GEOCAL / GEOCAL XL

User Manual

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CONTENT

1 INTRODUCTION

Important information: Read the manual carefully before using the device. Inappropriate utilization may cause damage to the device, to the DUT (device under test), and/or other components of your setup.

Keep these instructions in a safe place and pass them on to any future user.

1.1 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

1.2 Intended use

GEOCAL/GEOCAL XL consists of an illuminating hardware device and software for the 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.

1.3 General safety information

WARNING! GEOCAL/GEOCAL XL uses a laser diode for illumination.

LASER RADIATION CLASS 1M LASER PRODUCT

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

2 GETTING STARTED

2.1 Scope of delivery

- GEOCAL or GEOCAL XL hardware device
- The latest software version on the USB storage device
- Power supply + cable
- USB cable (type B to type A)
- Test report

2.2 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/GEOCAL XL to a power outlet and switch it on.
  Please note that the blue LED next to the power switch indicates that the power line is active and that GEOCAL is ready for operation.
- Install the latest GEOCAL software (Windows, 64bit)

3 OPERATING INSTRUCTIONS HARDWARE

3.1 GEOCAL / GEOCAL XL

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

3.2 Diffractive Optical Element (DOE)

A diffractive optical element (DOE) is used to split the incoming light beam 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).

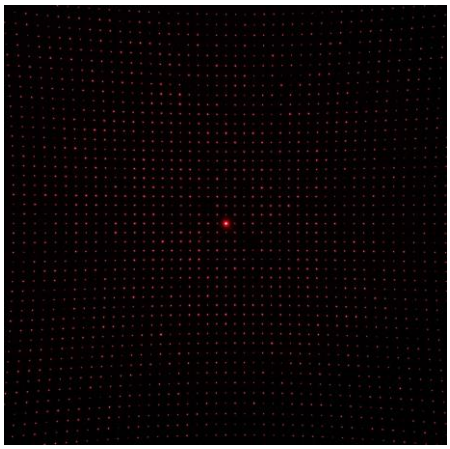

Figure 1: Calibration grid
(the brightest spot marks the center)

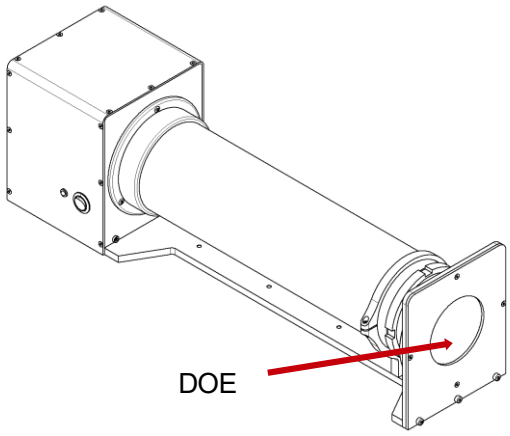

Figure 2: Location of the DOE

3.3 Camera settings

Set the camera to manual exposure mode. If manual mode is not available, use the automatic exposure mode. The image should be saved in a lossless format for best results. TIFF format is recommended, and PNG and JPEG (lossy) are also supported. If you convert RAW image data to another format, ensure the image is debayered in the process.

The autofocus must be turned off. Since GEOCAL / GEOCAL XL uses a collimated light beam virtually originating from infinity, the appropriate focus distance will be near infinity. Using manual focus, ensure the camera is focused on the light points.

Exposure program	Manual
Aperture	No default value
ISO Speed	Lowest value (e.g.,100)
Autofocus	Off
File type	TIFF is recommended. PNG and JPEG are also supported

3.3.1 Camera position and suitable lenses

Place the camera in front of the diffractive optical element in the circular opening on the front of GEOCAL/GEOCAL XL.

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. Achieve this by aligning the 0^{th} diffraction order, the brightest spot in the grid center, 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.

