GEOCAL FAQ

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Why did you develop GEOCAL?

We saw a need for a compact optical device to quickly calibrate camera-lens combinations to characterize and digitally remove geometric distortion. GEOCAL can also provide the camera's angular orientation (extrinsic) useful for aligning two cameras.

What is the accuracy?

We have achieved at least the accuracy level of conventional test-chart-based measurements. GEOCAL also provides the outer (angular) orientation, which can't be measured with traditional methods.

How good is repeatability?

The repeatability has shown to be very reliable.

What is the device-to-device variation?

We currently do not see a risk for significant device-to-device variation. Quantization is still ongoing.

In the case of calibrating stereo pairs, how long can the stereo base be?

This case depends on the diameter of the DOE (Diffractive Optical Element) and the diameter of the camera's entrance pupil. We currently expect a stereo base of 60 mm for cameras with small lenses for the first GEOCAL device and much larger ones for future devices with larger beam diameters.

Can the wavelength of the laser be modified?

It may be possible to select a laser with a different wavelength, but the laser and the DOE work as a system, and therefore a change in one component needs to be verified in the other. Thus, we start with 633 nm, an excellent choice to bridge visible and IR wavelengths to each other and 935nm specifically for NIR applications.

What is the limit of the distortion model?

We are using rotationally symmetric distortion models, mainly the ones based on open CV. In some cases, e.g., for cameras behind a windshield, this model may not work accurately. Therefore, we are investigating other models that may be more appropriate for some applications.

What is the uniformity of the illumination?

We are working with a DOE and a standard frequency-stabilized laser. This combination creates some variation in uniformity. However, we keep the uniformity high enough to achieve good geometric measurement results within most cameras' dynamic range.

Do you offer evaluation software for GEOCAL?

Yes, we offer a standalone software and a C and C++ API.

What about eye safety?

We use a low-power laser diode with an expanded laser beam and even reduce its power to reach reasonable exposure times with the devices under test. As long as the housing is not opened and the users do not use magnifiers to look into the beam, GEOCAL will not compromise eye safety.

Can GEOCAL be used in a production environment?

Yes. With our experience building hardware for production, we see GEOCAL being useful in development labs and on the production floor, performing geometric calibrations and alignment for a wide variety of cameras.

What are the advantages of the GEOCAL API?

The GEOCAL API allows you to implement GEOCAL functionality into your applications, such as daily workflow software, production line solutions, or device testing applications.

Can the number of dots in the camera sensor be adjusted?

The number of visible dots in the image depends on the field of view. The design of the standard DOE is for a field of view between 30° - 120°. Please contact us if your application is outside of this range. We also offer a DOE with a grating constant of 15µm, which might be an option if your camera is wide angle and low resolution.

Why do we use red light dots instead of white?

We use red light dots because we need monochromatic light. White light consists of different spectra, and, at this time, the only available stabilized laser that uses monochromatic light has a red wavelength. The red wavelength is also the lowest available wavelength.

What is the number of captured points in GEOCAL vs. GEOCAL XL?

The number of points captured by the camera should be the same between the XL and the standard version of GEOCAL. The grating constant and the laser wavelength are the same. Therefore, the angles of the points are also the same in both versions.

The number of points viewed can be approximately derived from the resolution of 0.9° (this is just an approximation! The angle between 0 and the first order is 0.826°, but it increases with higher orders). With an HFoV of 90°, one would have ~100 points horizontally.

Is there any deviation in the grating period, particularly in the higher orders?

There is no outward growing deviation from the manufacturing side, and the grating is constant over the entire DOE.

Measurement of the grid constant of the DOE

The structure of the master DOE was examined under a 3D measuring microscope. The mentioned grid constant of 43.9 x 43.9 um was measured. Direct copies are generated from this master using mask technology. While our supplier has quality assurance processes, we do not get a measurement report on each DOE.

Can the intensity output of GEOCAL be decreased?

It has been discussed before but is currently not planned for implementation.

