megapixel)
Sensorgröße: DX-Format (23.584 mm x 15.664 mm)

c_{mittel} = (20.466 + 20.467)/2 = 20.4665 mm

Öffnungswinkel: 61.682°(horizontal), 43.010° (vertikal)

Tabelle der Verzeichungswerte

$r\ (mm)$	$\Delta r\ (mm)$	$\Delta r\ (Pixel)$
0.0	0.0	0.0
4.0	-2.2	-0.4
8.0	-17.4	-3.2
12.0	-56.4	-10.3
16.0	-126.5	-23.0
20.0	-228.8	-41.6
24.0	-357.1	-64.9
28.0	-495.1	-90.0

Kamerakonstante in x-/y-Richtung

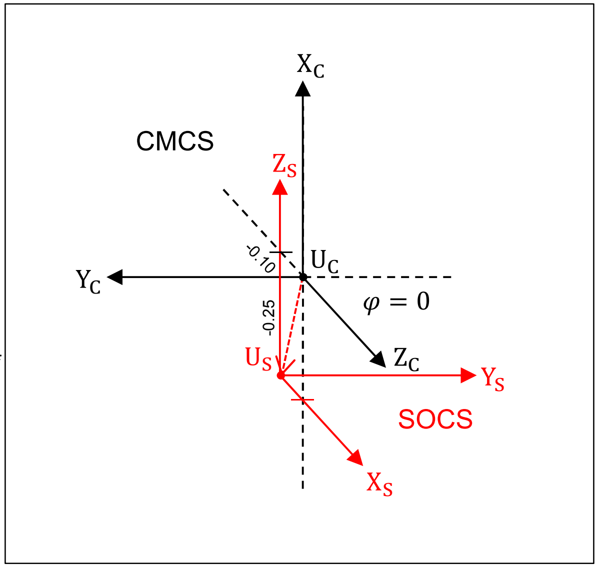
Bildhauptpunkt

Radial-symmetrische Verzeichnung

Tangentiale und radial-asymmetrische Verzeichnung

```
<!-- ************************************************************************************** -->
<!-- * There is single mountcalibs tag in the project which may contain numerouse mountcalib tags.  * -->
<!-- * Each mountcalib tag describes the transformation associated with the mounting of the camera  * -->
<!-- * with respect to the scanners coordinate system, in case the scanner is positioned in a      * -->
<!-- * reference position (usually phi = 0).                                                       * -->
<!-- *                                                                                             * -->
<!-- * The transformation is described by a rotation matrix R and a translation vector T           * -->
<!-- *                                                                                             * -->
<!-- *       | r11  r12  r13 |       | t1 |                                                        * -->
<!-- *  R =  | r21  r22  r23 |  T =  | t2 |                                                        * -->
<!-- *       | r31  r32  r33 |       | t3 |                                                        * -->
<!-- *                                                                                             * -->
<!-- * As the camera on a LMS-Z series instrument is usually mounted looking into the +x direction * -->
<!-- * of the SOCS system and is usually tilted by 90 deg around the camera's z-axis, the standard * -->
<!-- * rotation matrix is R0 and the translation in the camera's coordinate system is 0.25 m above * -->
<!-- * the origin of the scanner and 0.1 m in the direction of the camera's z-axis.                * -->
<!-- *                                                                                             * -->
<!-- *        | 0   0  1 |        | -0.25 |                                                      * -->
<!-- *  R0 =  | 0  -1  0 |   T0 = |  0.00 |
<!-- *        | 1   0  0 |        | -0.10 |
<!-- *
<!-- * For convenience R and T are combined to form a 4 x 4 matrix
<!-- *
<!-- *        | r11  r12  r13  t1 |
<!-- *  RT =  | r21  r22  r23  t2 |
<!-- *        | r31  r32  r33  t3 |
<!-- *        |  0    0    0    1 |
<!-- *
<!-- * RT converts into camera system (CMCS)
<!-- * values are given in order r11 r12 r13 t1 r21 ...
<!-- ************************************************************************
```

$= \mathbf{M}_{CMCS}$



Auszug aus «RiSCAN PRO/RiPROFILE - DOCUMENT TYPE DEFINITION»

