



User Manual

GEOCAL / GEOCAL XL / GEOCAL IR

Image Engineering GmbH & Co KG



Project name: GEOCAL / GEOCAL XL / GEOCAL IR

Trade name: GEOCAL / GEOCAL XL / GEOCAL IR
Product name: GEOCAL / GEOCAL XL / GEOCAL IR

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Contents

1	About these operating instructions	6
1.1	General information	6
1.2	Presentation of information	7
	Structure of instructions.....	7
	Structure of the warnings	7
	Technical terms and abbreviations used.....	8
2	General safety regulations	9
2.1	Principles	9
2.2	Intended use	9
2.3	Foreseeable misuse.....	10
2.4	Safety regulations	11
	General information	11
	During operation	11
	Care, maintenance, and inspection work	12
2.5	Residual risks	12
2.6	Selection and qualification of personnel	12
2.7	Safety signs	13
3	Scope of delivery of the device.....	14
4	Structure and function.....	15
4.1	General overview	15
4.2	Sub-assembly 1 - Electronic unit.....	15
4.3	Sub-assembly 2 - Optical unit	16
4.4	Sub-assembly 3 - DOE and DOE holder	16
4.5	Interfaces and power supply requirements.....	16
4.6	Functional diagram / functional sequence	17
5	Transportation and storage.....	18



5.1	Transportation.....	18
	Requirements for the installation site.....	18
	Transporting the device.....	18
5.2	Storage	19
	Requirements for the storage location	19
6	Installation and commissioning.....	20
6.1	Installation.....	20
	Establish power connection	20
6.2	Commissioning	21
6.3	Optional modification for use on production lines	21
7	Operating and display elements	22
7.1	Control elements on the device.....	22
8	Operating the device.....	23
8.1	Operate device.....	23
8.2	Switch off the device	28
9	Differences between the GEOCAL variants	29
9.1	Why a larger version of the GEOCAL?.....	29
9.2	Why an infrared version of the GEOCAL?.....	30
10	Operating software	31
10.1	Installing the GEOCAL software.....	31
10.2	Configuration file (XML format)	31
10.3	Artificially generated sample images	37
10.4	Loading images for analysis.....	38
10.5	Delete images	38
10.6	Image analysis	39
10.7	Save results	41
10.8	Export detected point grids	41
10.9	Visualization of the results data.....	41



10.10	Logging	42
10.11	Exit	42
11	Troubleshooting.....	43
11.1	Procedure in the event of faults or errors	43
11.2	Fault and error messages	43
11.3	Eliminate faults.....	43
12	Care notes and recycling.....	44
12.1	Care.....	44
12.2	Disposal and recycling	44
13	Technical data.....	45
14	Appendix	47
14.1	Service addresses	47



1 About these operating instructions

You must read these operating instructions before operating GEOCAL/GEOCAL XL/GEOCAL IR (hereinafter referred to as GEOCAL unless a specific variant is described) for the first time or before carrying out any other work with GEOCAL.

Pay particular attention to **Chapter 2, “General safety regulations”**.

1.1 General information

These instructions are intended to make it easier to understand GEOCAL and use for its intended purpose.

NOTE

All procedures described in this manual regarding handling GEOCAL apply equally to GEOCAL, GEOCAL XL, and GEOCAL IR.

The differences between the individual variants are described in Chapter 9, “Differences between the GEOCAL variants.”

The operating instructions contain important information on operating GEOCAL safely and adequately. Observing them will help:

- Avoid dangers
- Reduce repair costs and downtime
- Increase the reliability and service life of the product

Everyone tasked with working with GEOCAL must read and apply these instructions.

In addition to these operating instructions, the accident prevention and environmental protection regulations applicable in the country of use and the place of use must also be observed.



1.2 Presentation of information

Structure of instructions

Instructions for action are divided into:

- Action steps
- Results of the actions
- Application tips for optimal use

A symbol identifies each piece of information:

Icon	Meaning
1. 2. 3.	Action steps: These action steps are numbered consecutively and must be carried out in the specified order from top to bottom.
✓	Result symbol: The text after this symbol describes the result or intermediate result of an action.
TIP:	Application tip: Additional information on optimal use of the product.

Tab. 1.1 Meaning of symbols

Structure of the warnings

Signal word	Use for ...	Possible consequences if the safety instructions are not observed:
DANGER	Personal injury (imminent danger)	Death or serious injury!
WARNING	Personal injury (potentially dangerous situation)	Death or serious injury!
CAUTION	Personal injury	Slight or minor injuries!
NOTE	Material damage	Damage to the device and the surrounding area

Tab. 1.2 Warning levels

The warnings are structured as follows:

- Warning sign with signal word corresponding to warning level



- Type of hazard (description of the hazard)
- Hazard consequences (description of the consequences of the hazard)
- Averting danger (measures to prevent danger)



DANGER!

Type of hazard

Consequences of danger

1. Emergency response

Warning signs

Special warnings are provided at the relevant points. They are marked with the following symbols.



General danger zone

This sign warns of personal injury.

If there is a clear source of danger, it is preceded by one of the following symbols.



Laser radiation

This sign warns of visible or invisible laser radiation.

Technical terms and abbreviations used

Abbreviation	Meaning
DOE	Diffraction optical element, diffraction grating
DUT	Device under test
ROI	Region of Interest

Tab. 1.3 Abbreviations used



2 General safety regulations

2.1 Principles

Before putting the appliance into operation, ensure that the appliance is:

1. In perfect working condition visually
2. Securely placed on a plane and level surface

Before switching on the device, please ensure that there are no optical instruments/lenses in front of the device that focus the emitted light on a single point.



CAUTION!

**Visible or invisible laser radiation
of laser protection class 1M**

Danger to the human eye with refocusing

Do not look into the beam with optical instruments!

Important information:

Read the manual carefully before using this device.

Improper use may damage the GEOCAL, the device under test, and/or other components of your setup. Please keep this manual safe and pass it on to future users.

2.2 Intended use

GEOCAL is designed to geometrically calibrate camera systems using a grid of light points projected from infinity. GEOCAL provides the hardware basis with which the calibration pattern can be recorded. The recorded images are evaluated using the software supplied. The device may only be operated indoors.



2.3 Foreseeable misuse

1. Operation of GEOCAL on an inclined or movable surface (risk of falling or tipping over)



CAUTION!

Risk of crushing due to the appliance falling down

Only place GEOCAL on stable, level, and horizontal surfaces.

2. Looking into the optics or the DOE of the GEOCAL for an extended period of time
3. Removal of the diffractive optical element (DOE) by the user
4. Looking into the beam with optical instruments (refocusing the laser light on the retina)



CAUTION!

**Visible or invisible laser radiation
of laser protection class 1M**

Danger to the human eye with refocusing

Do not look into the beam with optical instruments!

5. Open the housing to expose the laser (danger to eyes, impact on the environment due to laser radiation)
6. Dismantling the optics to expose the laser (danger to the eyes, impact on the environment due to laser radiation)



WARNING!

**Visible or invisible laser radiation of laser protection
class 3B when the housing is open**

Immediate danger to the human eye

The housing must not be opened under any circumstances!

7. Power supply outside the specification defined by IE (e.g., use of an incorrectly set universal power supply unit).

There is no power supply unit included with GEOCAL. When selecting a power supply unit, please note the requirements below:



Power supply:

Limit values: +5 VDC, 4A min.
recommended: +5VDC, 25W

Protective devices: 2x Means Of Patient Protection
(MOPP, according to IEC 60601)

Connector plug: DC hollow plug
2.1mm inner diameter
5.5mm outer diameter

Recommended power supply unit: Mean Well GSM40A05-P1J

2.4 Safety regulations

General information



CAUTION!

Do not open the device!

The device is maintenance-free and must not be opened by the user.



CAUTION!

**Visible or invisible laser radiation
of laser protection class 1M**

Danger to the human eye with refocusing

Do not look into the beam with optical instruments!



WARNING!

**Visible or invisible laser radiation of laser protection
class 3B when the housing is open**

Immediate danger to the human eye

The housing must not be opened under any circumstances!

During operation

Before switching on the device, please ensure that there are no optical instruments/lenses in front of the device that focus the emitted light on a single point.



CAUTION!

**Visible or invisible laser radiation
of laser protection class 1M**



Danger to the human eye with refocusing

Do not look into the beam with optical instruments!

Care, maintenance, and inspection work

The device is maintenance-free.

Any repairs that may be necessary may only be carried out by Image Engineering and specialist personnel appointed by Image Engineering.

2.5 Residual risks

Despite all the measures taken to avoid or mitigate risks, a small residual risk remains when using GEOCAL. Therefore, please ensure that you and all other users follow the safety instructions in this operating manual.



CAUTION!

**Visible or invisible laser radiation
of laser protection class 1M**

Danger to the human eye with refocusing

Do not look into the beam with optical instruments!

