User Manual

GEOCAL / GEOCAL XL / GEOCAL IR

Image Engineering GmbH & Co KG

Translated version
Issue EN 2025-09

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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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 meant) for the first time and before carrying out any other work on GEOCAL.

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

1.1 General information

These instructions are intended to help you familiarize yourself with GEOCAL and use it for its intended purpose.

NOTE

All procedures described in this manual regarding the handling of 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 how to operate GEOCAL safely and properly. Observing them will help you to:

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

These instructions must be read and applied by every person who is tasked with working on GEOCAL.

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

1.2 Presentation of information

Structure of instructions

Instructions for action are made up of:

- Action steps
- Results of the actions

- Application tips for optimal use

Each type of information is identified by a symbol:

Symbol	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	Used 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 the signal word corresponding to the 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

Emergency response

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	Diffractive 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 device into operation, make sure that the device is:

1. Visually in perfect condition
2. Securely placed on a flat 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 class 1M

Danger to the human eye if the beam is refocused

Do not view the beam directly with optical instruments!

Important information:
Read the manual carefully before using this device.
Improper use may result in damage to the device, the device under test and/or other components of your setup. Please keep this manual in a safe place 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 if the device falls

Only place GEOCAL on stable, level and horizontal surfaces.

2. Looking into the optics or the DOE of GEOCAL for a prolonged period

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 class 1M

Danger to the human eye if the beam is refocused

Do not view the beam directly with optical instruments!

5. Opening the housing and thereby exposing the laser (danger to the eyes, impact on the environment due to laser radiation)

6. Dismantling the optics and thereby exposing the laser (danger to the eyes, impact on the environment due to laser radiation)

WARNING!

Visible or invisible laser radiation of laser 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 Image Engineering (e.g. use of an incorrectly set universal power supply unit).

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

   Power supply:

Limit values:	+5 VDC, 4 A min.
recommended:	+5 VDC, 25 W
Protective devices:	2 x Means of Patient Protection (MOPP, according to IEC 60601)
Connector plug:	DC hollow plug 2.1 mm inner diameter 5.5 mm 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 class 1M

Danger to the human eye if the beam is refocused

Do not view the beam directly with optical instruments!

WARNING!

Visible or invisible laser radiation of laser 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 class 1M

Danger to the human eye if the beam is refocused

Do not view the beam directly 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 or by 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 class 1M

Danger to the human eye if the beam is refocused

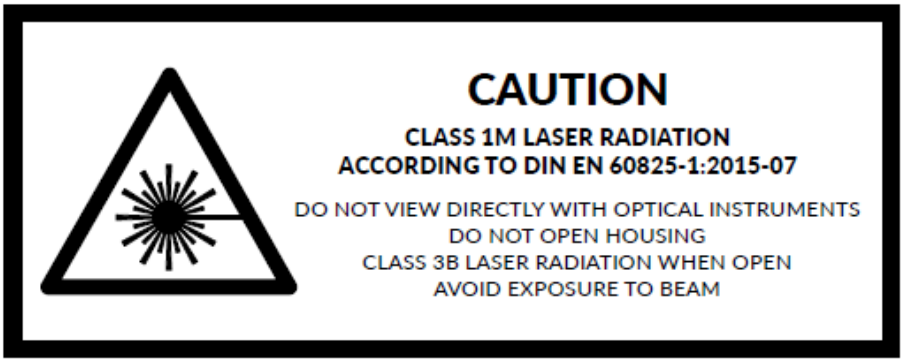
Do not view the beam directly with optical instruments!

2.6 Selection and qualification of personnel

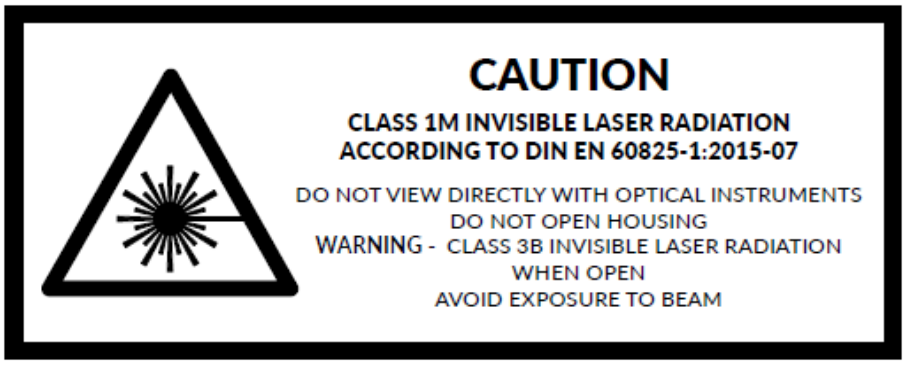
GEOCAL may only be operated by people who have carefully read these operating instructions.

2.7 Safety signs

The following warning is attached to the side of the housing of GEOCAL 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
- 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

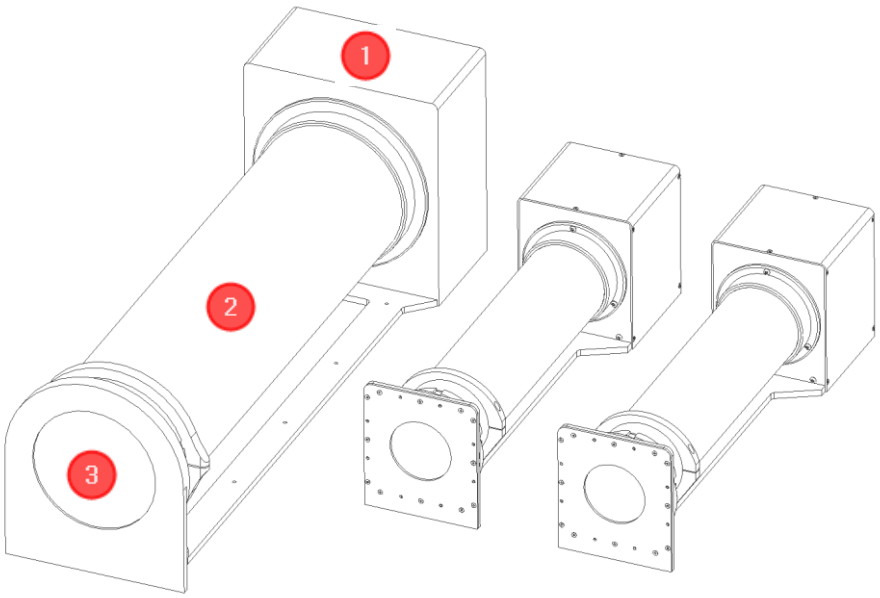


Fig. 4.1 from left to right - GEOCAL XL, GEOCAL, GEOCAL IR

1. Sub-assembly 1 - Electronic unit
2. Sub-assembly 2 - Optical unit
3. Sub-assembly 3 - DOE and DOE holder

4.2 Sub-assembly 1 - Electronic unit

Sub-assembly 1 contains all the electronics required for the operation of GEOCAL.

These are:

- 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 optical unit, which expands and collimates the laser beam to the exit diameter.

4.4 Sub-assembly 3 - DOE and DOE holder

Sub-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 diffracted in a defined way by the finely etched structure of the DOE so that the grid of light points required for calibration is generated by constructive and destructive 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 without function.

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

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

Power supply:

Recommended: +5 VDC, 25 W

Protective devices:	2 x Means of Patient Protection (MOPP, according to IEC 60601)
Connector plug:	DC hollow plug 2.1 mm inner diameter 5.5 mm 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

The use of GEOCAL can be represented schematically as follows.

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

Further information on creating recordings and using the software can be found below 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 knocking it over, 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 device due to installation on an inclined or movable surface

Falling of the device due to impact

Observe the instructions above.

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 device, 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 °C to +35 °C
- No direct, permanent UV radiation
- Sand and dust-free environment
- Rel. humidity: max. 75 %, non-condensing

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 knocking it over, 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 device due to installation on an inclined or movable surface

Falling of the device due to impact

Observe the instructions above.

Establish power connection

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

NOTE
Impairment of function or destruction of the
device caused 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 for analyzing the recordings made and not for operating the hardware.

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

Caution!

Visible or invisible laser radiation
of laser class 1M

Danger to the human eye if the beam is refocused

Do not view the beam directly with optical instruments!

6.3 Optional modification for use on production lines

By default, GEOCAL cannot be switched on and off by the power supply alone, even if the power switch is in the “ON” position. 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, all you need to do is move the switch to the “ON” position. The device then switches on immediately when it is supplied with power, without the switch having to be operated again.

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

7 Operating and display elements

7.1 Control elements on the device

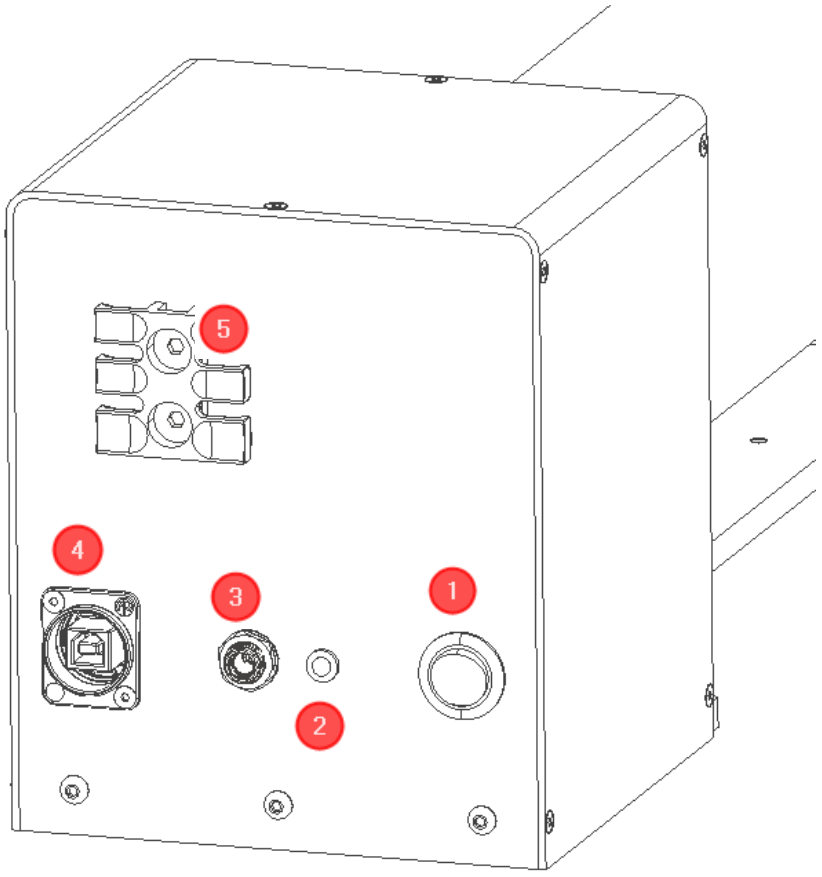


Fig. 7.1 Operating and display elements on GEOCAL

1. Main switch
2. Control LED (blue)
3. Power connection socket
4. USB type B interface (reserved for future functions)
5. Cable strain relief (GEOCAL and GEOCAL IR only)

8 Operating the device

8.1 Operate device

GEOCAL:
GEOCAL is ready for use immediately after switching it 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 638 nm (GEOCAL, GEOCAL XL) or 935 nm (GEOCAL IR). The DOE is attached to the front of GEOCAL (visible glass plate in round cut-out, see Figure 8.1.1).

