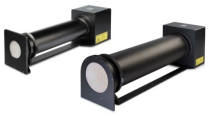
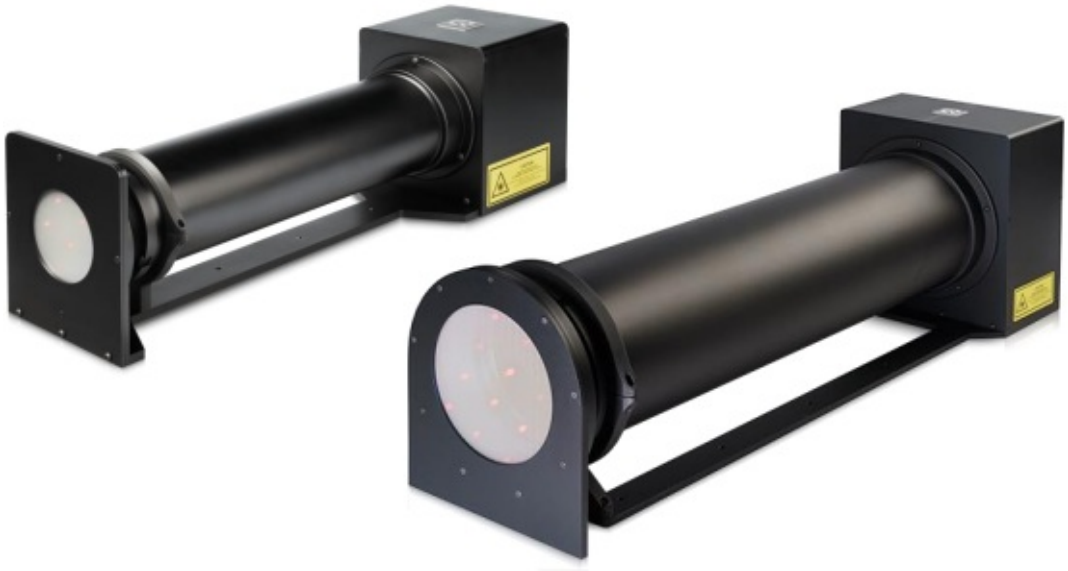


Image Engineering GEOCAL XL Measurement Device User Manual

Contents

Image Engineering GEOCAL XL Measurement Device



INTRODUCTION

Important information:
Read the manual carefully before using the device. Inappropriate utilization may cause damage to the device.

Conformity
We, Image Engineering GmbH & Co. KG hereby declare, that GEOCAL/GEOCAL XL corresponds to the essential requirements of the following EC directives

- 2011/65/EU – RoHS 2
- 2014/35/EU – Low Voltage
- 2014/30/EU – Electromagnetic Compatibility

and standards or normative documents:

- EN 61326-1:2013 – Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements
- EN 61000-3-2:2014 – Electromagnetic compatibility (EMC) – Part 3-2: Limits – Limits for harmonic current emissions
- EN 61000-3-3:2013 – Electromagnetic compatibility (EMC) – Part 3-3: Limits
- EN 62471-2:2009 – Photobiological safety of lamps and lamp systems
- DIN EN 60825-1 – Safety of laser products – Part 1: Equipment classification and requirements

Intended use
GEOCAL/GEOCAL XL consists of an illuminating hardware device and software for geometric calibration of camera systems. The GEOCAL software is used for calculating the calibration parameters from a single image taken with a camera system of the point grid generated by the GEOCAL hardware device.

- Only suitable for indoor use.
- Place the system in a dry and constant tempered environment. Avoid high air humidity.

General safety information

WARNING! GEOCAL uses a laser diode for illumination.

LASER RADIATION CLASS 1M LASER PRODUCT

- Do not stare into beam
- Do not view directly with optical instruments
- Do not open the housing of GEOCAL/GEOCAL XL under any circumstances

GETTING STARTED

Scope of delivery

- GEOCAL/GEOCAL XL hardware device
- Latest software version on USB storage device
- Power supply + cable
- USB cable (type B to type A)
- Test report

Commissioning

- Remove the packaging material.
- The power socket and the main power switch are located on the back side of the device next to the USB type B socket.
  Connect GEOCAL to a power outlet and switch it on.
  Please note: the blue LED next to the power switch indicates that the power line is active and GEOCAL is ready for operation.
- Install the latest GEOCAL software (Windows, 64bit)

OPERATING INSTRUCTIONS HARDWARE

GEOCAL / GEOCAL XL

- After switching on, GEOCAL / GEOCAL XL is ready for use. No warm-up phase is required.

Diffractive Optical Element (DOE)

A diffractive optical element (DOE) is used to split the incoming beam of light and generate a calibration grid of evenly distributed light spots with a wavelength of 633 nm. The DOE is mounted on the front of the GEOCAL / GEOCAL XL device (visible glass plate mounted in circular cutout, see Figure 2).