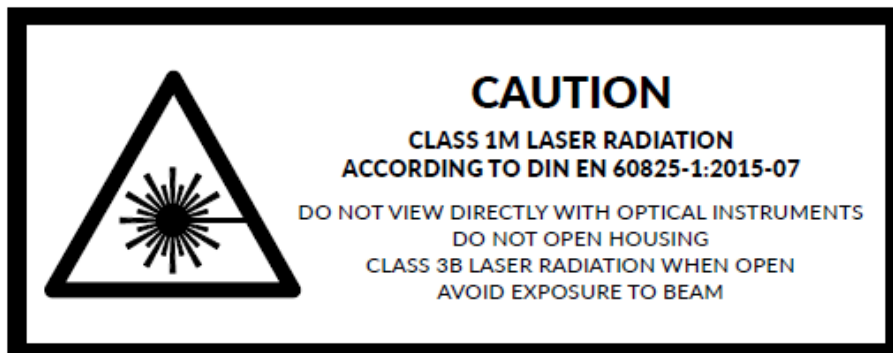
2.6 Selection and qualification of personnel

GEOCAL may only be operated by persons who have read these operating instructions carefully.

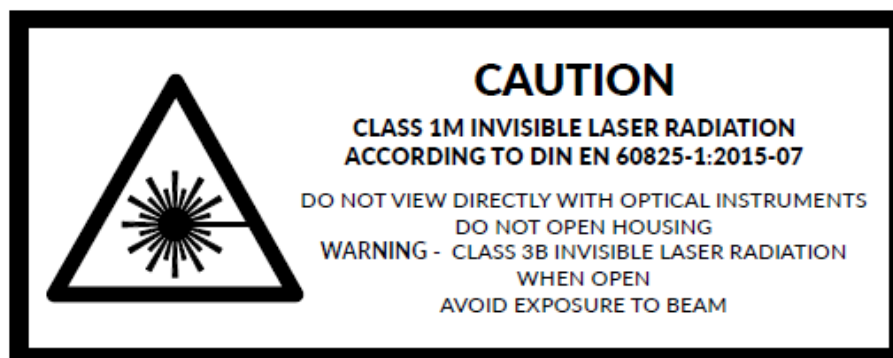


2.7 Safety signs

The following warning is attached to the side of the housing of GEOCALI and GEOCAL XL:



The following warning is attached to the side of the GEOCAL IR housing:



When closed (state of delivery), all variants are laser class 1M products.

WARNING:

When the housing is opened, these are laser class 3B products. The housing must not be opened under any circumstances.



3 Scope of delivery of the device

GEOCAL is supplied fully assembled.

The following is included in the scope of delivery:

- GEOCAL hardware device
- The current software version on a USB storage medium
- USB cable (type B to type A)
- Acceptance protocol
- Operating instructions in printed form

NOTE

The desktop power supply is not part of the product and must be purchased separately.

When selecting a power supply unit, observe the requirements and recommendations in **Chapter 4.5 – “Interfaces and power supply requirements.”**



4 Structure and function

4.1 General overview

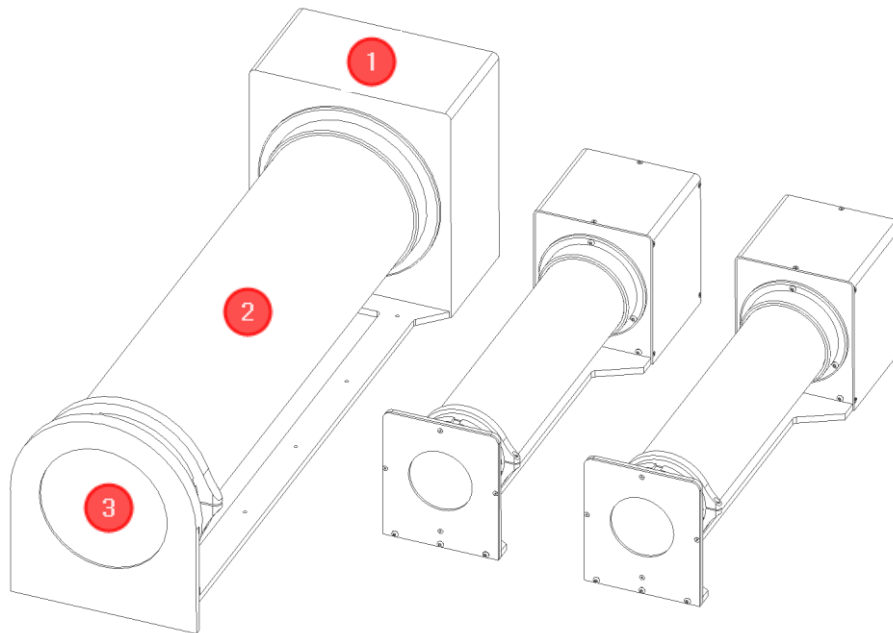


Fig. 4.1 from left to right - GEOCAL XL, GEOCAL, GEOCAL IR

1st Sub-assembly 1 - Electronic unit

2nd Sub-assembly 2 - Optical unit

3rd Sub-assembly 3 - DOE and DOE holder

4.2 Sub-assembly 1 - Electronic unit

Module 1 contains all the electronics required for the operation of GEOCAL.

These include:

- Laser diode
- Laser controller
- USB interface
- Power connection socket



- Rear indicator light
- Main switch

4.3 Sub-assembly 2 - Optical unit

Sub-assembly 2 is the optics used to expand and collimate the laser beam to the exit diameter.

4.4 Sub-assembly 3 - DOE and DOE holder

Assembly 3 consists of the DOE and the DOE holder. The expanded and collimated laser beam hits the DOE from the inside. The incident light is deflected in a certain way by the finely etched structure of the DOE so that the grid of light points required for calibration is generated by positive and negative interference.

4.5 Interfaces and power supply requirements

GEOCAL has a USB type B interface and a power connection socket on the back of the housing.

USB interface:

Currently still without function

Power connection socket:

GEOCAL has a power connection socket for a hollow plug (internal diameter: 2.1mm, external diameter: 5.5mm), e.g., Mean Well type P1J.

There is no power supply unit included with GEOCAL. When selecting a power supply unit, please note the requirements below:

Power supply:

Recommended: +5VDC, 25W

Protective devices: 2x Means Of Patient Protection (MOPP, according to IEC 60601)

Connector plug: DC hollow plug
2.1mm inner diameter
5.5mm outer diameter

Recommended power supply unit: Mean Well GSM40A05-P1J



NOTE

The desktop power supply is not part of the product and must be purchased separately.

When selecting a power supply unit, observe the requirements and recommendations in Chapter 4.5 – “Interfaces and power supply requirements.”

4.6 Functional diagram / functional sequence

A brief schematic representation of the use of GEOCAL is as follows.

1. Switch on GEOCAL
2. Place your camera / DUT on a tripod or similar in front of the GEOCAL
3. Create one or more images of the point grid generated by GEOCAL
4. Load the created recordings into the GEOCAL software
5. Either load one of the standard configuration files stored in the installation directory or modify it according to your requirements
6. Perform the detection of the displayed points in the software
7. Carry out the analysis of the recordings
8. Save the results as .CSV or .XML

Further information on creating recordings and using the software can be found later in these operating instructions.



5 Transportation and storage

5.1 Transportation

Requirements for the installation site

GEOCAL may only be operated indoors.
Place GEOCAL on a stable, level, non-inclined surface

To minimize the risk of bumping, GEOCAL requires a minimum footprint of approx. 85 x 25 cm (GEOCAL XL) or 58 x 15 cm (GEOCAL / GEOCAL IR).



CAUTION!

Loss of stability

Tipping of the appliance due to installation on an inclined or movable surface

Falling of the device due to impact

Observe the above instructions for commissioning

Transporting the device

Before transporting GEOCAL, remove all cables from the device. GEOCAL can be transported by hand over short distances indoors. However, always carry GEOCAL with two hands to prevent the device from falling and crushing injuries.



CAUTION!

Falling of the appliance, risk of crushing

Do not carry the device with one hand, and do not lift it by the DOE holder!

Always carry GEOCAL with two hands or transport it in the case supplied.



5.2 Storage

Requirements for the storage location

- Temperature range: +15 - +35°C
- No direct, permanent UV radiation
- Sand and dust-free environment
- Rel. humidity: max. 75% without condensation



6 Installation and commissioning

6.1 Installation

GEOCAL may only be operated indoors.
Place GEOCAL on a stable, level, non-inclined surface

To minimize the risk of bumping, GEOCAL requires a minimum footprint of approx. 85 x 25 cm (GEOCAL XL) or 58 x 15 cm (GEOCAL / GEOCAL IR).



CAUTION!

Loss of stability

Tipping of the appliance due to installation on an inclined or movable surface

Falling of the device due to impact

Observe the above instructions for commissioning

Establish power connection

Connect GEOCAL to the mains using a suitable power supply unit and a power cable.

NOTE

Impairment of the function or destruction of the device by using a power supply unit outside the specification

NOTE

The desktop power supply is not part of the product and must be purchased separately.