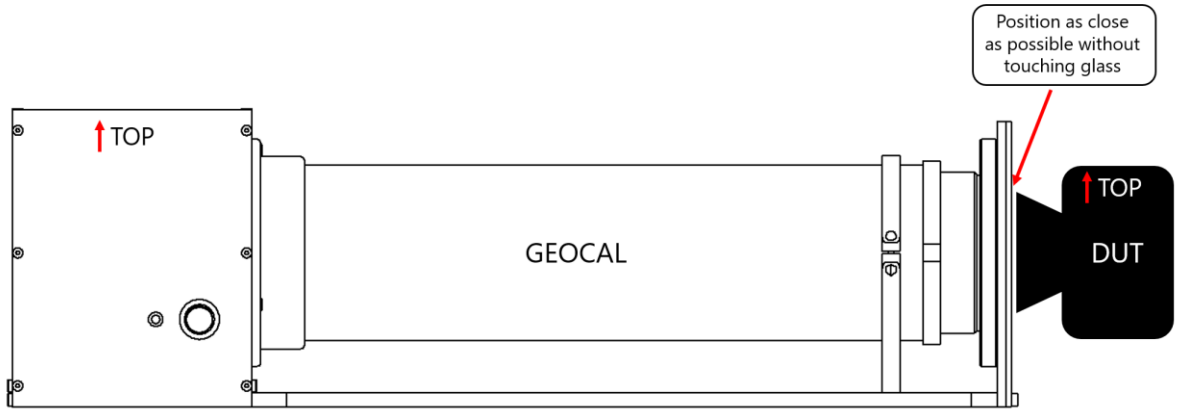

Figure 3: Setting the distance between the camera and GEOCAL/GEOCAL XL

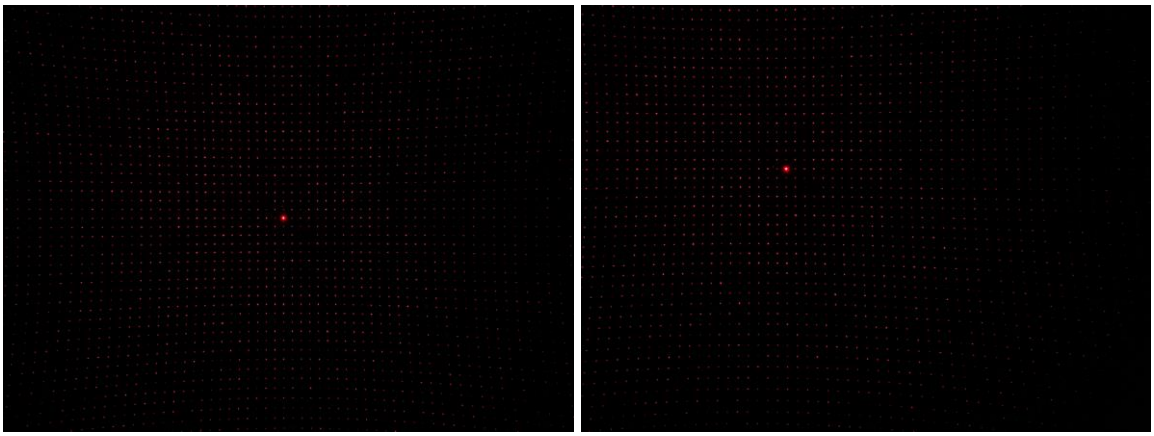

Figure 4: Good alignment (0^{th} order in the center of image) Bad alignment (0^{th} order far off center)

The top side of GEOCAL/GEOCAL XL 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 camera's translation does not influence the mapping of the light points. The camera rotation to the DOE is part of the calibration and is determined during the process and reported as part of the result.

The lens's front element must not be larger than 77 mm in diameter for GEOCAL or 155 mm for GEOCAL XL to capture the point grid in full format.

Note: Please use caution when positioning the camera. The DOE is made of glass and has a thickness of only 1.5 mm.

Ensure the calibration is performed in a dark environment to avoid stray light, reflections, or similar interfering factors.

3.3.2 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 number of white pixels in the center of each point) with the exception 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.