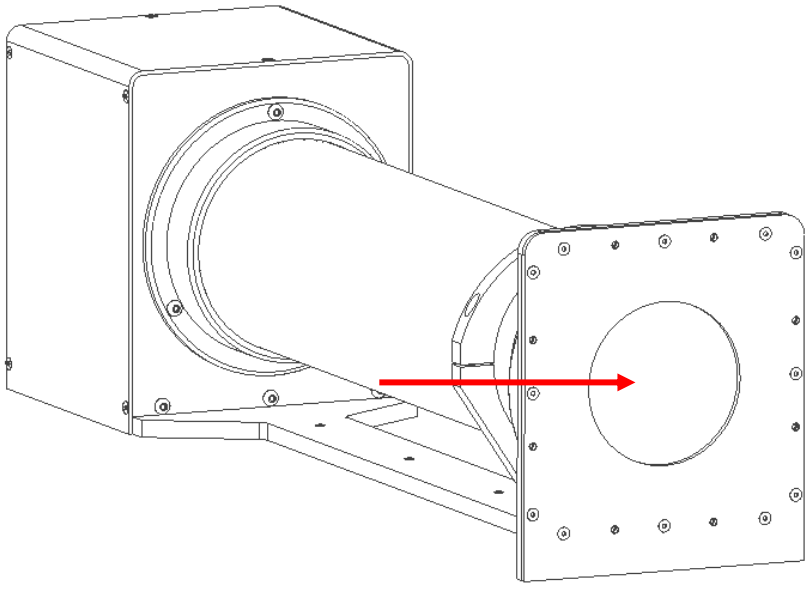


Fig. 8.1.1: DOE

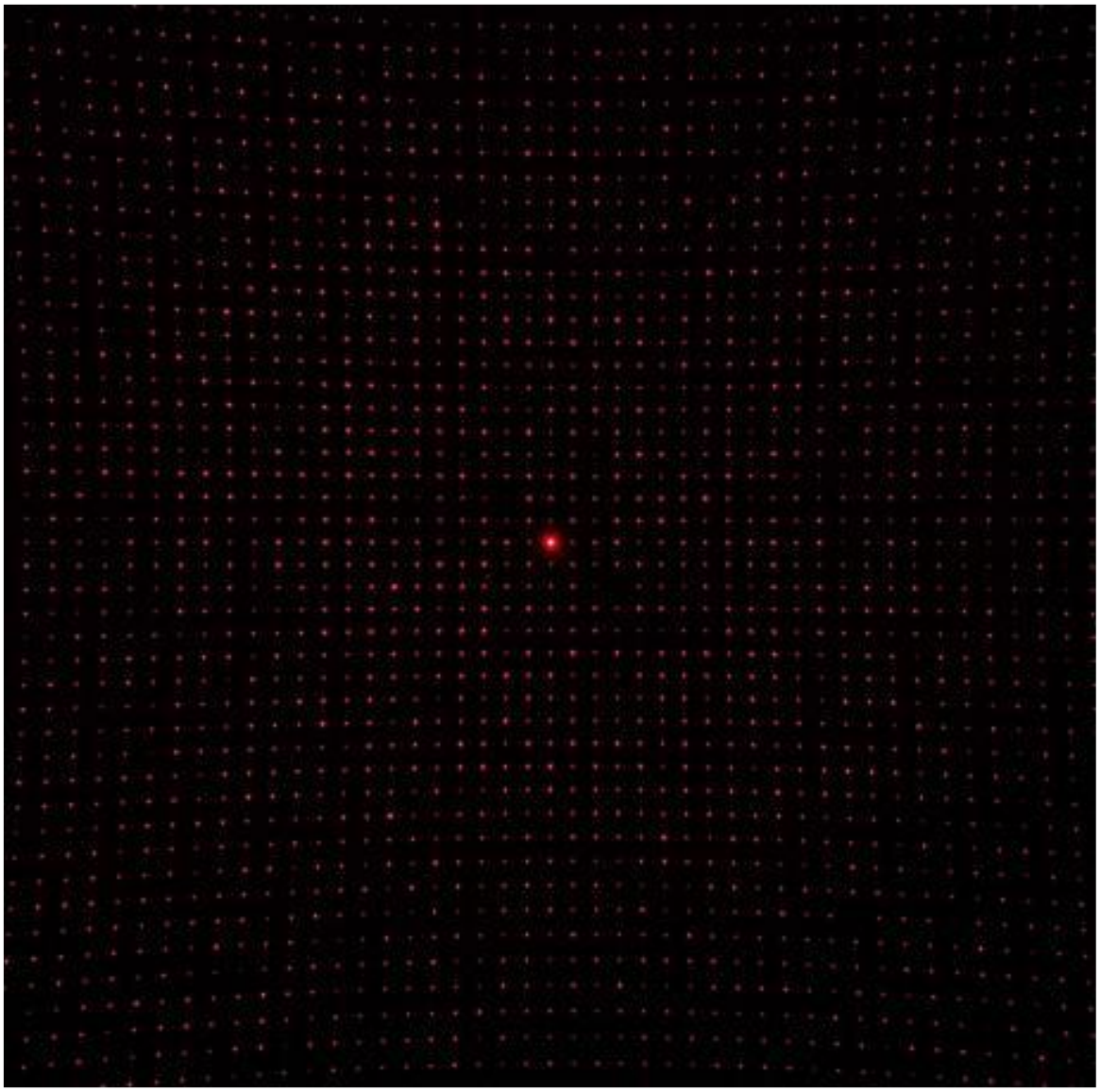


Fig. 8.1.2: Dot grid generated by the DOE. The brightest point is the zeroth diffraction order and thus the center of the diffraction pattern.

Camera settings:

Set the camera to manual exposure mode. If manual mode is not available, use automatic exposure mode. To achieve optimum results, the image should be saved in a lossless format. The TIFF format is recommended, but PNG and JPEG (lossy) are also supported. If you convert RAW image data to another format, make sure that 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, make sure that 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, PGM and JPG supported

Camera position and suitable lenses:

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

The camera can be placed directly in front of the DOE; a minimum distance is not required (see Figure 8.1.5 below). The optical axis of the lens should be aligned approximately perpendicular to the DOE. This 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 8.1.3 and 8.1.4 for reference. Make sure that the dot grid covers the entire image and that the edge of the DOE is not visible.

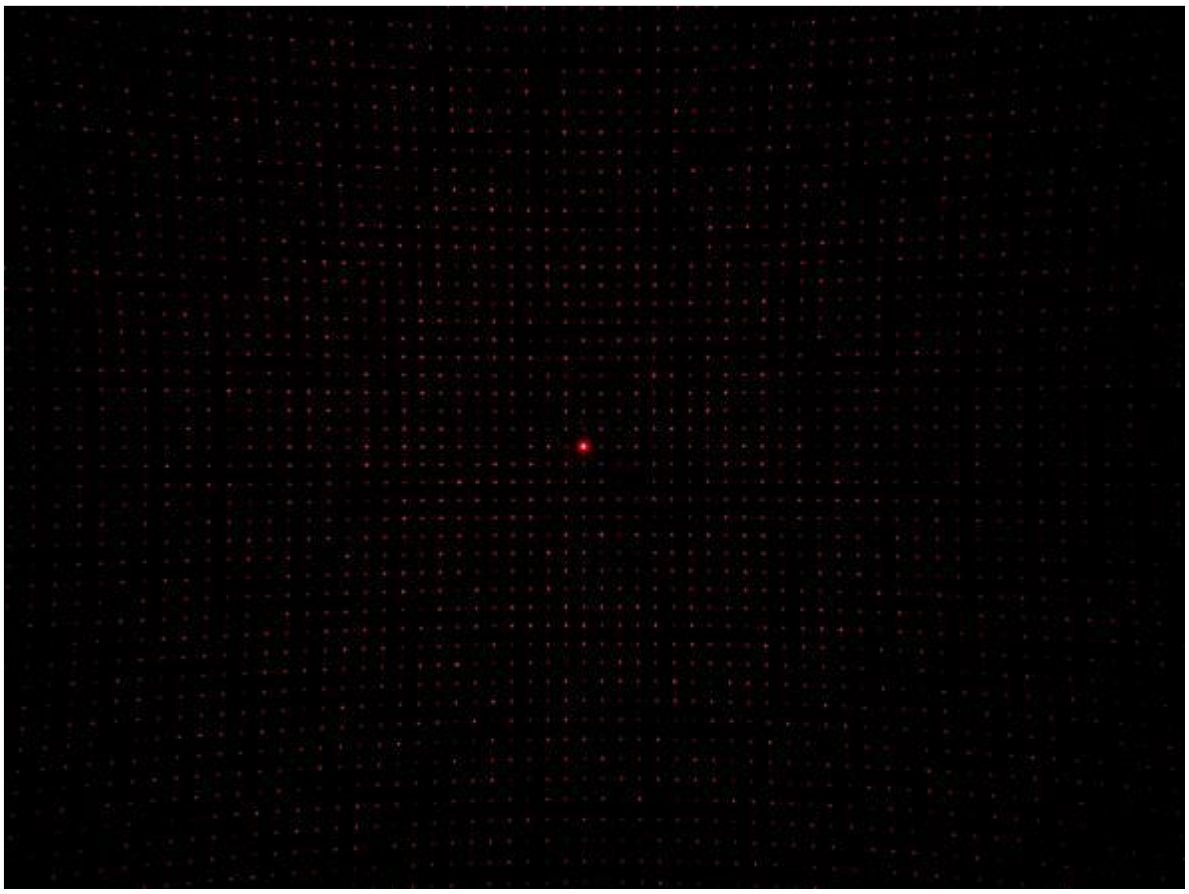


Fig. 8.1.3: Good alignment of the camera, zero order in the center

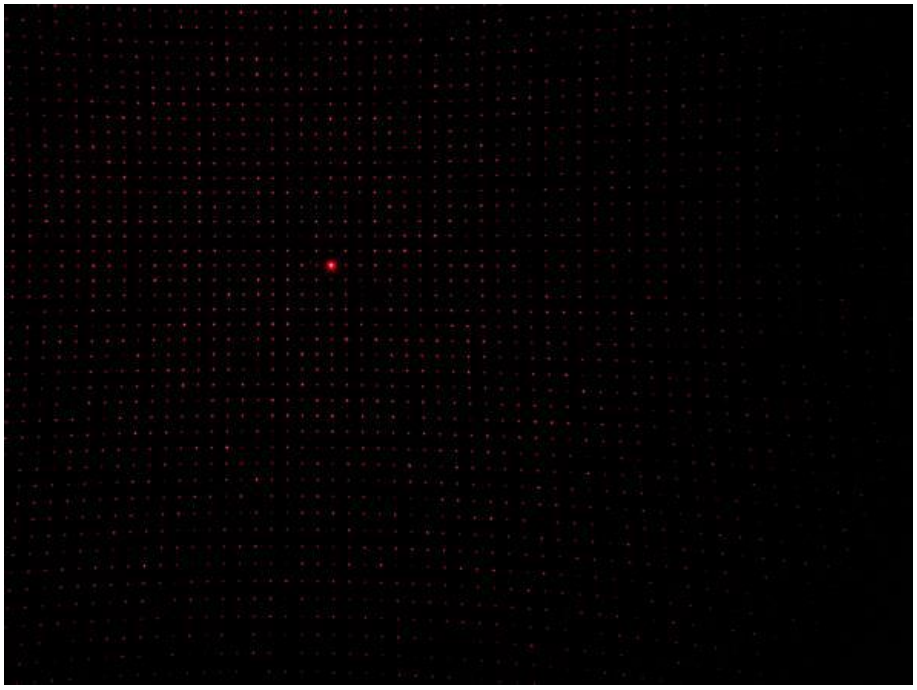


Fig. 8.1.4: Poor alignment of the camera, zero order not in the center

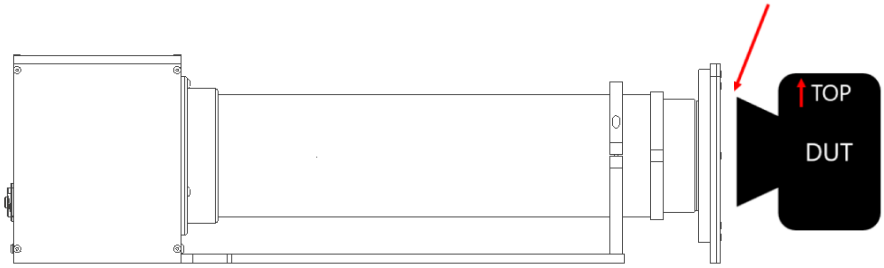


Fig. 8.1.5: Distance between camera and GEOCAL

The top of GEOCAL and the top of the camera must have the same orientation as shown in Figure 8.1.5. A rotation of the camera around the optical axis of approx. +/- 2° is tolerated. No further alignment steps are required. The parallel shift of the camera in relation to the DOE has no influence on 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 element of the lens must not exceed a diameter of 77 mm for GEOCAL / GEOCAL IR or 155 mm for GEOCAL XL in order 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.
Make sure that 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), with the exception of the zeroth order. The zeroth order will always be significantly brighter than the points surrounding it. See Figures 8.1.6 and 8.1.7 below for examples.

