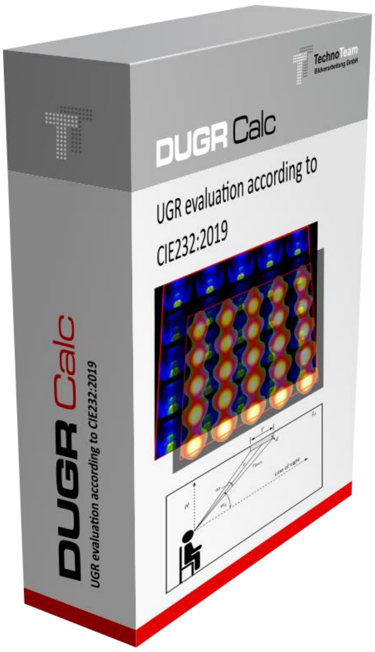
Software Manual

DUGR Calculator



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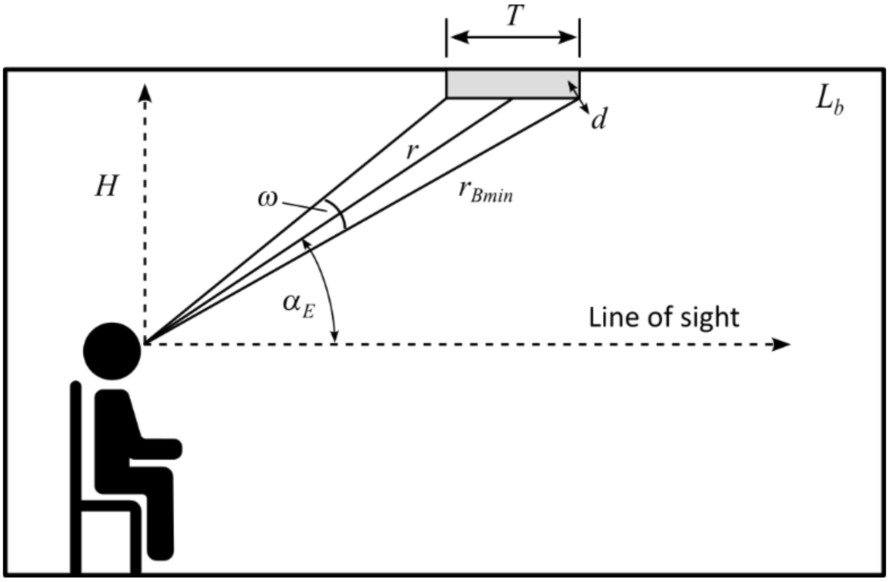
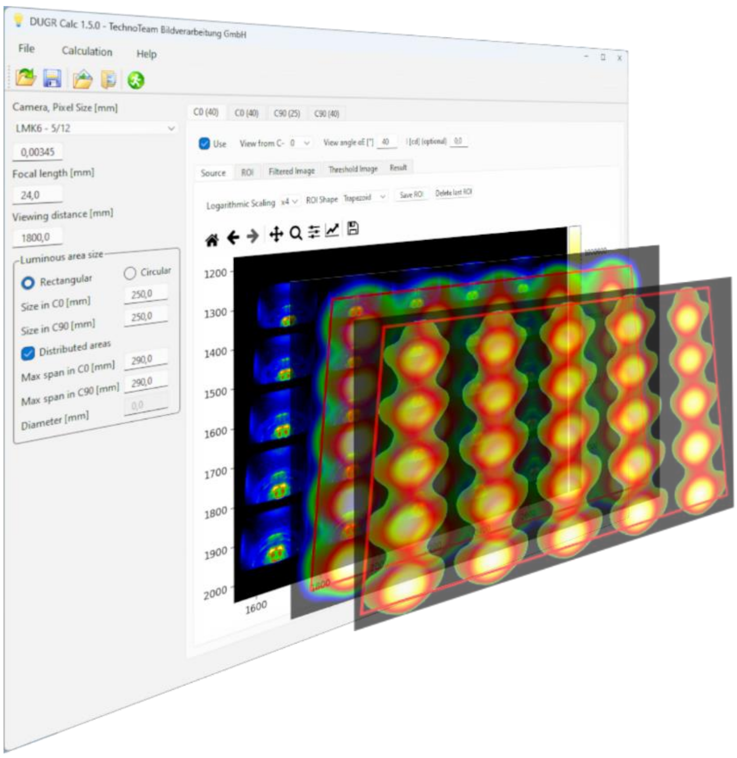
2 Introduction