When selecting a power supply unit, observe the requirements and recommendations in **Chapter 4.5 – “Interfaces and power supply requirements.”**



6.2 Commissioning

Once the power supply has been established and the blue control LED on the back of the housing lights up, GEOCAL is ready for operation.

The software supplied is only required to analyze the recordings and not to operate the hardware.

To put GEOCAL into operation, press the on/off switch on the back of the housing.



CAUTION!

**Visible or invisible laser radiation
of laser protection class 1M**

Danger to the human eye with refocusing

Do not look into the beam with optical instruments!

6.3 Optional modification for use on production lines

If you want to use GEOCAL in a production line, we offer the option of modifying the device so that the switch no longer needs to be operated to switch it on and off.

After the modification, you only need to move the switch to the “ON” position. The appliance switches on immediately when supplied with power, without having to operate the switch again.

For more information on this option, please contact Image Engineering.

7 Operating and display elements

7.1 Control elements on the device

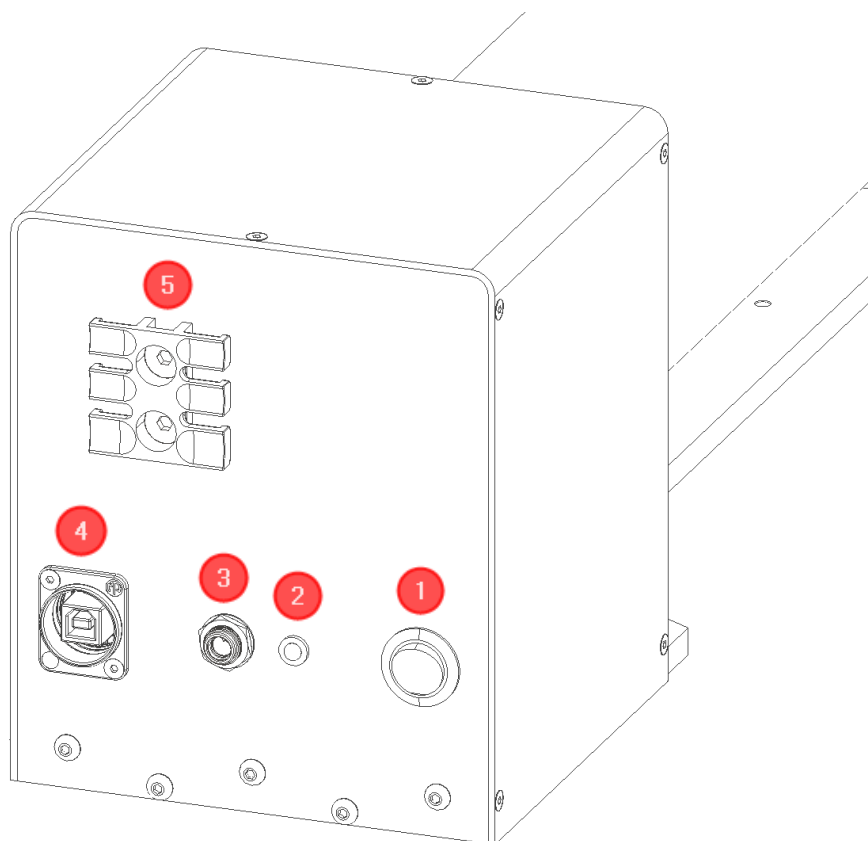


Fig. 7.1 Operating and display elements on GEOCAL

- 1st** Main switch
- 2nd** Control LED (blue)
- 3rd** Power connection socket
- 4th** USB type B interface (still without function)
- 5th** Cable strain relief (GEOCAL IR only)



8 Operating the device

8.1 Operate device

GEOCAL:

GEOCAL is ready for use immediately after switching on. A warm-up phase is not required.

Diffractive optical element (DOE):

A diffractive optical element (DOE) is used to split the incident light beam and create a calibration grating of evenly distributed light spots with a wavelength of 633nm (GEOCAL, GEOCAL XL) or 935nm (GEOCAL IR). The DOE is attached to the front of the GEOCAL (visible glass plate in round cut-out, see Figure 8.2.1).

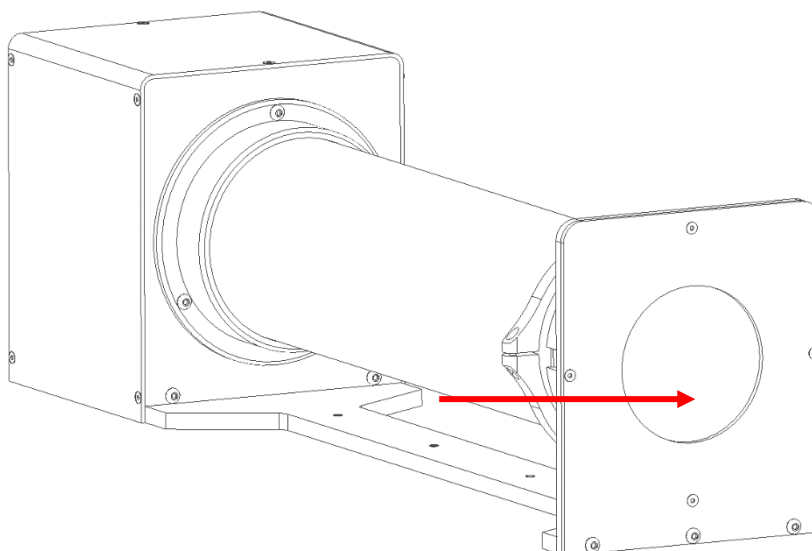


Fig. 8.1.1: DOE

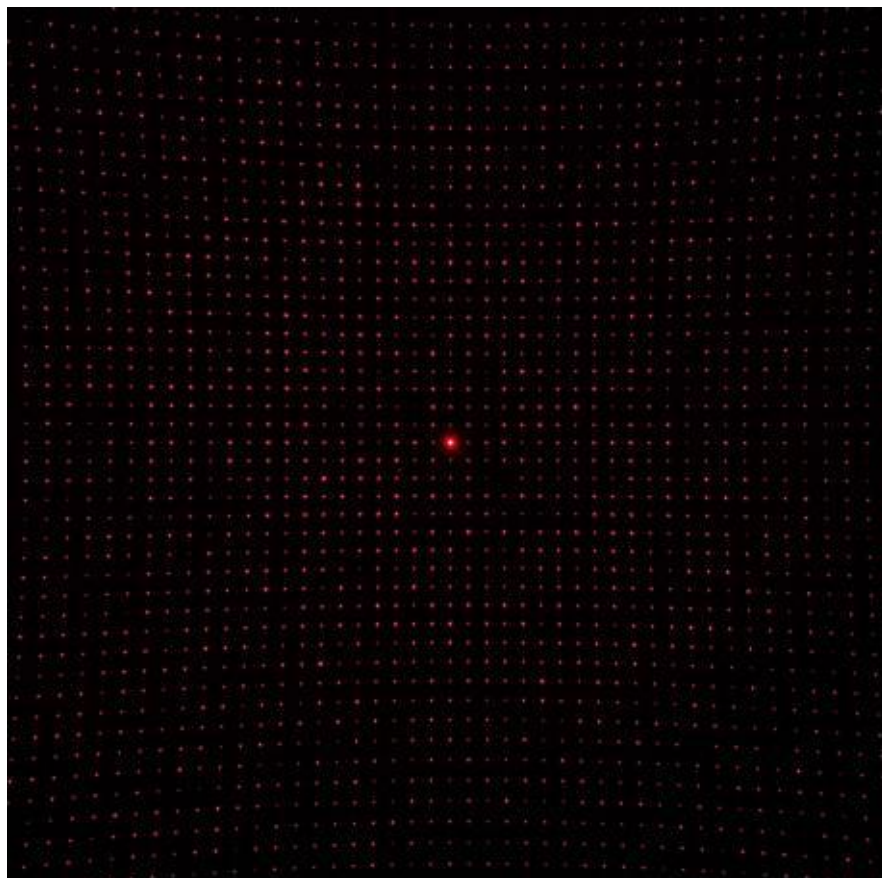


Fig. 8.1.2: Dot grid generated by the DOE. The brightest point is the zeroth diffraction order and, thus, the center of the diffraction pattern.

Camera settings:

Set the camera to manual exposure mode. If manual mode is not available, use automatic exposure mode. The image should be saved in a lossless format to achieve optimum results. The TIFF format is recommended, but PNG and JPEG (lossy) are also supported. If you convert RAW image data to another format, ensure the image is demosaiced, or the Bayer pattern is removed.

The autofocus must be switched off. As GEOCAL uses a collimated beam of light that comes practically from infinity, the suitable focus distance is infinity. When focusing manually, ensure the camera is focused on the light points.