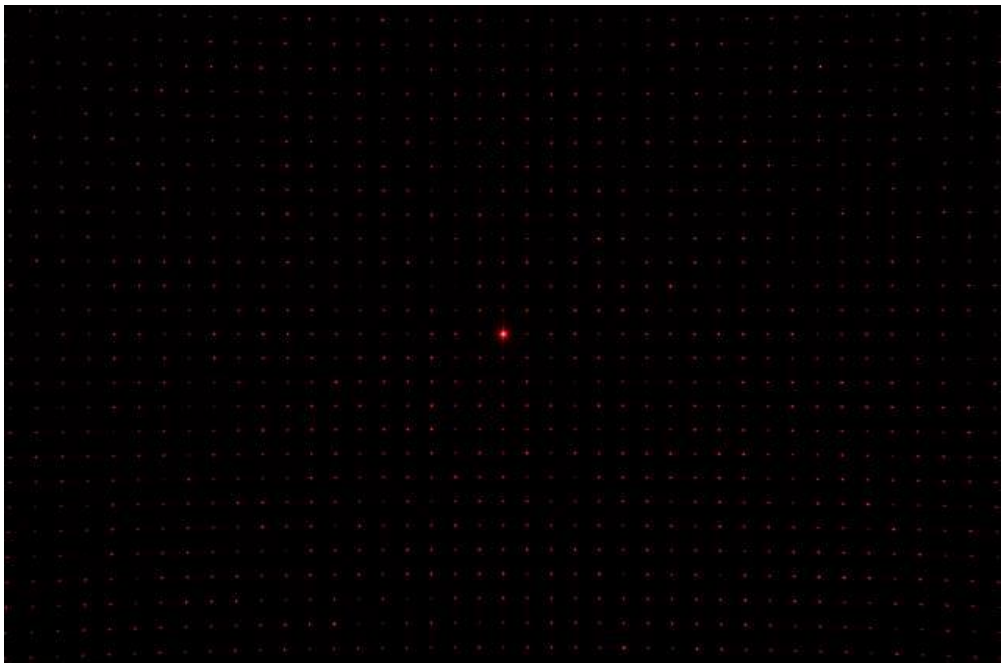


Fig. 8.1.6: Suitable exposure

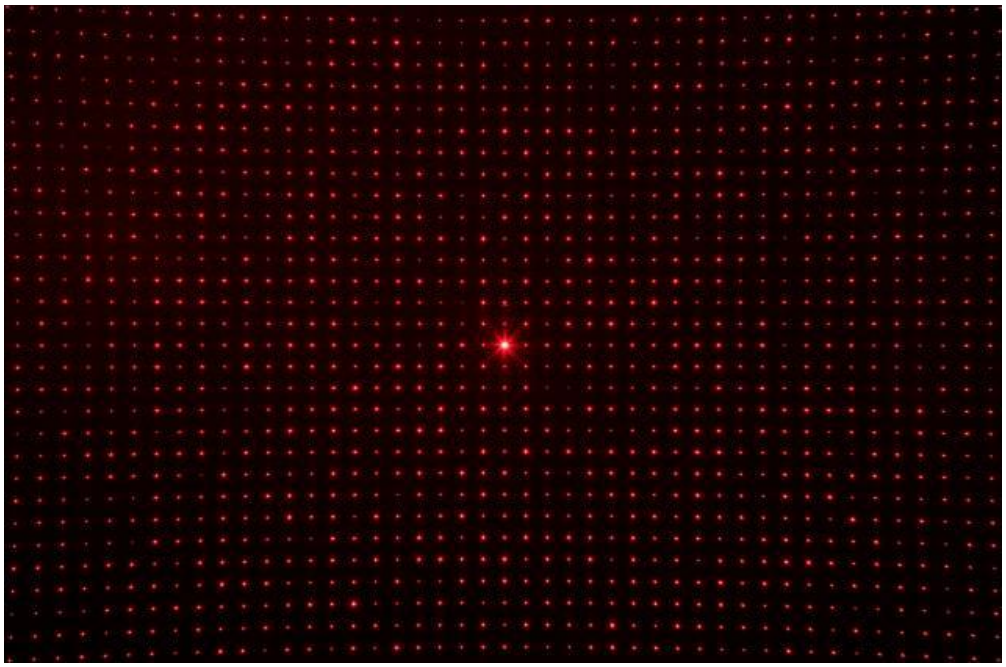


Fig. 8.1.7: Exposure too bright (red background, larger, saturated dots)

Depending on the camera, you may encounter different problems, for example:

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.
- Use a smaller aperture (higher f-number) 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**
> The introduction of any additional optical element into the beam path will have an influence on the calibration result and must be taken into account by the user.

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

The intensity of the grid decreases across the field. Additionally, the camera may cause shading towards the edges. This problem is especially likely to occur with ultra-wide-angle lenses. Compensate for this effect using the “Merge two images” function, which is explained in a later section.

8.2 Switch off the device

Switch GEOCAL off using the toggle switch on the back of the housing. Note that the blue light only indicates that GEOCAL is supplied with power. It does not indicate whether the grid is visible. Also note that, by default, GEOCAL cannot be switched on and off by controlling the power supply.

If GEOCAL is taken out of operation for a longer period of time, disconnect the device from the mains.

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 lies in the wavelength of the laser diode used.
GEOCAL and GEOCAL XL use light with a wavelength of 638 nm and are used for the calibration of cameras that work with the VIS spectrum of light (380–780 nm).
GEOCAL IR uses light with a wavelength of 935 nm and is used for the calibration of 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 GEOCAL XL, whose DOE has twice the diameter of the standard version (155 mm instead of 77 mm).

As long as there is no shading, the point grid shown 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 155 mm* and guarantee the same accuracy as the standard version.

*within the specifications of the data sheet

Longer distances:
Another reason for a larger DOE is, for example, if the windshield of a car is between GEOCAL and the DUT. As mentioned in chapter 8.1, subsection “Camera position and suitable lenses”, the generated dot grid must cover the entire camera sensor to ensure reliable calibration.

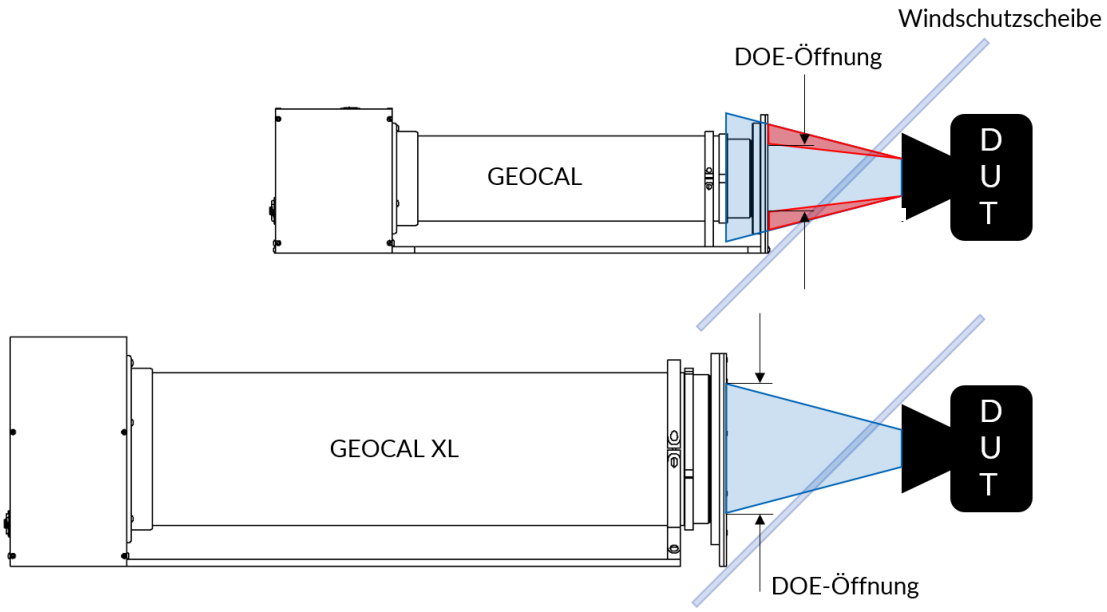


Fig. 9.1: Purpose of a GEOCAL XL with large DOE

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?

Calibration of infrared cameras is important for certain applications to ensure that 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 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 are used in building and construction inspection to 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 GEOCAL software

With the GEOCAL software, you can analyze the captured images of your GEOCAL and perform a geometric calibration. It creates an undistorted reference grid based on the laser wavelength and grating constant that match your GEOCAL. The software then calculates the intrinsic camera matrix, the distortion coefficients and other parameters required to distort the reference grid in a way that best matches the detected grid. We call the distorted reference grid the reprojected grid.

The results can be saved as CSV or XML files.

10.1 Installation

The GEOCAL software requires Windows 10 or Windows 11.

Run the GEOCAL installer and follow the instructions to install the software.

10.2 Overview

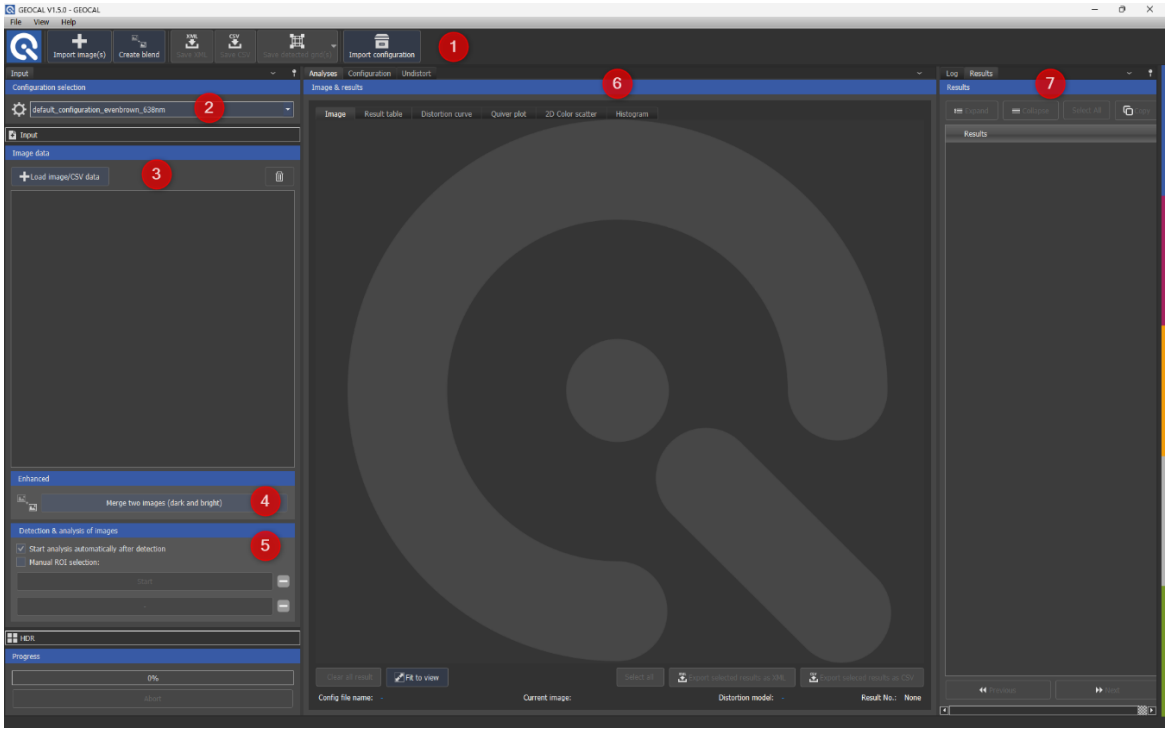
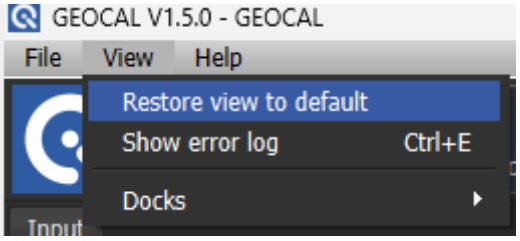


Fig. 10.2.1 - Overview of the user interface

1. Toolbar

2. Configuration selection
3. Image data
4. Enhanced
5. Detection & Analysis of images
6. Analysis / Configuration / Undistortion tab
7. Log and Results

Note that you can adjust the user interface by dragging the tabs into different positions. You can always return to the default state by clicking “Restore view to default” from the top menu.

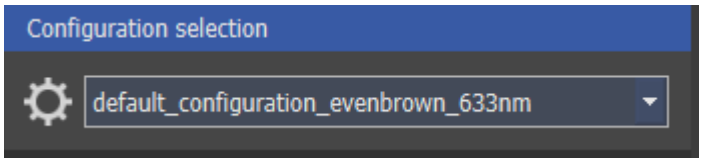


10.3 Perform a Geometric Calibration

For a quick test you can use one of the artificially created sample images which are located here:

C:\Users\Public\Documents\GEOCAL\Sample Images

First choose a configuration in the “Configuration selection” section (2).



You can use one of the default configurations. **Please be careful to choose the configuration which corresponds to the laser wavelength of your GEOCAL.** The artificial sample images are based on a 633 nm laser.

How to create a new custom configuration is explained in chapter 10.11.

Click on "Import image(s)" (Ctrl+O) in the toolbar (1) → navigate to the folder containing the images → select one or more images and click on "Open".

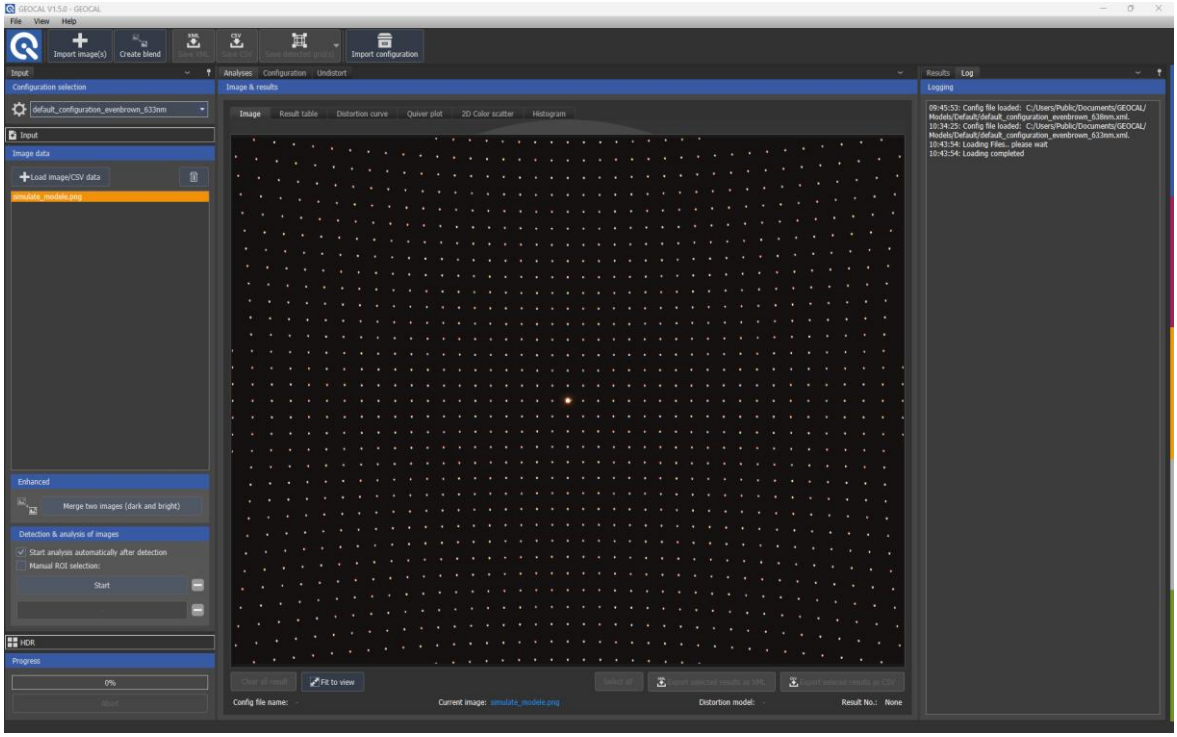
The software supports the analysis of 8bit and 16bit images.