Point detection - Halo

Some orders are left out from detection because they are affected by Halos from the brighter orders. This affects, for example, the points around the 49th order.

What is your definition of the principal point?

For us, the principal point is the center of distortion, where we would get the best results with the reprojection. We determine the PP with an iterative process, working towards a specific optimization value. We assume the principal point is in the image center and then "look around." The algorithm stops when the distance between the detected and reprojected point is as close as possible for a particular image.

We take the principal point as the center of distortion because the model says so and defines it that way. There are sometimes other names, but they mean the same thing, and according to our definition, these two points are the same.

How can you determine the rotation of the camera relative to the DOE?

The camera's orientation relative to the DOE can be derived from the location of the 0 and 1st orders in the image. As the points are coming from infinity, translation has no influence. That means that an offset of these orders to the image center can only be caused by rotation. We cannot provide the exact calculation.

Can you calculate the magnification?

That's possible as the software calculates the focal length. By the known size of the grid and the focal length, the image scale can be derived, but our software does not provide it as a result.

Can the GEOCAL be used for position determination of the DUT?

The rotation of the DUT is a result of the analysis. The translation cannot be calculated because the rays come from infinity and are thus translation invariant.

Which distortion model is suitable for the study of distortion through windshields?

Currently, only the EVEN_BROWN_MODEL and the OpenCV Fisheye Model are implemented. Both are rotationally symmetric, and symmetry is unfortunately not given with a windshield in front. Therefore, the models are not very suitable. However, you can develop an individual model and ask us to implement it in the software.

How to calibrate cameras with fixed focus, depth of field, and grid detection?

In the best case, the camera can be focused on infinity, but the calibration might also work if the depth of field is limited and the points are slightly blurry. However, other image quality factors like noise or resolution also play a role. Therefore, it makes sense to make some test images, especially when the camera is more on the low image quality end.

However, if the focus is limited to a close distance (e.g., indoor cameras) that is not hyperfocal, then using an infinity method won't be easy.

Implementation of new distortion models

We have designed the software so that we can implement different models on short notice. Please contact our our support team for more details, support@image-engineering.de.

Is the DOE the same for every GEOCAL?

Currently we offer two different DOEs. One is for the standard GEOCAL and has a grating constant of 43.9µm, the other is meant for the GEOCAL IR and has a grating constant of 15µm.

How large are light dots?

They are indefinitely small as they come from infinity.

Is eye safety an issue on the production line?

No, the Laser Device is Class 1m - no harm is expected.

Is there a warm-up time?

No warmup time is needed.

Which effect does the chromatic aberration have on the GEOCAL measurement, and is there any other laser wavelength available in a range of 455-655 nm?

There are no low-power, frequency-stabilized laser diodes available below 632 nm. For this reason, we can unfortunately not offer the requested range.

However, suppose your optical system has a chromatic aberration that is large enough to lead to significantly different distortion coefficients. In that case, you must correct the chromatic aberration anyway, ideally before you fix the distortion. The optical design usually gives chromatic aberration and does not vary significantly from camera to camera. What may change is the principal point, but that can be determined using the GEOCAL and is independent of the chromatic aberration.

So, the workflow that we would suggest if your camera has a significant chromatic aberration would be:

1) Capture the GEOCAL image at the given wavelength

2) Calculate the values for the principal point, angles, and coefficients using the GEOCAL software

3) Correct the chromatic aberration centered around the principal point based on the optical design

4) Correct the distortion using the GEOCAL results

If you don't know the chromatic aberration, it can be measured using one of our grid charts in combination with the iQ-Analyzer-X.

We need to know the separation angle between each spot. Can you please share this value?

We are talking about an angle of 0.826° at the first order, and with orders further out, the angles per step increase slightly. If you want to do the math yourself, the grid constant is 43.9 microns, and the design wavelength of the laser is ~632.8 nm.