Exposure program	Manual
Aperture number	No specification
ISO value	Smallest possible (e.g. 50, 100)
Autofocus	OFF



file format	TIFF recommended, PNG, BMP, and JPG supported
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Camera position and suitable lenses:

Place the camera in front of the DOE, facing the circular opening on the front of the GEOCAL.

The camera can be placed directly before the DOE; a minimum distance is not required (see Figure 8.2.3 below). The lens's optical axis should be aligned approximately perpendicular to the DOE. This setup is achieved by aligning the zeroth diffraction order, the brightest point in the center of the grating, with the center of the image. See Figures 8.2.4 and 8.2.5 for reference. Ensure that the dot grid covers the entire image and that the edge of the DOE is not visible.

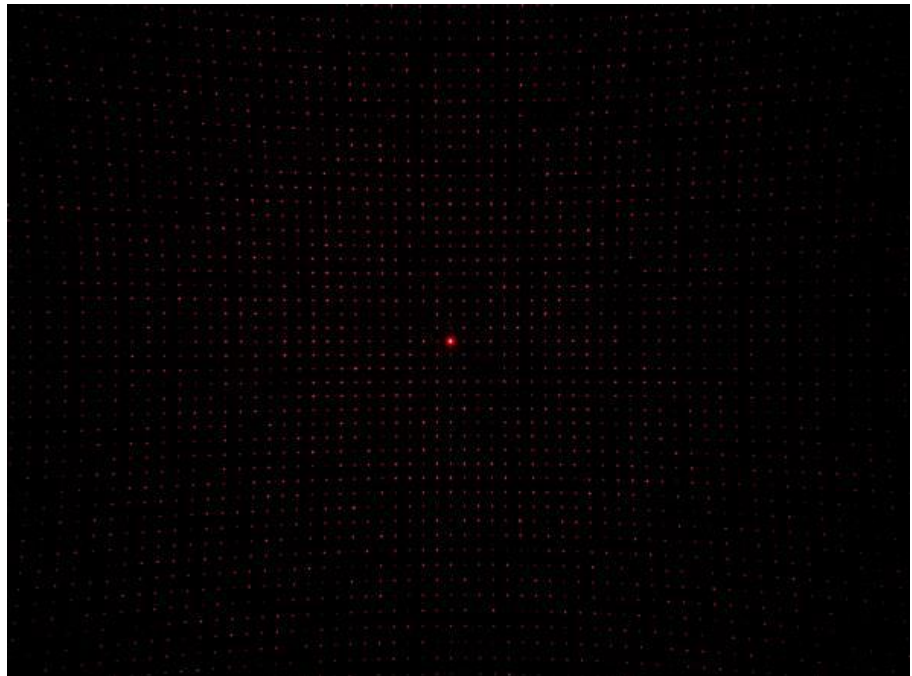


Fig. 8.2.4: Good alignment of the camera, zero order in the center

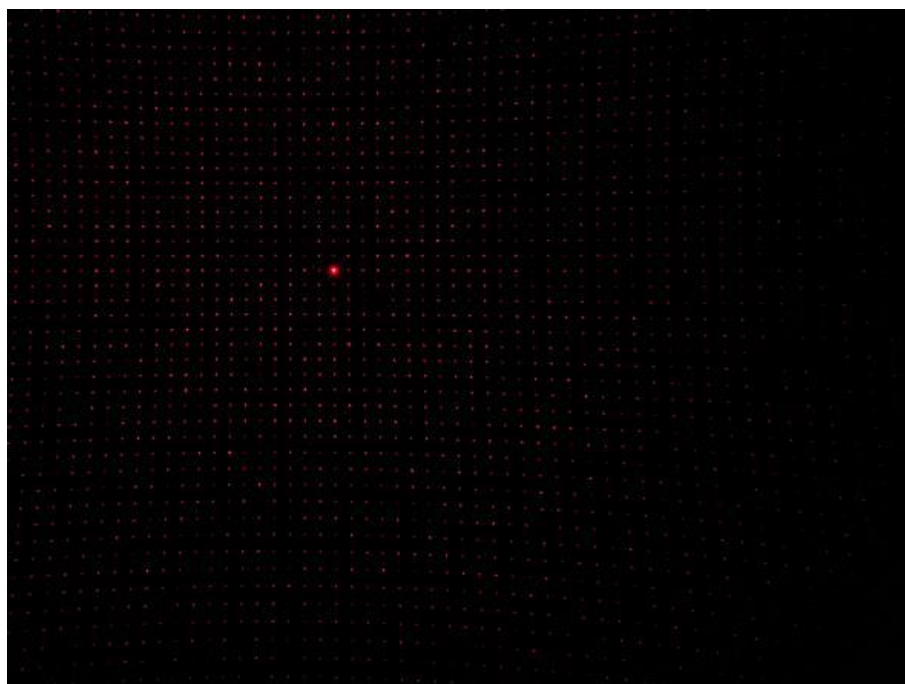


Fig. 8.2.5: Poor alignment of the camera, zero-order not in the center

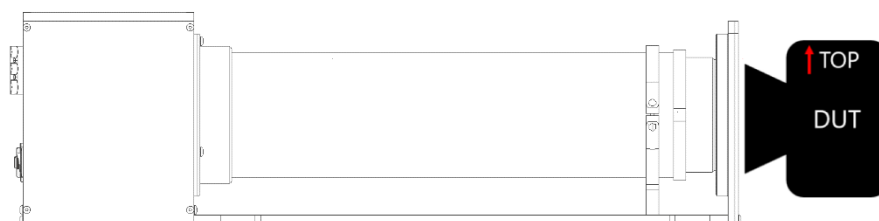


Fig.8.2.6: Distance between camera and GEOCAL

The top of GEOCAL and the top of the camera must have the same orientation, as shown in Figure 8.2.6. A rotation of the camera around the optical axis of approx. $\pm 2^\circ$ is tolerated. No further alignment steps are required. The parallel shift of the camera to the DOE does not influence the position of the light points. The camera rotation in relation to the DOE is part of the calibration and is determined during the process and output as part of the result.

The front lens of the objective must not exceed a diameter of 77 mm for GEOCAL/GEOCAL IR or 155 mm for GEOCAL XL to capture the dot grid in full format.

NOTE

Be careful when positioning the camera. The DOE is made of glass and is only 1.5 mm thick. Ensure the calibration is carried out in a dark environment to avoid stray light, reflections, and similar disturbing factors.

**Exposure:**

For best results, the exposure should be selected so that the individual light points are not saturated (i.e., no white pixels or a minimum number of white pixels in the center of each point), except for the zeroth order. The zeroth order will always be significantly brighter than the points surrounding it. See Figure 8.2.7 below for an example.

Fig. 8.2.7: Suitable exposure

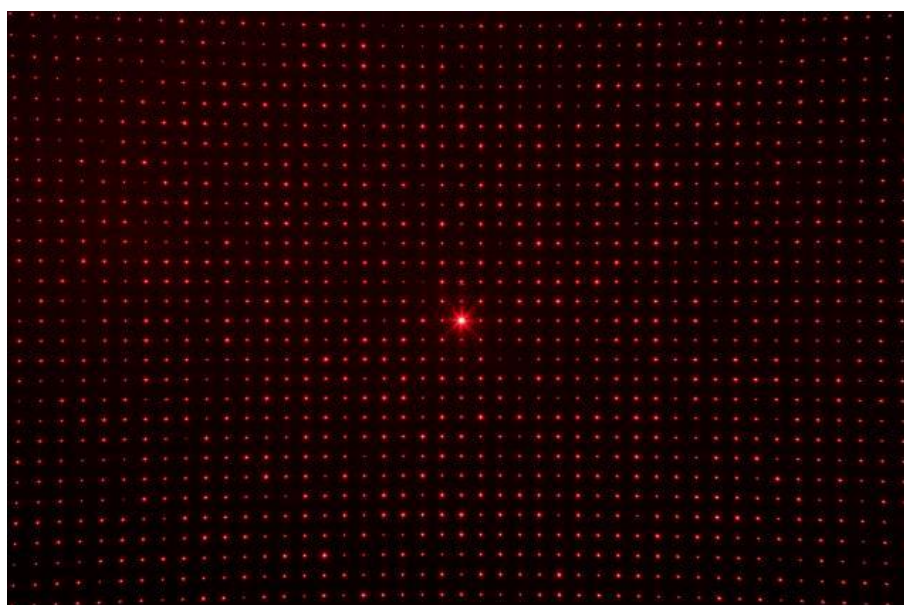
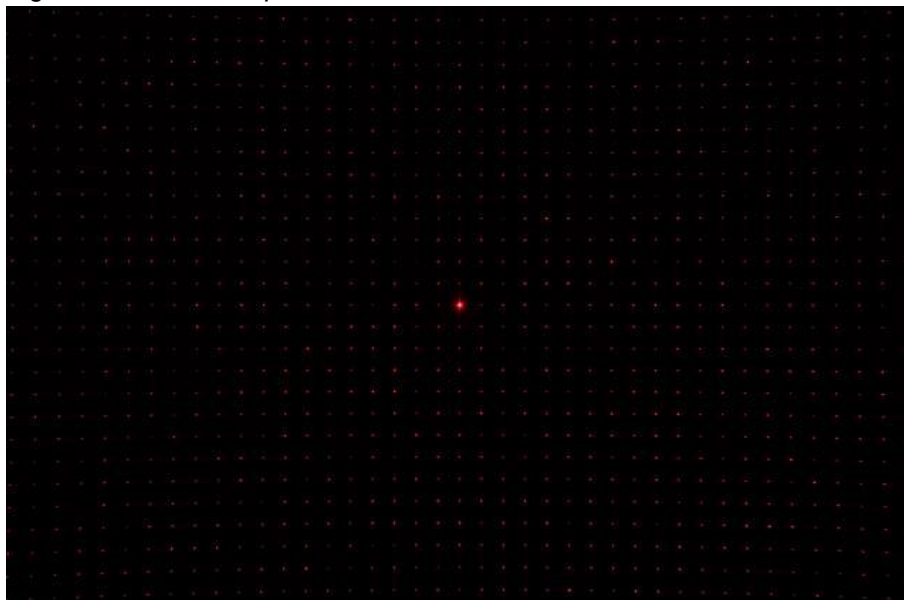