The *DUGR Calculator* is a free and open-source test environment written in Python for calculating UGR characteristic values according to CIE 232:2019 (CIE, 2019). Since there was previously no universal program for calculating these values from luminance images, the *DUGR Calculator* was developed by TechnoTeam to facilitate a broad application of the method and to test the practical application.





3 UGR – Unified Glare Rating

3.1 Basics

The UGR (Unified Glare Rating) method was developed by the CIE in 1995 (CIE, 1995). The glare level of the psychological direct glare of a lighting system is determined from an observer's position. The UGR rating is calculated using the following formula:

$$R_{UG} = 8 \cdot \log_{10} \frac{0.25}{L_b} \sum_{i=1}^{n} \frac{L_{s,i}^2 \cdot \omega_i}{p_i^2} . \quad (1)$$

where

R_{UG}	is the UGR glare value ($10 \leq R_{UG} \leq 31$);
L_b	is the background luminance;
n	is the number of light sources;
$L_{s,i}$	is the average luminance of the light source i;
ω_i	is the solid angle at which the light source is seen;
p_i	is the position index of the light source i in relation to the observer's viewing direction according to Guth.

The UGR value always refers to a lighting situation with luminaires from an observer position and is therefore not a fixed parameter for a luminaire. One way of calculating UGR is to define a model for a lighting system in a standard room and derive the required values from this. This is realized in the so-called table method according to CIE 117:1995 (CIE, 1995). This makes it possible to compare different luminaires in terms of their glare levels using a standard arrangement.

Another possibility is the direct measurement of a real lighting situation using an imaging photometer (ILMD - imaging luminance measuring device)[1], see (Porsch, et al., 2015), (Porsch & Schmidt, 2007), (Porsch & Schmidt, 2007).

3.2 Corrected UGR method according to CIE 232:2019

The UGR method was originally designed for the light sources commonly used in the 1990s, i.e. luminaires with fluorescent lamps, incandescent lamps or halogen lamps. The valid solid angle range is therefore limited to 0.0003 sr to 0.1 sr. Even though CIE 147:2002 (CIE, 2002) created an extension of the method for smaller and larger luminaires, application to complex and inhomogeneous luminance distributions is not taken into account. This is where the application of image-resolving luminance measurement technology comes into play. CIE 232:2019 (CIE, 2019) presents a method that corrects the classic UGR characteristic values on the basis of measured luminance images.

To adapt the luminance distributions to human perception, the distributions are filtered according to the visual acuity or the size of the receptive fields on the retina using a Gaussian filter. Subsequently, only luminances above a certain threshold relevant for psychological glare are taken into account.

[1] https://www.technoteam.de/products/imaging_photometer_colorimeter/index_eng.html

Based on equation (1), a correction factor k^2 is introduced to calculate the corrected UGR value $R_{UG,corr}$. For the sake of simplicity, only the calculation for one luminaire is considered below.

$$R_{UG,corr} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} k^2 \frac{L_s^2 \cdot \omega}{p^2}\right). \tag{2}$$

$R_{UG,corr}$ also results directly from the effective luminance L_{eff}, which is relevant for glare, and the associated effective solid angle ω_{eff}:

$$R_{UG,corr} = 8 \cdot \log_{10}\left(\frac{0.25}{L_b} k^2 \frac{L_{eff}^2 \cdot \omega_{eff}}{p^2}\right). \tag{3}$$