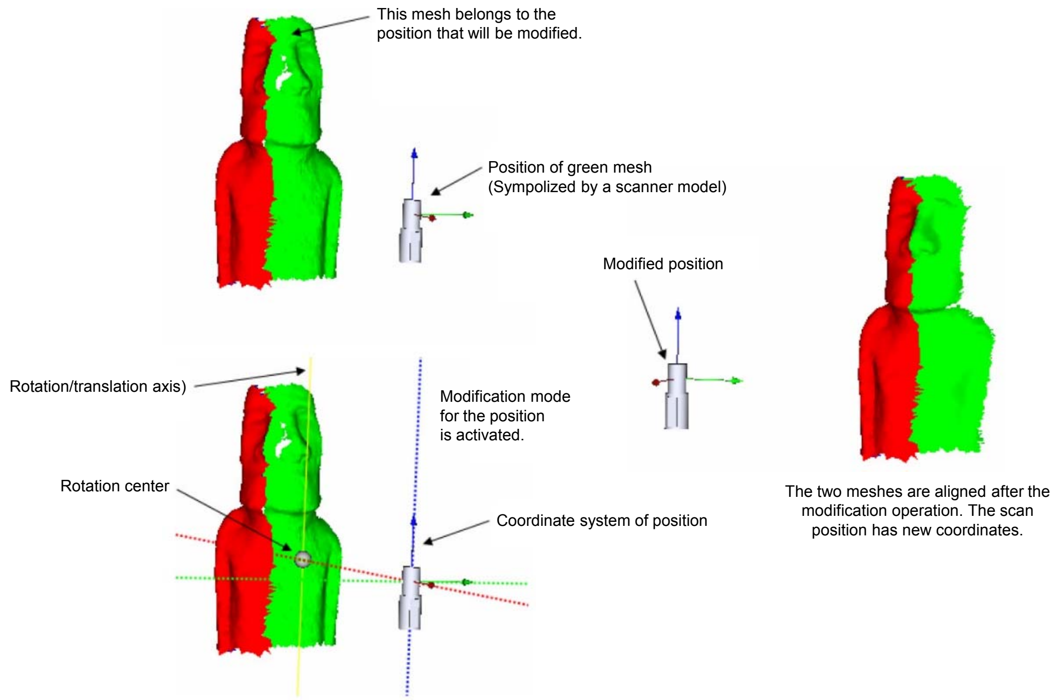
- rotation about the scanner's **x-axis** = **roll** angle
- rotation about the scanner's **y-axis** = **pitch** angle
- rotation about the scanner's **z-axis** = **yaw** angle

```
<!-- ************************************************************************************************ -->
<!-- * There is single camcalibs section in the project which may contain numerous camcalib       * -->
<!-- * nodes. RiSCAN makes use of the OpenCV camera model. The camera model is described in detail  * -->
<!-- * in the documentation of the "Open Source Computer Vision Library" maintained by Intel.      * -->
<!-- * (see http://opencvlibrary.sourceforge.net/                                                  * -->
<!-- *                                                                                             * -->
<!-- * Internal parameters include the camera's intrinsic matrix A:                                * -->
<!-- *                                                                                             * -->
<!-- *       | fx 0 cx |                                                                           * -->
<!-- *  A =  | 0 fy cy |                                                                           * -->
<!-- *       | 0  0  1 |                                                                           * -->
<!-- *                                                                                             * -->
<!-- * fx, fy are the focal lengths by the axes x and y                                            * -->
<!-- * cx, cy are the coordinates of the principal point in pixels                                 * -->
<!-- *                                                                                             * -->
<!-- * NOTE: fx and fy in dimensions of meters are gained by multiplying with dx, dy               * -->
<!-- *                                                                                             * -->
<!-- * The "undistorted" pixel coordinates (u,v) are computed by                                   * -->
<!-- *                                                                                             * -->
<!-- *   | u' |                                                                                    * -->
<!-- *   | v' | = A.RT.pWS                                                                         * -->
<!-- *   | w' |                                                                                    * -->
<!-- *                                                                                             * -->
<!-- * u = u' / w', and v = v' / w'                                                                * -->
<!-- *                                                                                             * -->
<!-- * Lens distortion is modelled by at least two radial and two tangential coefficients,         * -->
<!-- * k1, k2, k3, k4, p1, p2:                                                                     * -->
<!-- *                                                                                             * -->
<!-- * With x = (u - cx)/fx, y = (v - cy)/fy                                                       * -->
<!-- * the distorted pixel coordinates (ud, vd) are computed by:                                   * -->
<!-- *                                                                                             * -->
<!-- * ud = u + x*fx*(k1*r^2+k2*r^4+k3*r^6+k4*r^8) + 2*fx*x*y*p1 + p2*fx*(r^2 + 2*x^2)             * -->
<!-- * vd = v + y*fy*(k1*r^2+k2*r^4+k3*r^6+k4*r^8) + 2*fy*x*y*p2 + p1*fy*(r^2 + 2*y^2)             * -->
<!-- *                                                                                             * -->
<!-- *        r^2 = x^2 + y^2                                                                      * -->
<!-- * nx - number of pixels x direction (i.e. image width),                                       * -->
<!-- * ny - number of pixels y direction (i.e. image heigth),                                      * -->
<!-- * dx - effective X dimension of pixel (in m/pixel), and                                       * -->
<!-- * dy - effective Y dimension of pixel (in m/pixel).                                           * -->
<!-- ************************************************************************************************ -->
```