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

Please note: Bayer pattern images cause problems with point detection. This is because the center of the point cannot be detected correctly.

The images to be analyzed must be captured in such a way that the point grid completely fills the sensor. Please refer to “Operating the device” for more detailed instructions.

The imported image is listed in the “Image data” section (3). If you have imported multiple images, all images in this section are analyzed and results are provided for each of them. The image itself is shown in the “Analysis” tab (6).



Click on “Start” in the “Detection & Analysis of images” section to perform the geometric calibration. By default, point detection and the analysis of the image are performed consecutively. The analysis is complete when the progress bar at the bottom of the window reaches 100 %.

The numerical and graphical results are now shown in the “Image and results” section under the “Analysis” tab.

In the rare case that the automatic detection fails, for example when the 0^{th} order was not found, you can make a manual ROI selection by ticking the “Manual ROI selection” box in the “Detection & Analysis of images” section (5).

Five preset 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 0th 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 0th 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.

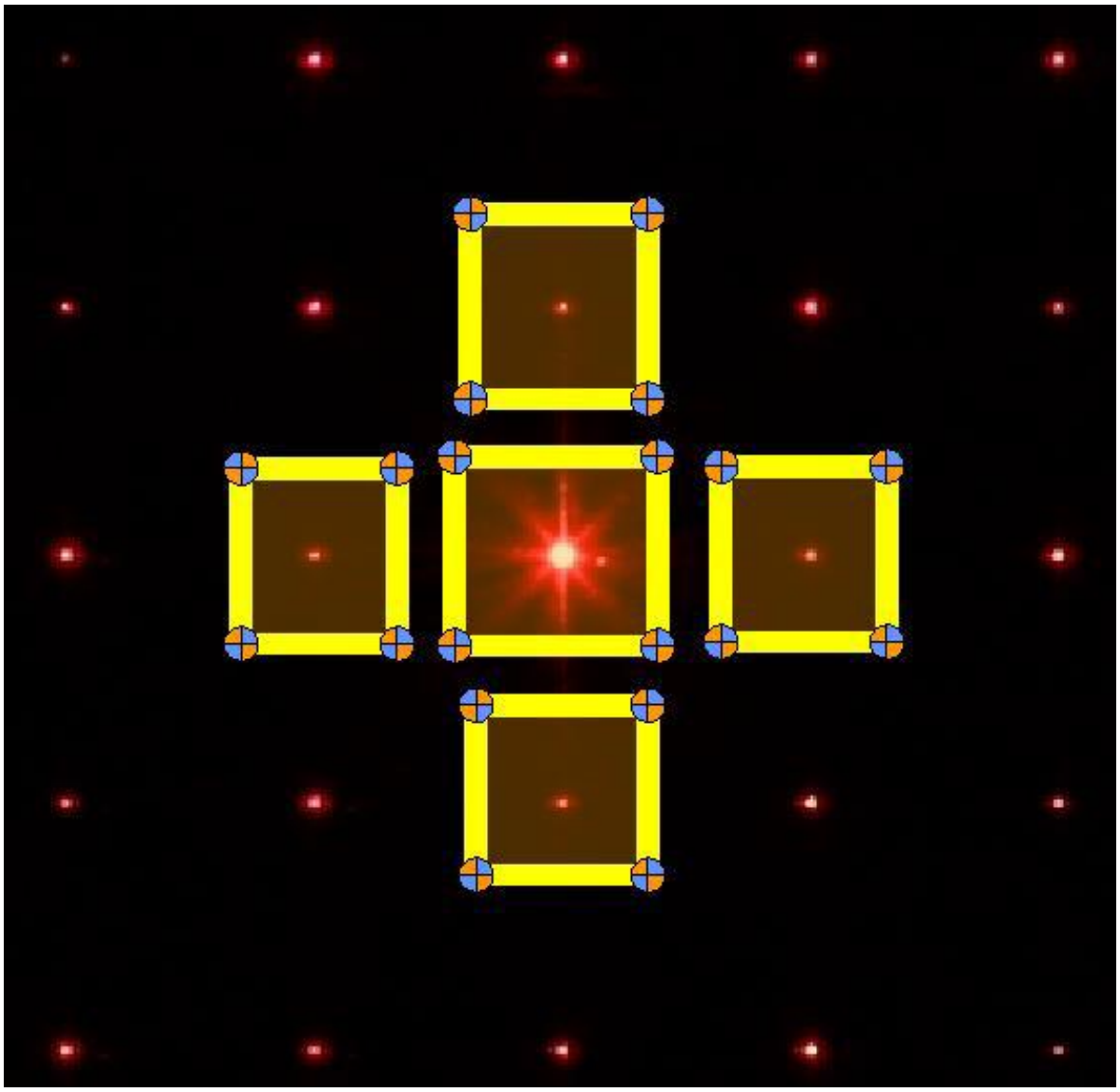


Fig. 10.6.2: Manual point detection

After adjusting the ROIs manually, click “Start” to perform the geometric calibration.

10.4 Merge two images

The intensity of the GEOCAL diffraction grid decreases across the field. Additionally, the camera may cause shading towards the edges. Both effects make it difficult for the point detection to work. This problem is especially likely to occur with ultra-wide-angle lenses. Compensate for this effect using the “Merge two images” function.

The “Merge two images” function creates a new image from two input images: one with a long exposure (bright) and one with a short exposure (dark). Both images are blended and merged into a single image, so that the short exposure is weighted more in the center and the long exposure towards the edges of the image.

Which exposures work best depends on the camera. Ensure that the points at the edges are exposed well in the bright exposure and the points in the center are exposed well in the dark exposure, as in the example below.

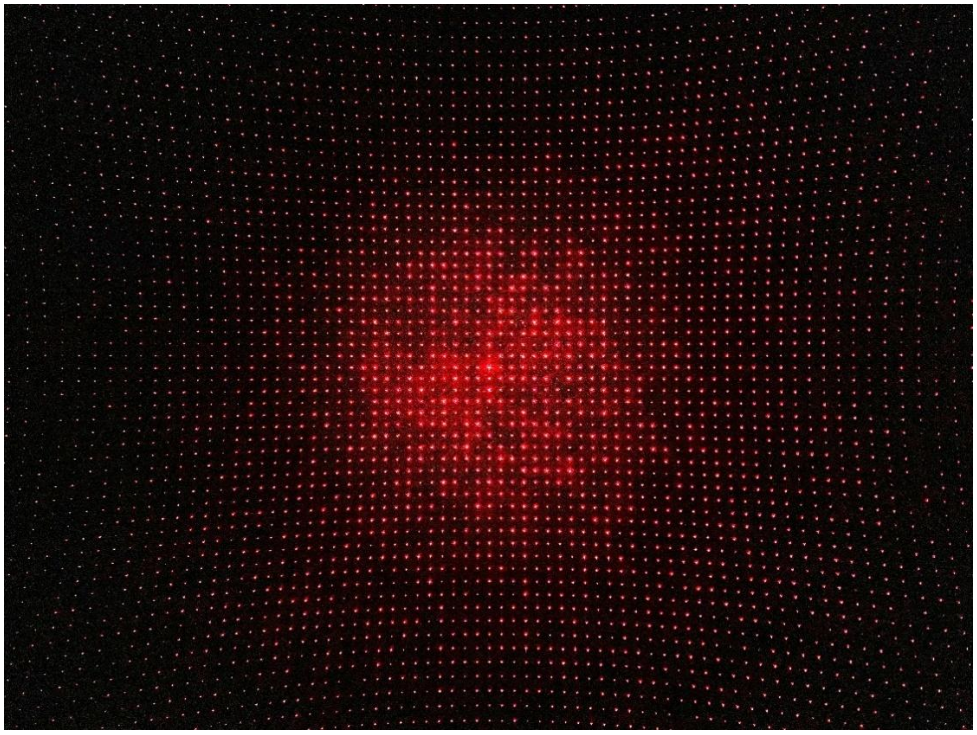


Fig. 10.4.1 Bright exposure: The points are too saturated in the center.

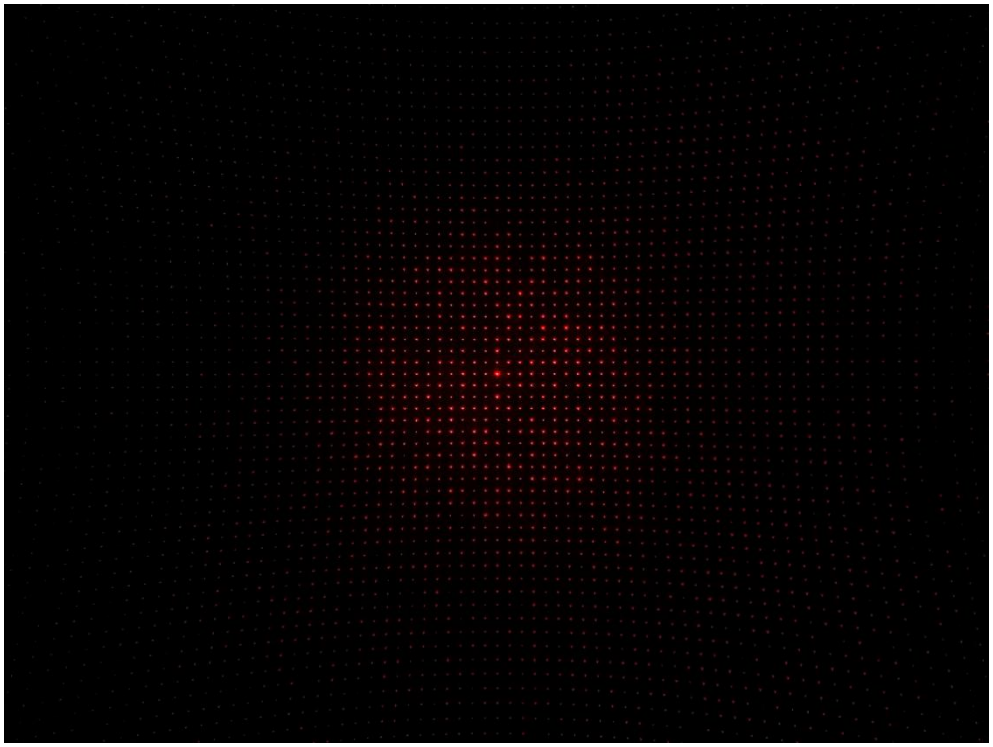


Fig. 10.4.2 Dark exposure: The points are too dark towards the edges.

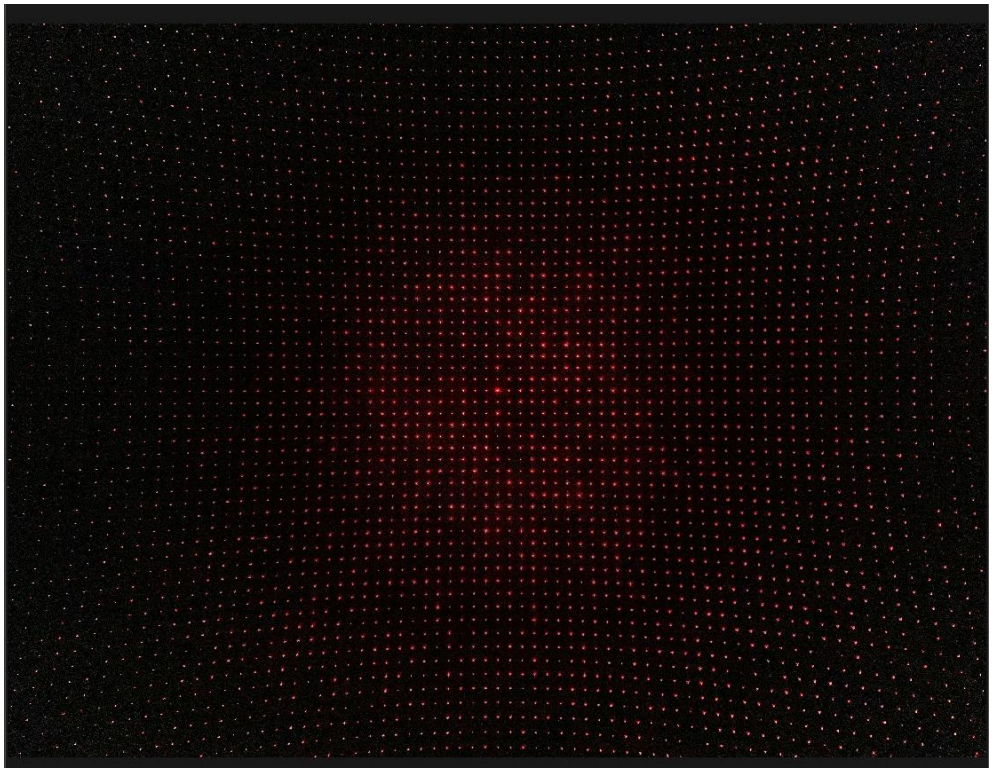
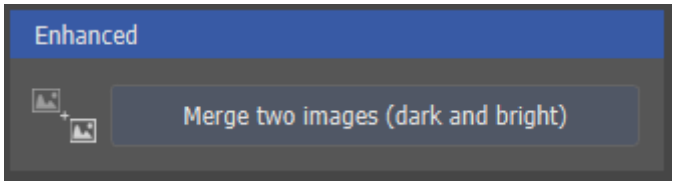


Fig. 10.4.3 Blended image: Image center and edges are well exposed.