The correction factor k^2 then results from (2) and (3) to

$$k^2 = \frac{L_{eff}^2 \cdot \omega_{eff}}{L_s^2 \cdot \omega} = \frac{L_{eff}^2 \cdot A_{p,eff}}{L_s^2 \cdot A_p} = \frac{L_{eff}^2 \cdot A_{eff}}{L_s^2 \cdot A}. \tag{4}$$

where

A_{eff}	is the effective area of the glare-relevant luminances;
$A_{p,eff}$	is the effective area projected from the observation angle;
A	is the area assigned to the average luminance L_s ("light emitting area");
A_p	is the light emission area projected from the observation angle $A_p = A\cos\alpha_E$.

If the average luminance is calculated from the luminous intensity in the direction of observation with

If the average luminance L_s is calculated from the luminous intensity I in the direction of observation with

$$L_s = \frac{I}{A_p}, \tag{5}$$

the result is

$$k^2 = \frac{L_{eff}^2 \cdot A_{eff} \cdot A_p}{I^2}. \tag{6}$$

A corrected area size A_{new} or the projected area $A_{p,new}$ is now introduced, which would result in the corrected UGR value $R_{UG,corr}$ from the classic UGR formula (1).

$$A_{new} = \frac{A}{k^2}. \tag{7}$$

A_{new} is therefore the area that is used instead of the simplified assumed light emission area to obtain the corrected UGR value. The UGR difference value results directly from k^2 as

$$DUGR = 8 \cdot \log_{10} k^2 \,. \tag{8}$$

The CIE 232:2019 method provides for the calculation of the DUGR values for the observation angles 25° ± 5° and 40° ± 5°. In the case of asymmetrical distributions, the measurements are taken in the longitudinal and transverse direction to the luminaire. The largest value determined is used as the result.

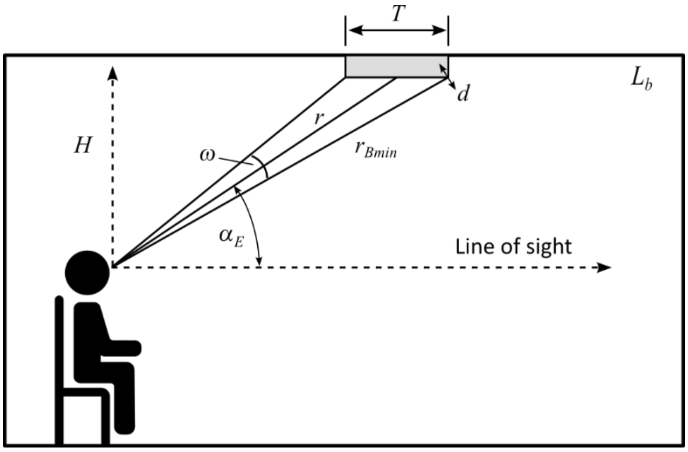


Figure 1: Lighting situation from the observer's direction

A practical guide to implementing the procedure in accordance with CIE 232:2019 is available, for example, in CIE TN 014:2023 (CIE, 2023) and (Funke, et al., 2021).

4 Implementation of the procedure according to CIE 232:2019 with the DUGR Calculator

4.1 Luminance images

The *DUGR Calculator* requires luminance images corresponding to the adjacent observer situation. The ILMD is positioned at a distance r and at an angle α_E to the luminaire, with the central viewing direction (optical axis) aligned to the center of the light emission surface.

The camera distance r must be at least 4.1 times the maximum extension D of the light-emitting surface.