Terrestrischer Laserscanner RIEGL LMS-Z620
Data registration

- Registration via tiepoints
- Registration via inclination sensors (optional)
- Registration via inclination sensors, compass and GPS
- Manual coarse registration
  – Interactive coarse registration
  – Coarse registration via corresponding points
- Backsighting

- Registration of scanposition images
- Registration of project images
  – via tiepoints
  – via angle definition



- Multi Station Adjustment

The standard registration process in RiSCAN PRO is based on corresponding tiepoints (finescanned reflectors). This gives a quick registration but even though the tiepoints fit together very well it's possible that the other scan data (the objects of interest) show alignment errors. The main reasons for this problem may be an unstable reflector set-up, non-optimal reflector positioning or measurement errors. Also the two cases "chain" and "ring" are problematic. In those cases each scan position is registered to it's direct predecessor. At the end there will be a more or less big error between the last and first scan position of the chain or ring.
To minimize these errors RiSCAN PRO has a plugin function called "Multi Station Adjustment" (MSA). The MSA tries to improve the registration of the scan positions. For that purpose the orientation and position of each scan position is modified in several iterations in order to calculate the best overall fit for them. To compare the scan positions the **tiepoints**, **tieobjects** and **polydata objects** (reduced point clouds) are used.

plane, sphere, cylinder

  – Manual definition of corresponding plane surface patches
  – Automatic search for corresponding points using the iterative closest point algorithm (ICP)

Prerequisite for calibrating a camera is one or more images showing identifiable objects with precisely known coordinates. The first step to obtain a data set for calculating the model parameters is to

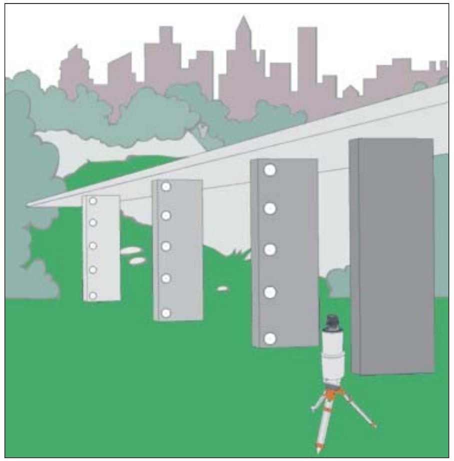
- determine the image coordinates of the object, i.e. find the image points, and to
- link the objects to the image points, i.e., to find the correspondences.