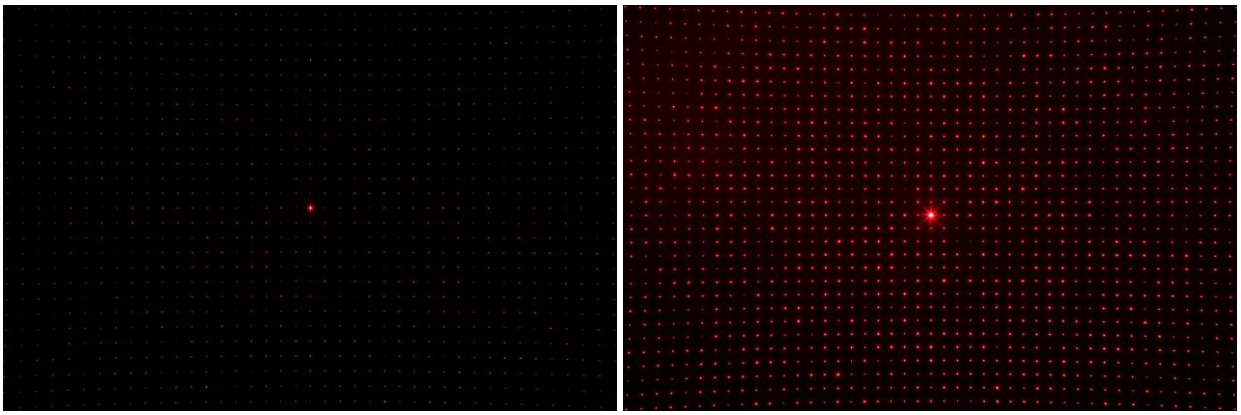

Figure 5: Suitable exposure (dark background, small points) Exposure too bright (red background, larger, saturated points)

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 drop-off is too steep towards the edges of the image, and no more points are visible.
This problem may occur for ultra-wide-angle lenses. If the images cannot be adequately 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 into a high dynamic range image to achieve more or less uniform exposure across the entire sensor. Do not change the camera's orientation between images because the points would no longer be aligned to one another through multiple images.

4 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 functional diameter of 155 mm.

4.1 Why a larger version of the GEOCAL?

A larger DOE is needed when the device under test (DUT) cannot be placed directly in front of the DOE, for example, when a car's windshield 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 to provide a reliable calibration.

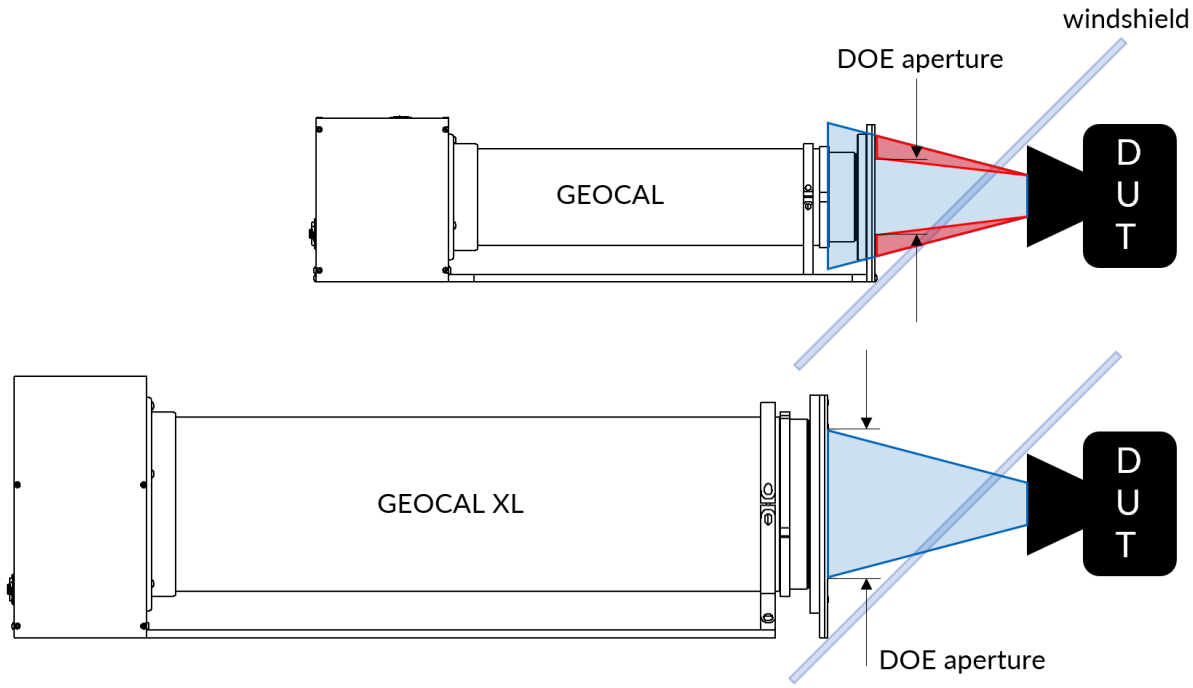

Figure 6: Use case for the larger DOE provided in the GEOCAL XL

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

5 OPERATING INSTRUCTIONS SOFTWARE

The GEOCAL software allows you to calibrate your camera system in a matter of seconds.