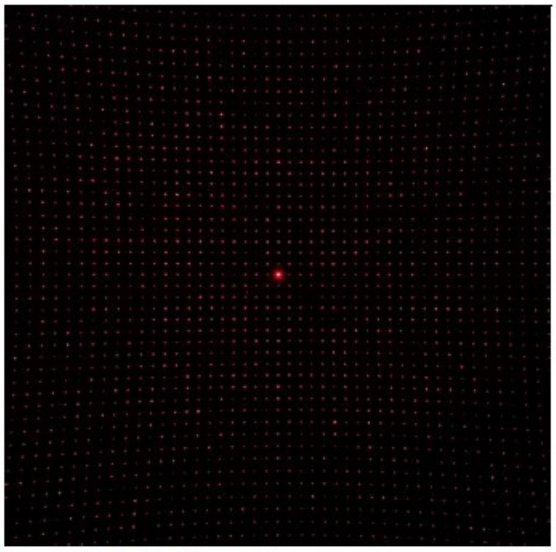


Figure 1: Calibration grid
(the brightest spot marks the center)

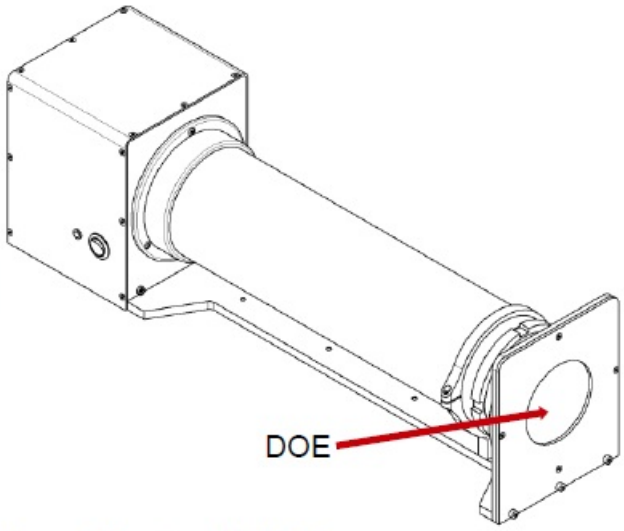


Figure 2: Location of the DOE

Camera settings

Set the camera to manual exposure mode. If manual mode is not available, use the automatic exposure mode. For best results, the image should be saved in a lossless image format. TIFF format is recommended, PNG and JPEG (lossy) are also supported. If you convert RAW image data to another format, make sure the image is being debayered in the process. Auto focus must be turned off. Since GEOCAL uses a collimated light beam virtually originating from infinity, the appropriate focus distance will be near infinity. Using manual focus, make sure that the camera is focused on the light points.

- **Exposure program** Manual
- **Aperture** No default value
- **ISO Speed** Lowest value (e.g.,100)
- **Auto focus** Off
- **File type** TIFF recommended, PNG and JPEG also supported

Camera position and suitable lenses

Place the camera in front of the diffractive optical element that is located in the circular opening on the front of GEOCAL. The camera can be placed directly in front of the DOE, no minimum distance is needed (view Figure 3 below). The principal axis of the lens should be aligned approx. perpendicular to the DOE. Do this by aligning the 0th diffraction order, which is the brightest spot in the center of the grid, with the center of the image. See Figure 4 for reference. Make sure that the point grid covers the whole image and that the border of the DOE is not visible.