Fig. 8.2.8: Exposure too bright (red background, larger, saturated dots)



Depending on the camera, you may encounter different problems:

The exposure time of my camera cannot be set short enough to avoid saturation.

Possible solutions:

- Set the ISO value to the lowest available value.
- Reduce the aperture if possible.
- If the exposure is still too long, you can use an ND filter to reduce the amount of light reaching the image sensor.

NOTE

Introducing any additional optical element into the beam path will influence the calibration result and must be considered by the user.

The intensity decreases too much towards the edges of the image, and the dots are no longer visible.

This problem can occur with ultra-wide-angle lenses. If the images cannot be adequately analyzed, try the following:

Create an HDR image by taking several images of the dot grid with different exposure times (do not change the aperture settings in this case) and combine them to create an image with a high dynamic range to achieve a more or less even exposure across the entire sensor. Do not change the camera's orientation between shots, as the dots would no longer be aligned if several shots were taken.

8.2 Switch off the device

Switch the GEOCAL off using the toggle switch on the back of the housing.

If GEOCAL is taken out of operation for longer, disconnect the device from the main power supply.



9 Differences between the GEOCAL variants

Physical size:

The main difference between GEOCAL / GEOCAL IR and GEOCAL XL is the size of the diffractive optical element (DOE) that creates the dot pattern.

While the standard GEOCAL / GEOCAL IR has a usable diameter of 77 mm, GEOCAL XL offers a functional diameter of 155 mm.

Laser wavelength:

The difference between GEOCAL / GEOCAL

XL and GEOCAL IR is in the wavelength of the laser diode.

GEOCAL and GEOCAL XL use light with a wavelength of 633nm and are used to calibrate cameras that work with the VIS spectrum of light (380-780nm).

GEOCAL IR uses light with a wavelength of 935nm and calibrates cameras that work with the NIR spectrum of light.

9.1 Why a larger version of the GEOCAL?

A larger DOE can be helpful in two cases: if the device under test (DUT) either has a lens with a front element that is too large or if it cannot be placed directly in front of the DOE.

Large lens diameters:

Large lens diameters (e.g., for video special effects applications, AR/VR imaging, aerial photography, etc.) can be the reason why the dot grid cannot be recorded to fill the format, as the frame of the DOE is simply visible in the recordings and shadows the light of the GEOCAL. In this case, we recommend the GEOCAL XL, whose DOE has twice the diameter of the standard version (155mm instead of 77mm).

As long as there is no shading, the point grid for both GEOCAL variants is the same. The size of the DOE is irrelevant. Therefore, GEOCAL XL makes it possible to calibrate any camera up to a lens diameter of 155mm* and guarantee the same accuracy as the standard version.

*within the specifications of the datasheet

Longer distances:

Another reason for a larger DOE is, for example, if the windshield of a car is between the GEOCAL and the DUT. Chapter 8.1, subsection “Camera position and suitable lenses,” mentions that the generated dot grid must cover the camera sensor to ensure reliable calibration.

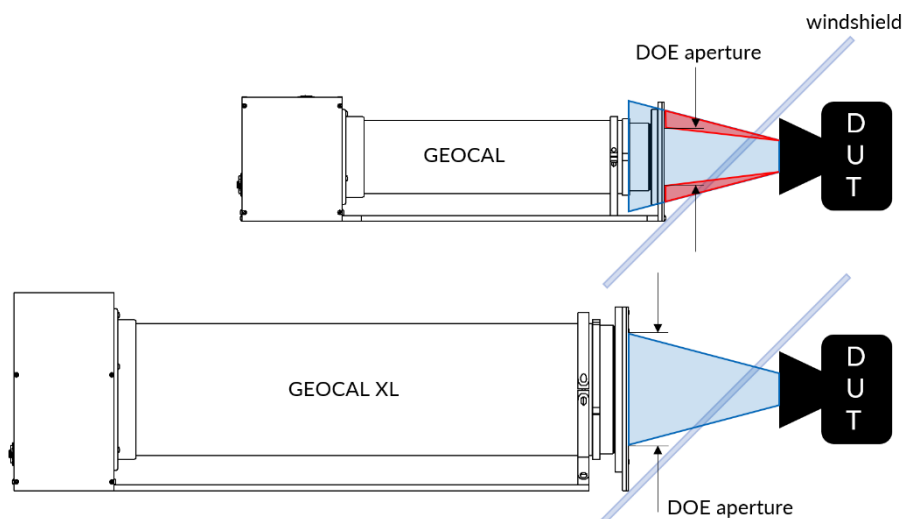


Fig. 9.1: Purpose of a GEOCAL XL with large DOE

As shown in Figure 9.1, the angle of the windshield prevents the standard GEOCAL from being placed close enough to the camera to provide a full-frame image of the standard DOE. This shooting situation would result in a less accurate and less reliable calibration.

9.2 Why an infrared version of the GEOCAL?

The calibration of infrared cameras is essential for specific applications to ensure the data they capture is accurate and reliable. Examples:

Advanced driver assistance systems (ADAS): Infrared cameras are used in advanced driver assistance systems (ADAS) to monitor the vehicle’s surroundings and detect potential hazards. Calibrated infrared cameras ensure that the data captured is precise, enabling accurate detection of pedestrians, vehicles, and obstacles. This accuracy allows ADAS functions such as collision warning, lane departure warning, and adaptive cruise control to work more effectively and help improve vehicle safety.

Building and construction inspection: Infrared cameras identify moisture damage and other structural problems. Calibrated infrared cameras ensure that the images and data captured are accurate, allowing inspectors to recommend appropriate repair measures.



10 Operating software

With the GEOCAL software, you can calibrate your camera system in seconds.

The results can be saved as .CSV or .XML files.

10.1 Installing the GEOCAL software

- Run the GEOCAL installer and follow the instructions
- ✓ The GEOCAL software is now ready for use.

10.2 Configuration file (XML format)

For GEOCAL/GEOCAL XL (light with a wavelength of 633nm) and GEOCAL IR (light with a wavelength of 935nm), four standard configuration files in XML format are supplied with the software, which are preconfigured for the respective light wavelength of the GEOCAL variant.

If your calibration procedure does not require unique settings, you can use one of the four configuration files for the desired distortion model. You can change these files by copying them from the installation location:

C:\Program Files\Image Engineering\GEOCAL 1.x.x\configuration

to a user-defined folder, where you can change and load them into the software.

Loading a configuration file:

Click on File → Load configuration (Ctrl+C) → navigate to the folder containing the file → select the file and click “Open.”

Explanation of the parameters from the configuration file:

Device Parameter:

- **Wavelength**
This parameter describes the wavelength of the built-in laser.
- **Grating constant**
This parameter describes the grating constant of the built-in DOE.



Detection Parameters:

- **UnusedImageBorder**
This parameter is used to define a detection margin. It can happen that points at the edge of the image cannot be recognized correctly. You can use this parameter to ignore a defined border area.
- **RadiusFilterForDetectedPoints**
This parameter defines a relative radius (0.0 ... 1.0) from the center of the image to the corners. Detected points that lie outside the relative radius are ignored during the analysis. The value 1.0 means that no point is omitted. A value of 0.8 would exclude all points outside a radius of 80% of the diagonal from the center of the image to the corner.