There are three different approaches that differ in the way the object coordinates in 3D are obtained and the way the correspondences are determined. All approaches are implemented in RiSCAN PRO:

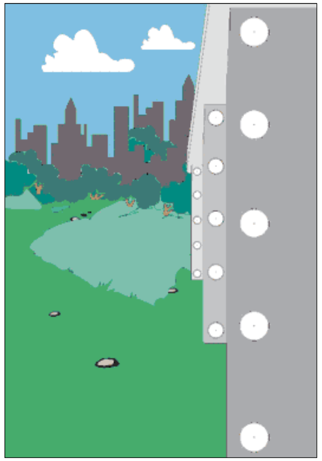
1. Calibration based on reflector column

The basic idea is to set up a test field made up of a number of retroreflective targets positioned in a vertical column in a scene when viewed by the camera. The targets should (1) cover the vertical field of view of the camera and (2) should have a variation in depth. it is not required that the calibration field is long-term stable. The camera to be calibrated is mounted on top of the scanner and the test field is surveyed by the laser scanner by carrying out a number of tiepoint scans on the automatically detected targets. Then a series of images with flash is taken at different angular positions of the camera (automatically carried out by the calibration task). In every image the centers of the reflectors are automatically extracted and the extracted reflectors are automatically linked to the 3D coordinates of the targets. With this procedure, a virtual test field is generated covering the entire field of view of the camera.

The major advantage is that the test field can be put up easily, no total station is required, and the calibration task gives both the internal camera calibration parameters and the mounting calibration parameter (Handbuch RiSCAN PRO, 2011).



Calibration using a vertical plane point field



Selected camera image

2. Calibration based on flat check pattern images

Especially for wide-angle lenses calibration based on flat check pattern images has been found to be useful. One example of an image is shown on the right, which shows a flat check pattern printed on white paper used to calibrate a camera with a 14 mm lens. The size of one square is 0.1 x 0.1 m. The check pattern is glued to a planar board to ensure the pattern is really flat.

For calibration the flat check pattern is captured by the camera to be calibrated several times. The whole image area should be covered, and in each image the complete pattern has to be visible. The inner check pattern corners are automatically detected by the calibration software and are automatically linked to the 3D coordinates of the flat check pattern corners (z is always 0).
(Handbuch RiSCAN PRO, 2011)

Calibration using a plane point field

3. Calibration based on reflector array

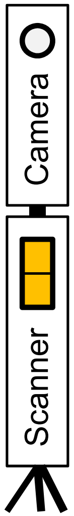
Especially for telephoto lenses, the calibration approach based on imaging flat check patterns is inconvenient as for a fixed focus of infinity the minimum range to the pattern would have to be quite large and thus the dimensions of the flat check pattern would be inconveniently large as well. This second approach is based on imaging a field of reflectors with known coordinates in 3D, henceforth referred to as reflector array. The reflectors must not lie in a single plane, but have to be distributed over a volume with sufficient depth. In the example below the reflectors have been fixed to a building to both sides of one corner and also to the roof. The reflector positions have been surveyed by means of a total station with mm accuracy (Handbuch RiSCAN PRO, 2011).

Calibration using a spatial point field

Colorizing point clouds

For Image@scan position:

- $\mathbf{X}_{\mathrm{CMCS}_{\mathrm{N,M}}} = \mathbf{M}_{\mathrm{CMCS}} \mathbf{M}_{\mathrm{COP}_{\mathrm{N,M}}}^{-1} \mathbf{M}_{\mathrm{SOP}_{\mathrm{N}}}^{-1} \mathbf{M}_{\mathrm{POP}}^{-1} \mathbf{X}_{\mathrm{GLCS}}$
- Perform perspective projection to obtain pixel coordinates
- Perform undistorted-to-distored transformation on pixel coordinates using the intrinsic parameters of the camera
- Interpolate RGB-value



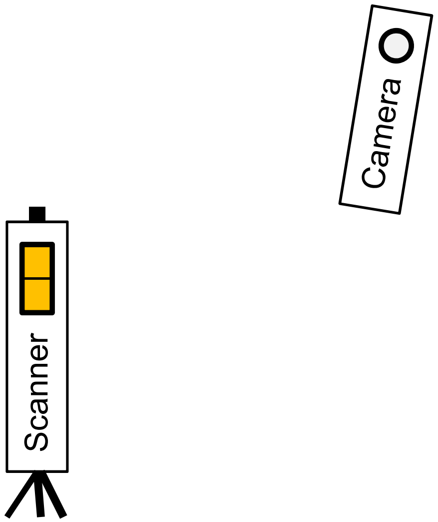
- Re-adjustment of camera mounting (Improving the mounting calibration)

  In order to improve the mounting calibration at least 3 points are needed.