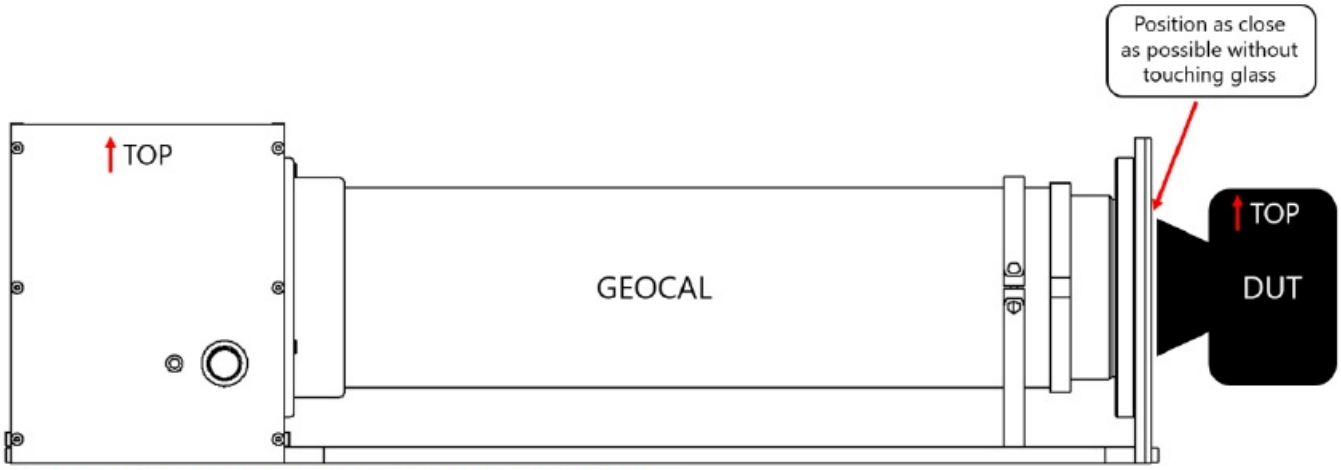


Figure 3: Setting the distance between camera and GEOCAL

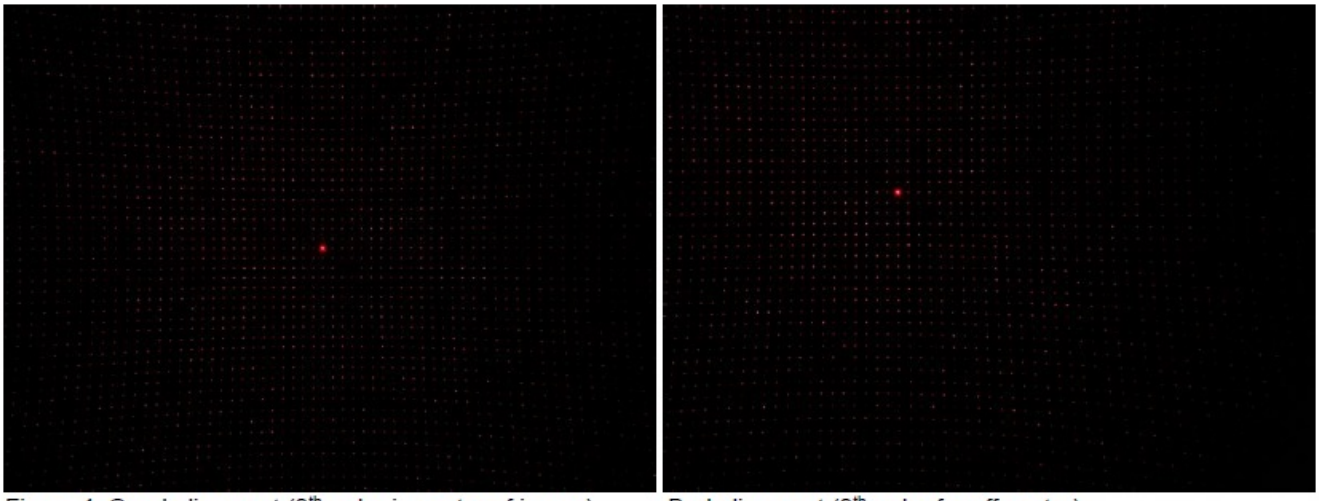


Figure 4: Good alignment (0^{th} order in center of image) Bad alignment (0^{th} order far off center)

The top side of Geocal and the top side of the camera must have the same orientation. A rotation of the camera around the optical axis of approx. +/- 2° will be tolerable.
No further alignment steps are necessary. The mapping of the light points is not influenced by the translation of the camera. The rotation of the camera to the DOE is part of the calibration and is determined during the process and reported as part of the result. The front element of the lens must not be larger than 77 mm in diameter in order to capture the point grid in full format. GEOCAL has been tested using various lenses with a field of view between 30° and 120°. Avoid using lenses that exceed or fall below these values, otherwise, no reliable calibration results can be guaranteed.

Note: Please use caution when positioning the camera. The DOE is made of glass and has a thickness of only 1.5 mm. Ensure that the calibration is performed in a dark environment to avoid stray light, reflections, or similar interfering 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 minimal amount of white pixels in the center of each point) with excepton of the 0th diffraction order. The 0th order will always be much brighter than the points surrounding it. See Figure 5 below for an example.

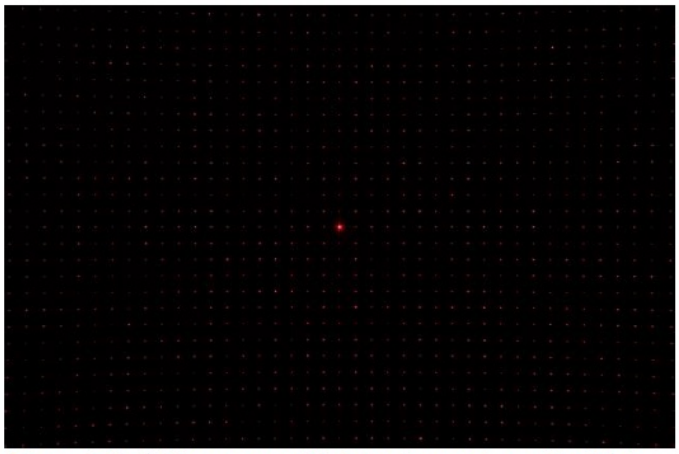
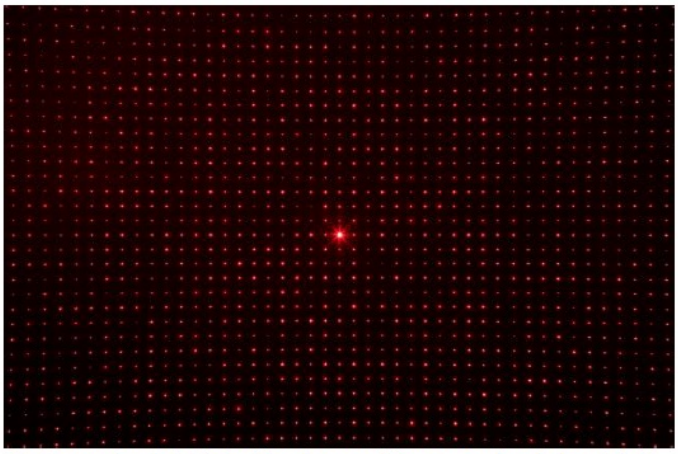