Control Parameters:

- **MinF**
This parameter describes the stop strategy, at which the optimization value of the analysis is stopped (0.0...10.0 - default: 1.0)
The smaller the value, the more accurate the analysis becomes, but the analysis time also increases.
- **MinDelta**
This parameter describes a further stop strategy. If the change in the optimization value between two iterations is smaller than the delta, the analysis is stopped (0.0...10.0 - default: 1e-7).
The smaller the value, the more accurate the analysis becomes, but the analysis time also increases.
- **Objective**
This parameter defines the objective function to be used during optimization. You can choose between CARTESIAN, POLAR, POLAR2, and CONSTRAINED. CARTESIAN and POLAR use a cost function that minimizes the MSE (Mean Square Error) between the estimated and detected points. They are calculated slightly differently but should perform the same. The difference is the MSE in the case of CARTESIAN, which is the average error in Delta X and Delta Y. In POLAR, the RMSE is the average error in the Euclidean distance between the estimated and detected points. POLAR2 performs a two-stage optimization, where first, an optimization is performed to minimize the error concerning the square of the MSE. This optimization is followed by a second optimization to minimize the MSE. This optimization can lead to faster convergence and a lower MSE. The CONSTRAINED option is currently a beta option and is still being evaluated. If this option is selected, constraints are imposed on the optimized values to determine a feasible solution.



- **Focal Estimate**

This parameter specifies how the focal length estimation process is to be used. If Use= "false" is specified in this parameter, the focal length is not pre-estimated. Instead, the estimate is determined during the primary optimization. If Use= "true," then there are two options to which this parameter can be set. One is FREEZE. In this case, the values determined in the focal length estimation phase are fixed and may not be changed in the primary optimization. If the value is set to ADJUST, the values determined during the focal length estimation can vary during the primary optimization. The initial values for the focal length correspond to those defined during the estimation.

Distortion Models:

- **Model**

This parameter can be used to select the model to be used. The following models are currently implemented:

- EVEN_BROWN_MODEL
- FISHEYE_MODEL
- CUSTOM_MODEL_2 (Division Model)

Focal estimation parameters:

These parameters control an optimizer that estimates the focal lengths before the primary optimization process. They are only valid if FocalEstimate Use= "true" is specified in the ControlParameters.

- **AngleSearch**

The +/- range in degrees is specified here, and it is searched for when determining the camera rotation in the focal estimation phase.

- **CropSize**

The middle part of the image used to determine the focal point estimate is specified here. This estimate should be a power of 2.

- **ImageScale**

The scaling value for the middle part is specified here. This scaling helps to achieve subpixel precision in the estimation during the autocorrelation calculation.

- **CorrelationPeakThreshold**

Defines a threshold value (scaled from 0 to 1) below which the correlation peaks are removed when determining the offset with the highest correlation.

- **VecNumSamples**

Specifies a 1-D signal interpolation using cubic splines to estimate the location of a correlation peak.



Scale factors:

All values to be optimized should be similarly scaled to ensure good convergence. Therefore, scaling factors can be specified and applied to optimize the different values. Suppose a particular parameter in the ScaleFactors section is specified as `IsActive= "true,"` and an initial value is defined for this term. In that case, the initial value should be scaled with the correct scaling factor. For example, if `<FocalLengthScale IsActive= "true">1000</FocalLengthScale>` is specified, a value specified for `FocalLengthX` or `FocalLengthY` should be divided by 1000, as it is assumed that it must be multiplied by 1000 to obtain the actual value.

- **AngleScale**
Specifies a scaling factor applied to the estimated angles to ensure they remain within an ideal range for the optimizer.
- **RadialDistortionScale**
Specifies a scaling factor applied to the radial distortion coefficients to ensure they remain within an ideal range for the optimizer.
- **TangentialDistortionScale**
Specifies a scaling factor applied to the tangential distortion coefficients to ensure they remain within an ideal range for the optimizer.
- **FocalLengthScale**
Specifies a scaling factor applied to the `FocalLengthX` and `FocalLengthY` values to ensure they are within an ideal range for the optimizer.
- **PrincipalPointScale**
Specifies a scaling factor applied to the values of `PrincipalPointX` and `PrincipalPointY` to ensure they are within an ideal range for the optimizer.

Analysis parameters:

- **Alpha and beta angle**
These angles describe the alignment of the diffractive optical element to the incident expanded and collimated laser beam. These values are determined during optimization and are part of the output parameters. However, they can be set to zero for troubleshooting purposes. These angles are specific to GEOCAL and unrelated to the calibrated camera.
- **Angle Omega (roll), Phi (pitch), Kappa (yaw)**
These angles describe the alignment of the test specimen to the diffractive optical element. These values are determined during calibration and are output as results. However, they can be set to a fixed value for troubleshooting purposes.
- **Radial Distortion Coefficients 1-15**
The radial distortion coefficients that model the distortion are referred to below as k_1, k_2, \dots :

$$x_{\text{distorted}} = x(1 + k_1 * r^2 + k_2 * r^4 + \dots + k_{15} * r^{30})$$



$$y_{\text{distorted}} = y(1 + k_1 * r^2 + k_2 * r^4 + \dots + k_{15} * r)^{30}$$

These values are determined during calibration and are output as results. However, they can be set to a fixed value for troubleshooting purposes.

- **Tangential Distortion Coefficients 1+2**

The tangential distortion coefficients model this type of distortion and are referred to below as p_1 , p_2 :

$$\begin{aligned} x_{\text{distorted}} &= x + [2p_1 xy + p_2 (r^2 + 2x^2)] \\ y_{\text{distorted}} &= y + [p_1 (r^2 + 2y^2) + 2p_2 xy] \end{aligned}$$

These values are determined during calibration and are output as results. However, they can be set to a fixed value for troubleshooting purposes.

- **Focal Length X and Y**

The focal length values of the test specimen in X and Y are determined during calibration and output as a result in pixel dimensions. However, they can be set to a fixed value for troubleshooting purposes.

- **Skew Coefficient**

The skew coefficient is set to 0 by default. It is not equal to zero if the image axes are not at right angles.

- **Principal Point**

The main point describes the point at which the optical axis of the camera lens intersects with the image sensor. It is determined during calibration and is output as a result. However, it can be set to a fixed value for troubleshooting purposes.

Open it in a text editor to change the default configuration file. You should make a copy of the standard version before editing it.

Version:

<Configuration Version="3" Description="Translation">

The latest configuration file is always installed when installing the latest software.

Edit Control Parameters:

Example:

<MinF Use="false">0.1</MinF>

The "Use" flag indicates whether the following value is used for the calibration procedure. If it is set to "false," it is not used, and the default value is used instead. To use a user-defined value, write "true" instead of "false" and change the value ("0.1" in this example) as required. The new value will be used for each calibration until you return the "Use" flag to "false."

Edit Analysis Parameters:



Example:

```
<Alpha IsInvariant="false" UseAsStartValue="false" Unit="Degree">0</Alpha>
```

The “IsInvariant” flag specifies whether the following value is calculated during calibration or set to a fixed value. The value is calculated during each calibration if set to “false.” To set it to a fixed value, write “true” instead of “false” and change the value (“0” in this example) as desired. The new value is used for each calibration until you set the “IsInvariant” flag to “false” again.

You can use the “UseAsStartValue” flag to specify a start value for the analysis. If you set the flag to “true,” the following value is used as the start value. If you set the flag to “false,” the default value is used. The default value is always “0”. By default, the center of the image is used for the principal point.

If the “IsInvariant” flag is set to “true,” the “UseAsStartValue” flag is ignored.

Information on the supported directory models:

Example of use with six radial distortion coefficients released for optimization.

NOTE

We recommend that you do not set the number of distortion coefficients higher than absolutely necessary, as an unnecessarily high number can lead to “over-sampling” artifacts.

The usual default values for each distortion model are stored in the respective configuration file included in the installation.

```
<RadialDistortionCoefficient1 IsInvariant="false" UseAsStartValue="true" Unit="">0.5</RadialDistortionCoefficient1>
<RadialDistortionCoefficient2 IsInvariant="false" UseAsStartValue="true" Unit="">0.5</RadialDistortionCoefficient2>
<RadialDistortionCoefficient3 IsInvariant="false" UseAsStartValue="true" Unit="">0.5</RadialDistortionCoefficient3>
<RadialDistortionCoefficient4 IsInvariant="false" UseAsStartValue="true" Unit="">0.5</RadialDistortionCoefficient4>
<RadialDistortionCoefficient5 IsInvariant="false" UseAsStartValue="true" Unit="">0.5</RadialDistortionCoefficient5>
<RadialDistortionCoefficient6 IsInvariant="false" UseAsStartValue="true" Unit="">0.5</RadialDistortionCoefficient6>
<RadialDistortionCoefficient7 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient7>
<RadialDistortionCoefficient8 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient8>
<RadialDistortionCoefficient9 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient9>
<RadialDistortionCoefficient10 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient10>
<RadialDistortionCoefficient11 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient11>
<RadialDistortionCoefficient12 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient12>
<RadialDistortionCoefficient13 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient13>
<RadialDistortionCoefficient14 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient14>
<RadialDistortionCoefficient15 IsInvariant="true" UseAsStartValue="true" Unit="">0</RadialDistortionCoefficient15>
```