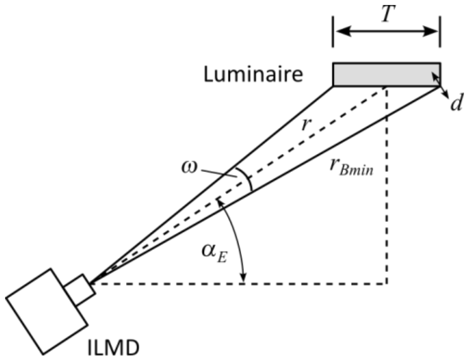


Figure 2: Positioning the ILMD

In CIE232:2019, the minimum resolution of the luminance image was set to $d = 12\ \text{mm}$. For the derivation of this measure, see A.1 (CIE, 2019). When measuring luminance, an image resolution of at least $d/10\text{px} = 1.2\ \text{mm/px}$ should be guaranteed.

4.2 Camera coordinate system

The central projection model is used for the camera coordinate system in the *DUGR Calculator* (Figure 3).

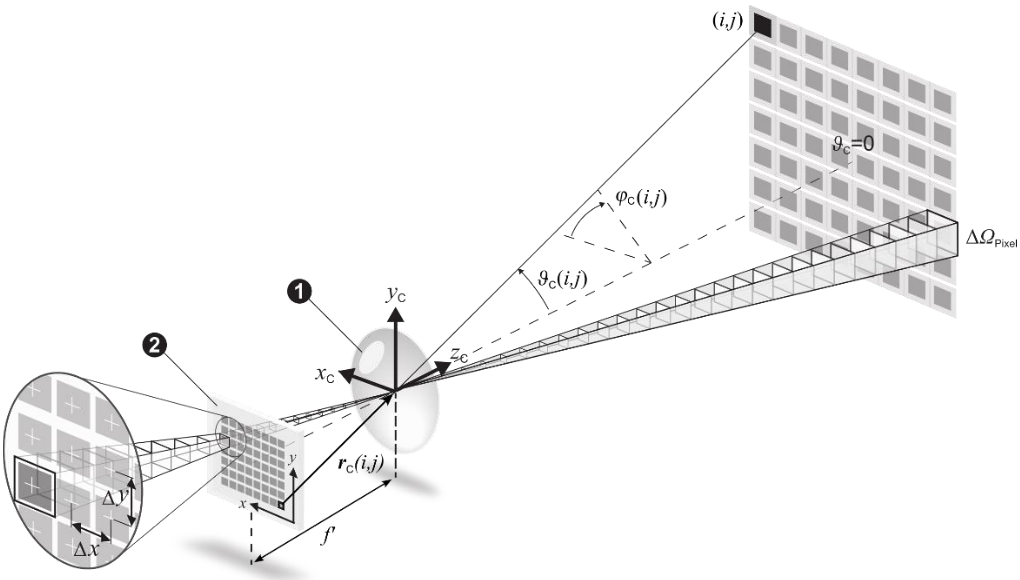


Figure 3: Camera coordinate system

where

x, y	are the sensor coordinates;
$\Delta x, \Delta y$	are the pixel pitches, assuming that $\Delta x = \Delta y$;
f'	is the focal length of the lens on the image side;

$\Delta\Omega_{\text{Pixel}}$ is the solid angle of a pixel;

$\boldsymbol{r}_C(i,j)$ is the vector from a pixel to the projection center;

$\vartheta_{\text{C}}(i,j)$, $\varphi_{\text{C}}(i,j)$ are the angles of $\boldsymbol{r}_C(i,j)$ in spherical coordinates.

Das Projektionszentrum ist die Eintrittspupille des Objektivs, d.h., bei der Bestimmung des Kameraabstandes muss die Lage der Eintrittspupille bekannt sein. Ebenso muss die bildseitige Brennweite des Objektivs möglichst genau stimmen, da hieraus die Winkel und korrespondierenden Raumwinkelelemente berechnet werden.

The center of projection is the entrance pupil of the lens, i.e. the position of the entrance pupil must be known when determining the camera distance. The focal length of the lens on the image side must also be as accurate as possible, as this is used to calculate the angles and corresponding solid angle elements (see Plausibility Test in 5.8.4).