Figure 5: Suitable exposure (dark backgroumd, small points)



Exposure too bright (red background, larger, saturated points)

Depending on your camera you might encounter different problems:

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

- Set the ISO to the lowest native value available (ISO 100 for most cameras)
- Stop down the aperture if possible
- If the image is still too bright, you could use an ND-Filter to reduce the amount of light reaching the image sensor

The intensity dropoff is too steep towards the edges of the image. There are no more points visible. This problem may occur for ultra wide-angle lenses. If the images can not be properly analyzed, try the following. Generate an HDR image by taking multiple images of the point grid using a range of exposure times (do not change aperture settings in this case) and combine them to a high dynamic range image in order to achieve more or less uniform exposure across the entire sensor. Do not change the orientation of the camera in between images because the points would be no longer aligned to one another through multiple images.

DIFFERENCES BETWEEN GEOCAL AND GEOCAL XL

The key difference between GEOCAL XL and the standard GEOCAL is the physical size of the diffractive optical element (DOE) that generates the point grid. While the standard GEOCAL has a usable diameter of 77 mm, the GEOCAL XL provides a usable diameter of 155 mm.

Why a larger version of the GEOCAL?

- A larger DOE is needed whenever the device under test (DUT) can not be placed directly in front of the DOE, for example when the windshield of a car is involved. As mentioned in chapter 3.3.1 “Camera position and suitable lenses”, the generated point grid needs to cover the entire camera sensor in order to provide a reliable calibration.