To create and analyze a blended image, click on “Merge two images”.



In the dialog that opens, select the two images you want to merge and click “Open”. The software automatically recognizes which one is the bright and which one is the dark exposure, blends the two images and adds the merged image to the image data section with the prefix “merge_”. From there it can be processed like any other image.

10.5 Numerical and graphical Results

All numerical and graphical results are shown under the “Analysis” tab or in the result list.

Image

After a successful analysis, the detected and reprojected points are displayed on the original image.

Zoom into the image with the scroll wheel to get a better view. The dots have a size of one pixel. The green pixels show the detected, the magenta pixels the reprojected grid. **Note that distances between the grids can only be shown with one-pixel accuracy, but may in fact be smaller.**

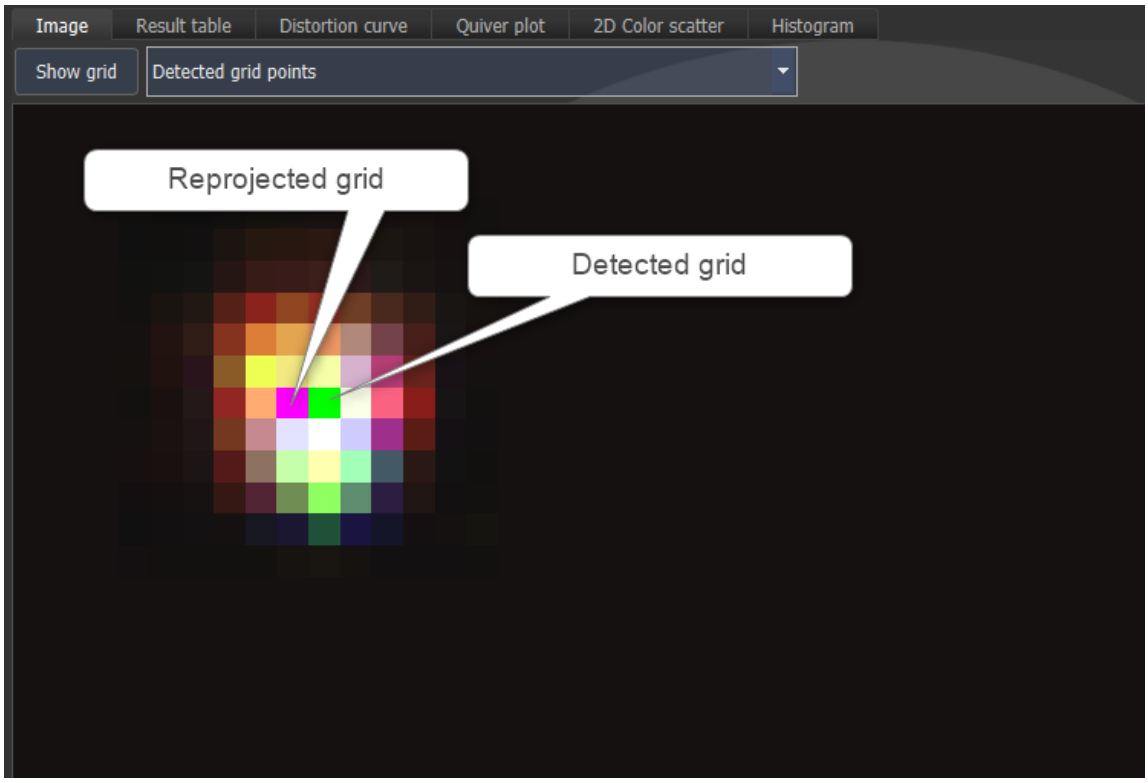
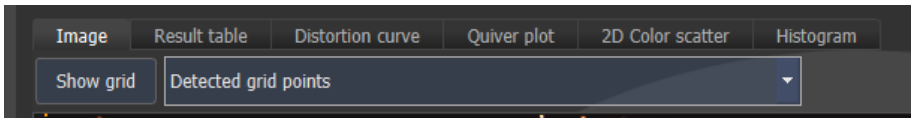


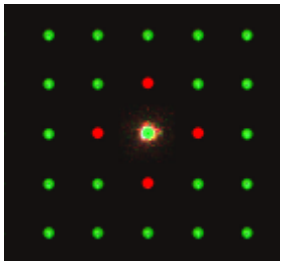
Fig. 10.5.1 – Reprojected and detected grid in image view after point detection

The better the detected and the reprojected grid match, the better the calibration result is. An indicator for a good reprojection is the RMSE value which is explained later.

Click on “Show grid” to get a scaled, better visible view of different grids which you can select in the dropdown menu.



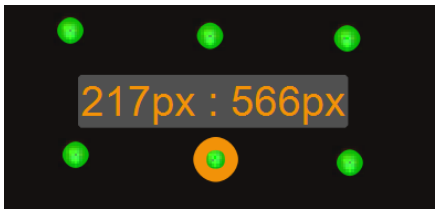
Detected grid points: All points which were detected by the software (green). The red points are either not found or ignored points. Some points are intentionally ignored, for example around the 0th order.



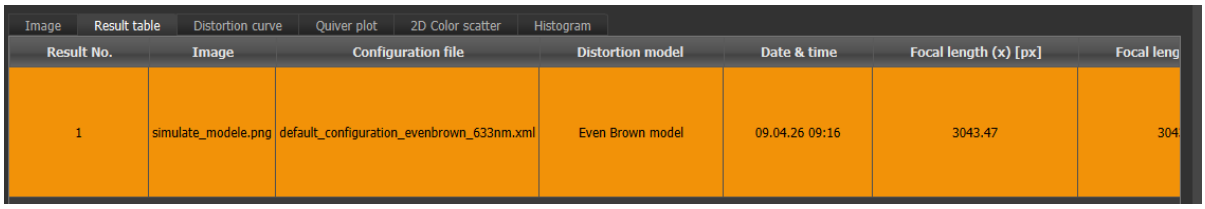
Grid points included in analysis (blue): All points which are used to perform the geometric calibration. For example, if you have applied a radius filter in your configuration, the points outside this radius will not be included in performing the calibration.

Reprojected points (magenta): All the reprojected points based on the performed calibration results. The calculated intrinsic matrix and the distortion coefficients of the chosen distortion model were used to reproject the reference grid on to the detected grid.

If you hover over a point, it shows the pixel coordinates of the detected point. This function is useful, for example, for finding the point in the CSV files that contain the point coordinates.



Result table tab



The result table shows the following information:

Result No.: The unique result number.

Image: The filename of the image.

Distortion model: The distortion model which was applied.

Focal length: The focal length in x and y direction in pixels. You can use the pixel pitch of your camera to convert the focal length into mm or other units.

Principal point: The position of the calculated principal point in x and y direction in pixels.

Alpha and Beta: Alpha and beta represent the angle of the DOE relative to the plane of the laser beam in degrees.

Roll, Pitch and Yaw: The rotation angles of the camera relative to the DOE, also referred to as Omega, Phi and Kappa. **Pitch** refers to the rotation around the lateral axis, tilting the camera up or down. **Yaw** is the rotation around the vertical axis, panning the camera to the left or right. **Roll** describes the rotation around the longitudinal (lens) axis, causing the camera to tilt sideways.

Distortion coefficients: The calculated radial distortion coefficients which are applied to perform the reprojection. The number of coefficients can be set in the configuration file.

Tangential coefficients: The tangential distortion coefficients which are not calculated by default.

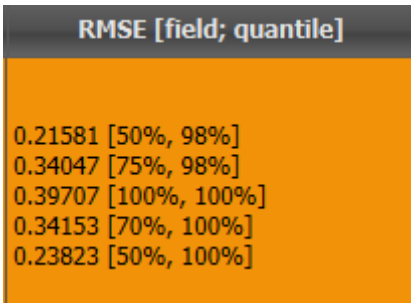
Skew: The axis skewness, which is usually 0.

RMSE: The root mean squared error of the reprojected grid relative to the detected grid. n indicates the number of grid points, and y_i and $\tilde{y}_i$ the detected and the calculated grid point positions.

$$\mathrm{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2}$$

The RMSE provides great feedback regarding the quality of geometric calibration. The lower the RMSE the better.

The RMSE is calculated for various image fields and quantiles (RMSE filter). The first number in parentheses is the image field, and the second is the quantile. [100%, 100%] thus covers all detected points included in the analysis.



Defining an image field can be useful for examining how the RMSE changes across the field, or if you need to meet specific requirements within a particular field.

The quantile is useful for excluding outliers from the RMSE calculation. For example, a 98% quantile means that the 2% of grid points with the highest RMSE values are excluded from the analysis. Radial image field filtering is performed before the statistical exclusion.

Please note that the software distinguishes between these two filters:

- Radius filter (before calibration): Determines which point pairs are used for calibrating the camera system.

- RMSE filter (after calibration): Determines which point pairs are included in the RMSE error calculation. These can be point pairs within a specific quantile or radius.

Important note on behavior: If, for example, you set the radius filter to 70% (0.7), the system is calibrated exclusively based on this range. If you evaluate the RMSE for a larger field, points outside the calibration range are also included. Since this outer range was not included in the calibration, the RMSE error there typically increases significantly. The radius and RMSE filters use the same filter (GRID_ORDER or IMAGE_FIELD) defined in the configuration. If you want to change the quantile or field used by the RMSE filter, you must modify the entries in the configuration file. This is currently not possible in the GUI. Here, the first number is the quantile and the second is the field. You can also add multiple entries, e.g., {100:70};{95:60},…

<QuantileRMSEParameters Use="true">{98:75};{98:50}</QuantileRMSEParameters>

F min: The value is returned from the optimizer after the last iteration. It can be used for comparison of the quality of the whole parameter optimizing procedure. It is not a direct measurement result value.

Estimated FOV (vertical, horizontal, diagonal) in degrees: The camera's field of view in various directions. Since the points in the GEOCAL grid have a defined angle of incidence, the camera's field of view can be derived by extrapolating the angles of the detected points across the field. The calculation of the FoV is highly dependent on point detection at the edges and on the camera system and should be considered more of an estimate.

Analysis time: Total time of analysis in seconds.

Number of points: Total number of points which have been detected.

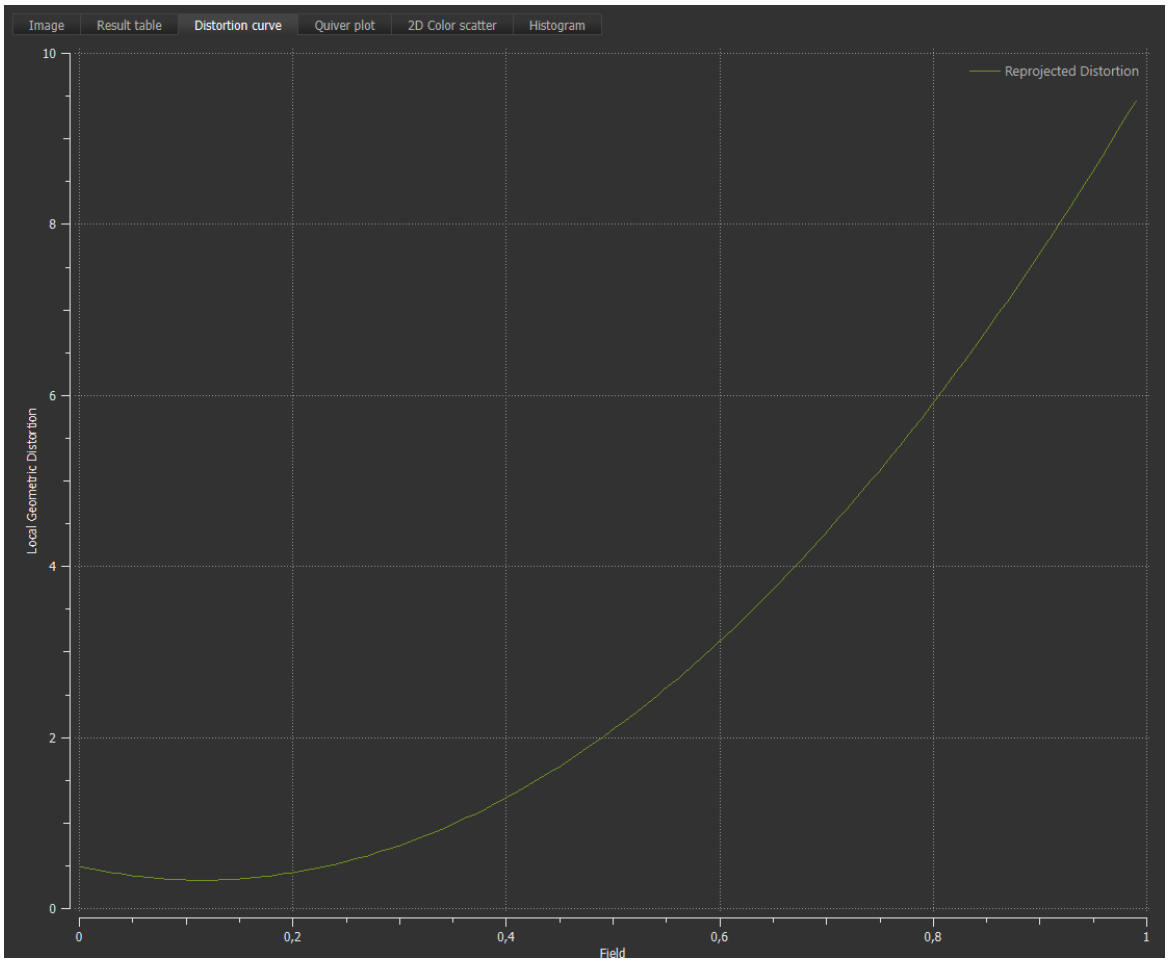
Field: The image field in which the points were included for analysis, ranging from 0 % to 100 % (0 to 1) depending on the type of radius filter specified in the configuration. **Note, that the radius filter can currently only be modified in the <RadiusFilterForDetectedPoints> entry of a configuration file, not in the GUI.** There are two options that can be set in the “Unit” attribute:

- **GRID_ORDER**: The field depends on the Euclidean distance of the farthest detected grid point from the center grid point in units of grid order. This distance is then interpreted as 100 % field.