For the primary maxima, the following formula is valid:

$$\lambda = \frac{g \cdot \sin \varphi_n}{n}$$

lambda: laser wavelength

g: grid constant

Phi: deflection angle of the considered maximum

n: considered maximum (1, 2, 3, ..., n)

What represents the RMSE (Root Mean Square Error)? Can we consider that it is the distortion calibration error in pixels?

In principle, yes. It is the average deviation between the detected and "reprojected" points. So with the help of the determined angle values, the focal length, the principal point, and the coefficients for the distortion model, the position of the light points is reconstructed or reprojected. This means that not only does the distortion play a role, but there are also deviations in determining the other parameters.

Can the GEOCAL image be used for visual assessment?

No, the grid of the light dots is formed by diffraction generated by the diffractive optical element. Diffraction does not generate a regular grid with equal distances. If you look at the light dots using a camera with no distortion and a wide field of view, the grid formed by diffraction looks like a pincushion-distorted regular grid. When using a camera with a smaller field of view, the diffraction pattern looks as if the pincushion style reduces until it is almost invisible for smaller fields of view. This point means that the light dot images cannot be used to judge the distortion visually!!! To evaluate the distortion, you need to use an actual image of a scene, e.g., depicting a checkerboard or similar.

Were there comparative measurements with other "standard" calibration methods?

We have performed comparison measurements with the classical openCV methods and obtained excellent results.

See the following paper: https://www.image-engineering.de/content/library/conference_papers/2020_03/Wueller_geometric_calibration_paper.pdf

We also did a comparison with the Checkerboard Calibration: https://www.image-engineering.de/library/blog/articles/1262-a-comparison-with-currently-established-geometric-calibration-methods

How are the positions of the individual points detected?

Currently, we determine the center of gravity of the individual light points. Although the results are already very good, we are still optimizing here, which will partly help with aberrations, etc. The exposure should be chosen so that no point is in saturation.

Are all points detected in the image used for the evaluation, or can "outliers" be excluded?

All detected points are included except that a frame can be defined at the edge, which is excluded, e.g., in order not to use clipped points. In the latest software version you can also define a radius for the points which should be taken into account.

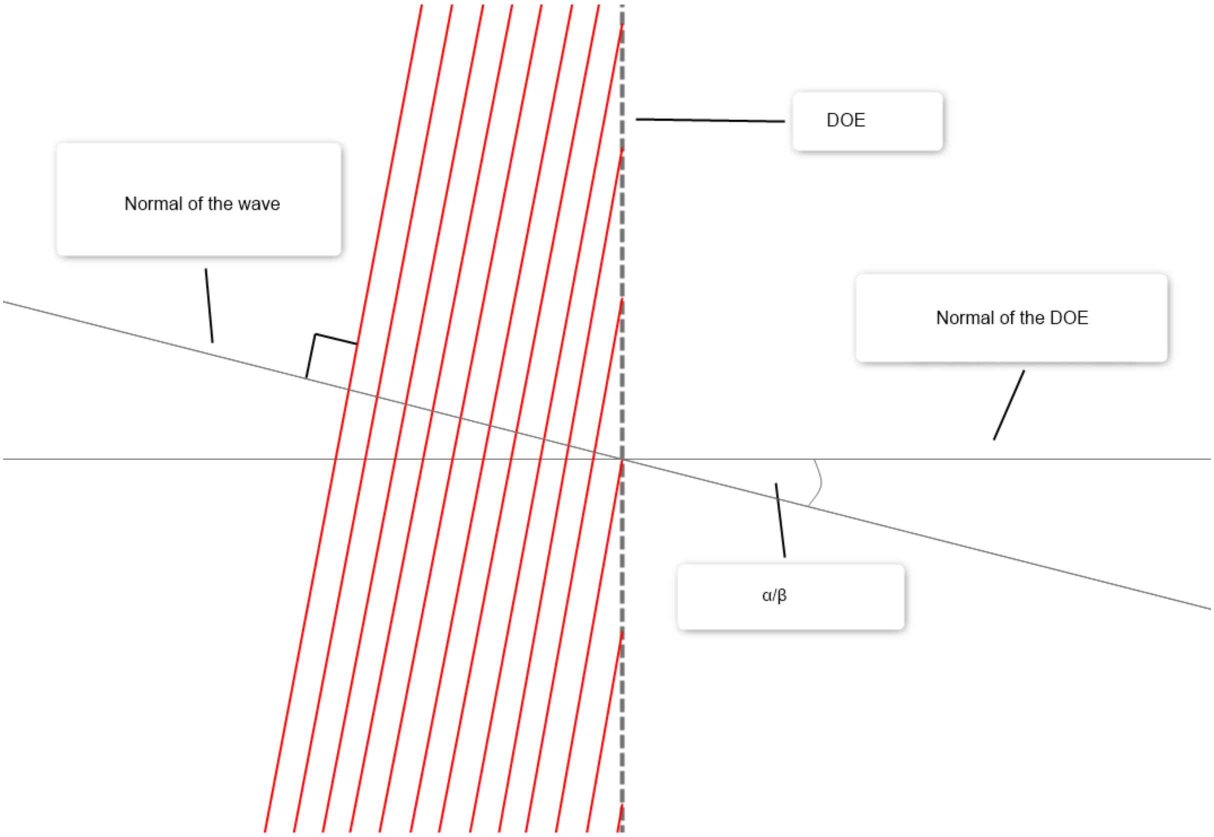
With the API, you can read out the points and, in principle, read them in again, thus defining for yourself which points are used.