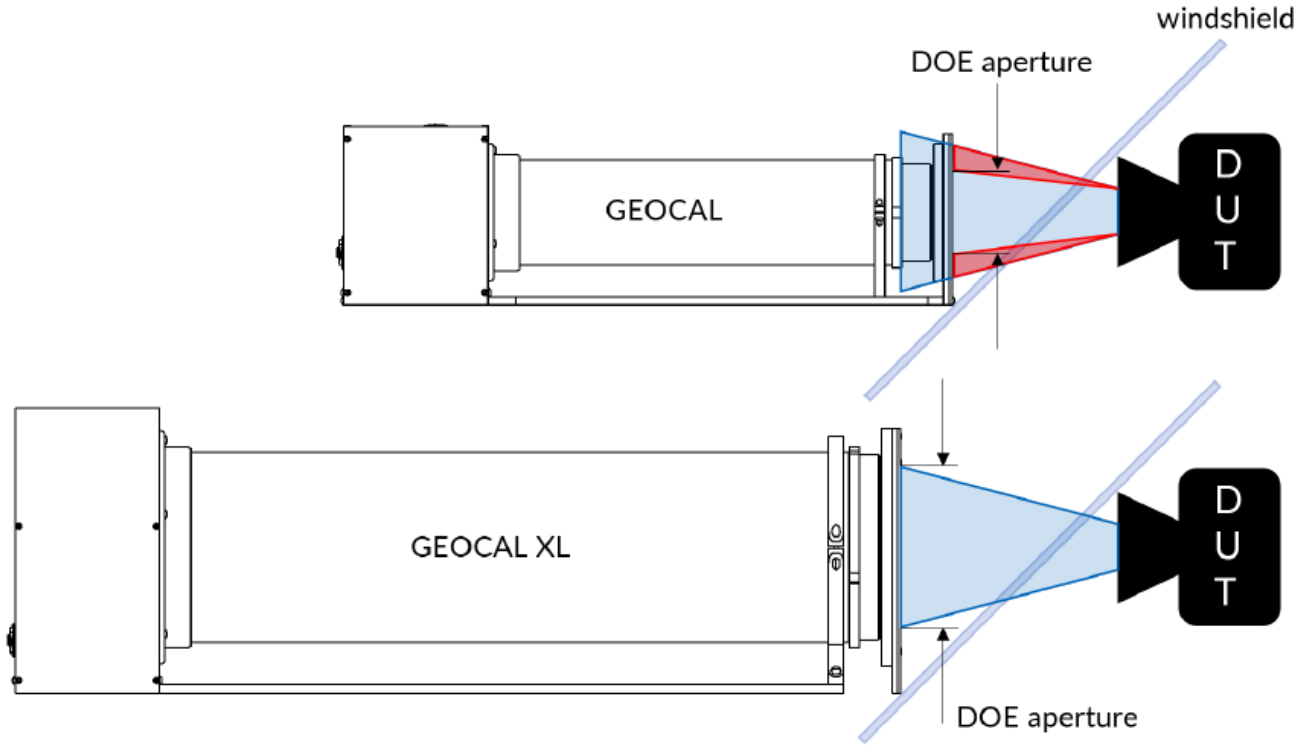


Figure 6: Use case for the larger DOE provided in the GEOCAL XL

As illustrated in Figure 6 above, the angle of the windscreen prevents the standard geocal from being placed close enough to the camera to provide a full-frame image of the standard DOE. This would result in a less precise and less reliable calibration.

OPERATING INSTRUCTIONS SOFTWARE

The GEOCAL software enables you to perform a complete calibration of your camera system in a matter of seconds. The results can be saved as CSV or XML files.

Installing GEOCAL software

- Execute the GEOCAL installer (GEOCAL_Vx.x.x.exe, 64 bit) and follow the instructions.
- The software is now ready for use.

Configuration File (XML)

A standard config file will be installed with the software. If your calibration does not require very specific settings you do not need to load a config file manually or manipulate the existing one. At each program start the default configuration is executed. If you have your own default settings, you can modify this file so that your settings are loaded at program start. You can find and manipulate the default settings here "…\AppData\Roaming\Image Engineering\GEOCAL". If you do need to make adjustments, the parameters of the config file are listed below.

- **Device Parameter:** Wavelength

  This parameter describes the wavelength of the built-in laser.
- **Device Parameter:** GratingConstant

  This parameter descirbes the grating constant of the built-in DOE.
- **Control Parameter:** MinF

  This parameter describes the stop strategy, at which optimization value 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.

- **Control Parameter:** MinDelta

  This parameter describes another stop strategy. When the change of the optimization value between two iterations is less than the delta, the analysis stops (0.0…10.0 – default: 1e-7).

  The smaller the value, the more accurate the analysis becomes, but the analysis time also increases.
- **Detection Parameter:** Margin

  This parameter is used to set a detection margin. It happens that points at the edge of the image cannot be detected properly. With this parameter you can ignore the edge.
- **Distortion Model:** Model

  With this parameter the model can be selected. Currently the following models are implemented:
  - EVEN_BROWN_MODEL, CUSTOM_MODEL_1 (for more informations about the models take a look in to the API documentation)
- **Analysis Parameter:** angles Alpha and Beta

  These angles describe the orientation of the diffractive optical element to the incident expanded and collimated beam of light. They are determined during the acceptance procedure at Image Engineering and written in the config file. These values may not be changed unless the diffractive optical element has to be replaced. Nevertheless, they can, for example, be set to zero for troubleshooting.
- Analysis Parameter: angles Omega (roll), Phi (pitch), Kappa (yaw)

  These angles describe the orientation of the device under test to the diffractive optical element. These values are determined during calibration and output as results. Nevertheless, they can be set to a fixed value for troubleshooting.
- Analysis Parameter: Radial Distortion Coefficients 1-5 The radial distortion coefficients model this type of distortion. The distorted points are denoted as: xdistorted = x(1 + k1*r2 + k2*r4 + k3*r6 + k4*r8 + k5*r10) ydistorted= y(1 + k1*r2 + k2*r4 + k3*r6 + k4*r8 + k5*r10)

  These values are determined during calibration and output as results. However, they can be set to a fixed value for troubleshooting.
- Analysis Parameter: Tangential Distortion Coefficients 1+2 The tangential distortion coefficients model this type of distortion. The distorted points are denoted as:
  - xdistorted = x + [2p1xy + p2(r^2 + 2x^2)]
  - ydistorted = y + [p1(r^2 + 2y^2) + 2p2xy]

    These values are determined during calibration and output as results. However, they can be set to a fixed value for troubleshooting.
- Analysis Parameter: Focal Length X and Y

  The focal length values of the device under test in X and Y are determined during calibration and output as results in pixel dimensions. Nevertheless, they can be set to a fixed value for troubleshooting.
- Analysis Parameter: Skew coefficient

  The skew coefficient is set to 0 by default. It is non-zero if the image axes are not perpendicular.
- Analysis Parameter: Principal Point The principal point (optical center) describes the point where the optical axis of the camera lens intersects the image sensor. It is determined during calibration and output as a result. Nevertheless, it can be set to a fixed value for troubleshooting.

To make changes to the standard config file, open it in a text editor. It is advised to make a copy of the standard version before editing it.

Version:
<Configuration Version=”3″ Description=”Translation”>
Installing the latest software always installs the latest configuration file. Make sure that you always use the latest version. The latest version of the configuration file is “2”.