- **IMAGE_FIELD**: In this case the Euclidean distance from the corners of the image to the center is interpreted as 100 % field.

Inversion coefficients: The inversion coefficients for custom model 2.

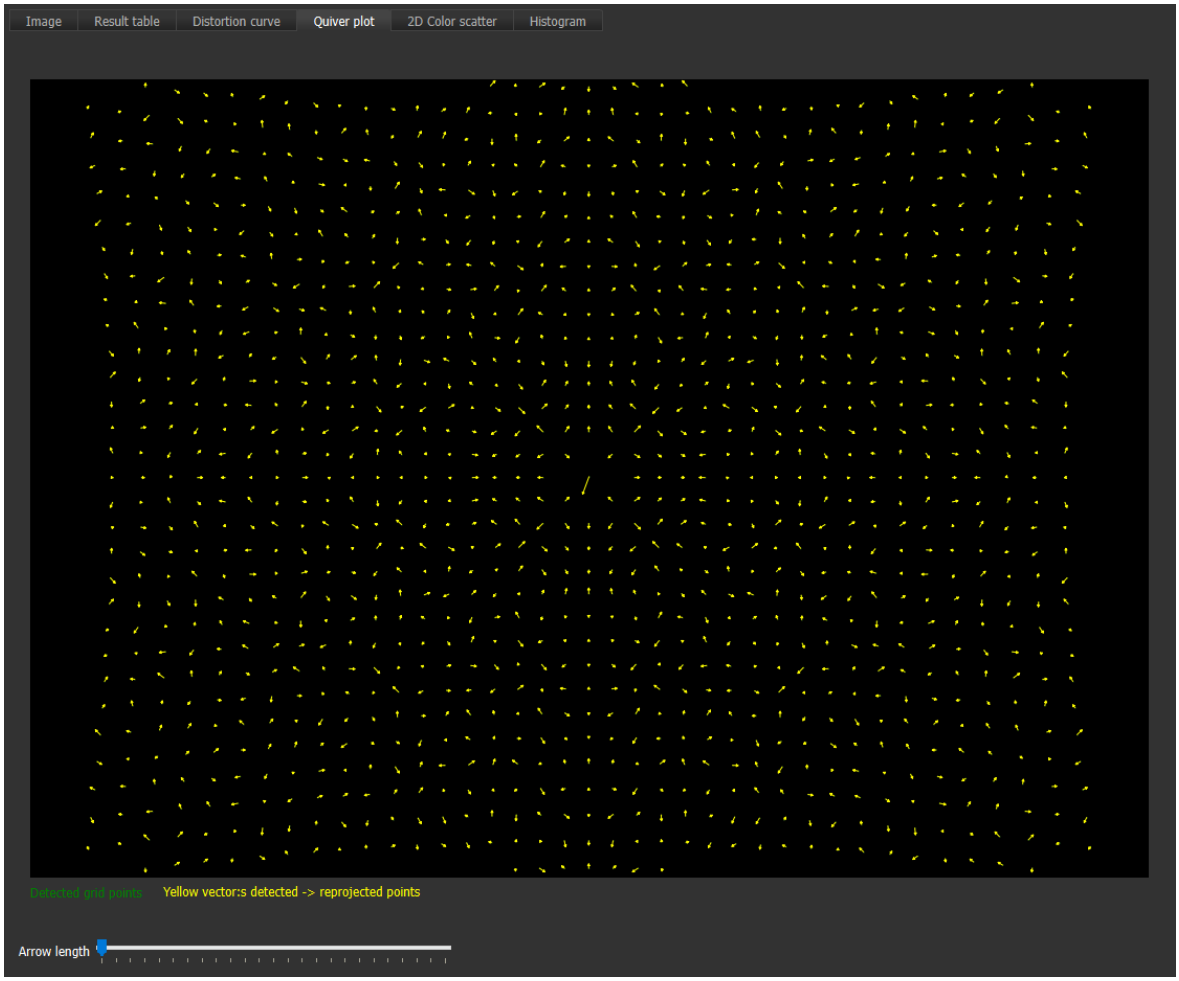
Distortion Curve



The curve is calculated from the distortion coefficients and shows how the distortion of the lens changes from the optical axis to the edge of the image field (Field 0...1).

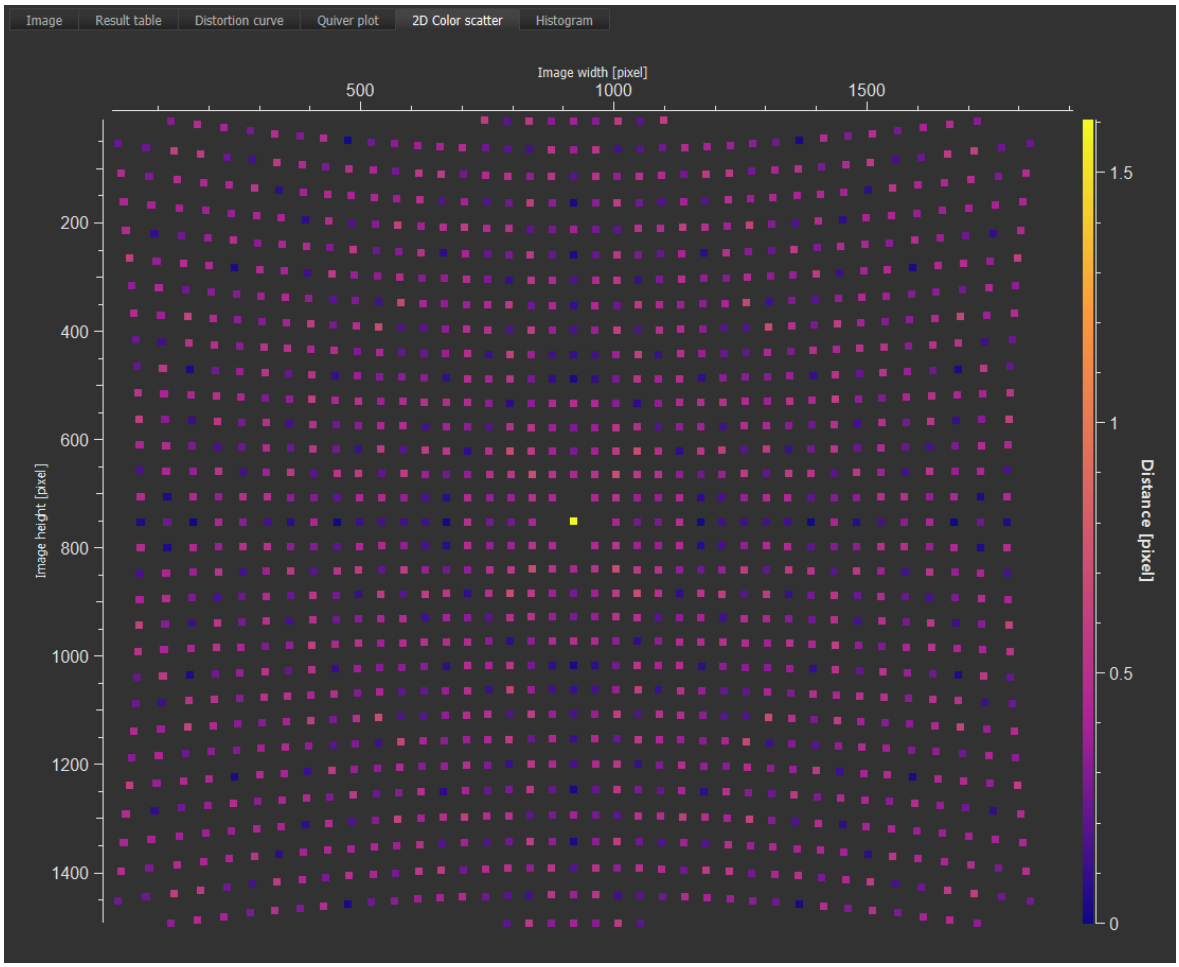
Quiver Plot

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



Note that you can change the scaling of the arrows with the slider below the image to get a better impression about changing directions. This view is suitable for identifying patterns in the geometric calibration rather than real measurements.

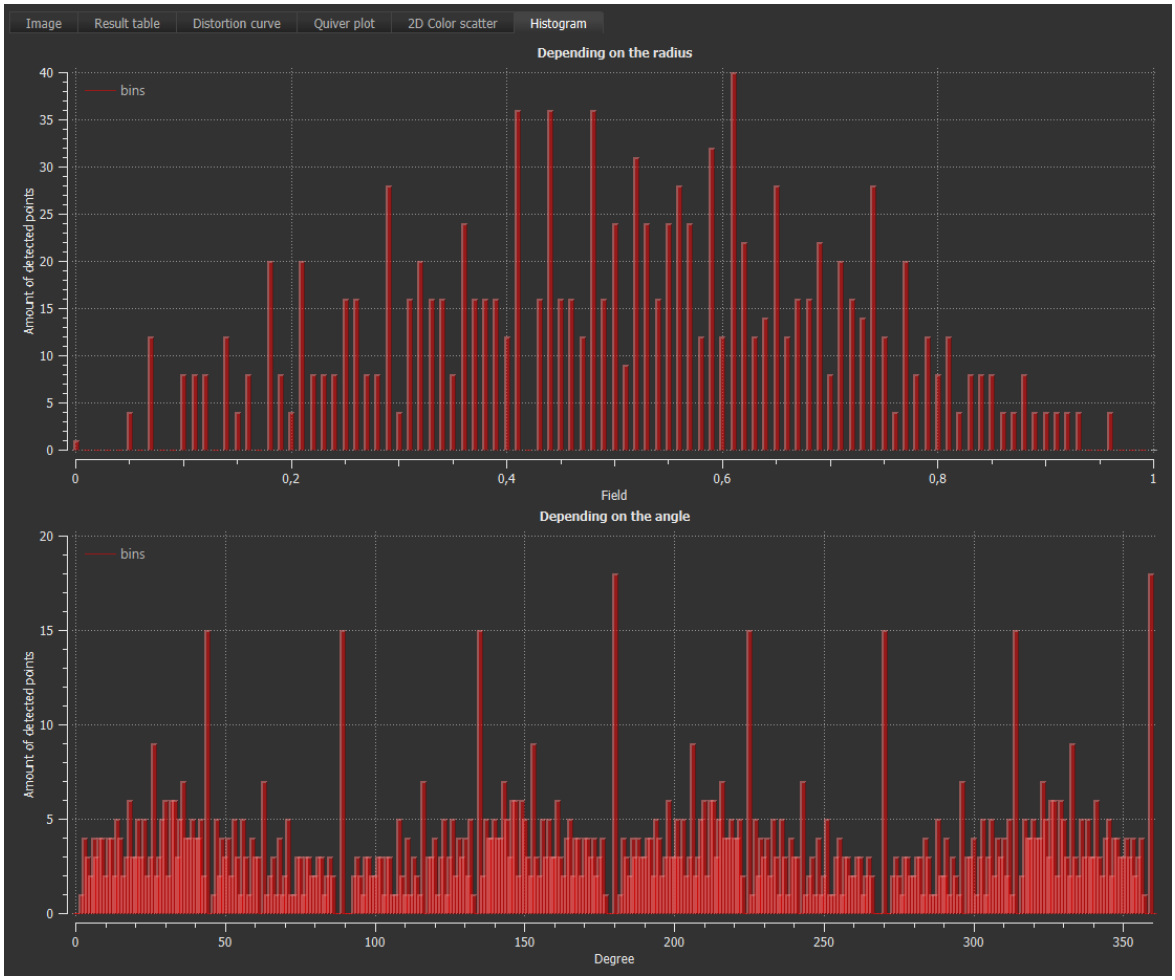
Color Scatter plot



This plot shows a grid of color-coded squares, with each square representing the distance between a detected and reprojected point in pixels. The scale on the right shows the individual color coding.