The results can be saved as CSV or XML files.

5.1 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.

5.2 Configuration file (XML format)

Four default configuration files in XML format are provided with the software. If your calibration procedure does not require special settings, you can use one of the four configuration files for the desired distortion model. You can modify these files by copying them from the install location in:
C:\Program Files\Image Engineering\GEOCAL 1.x.x\configuration
to some other folder, modify them and then load them with the software for usage.

See document GEOCAL_calibration_models_.pdf for details on the usage of the configuration files.

Loading a config file:

Click File → Load configuration (Ctrl+c) → navigate to the folder containing the file → select the file and click "open."

5.3 Artificial sample images

There are four sample images available, which can be found in this location:
C:\Program Files\Image Engineering\GEOCAL 1.x.x\samples
These images were synthetically created 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_model1.png	CUSTOM_MODEL_1	[1, 0.1, 0.1, 0.1, 0.1, 0.1]
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 various models and the interactions of the parameters in the configuration files, you can use the default configurations given for each model and execute the GEOCAL software on the simulated images. You should obtain results that are close to those used to create the simulated images.

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

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

Images for analysis must be taken so that the point grid fills the sensor completely.

5.5 Deleting images

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

5.6 Image analysis

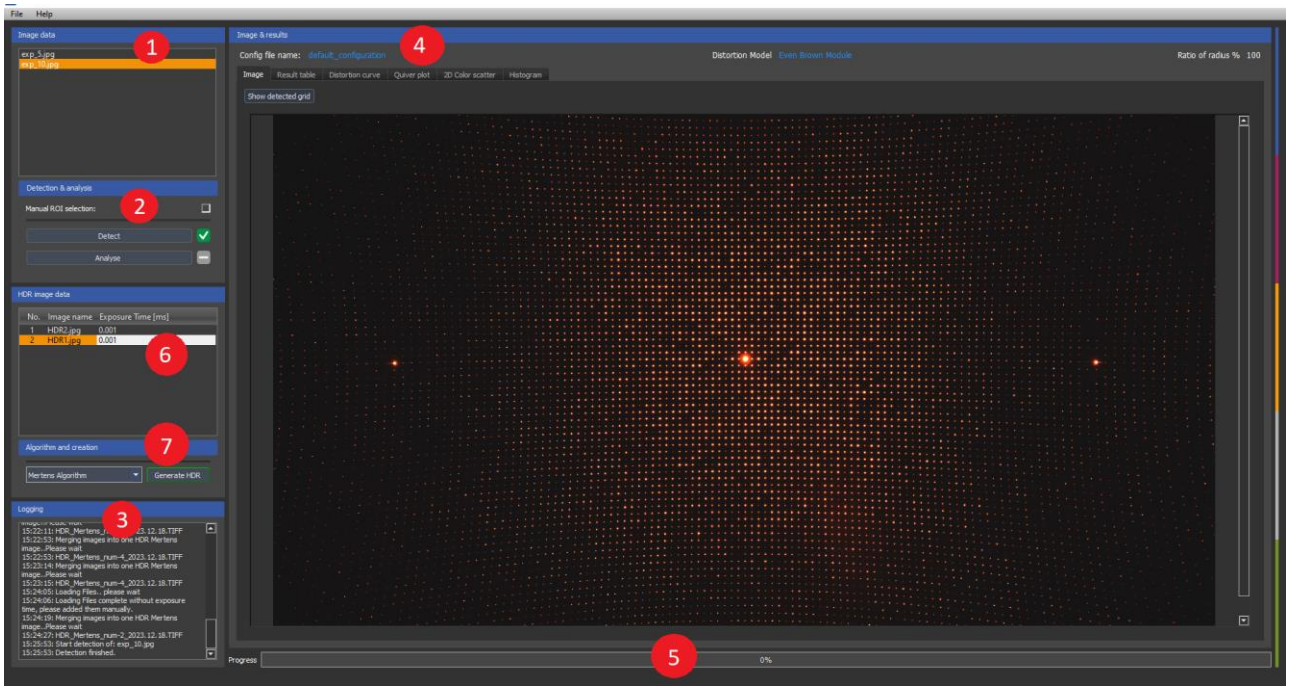

Figure 7: Software user interface overview

- **Image selection:** Select an image from the list in the "Image data" section (1). The image will then be displayed in the "Image" section (4) under the "Image" tab. You can zoom in and out of the image using your mouse wheel; the zoom will be centered around the position of your cursor.
- **Point detection:** Detect the grid points in the image by clicking 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 clicking "Show Detected Grid" under the image tab, you can display a visualization of the detected points.