Editing Control Parameters:

Example: <MinF Use=”false”>0.1</MinF>
The “Use” flag indicates if the following value is used for the calibration procedure. If it says “false”, it is not used and the standard value is used instead. To use a custom value, write “true” instead of “false” and change the value (“0.1” in this example) as desired. The new value will be used in every calibration until you set the “Use” flag back to “false” again.

Editing Analysis Parameters:

Example: <Alpha IsInvariant=”false” UseAsStartValue =”false” Unit=”Degree”>0</Alpha>

The “IsoInvariant” flag indicates if the following value is calculated during calibration or set to a fixed value. If it is set to “false”, the value is calculated in each calibration. 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 will be used in every calibration until you set the “IsInvariant” flag back to “false” again. With the “UseAsStartValue” flag you can set a start value for the analysis. If you set the flag to “true”, the following value will be used as start value. If you set the flag to “false”, the default value will be used. The default is always “0”. Except for the focal length and principal point, for the focal length a speculation is automatically made after the detection. For the principal point the center of the image is taken as default.
If the “IsInvariant” flag is set to “true”, the “UseAsStartValue” flag is ignored.

Loading a config file: Click File → Load configuration (ctrl+c) → navigate to the folder containing the file → select the file and click “open”.

Loading images for analysis

Click File → Load images (ctrl+o) → navigate to the folder containing the images → select one or multiple images and click “open”. In the current state, the software supports the analysis of 8bit and 16bit images. The following file types are supported (debayered images): .TIFF, .JPG, .PNG Images for analysis need to be taken so that the point grid fills the sensor completely.

Delete images
Right-click on the selected image in the list to open a delete option.

Image analysis

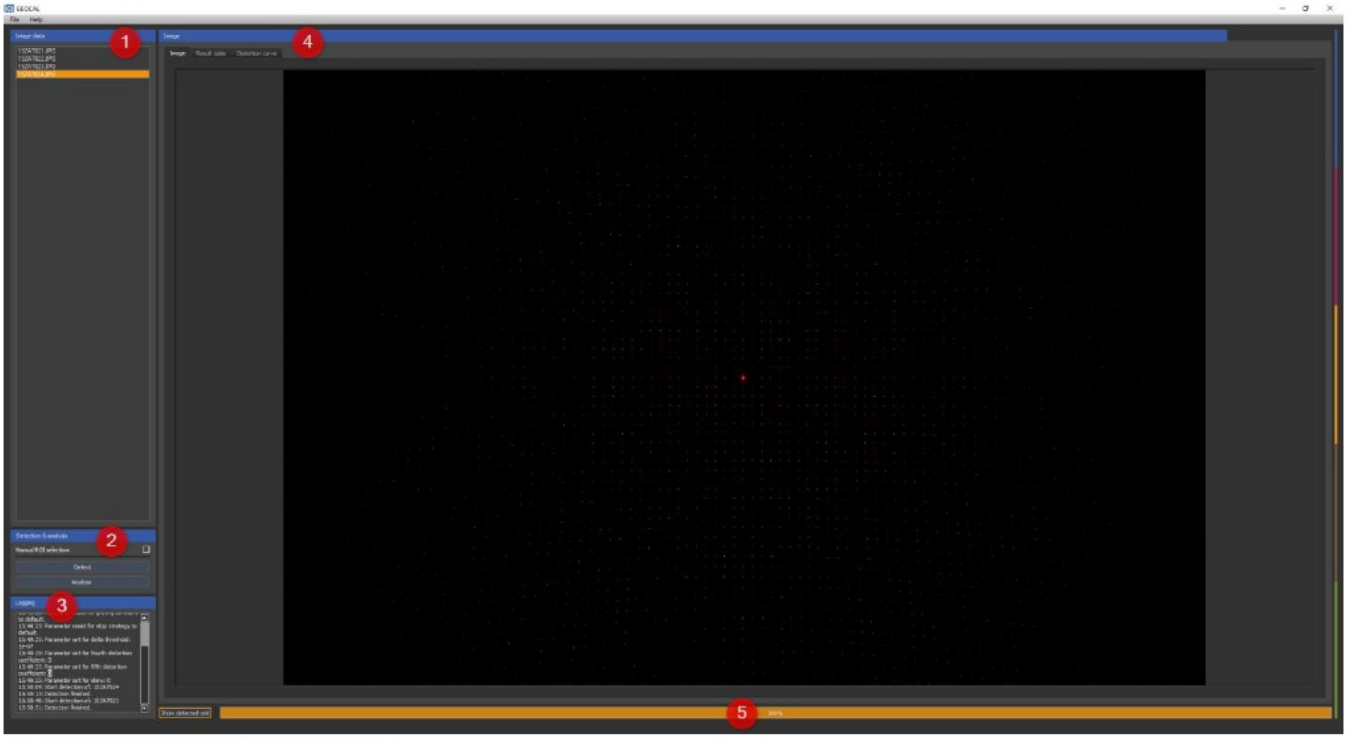


Figure 7: Software user interface overview

- **Image selection:** Select an image from the list in the “Image data” section (1). The image will then be visualized in the “Image” section (4) under the “Image” tab. You can zoom into and out of the image using your mouse wheel. The zoom will be centered around the position of your cursor.
- **Point detection:** Detect the points in the image by pressing the “Detect” button in the “Detection & analysis” (2) section.