1st EVEN BROWN MODEL

```
<DistortionModel>
|
|   <Model Use="true" NormalizeToImageRadius="false">EVEN_BROWN_MODEL</Model>
|
</DistortionModel>
```

The radial distortion coefficients, which model the distortion, are described as follows :

$$\begin{aligned} x_{\text{distorted}} &= x(1 + k_1 * r^2 + k_2 * r^4 + \dots + k_{15} * r^{30}) \\ y_{\text{distorted}} &= y(1 + k_1 * r^2 + k_2 * r^4 + \dots + k_{15} * r^{30}) \end{aligned}$$

2. FISHEYE MODEL

```
<DistortionModel>
|
|   <Model Use="true" NormalizeToImageRadius="false">FISHEYE_MODEL</Model>
|
</DistortionModel>
```

The radial distortion coefficients, which model the distortion, are designated as follows:

$$\theta_d = \theta(1 + k_1 * \theta^2 + k_2 * \theta^4 + k_3 * \theta^6 + k_4 * \theta^8)$$

3. CUSTOM MODEL 2 (DIVISION MODEL)

```
<DistortionModel><!-- we need to NormalizeToImageRadius with CUSTOM_MODEL_2, true means yes!-->
|
|   <Model Use="true" NormalizeToImageRadius="true">CUSTOM_MODEL_2</Model>
|
</DistortionModel>
```

The radial distortion coefficients that model the distortion are designated as follows:

$$\begin{aligned} x_{\text{distorted}} &= x / (1 + \text{sign}(k_1) * k_1 * r_1^2 + \text{sign}(k_2) * k_2 * r^4 + \dots + \text{sign}(k_8) * k_8 * r^{15})^{30} \\ y_{\text{distorted}} &= y / (1 + \text{sign}(k_1) * k_1 * r_1^2 + \text{sign}(k_2) * k_2 * r^4 + \dots + \text{sign}(k_8) * k_8 * r^{15})^{30} \end{aligned}$$

10.3 Artificially generated sample images

Four sample images are available, which you can find in the following directory.

C:\Program Files\Image Engineering\GEOCAL 1.x.x\samples

These images were created synthetically with the following parameters

Focal lengths [fx,fy]:	3030
Skew:	0
Tangential coefficients:	0



Principal point [u0,v0]:	[960, 752]
DOE parameters [grating constant, wavelength]:	[43.9, 0.6328]
DOE and camera angles [alpha, beta, omega, phi, kappa]:	0

Image	Model	Radial coefficients[1 to 6]
simulate_model2.png	CUSTOM_MODEL_2	[1, 1, 1, 1, 1, 1] * 10 ⁻⁶
simulate_modelf.png	FISHEYE_MODEL	[0.5, 0.5, 0.5, 0.5, 0.5, 0.5]
simulate_modelde.png	EVEN_BROWN_MODEL	[0.5, 0.5, 0.5, 0.5, 0.5, 0.5]

To familiarize yourself with the different models and the interactions of the parameters in the configuration files, you can use the default configurations specified for each model and run the GEOCAL software on the simulated images.

You should get results very close to those used to create the simulated images.

10.4 Loading images for analysis

Click on “File” → “Load images” (Ctrl+O) → navigate to the folder containing the images → select one or more images and click on “Open”.

In its current state, the software supports the analysis of 8-bit and 16-bit images.

The following file types are supported (de-bayered images): .TIFF, .JPG, .BMP, .PNG

The images to be analyzed must be recorded in such a way that the dot grid completely fills the sensor.

10.5 Delete images

Right-click on the selected image in the list to open a context menu containing a delete option



10.6 Image analysis

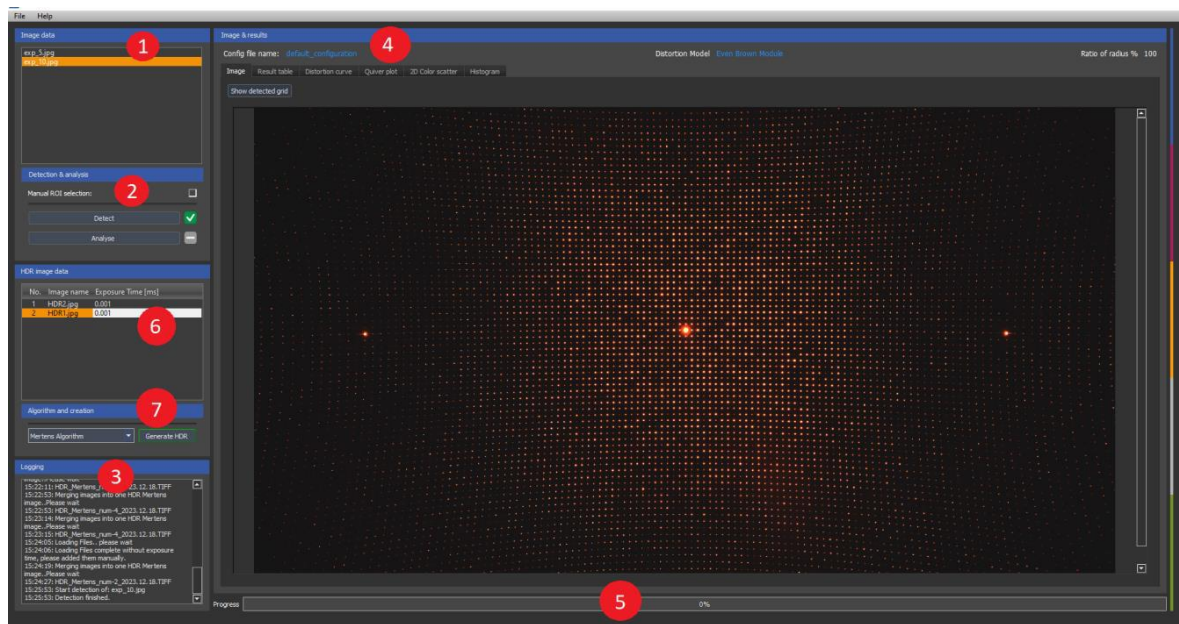


Fig. 10.6.1: Software user interface overview

- **Image selection:** Select an image from the list in the “Image Data” area (1). The image is then displayed in the “Image & Results” area (4) on the “Image” tab. You can zoom in and out of the image using the mouse wheel.

The zoom is centered around the position of the mouse pointer.

- **Point detection:** Detect the light points in the image by clicking on the “Detect” button in the “Detection & Analysis” section (2).

Detection is complete when the progress bar at the bottom of the window (5) reaches 100%. You can visualize the detected light points by clicking “Show detected Grid” under the “Image” tab.

If the automatic detection fails, you can make a manual ROI selection by ticking the box in the “Detection & Analysis” section (2). Five pre-set ROIs will then appear in the visualized view.

The size and position of these ROIs can be adjusted by clicking and dragging.

An ROI must be positioned on the zeroth diffraction order (the brightest point in the center of the grid).

Adjust the size of the ROI so that it contains only one point.

The four remaining ROIs must be positioned on the points closest to the zeroth diffraction order, i.e., the points at the top, bottom, left, and right. These four ROIs must also contain only one point. In addition, the individual ROIs should not overlap significantly. See Figure 10.6.2 below for reference.

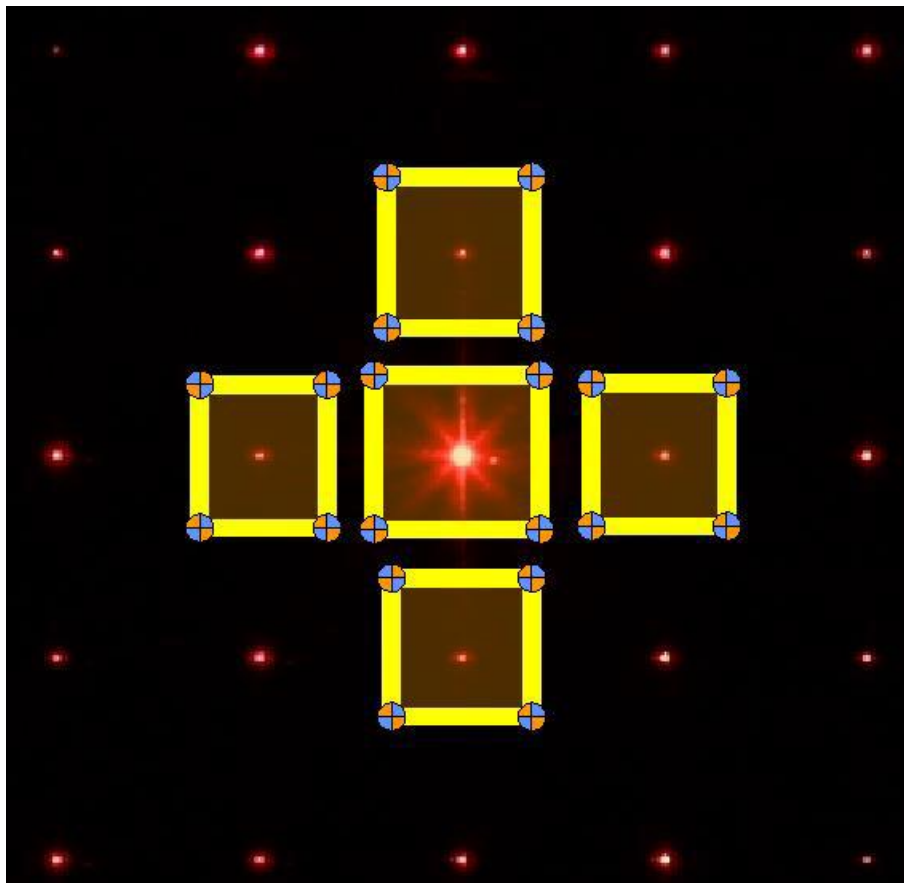


Fig. 10.6.2: Manual point detection

- **Analysis:** After detection, the actual analysis can be carried out. Click on the “Analyze” button in the “Detection & Analysis” section (2) to start the calibration. The progress bar (5) shows when the calibration is complete.