  If auto-detection fails, you can make a manual ROI selection by setting the checkmark in the "Detection & analysis" section (2). Five preset ROIs will then appear in the visualized image.
  The size and position of these ROIs are adjustable by clicking and dragging.

  One ROI must be positioned on the 0^{th} 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 points closest to the 0^{th} diffraction order, i.e., the one above, below, and to the left and right. These four ROIs may also only contain one point. Furthermore,

the individual ROIs should not significantly overlap. See Figure 8 below for reference.

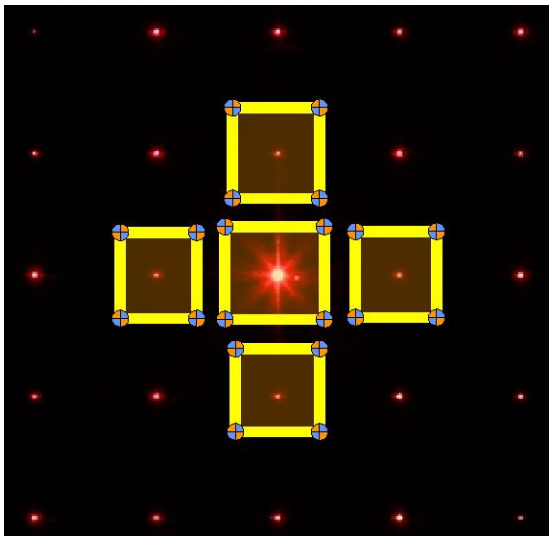

Figure 8: Manual point detection

- **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 detected, the time needed for calibration may vary slightly.
- **Calibration results:** the results will be listed under 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. You can clear the result table if needed 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).
- **Generate HDR image:** Set the exposure times for every HDR image data (6). Choose an algorithm (Mertens, Debevec or Robertson) for the generation and click the “Generate HDR” button (7). A subfolder “HDR” is generated in the HDR image data folder, in which all generated images will be saved.

5.7 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 one or multiple images 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

If you selected multiple images, all results would be saved in one CSV or XML file.

5.8 Export Grids

You can export three different grids, which 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 to the desired location → click Save.

Available grids:

- Detected grid: Describes the grid type containing 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 includes only distortion given by the DOE physics and the determined extrinsic and intrinsic parameters.

5.9 Plotting

There are several plots available:

5.9.1 Grid view

After a successful analysis, the detected and reprojected points are displayed on the original image. Zoom into the image for a clearer view. The points have a size of one pixel.

5.9.2 Distortion curve

The curve is calculated from the distortion coefficients and shows the grid of the analyzed distortion.

5.9.3 Quiver plot

The quiver plot shows the direction of deviation. The respective arrows indicate how the detected points are located concerning the reprojected points.

5.9.4 2d color scatter

This plot shows a grid of color-coded points, with each point representing the distance ratio between detected and reprojected points. The scalar on the right side shows the individual color coding.

5.9.5 Histogram

Two different histograms are shown. The first histogram contains the successfully detected diffraction points dependent on 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 dependent on 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.

5.10 Logging

The 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.

5.11 Quit

Click File (Quit (Ctrl+q) to exit the software or close the window.

5.12 TRADEMARK AND COPYRIGHT

Trademarks

Windows is a registered trademark of Microsoft Corp.

Copyright Information

See separate Terms and Conditions document.

6 ADDITIONAL INFORMATION

6.1 Disposal instructions

After the service life of GEOCAL/GEOCAL XL, it must be disposed of properly. Electrical and electromechanical components are included in GEOCAL/GEOCAL XL. Observe all national regulations. Ensure that third parties cannot use GEOCAL/GEOCAL XL after disposing of it.

Contact Image Engineering if assistance for disposal is required.

6.2 Power circuit modification for production line use

If you plan to use your GEOCAL/GEOCAL XL 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, moving the switch to the "ON" position is sufficient. The unit will immediately start operating when power is supplied without having to press the switch again.

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

7 TECHNICAL DATA SHEET

See the website of Image Engineering: https://image-engineering.de/support/downloads.