Histogram

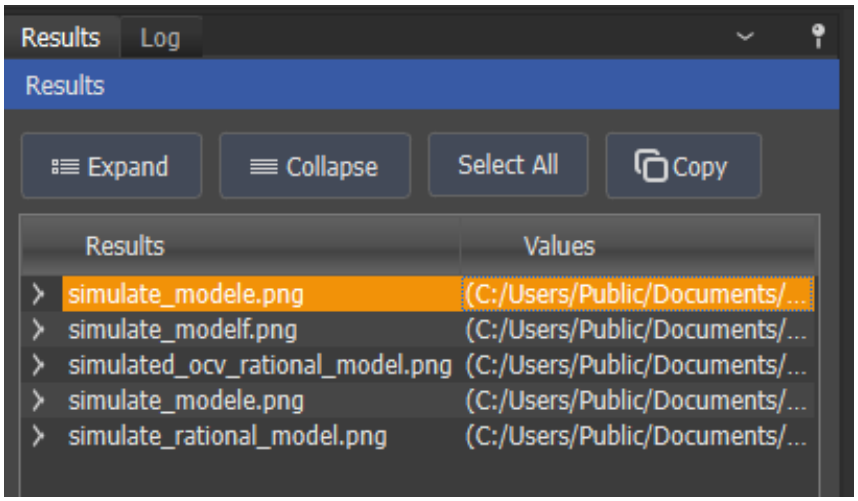
The histogram provides information about the distribution of the grid points across the field in relation to the angle and in relation to the radius.



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 (principal point) and run along the image diagonal up to the image corner (one).

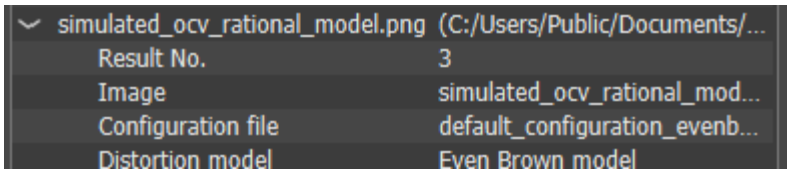
The second histogram contains the successfully detected diffraction points as a function of the angle. The values are based on a straight line that runs from the principal point to the right edge of the image. The angles increase in the counter-clockwise direction.

Result List



On the right side of the user interface is the results list, which lets you quickly navigate through your results. Whenever you select a result from the list, it is also marked in the result table, and the graphical results change accordingly.

Select multiple results, copy them and paste them into an Excel spreadsheet for further investigation.



Expand the view to see all results by clicking on the small arrow next to the item or double-click.

10.6 Export point grids

You can export three different point grids as CSV files.

To export a grid, select an image in the results list or table, click on File → Save grid → select the desired grid → navigate to the desired storage location → click on Save.

You can also click on the “Save detected grid(s)” button in the toolbar.

Available grid types:

- **Detected grid:** Contains the detected points.
- **Reprojected grid:** Contains the reprojected points based on the performed geometric calibration.

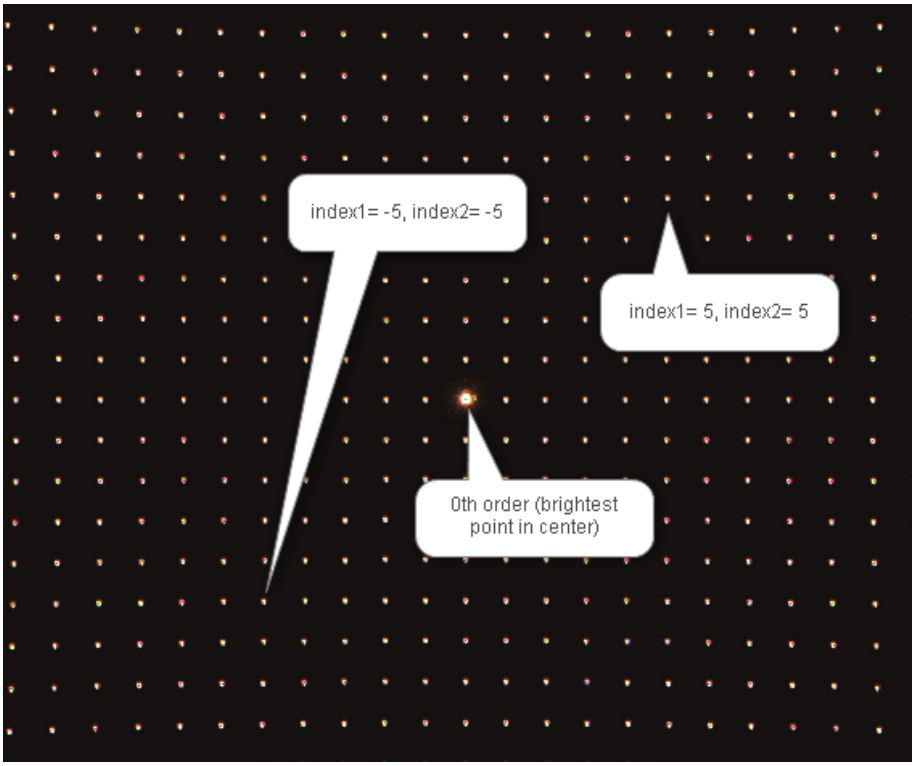
- **Undistorted reference grid:** Contains the reference grid without lens distortion. This grid contains only the distortion resulting from the DOE physics and the extrinsic and intrinsic parameters determined.

All CSV files have the same structure as shown below.

width	height			
1920	1504			
index1	index2	x	y	found
-21	-17	0	0	false
-21	-16	0	0	false
-21	-15	0	0	false
-21	-14	0	0	false

Width and height are the image dimensions in pixels.

Index1 is the number of the order in horizontal direction, Index2 in vertical direction; both can be negative or positive depending on the location in the image relative to the 0th order. For example, index1 = -5, index2 = -5 is in the bottom left quadrant, index1 = 5, index2 = 5 in the top right corner relative to the 0th order.

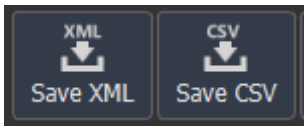


x and y are the coordinates of the points in the image and “found” shows, if the point was found (true) or not (false) by the software.

10.7 Save results

You can save your calibration results as either an XML or a CSV file. If you have analyzed several images, select the images whose results you would like to save from the list in the “Result table” tab or the results list on the right. Then click on File → Save result → Save XML or Save CSV → navigate to the desired storage location → click on Save.

You can also select the results and click on the “Save XML” or “Save CSV” on the toolbar or at the bottom of the “Analysis” tab.



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

10.8 Log

The logging data for each action appears under the "Log" tab on the right side of the user interface. This can be helpful if errors occur or for debugging.

10.9 Exit

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

10.10 Artificially generated sample images

Artificially generated sample images are available for each distortion model.

C:\Users\Public\Documents\GEOCAL\Sample Images

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_modele.png	EVEN_BROWN_MODEL	[0.5, 0.5, 0.5, 0.5, 0.5, 0.5]

To familiarize yourself with the different models and how the parameters interact in the configuration files, you can use the default configurations specified for each model and run the GEOCAL software on the simulated images. This should provide results that are very close to those used to create the simulated images.
Note that the radial distortion coefficients may deviate as they cancel each other out.

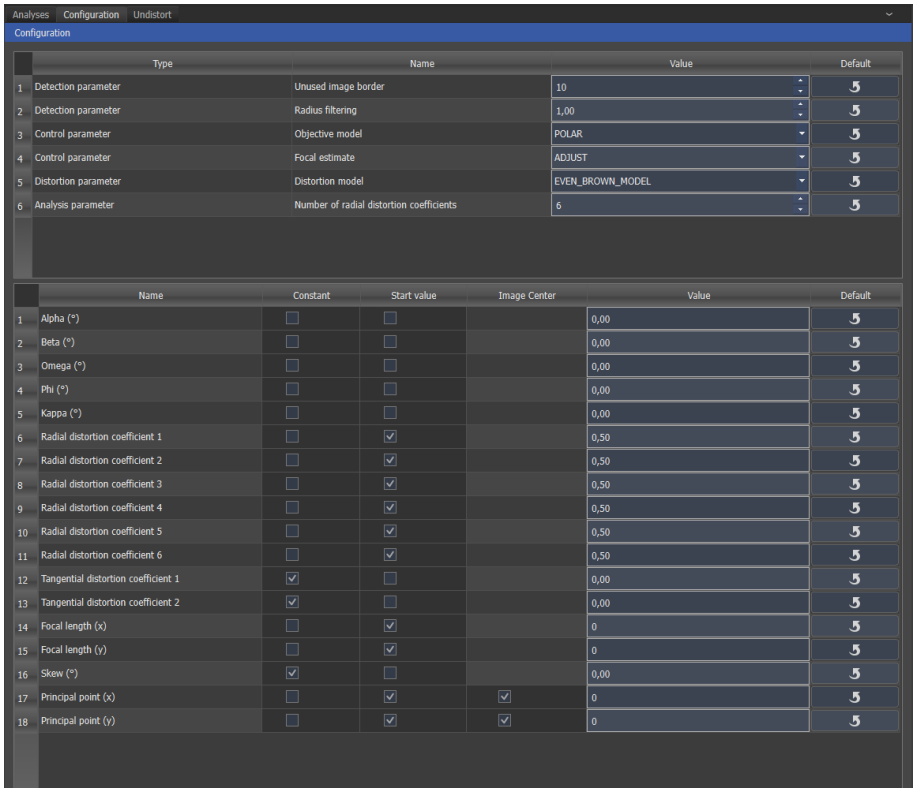
10.11 Configuration

For GEOCAL / GEOCAL XL (light with a wavelength of 638nm) and GEOCAL IR (light with a wavelength of 935nm), six default configuration files in XML format with different distortion models are provided with the software, which are preconfigured for the respective laser wavelength of the GEOCAL variant.

Note that if you have an older GEOCAL with a serial number lower than GC-10045 or a GEOCAL XL with a serial number lower than GC-XL-10013, you have a 633 nm laser and need to use the corresponding configuration files.

If your calibration procedure does not require any special settings, you can select one of the six configuration files to match the desired distortion model. Otherwise, you can adjust the configuration settings in the “Configuration” section.

Configuration section



In the configuration section some parameters can be adjusted, and a custom configuration can be created. This is the list of parameters which can be changed:

Unused image border: Because some image files may contain header data, a margin around the image can be defined that is not taken into account for the geometric calibration. It can also be applied if there are issues with the point detection close to the border.

Radius filtering: This parameter is used to define 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. A value of 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.

Objective model:

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 RMSE (Root Mean Square Error) between the estimated and detected points. They are calculated slightly differently but should perform the same. The difference is that the MSE in the case of CARTESIAN is the average error in Delta X and Delta Y. In POLAR, the RMSE is given as the average error in the Euclidean distance between the estimated point and the detected point. POLAR2 performs a two-stage optimization, where first an optimization is performed to minimize the error with respect to the square of the MSE. This is followed by a second optimization to minimize the MSE. This 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 values to be optimized to ensure that a feasible solution is determined.

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 determined during the estimation.

Distortion model:

This parameter can be used to select the model to be used. The following models are currently implemented and available for public use:

- EVEN_BROWN_MODEL
- FISHEYE_MODEL
- CUSTOM_MODEL_2 (Division Model)
- RATIONAL_MODEL
- OCV_RATIONAL_MODEL
- OCV_RATIONAL_CONSTRAINED_MODEL

Number of radial distortion coefficients:

This setting lets you choose how many radial distortion coefficients you want to use. You can add or remove coefficients from the list below. Please note that a reasonable number of coefficients depends on the model. Also, having more coefficients does not automatically improve calibration, as this could lead to overfitting. Three to six coefficients are usually sufficient for a good calibration.

Alpha(°), Beta(°):

These angles describe the alignment of the diffractive optical element to the incident expanded and collimated laser beam. These values are determined during the optimization process and are part of the output parameters. However, they can be set to zero for troubleshooting purposes, for example. These angles are specific to GEOCAL and are not directly related to the calibrated camera.

Focal length x and y:

The focal length values of the device under test (DUT) 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 principal point describes the point at which the optical axis of the camera lens intersects with the image sensor. It is determined during calibration and output as a result. However, it can be set to a fixed value for troubleshooting purposes.

Omega (roll), Phi (pitch), Kappa (yaw):

These angles describe the rotation of the device under test (DUT) relative to the diffractive optical element. These values are determined during calibration and output as a result. 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 in the example below as k_1 , k_2 , ...:

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

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

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

NOTE
We recommend that you do not set the number of distortion coefficients higher than necessary, as an unnecessarily high number can lead to overfitting artifacts.

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

Tangential Distortion Coefficients 1+2

The tangential distortion coefficients are referred to in the example below as p_1 , p_2 :

$x_{distorted} = x + [2p_1xy + p_2(r^2 + 2x^2)]$

$y_{distorted} = y + [p_1(r^2 + 2y^2) + 2p_2xy]$

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

Create a custom configuration

To create your own default configuration file, select the configuration you would like to change in the dropdown menu. The parameters and values in the configuration section will change accordingly. Now adjust the values to your needs and click on “Save configuration as…” to save it. You will be automatically directed to the “User” folder to save it.

C:\Users\Public\Documents\GEOCAL\Models\User

After the configuration file has been saved it is available in the dropdown menu and can be applied to a geometric calibration.

The default configurations are stored here and should not be overwritten:

C:\Users\Public\Documents\GEOCAL\Models\Default

10.12 Distortion models

EVEN BROWN MODEL

The **Even Brown Model** is also known as the Brown-Conrady model utilized in OpenCV. It represents radial distortion through a high-order power series, where the mapping between undistorted and distorted coordinates is defined as follows:

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

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

Where *r* is the radius, k_1 to k_{15} are the distortion coefficients. Note that the number of coefficients is usually smaller and can be set individually. A higher number of coefficients can lead to overfitting.