The time required for calibration may vary slightly depending on the number of points detected.

- **Calibration results:** The results are listed under the “Result table” tab in the “Image” section (4). The RMSE of the calibration is also included in the result table. If required, you can clear the results table by clicking “clear table.” Under the “Distortion curve” tab, you will also see a graphical visualization of the camera distortion determined (geometric distortion vs. field).
- **Generate HDR image:** Specify the exposure times for the individual HDR image data (6). Select an algorithm (Mertens, Debevec, or Robertson) for the generation and click the



“Generate HDR” button. An “HDR” subfolder is created in the HDR image data folder in which all generated images are saved.

10.7 Save results

You can save your results in an .XML or a .CSV file. If you have analyzed several images, select one or more images whose results you want to save from the list in the “Image data” section.

Then click on File → Save result → Save XML or Save CSV → navigate to the desired storage location → click on Save

If you have selected several images, all results are saved in a CSV or XML file.

10.8 Export detected point grids

You can export three different grids saved in .CSV files. Two files are saved for each exported grid, one for the x-coordinates and one for the y-coordinates.

To export a grid, click on File → Save grid → select the desired grid → navigate to the desired storage location → click on Save.

Available grid types:

- **Detected grid:** Describes the grid type that contains the detected light points.
- **Reprojected raster:** Describes the raster type that contains the reprojected light points used to determine the distortion.
- **Undistorted reference grid:** Describes the grid type that contains the reference grid points without lens distortion. This raster only contains the distortion given by the DOE physics and the extrinsic and intrinsic parameters determined.

10.9 Visualization of the results data

Various visualization types are available:

10.9. 1Grid view

After a successful analysis, the detected and newly projected points are displayed on the original image. Zoom into the image to get a better view. The dots are one pixel in size.



10.9. 2D Distortion curve

The curve is calculated from the distortion coefficients and describes the course of the determined distortion of the lens from the optical axis to the outer edge of the image (Field 0... 1).

10.9.3 “Quiver Plot”

The quiver plot shows the direction of the deviation. The respective arrows show how the detected points are arranged in relation to the reprojected points.

10.9.4 “2D Color Scatter”

This display shows a grid of color-coded dots, with each dot representing the distance ratio between detected and reprojected dots. The scale on the right shows the individual color coding.

10.9.5 Histogram

Two different histograms are displayed. The first histogram contains the successfully detected diffraction points as a function of the radius. The values start at zero (main point) and run along the image diagonal to the image corner (one).

The second histogram contains the successfully detected diffraction points as a function of the angle. The values are based on a straight line that runs from the main point to the right edge of the image. The angles increase in an anti-clockwise direction.

10.10 Logging

The browser displays the logging data for each action in the “Logging” section of the user interface. This data can be helpful if errors occur. The software also has a status bar at the bottom where error messages from the API are displayed directly.

10.11 Exit

Click on File → Exit (Ctrl+Q) to exit the software or close the window.



11 Troubleshooting

11.1 Procedure in the event of faults or errors

In the event of a malfunction, take GEOCAL out of operation immediately.

To do this, pull the mains plug out of the socket.

Then please contact Image Engineering Support.
(See Chapter 14.1 - Service addresses)

11.2 Fault and error messages

Below, you will find some examples of possible errors with suggested solutions.

Observation	Possible error	Possible solution
The control LED on the back does not light up.	The power supply was interrupted, or defect in the device.	Check all plug connections. Test a different desktop power supply or contact Image Engineering Support if the error persists.
No laser light is emitted.	The laser was switched off, or the holder was internally misaligned due to a fall or transport damage.	Check the position of the toggle switch on the back and the plug connection to the power supply unit. If the error persists, contact Image Engineering Support.

11.3 Eliminate faults

Faults that cannot be rectified without opening the device may only be remedied by specialist personnel trained by Image Engineering.

Please contact our support team.



12 Care notes and recycling

12.1 Care

If the housing or DOE of the GEOCAL is dirty, clean it with a dry cloth.

NOTE

Ensure you always use a clean cloth to clean the DOE to avoid scratches, which can lead to disturbing visual effects.

12.2 Disposal and recycling

At the end of its service life, GEOCAL must be disposed of properly. The device must not be disposed of with household waste.



If you wish to dispose of GEOCAL, please return the equipment to Image Engineering.

If you need assistance with the shipment or want a return slip, please contact one of Image Engineering's service addresses.



13 Technical data

Overview

Product name	GEOCAL / GEOCAL XL / GEOCAL IR
Principle	DOE-based, geometric calibration of digital cameras

Features

Hardware

Diffractive Optical Element (DOE)	Creates an evenly distributed grid of light points projected from infinity
DOE output window	GEOCAL / GEOCAL IR: Ø 77 mm GEOCAL XL: Ø 155 mm (Diameter of the camera lens ≤ exit opening)
Compatible FoV	approx. 30 - 120° (larger angles possible, depending on the camera. Please contact us for details).
Dimensions (L x W x H)	GEOCAL / GEOCAL IR: approx. 575 mm x 144 mm x 170 mm GEOCAL XL: approx. 850 mm x 244 mm x 270 mm
Mounting points	GEOCAL / GEOCAL IR: 3 x M5 x 0.8 internal thread in the base plate GEOCAL XL: 10 x M5 x 0.8 internal thread in the base plate

Illumination

(WARNING: Visible or invisible laser radiation!)



Light source	Frequency-stabilized laser diode
Wavelength	GEOCAL / GEOCAL XL: 633 nm GEOCAL IR: 935 nm
Optical power	5 mW
Laser class (diode only)	3B
Laser class (GEOCAL)	1M
Service life	>20.000h
Warm-up time	Not required

Software

System requirements	PC with Windows 7 operating system (or newer), USB connection
Functions	<ul style="list-style-type: none">• Load multiple recordings• Show recordings



	<ul style="list-style-type: none">• Perform calibration• Display detected point grid as an overlay• Various result visualization methods• Results export (CSV and XML)• Export of coordinates of detected points (CSV)
Output data	Extrinsic and intrinsic camera data, orientation of the DOE to the laser
API (C++)	Available as a separate option

General description of the hardware

Power consumption	Pmax = 2 W at 5VDC
Connections	USB type B
Weight	GEOCAL / GEOCAL IR: approx. 4.5 kg GEOCAL XL: approx. 9 kg
Temperature range	15 - 35 °C

Requirements for the Device Under Test (DUT)

Max. Dimensions	GEOCAL / GEOCAL IR: max. diameter of the lens: 77 mm GEOCAL XL: max. diameter of the lens: 155 mm
Usable FoV	Approx. 30 - 120° (larger values possible, depending on the camera. Please contact us.



14 Appendix

14.1 Service addresses

For support requests, please contact us directly:
support@image-engineering.de

Europe

Image Engineering GmbH & Co KG
Im Gleisdreieck 5
50169 Kerpen

Mon-Fri: 9:00 a.m. to 5 p.m. (CET)

Tel: +49 2273 99 99 1-0

Email: info@image-engineering.de

USA

Image Engineering USA, Inc.
3079 Harrison Avenue, Suite 6
South Lake Tahoe, CA 96150

Mon-Fri: 8 a.m. to 6 p.m. (CT)

Phone: +1 408 386 1496

Email: sales@image-engineering.us

China

Shenzhen Image Engineering Optoelectronic Equipment Co, Ltd (IE China Subsidiary)

深圳艾宜光电设备有限公司 (IE中国全资子公司)

Room 1508, Chengshi Shanhai Pingji Center,
Pingxin North Road No.51, Pinghu Street,
Longgang District, Shenzhen City, China

深圳市龙岗区平湖街道平新北路51号城市山海平吉中心15楼1508室

Mon-Fri: 9 a.m. to 6 p.m. (CST)

中国子公司工作时间：每周一至周五 上午9点-下午6点

Phone

+86 158 8961 9096

Email: leon.xiao@image-engineering.com



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