  Detection is finished when the progress bar at the bottom of the window (5) reaches 100%. By pressing “Show Detected Grid” next to the progress bar, you can display a visualization of the detected/undetected points.

For a successful analysis, it is not necessary to detect all of the points. If auto-detection fails, you can do a manual ROI selection by setting the checkmark in the “Detection & analysis” section (2). Five preset ROIs will then appear in the visualized image. Size and position of these ROIs are adjustable by click&drag. One ROI must be positioned on the 0th diffraction order (the brightest point in the center of the grid). Adjust the ROI size so that it contains only one point. The four remaining ROIs must be positioned on the four points closest to the 0th diffraction order, i.e., the one above, below, to the left and to the right. These four ROIs may also only contain one point. Furthermore, the individual ROIs should not overlap too much. See Figure 8 below for reference.

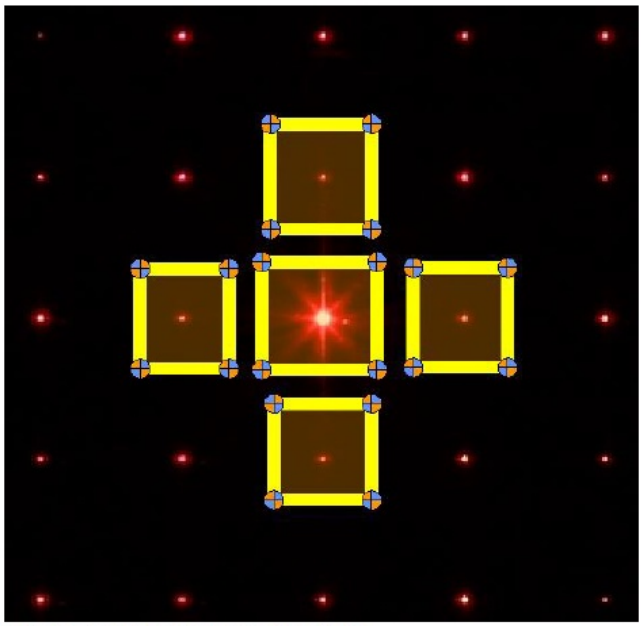


Figure 8: Manual point detection

- **Analysis:** After detection, the actual analysis can be performed. Click on the “Analyze” button in the “Detection & analysis” section (2) to start the calibration. The progress bar (5) indicates when the calibration is finished. Depending on the number of points to be detected, the time needed for calibration may vary slightly.
- **Calibration results:** the results will be listed unter the “Result table” tab in the “Image” section (4). Please find an explanation of the values in chapter 4.2 of this manual. The RMSE of the calibration is also included in the result table. If needed, you can clear the result table by clicking “clear table”. Under the tab “Distortion curve” you also get a graphical visualization of the determined distortion of the camera (Geometric Distortion vs. Field).

Saving results

You have the option to either save your results to an XML or CSV type file. If you have analyzed multiple images, select the one of which you would like to save the results from the list in the “Image data” section. Then click File → Save result → Save XML or Save CSV → navigate to the desired location → click Save

Export Grids

You can export three different grids. These are saved in CSV files. For each exported grid two files are saved, one for the x and one for the y coordinates. To export a grid click File → Save grid → choose the desired grid → navigate tot he desired location → click Save.

Available grids:

- **detected grid:** Describes the grid type, which contains the detected light points.
- **reprojected grid:** Describes the grid type that contains the reprojected light points used to determine the distortion.
- **undistorted reference grid:** Describes the grid type, which contains the points of the reference grid without lens distortion. This grid contains only distortion given by the DOE physics, the determined extrinsic and instrinsic parameters.

Plotting

There are several plots available:

Grid view

After a successful analysis, the detected points and reprojected points are displayed on the original image. To see them better, you can zoom into the image. The points have a size of one pixel.

Distortion curve
The curve is calculated from the distortion coefficients and shows the grad of the analyzed distortion. 5.7.2 Quiver plot The quiver plot shows the direction of deviation. The respective arrows show how the detected points are located in relation to the reprojected points.

2d Color scatter
This plot shows a grid of color coded points. Each point represents the distance ratio between detected and reprojected points. The scalar on the right side shows the individual color coding.

Histogram
Two different histograms are shown. The first histogram contains the successfully detected diffraction points in dependence of the radius. The values start at zero (principal point) and run along the image diagonal to the image corner (one). The second histogram contains the successfully detected diffraction points in dependence of the angle. The values start from a straight line defined from the principal point to the right edge of the image. The angles increase counterclockwise.