  – Modify rotation only
  – Modify rotation and translation
  – Modify translation only

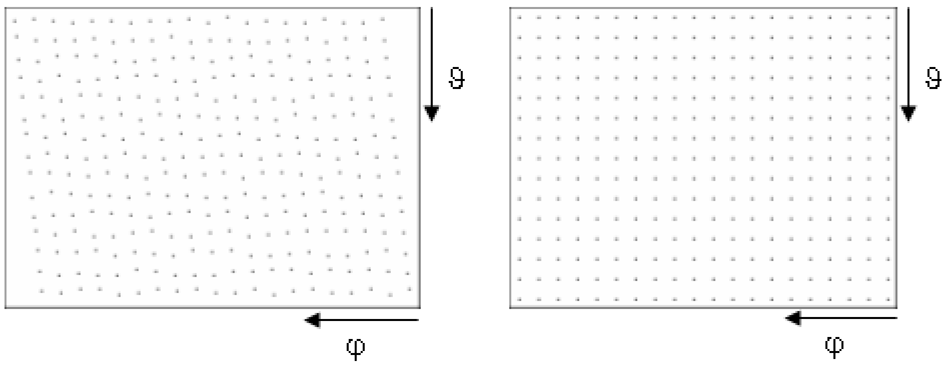
For Image@ProjectLevel:

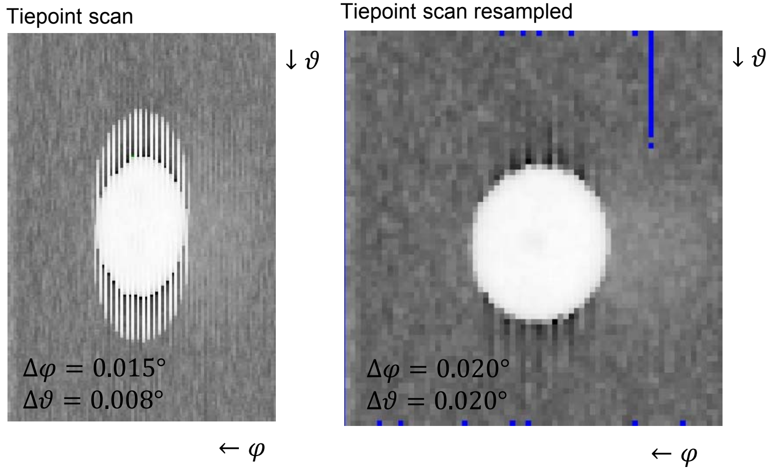
- $\mathbf{X}_{\mathrm{CMCS}_{\mathrm{N}}} = \mathbf{M}_{\mathrm{COP}_{\mathrm{N}}}^{-1} \mathbf{M}_{\mathrm{POP}}^{-1} \mathbf{X}_{\mathrm{GLCS}}$
- Perform perspective projection to obtain pixel coordinates
- Perform undistorted-to-distored transformation on pixel coordinates using the intrinsic parameters of the camera
- Interpolate RGB-value



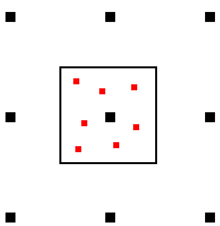
Resampling scan data

In most cases scan data of RIEGL laser scanners can be addressed as an organized point. The scan data is acquired sequentially on a more-or-less regular grid in a $\vartheta - \varphi$ plane, whereas ϑ and φ denote the polar angle and the azimuth angle respectively. This data acquisition can also be addressed as taking the scan line-by-line in azimuth direction and measurement-by-measurement within one line in polar direction (compare the left diagram in the Figure below).





By re-sampling a scan a new grid in the $\vartheta - \varphi$ plane is generated. The extent of the grid is defined by one of the original scans to be re-sampled. The resolution of the grid is defined by the user in a dialog. During the process of re-sampling all range and amplitude data falling within one cell of the grid is averaged (red dots in the Figure below). There are different options and parameters influencing the averaging.
The result of re-sampling is a 3D data set with a strictly regular grid in the $\vartheta - \varphi$ plane (compare the right diagram in the Figure above).



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