Can our GEOCAL measure LGD or TV-SIMA distortion in the future?

So far, LGD and TV distortion have not been on our list for GEOCAL, but in principle, it is no problem to add them to one of the future software versions.

Alpha and Beta angles

α and β are the angles between the normal of the laser wave and the DOE and are of no interest to the customer but need to be determined to achieve accuracy. They are for evaluation purposes only and are currently set to zero by default. We are working on a calibration protocol to measure these angles during the acceptance procedure.



DLR paper about GEOCAL technology

https://www.osapublishing.org/oe/fulltext.cfm?uri=oe-16-25-20241&id=175001

Can I use the device vertically so that the camera looks into the tube from above or below?

It's no problem to use the device vertically. Please remember that the "up direction" of the GEOCAL is the "up direction" of the camera.

What exactly does "Grating Constant" or "Grid Constant" mean? Is it necessary to change the value of the grating constant depending on the wavelength?

The DOE (Diffractive Optical Element) consists of a periodically repeating structure (structure blocks that look like a 3D QR code). The grating constant refers to the distance between these structural blocks; in our case, this is 43.9µm or 15µm. This value does not need to be calculated or changed, as it is a physical property of the component.

What is the lifetime of the laser diode?

At least 10000 h.

Mean Time To Failure (MTTF) 20000h.

Which FoV is still acceptable for working with the GeoCal?

One limiting factor for the camera's FoV is the image quality, specifically the pixel count. For example, if your camera has a low pixel count, you have fewer pixels per grid point, which makes it more difficult for the software to detect them in the test image. If you have a higher FoV, there are more GeoCAL grid points in your test image and therefore fewer pixels per point. The points are also closer together, making them harder for the software to distinguish. We specify a maximum FoV of 120 degrees, assuming the camera is of lower quality, but depending on your cameras image quality, you may be able to analyze images with FoVs larger than 120°. A case study has also proven the ability to support fisheye lenses with even greater fields of view.

Intensity drop in the higher diffraction orders.

Especially with wide FoVs, which cover more diffraction orders, there will be a drop in intensity towards the edges, making it more difficult to detect the entire grid. This is caused by the DOE design, which of course is limited somewhere and does not distribute the intensity perfectly evenly across all orders. Furthermore, shading, which is more present at higher FoVs, also might decrease intensity towards the edges. There is a HDR feature in our GeoCAL software V1.4 to compensate for this effect, which supports three different HDR tone mappings. However, not all points of the grid need to be detected to get a good result, i.e. coefficients that provide sufficient undistortion for your use case.