FISHEYE MODEL

The Fisheye Model is based on the equidistant projection model utilized in OpenCV. It represents radial distortion as a high-order polynomial of the angle of incidence, θ. The mapping between the ideal incident angle and the distorted angular position, θ_d, is defined by the following formula:

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

Where θ is the angle of the incoming light towards the optical axis and k_1 to k_4 are the distortion coefficients.

CUSTOM MODEL 2 (DIVISION MODEL)

The Division Model provides an alternative representation of radial lens distortion. Unlike the standard polynomial expansion, this model uses a rational function to relate undistorted and distorted coordinates. The mapping from the ideal coordinates to the distorted coordinates is defined as follows:

$$x_{distorted} = x / (1 + sign(k_1)*k_1*r^2 + sign(k_2)*k_2*r^4 +...+ sign(k_{15})*k_{15}*r^{30})$$
$$y_{distorted} = y / (1 + sign(k_1)*k_1*r^2 + sign(k_2)*k_2*r^4 +...+ sign(k_{15})*k_{15}*r^{30})$$

Where *r* is the radius, k_1 to k_{15} are the distortion coefficients.

OCV Rational Model

The Rational Model in OpenCV is used for calibrating high-distortion lenses, such as fisheye lenses or wide-angle action cameras.

Standard camera models use simple polynomials to correct lens distortion. For extreme wide-angle lenses, however, this approach breaks down at the image corners. The rational model addresses this by modeling radial distortion as the ratio of two polynomials (a rational function). This gives the model the flexibility to fit steep distortion curves without becoming unstable.

$$x_{distorted} = x * ((1 + k_1*r\^2 + k_2*r\^4 + k_3*r\^6) / (1 + k_4*r\^2 + k_5*r\^4 + k_6*r\^6))$$

$$y_{distorted} = y * ((1 + k_1*r\^2 + k_2*r\^4 + k_3*r\^6) / (1 + k_4*r\^2 + k_5*r\^4 + k_6*r\^6))$$

Rational Model

Based on the publication “A Rational Function Lens Distortion Model for General Cameras” by David Claus and Andrew W. Fitzgibbon.

Tangential distortion

In the default configurations, only the radial distortion is taken into account. The tangential distortion is set to zero. If you set it to be variable, the formula applied for tangential distortion is the same for all models.

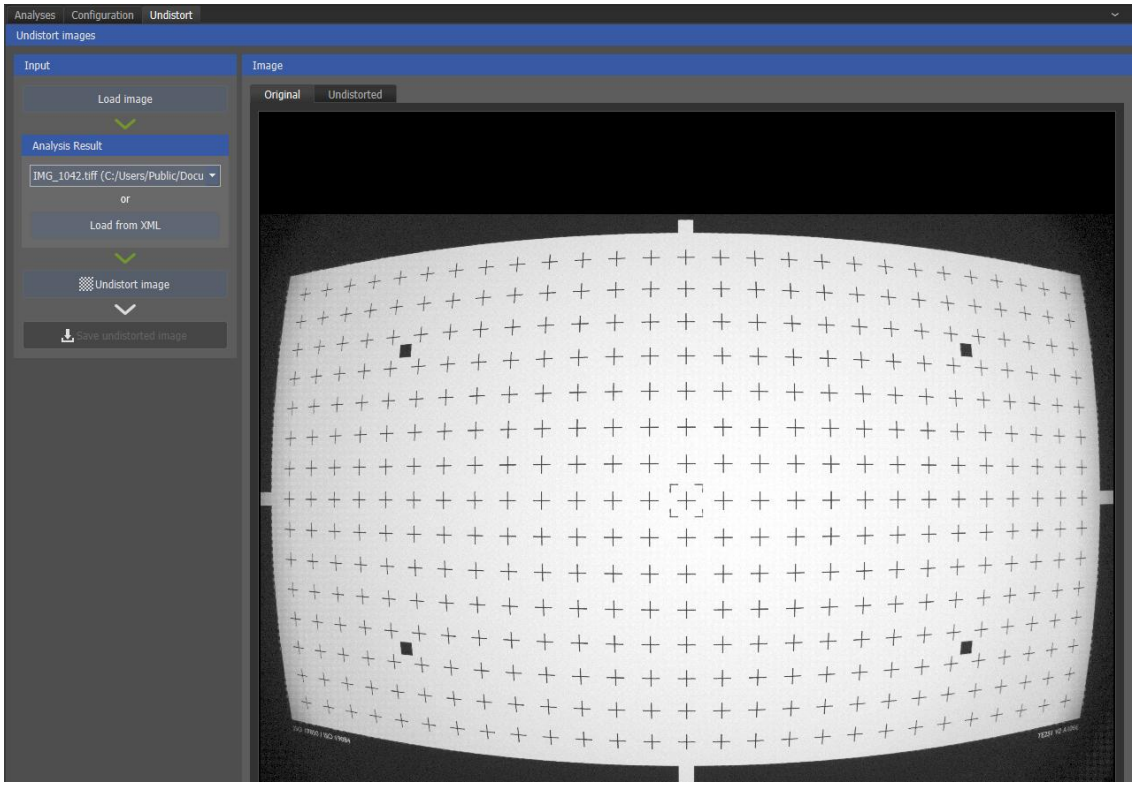
$x_{distorted} = x + [2p_1xy + p_2(r^2 + 2x^2)]$

$y_{distorted} = y + [p_1(r^2 + 2y^2) + 2p_2xy]$

10.13 Undistortion of images

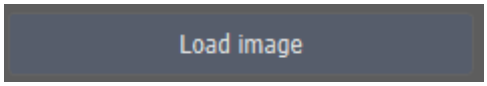
For two distortion models, Even Brown and Fisheye, the software offers a basic undistort function in the “Undistortion” tab. This feature allows you to visually verify the accuracy of the measurement results.

Please note that not every calibration for these models can be used for distortion correction. For the Fisheye Model, only calibrations with up to four radial coefficients are possible. Tangential coefficients are not taken into account and are set to zero. For the Even Brown Model, you can use calibrations with up to three radial and two tangential coefficients for distortion correction.



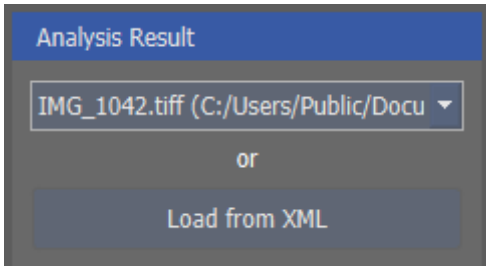
First, you need to perform a geometric calibration. The result of the calibration is then available in the drop-down menu.

Load an image containing straight lines or other straight patterns.



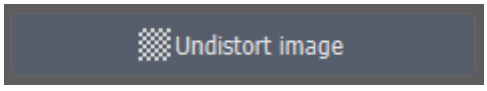
Please note that the GEOCAL grid is not equidistant, and therefore it is not suitable for visually assessing distortion!

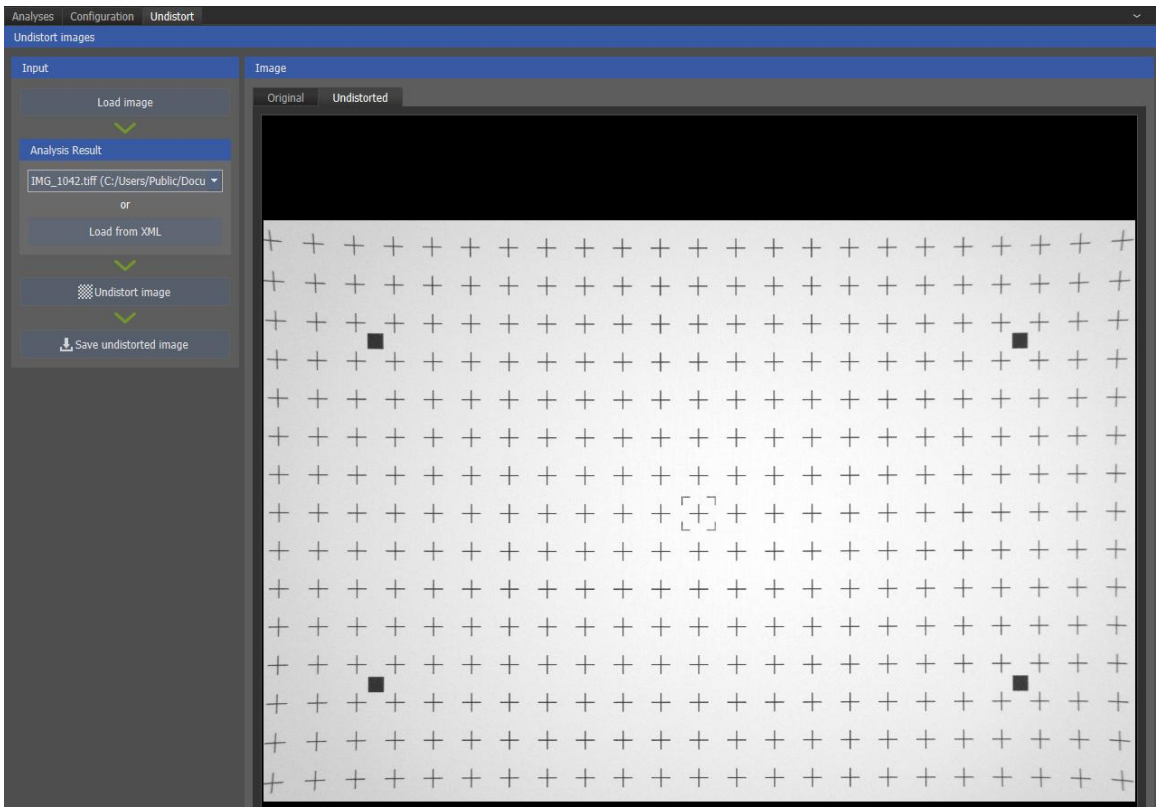
Now select the result you want to apply.



You can also load a .xml result file.

Click on “Undistort image” to start the process.





For further documentation or editing you can save the image.

11 Command Line Interface (CLI)

GEOCAL offers a CLI for automating simple tasks such as performing geometric calibrations on a batch of images with different configurations. This may be useful, for example, to find the best configuration for your application.

By typing C:\Program Files\Image Engineering\GEOCAL 1.5.0> geocal.exe -h into the command prompt, all available commands are listed.

```
Options:
  -c, --config, --configuration <configuration>  Defines the configuration that
                                                 is used for this analysis. This
                                                 may be the name of a known
                                                 configuration in the UI
                                                 application or a path to
                                                 configuration file.
  -l, --configurationList                        Prints out a list of available
                                                 configuration names from
                                                 application for use with the -c
                                                 option.
  -x, --xml <xml>                                Defines the XML output file
                                                 names.
  -v, --csv <csv>                                Defines the CSV output file
                                                 names.
  --exportXML <exportXML>                        Defines whether a XML output
                                                 will be created (e.g.
                                                 --exportXML=yes)
  --exportCSV <exportCSV>                        Defines whether a CSV output
                                                 will be created (e.g.
                                                 --exportCSV=no)
  --configMode <configMode>                      Defines the configuration
                                                 processing mode (mixed or
                                                 iterativ)
  -m, --mergeImages <mergeImages>                Merge two image files (bright
                                                 and dark). Enter two image file
                                                 paths (e.g. -m imageBright.png
                                                 -m imageDark.png
  -?, -h, --help                                 Displays help on commandline
                                                 options.
  --help-all                                     Displays help, including
                                                 generic Qt options.
```

An example script for batch processing is located here:

C:\Program Files\Image Engineering\GEOCAL 1.5.0\GEOCAL_CLI_cross_analysis_batch_v1.5.bat

12 Troubleshooting

12.1 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 15.1 - Service addresses)

12.2 Fault and error messages

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

Observation	Possible error	Possible solution
Control LED on the back does not light up	Power supply interrupted, defect in the device	Check all plug connections. If the error persists, test a different desktop power supply or contact Image Engineering Support.
No laser light is emitted	Laser switched off, laser holder internally misaligned due to 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.

12.3 Eliminate faults

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

Please contact our support team.

13 Care notes and recycling

13.1 Care

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

NOTE
Make sure that you always use a clean cloth to clean the DOE to avoid scratches, which can otherwise lead to disturbing visual effects.

13.2 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 return shipment or would like a return slip, please contact one of Image Engineering's service addresses.

14 Technical data

Overview

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

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 threads in the base plate GEOCAL XL: 10 x M5 x 0.8 internal threads in the base plate

Illumination
(WARNING: Visible or invisible laser radiation!)

Light source	Frequency-stabilized laser diode
Wavelength	GEOCAL / GEOCAL XL: 638 nm GEOCAL IR: 935 nm
Optical power	5 mW
Laser class (diode only)	3B
Laser class (GEOCAL)	1M
Service life	>20,000 h
Warm-up time	Not required

Software

System requirements	PC with Windows 10 operating system (or newer), USB connection
Functions	Load multiple recordings Show recordings Perform calibration Display detected point grid as 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++)	Optionally available separately

General description of the hardware

Power consumption	Pmax = 2 W at 5 VDC
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).

15 Appendix

15.1 Service addresses

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

Europe

Image Engineering GmbH & Co. KG
Im Gleisdreieck 5
50169 Kerpen
Germany

Mon–Fri: 9 a.m. to 5 p.m. (CET)

Tel: +49 2273 99 99 1-0

Email: info@image-engineering.de

USA

Image Engineering GmbH & Co. KG
Im Gleisdreieck 5
50169 Kerpen
Germany

Phone: +1 408 386 1496

Email: sales@image-engineering.us

China

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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
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