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

Quit
To exit the software, click File → Quit (ctrl+q) or simply close the window.

TRADEMARK AND COPYRIGHT

- **Trademarks**

  Windows is a registered trademark of Microsoft Corp.,
- **Copyright Information**

  See separate Terms and Conditions document.

ADDITIONAL INFORMATION

Disposal instructions
After the service life of GEOCAL, it must be disposed properly. Electrical and electromechanical components are included in GEOCAL. Observe all national regulations. Make sure that GEOCAL cannot be used by third parties after disposing of it. Contact Image Engineering if assistance for disposal is required.

Power circuit modification for production line use
If you are planning to use your Geocal on a production line, we offer the option of modifying the unit to eliminate the need to press the switch to turn it on and off. After the modification, it is sufficient to move the switch to the “ON” position. The unit will then start operating immediately when power is supplied, without having to press the switch again. For more information on this option, please contact Image Engineering.

DATA SHEET

Overview

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

Features

Diffractive Optical Element (DOE)	Generates a very evenly distributed grid of light points, virtually originating from infinity
Output window	**Geocal:** Usable aperture: Ø 77 mm **Geocal XL:** Usable aperture: Ø 155mm (camera lens needs to have an equal or smaller diameter)
Usable FoV	Approx. 30 – 120° (more extreme values need to be tested)
Dimensions (l x w x h)	**Geocal:** approx. 575 mm x 144 mm x 170 mm **Geocal XL:** approx.. 850 mm x 244 mm x 270 mm
Mounting points	**Geocal:** 3 x M5x0,8 tapped holes in base plate **Geocal XL:** 10 x M5x0,8 tapped holes in base plate

Illumination (CAUTION: DO NOT LOOK DIRECTLY INTO THE LIGHT SOURCE!)

Light source	Frequency-stabilized diode laser
Wavelength	633 nm
Output power	5 mW
Laser Class (diode only)	3B
Laser Class (GEOCAL)	1M
Lifetime	> 10.000h
Warm-up time	Not required

Software

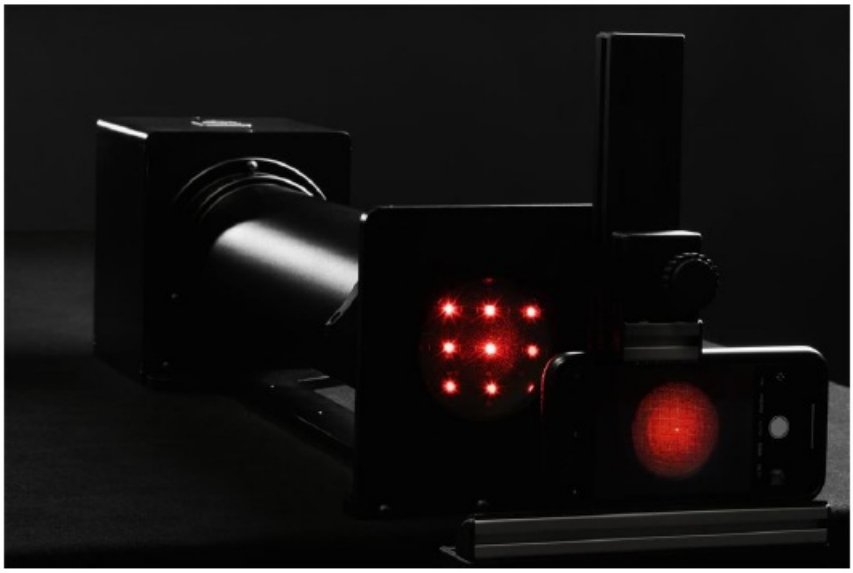
System requirements	PC with Windows 7 operating system (or higher) USB port
Functions	· Load multiple images · View selected image · Perform calibration · Overlay detected point grid · Distortion visualization (graph) · Export results (CSV and XML)
Output data	Camera intrinsic and extrinsic data, the orientation of DOE

General description hardware

Power supply / consumption	25W 5V/5A / Pmax = 2W
Ports	USB type B
Weight	**Geocal:** approx. 4.5 kg **Geocal XL:** approx. 8 kg? **(TBD!)**
Operating conditions	15 – 35°C

Requirements on the device under test (DUT)

Max. dimensions	**Geocal:** max. diameter of the camera lens: 77 mm **Geocal XL:** max. diameter of the camera lens: 155mm
Usable FoV	Approx. 30 – 120° (deviating values will have to be tested)



- Image Engineering GmbH & Co. KG
- Im Gleisdreieck 5
- 50169 Kerpen . Germany
- **T** +49 2234 2273 99 99 1-0
- **F** +49 2234 2273 99 99 1-10
- www.image-engineering.com

Documents / Resources

	Image Engineering GEOCAL XL Measurement Device [pdf] User Manual GEOCAL, GEOCAL XL, GEOCAL XL Measurement Device, GEOCAL XL, Measurement Device, Device

References

- Image Engineering - Solutions to test image Quality