4.3 Filterung

The filtering of the image serves to adapt to the resolution of the human eye. The half-width of the filter was set to 12 mm for the CIE232:2019 evaluation constellation (see 4.1). The evaluation can take place on perspective-distorted and rectified images.

4.3.1 *Application to perspective-distorted images*

To determine the filter width of the Gaussian filter, the minimum measurement resolution $R_{o,\min}$ is first calculated:

$$R_{o,\min} = \frac{\arctan\left(\dfrac{d}{r_{B\min}}\right)}{10\text{px}}, \tag{9}$$

with

$$r_{B\min} = \sqrt{r^2 + \left(\frac{T}{2}\right)^2 + r \cdot T \cdot \cos\alpha_E}, \tag{10}$$

where

$r_{B\min}$ is the maximum distance from the projection center to the boundary of the light-emitting surface;

T is the largest extension of the luminous surface from the observer's direction α_E.

The filter half-width (in pixels) is then calculated as follows

$$FWHM_o = \frac{R_{o,\min}}{R_o}. \tag{11}$$

For the standard deviation σ_o and the filter length F_o in pixels, we now obtain

$$\sigma_o = \frac{FWHM_o}{2.3548} \tag{12}$$

and

$$F_o = 2\cdot\lceil 3\cdot\sigma_o\rceil + 1. \qquad (13)$$

The luminance image is now filtered using a Gaussian filter with the calculated filter length.

4.3.2 *Application to perspective rectified images*

For perspective rectified images, the pixel resolution R_{mm} in mm/px is constant, i.e. the filter half-width results directly from

$$FWHM_{12\text{mm}} = \frac{12\text{mm}}{R_{mm}} \qquad (14)$$

and the standard deviation $\sigma_{12\text{mm}}$ and the filter length $F_{12\text{mm}}$ are equivalent to (12) and (13).

4.4 Luminance - threshold operation and evaluation

In accordance with CIE232:2019, only luminances above the threshold of 500 cd/m^2 are now to be taken into account. After the threshold operation, a luminance image is obtained from which the effective values A_{eff} or $A_{p,eff}$, L_{eff} and ω_{eff} can be determined using the camera coordinate system or, if the image is rectified, using the pixel resolution R_{mm}.

There are various approaches for calculating k^2. According to equation (4), only quantities that can be derived from the luminance image are used, i.e. also the mean luminance L_s of the entire light-emitting surface. In the classic UGR table method (CIE, 1995), this luminance is obtained from the luminous intensity in the corresponding direction using the simple calculation according to equation (5). In CIE232:2019, equation (6) equates the calculation of k^2 via the luminous intensity with the calculation via the measured luminance L_s, although the measuring distance may be well within the photometric limit distance ((CIE, 2015), (Jacobs, et al., 2015)). Caution is therefore required here and the results of both approaches must be checked.

Particularly with flat angles and well glare-free luminaires, the luminous intensity in these directions is already very low and therefore measurement errors and, above all, small deviations in the luminaire alignments can have a major impact on the result. The question also arises as to where the luminous intensities should be taken from, as the "official" product data may have been measured with a different luminaire and the data may have been post-processed (symmetrized, smoothed, measurement resolution changed, etc.), resulting in greater uncertainties when applying equation (6) in these critical areas. On the other hand, a DUGR value is to be determined that relates to the UGR values calculated using the "official" product data (UGR table method).

It would therefore be ideal to measure the luminous intensity distribution and luminance in a single measurement setup, for example with a *RiGO801 goniophotometer*[2].

[2] https://www.technoteam.de/products/goniophotometer_rigo801/index_eng.html

5 DUGR Calculator

5.1 Basics

As already explained in the introduction, the *DUGR Calculator* is an open-source program written in Python. To use the program, the Python sources[3] can be used directly with the appropriate knowledge or the installer can be used. The installer contains the independently executable distribution of all required components created with the *PyInstaller* tool.

The program starts with the following view.

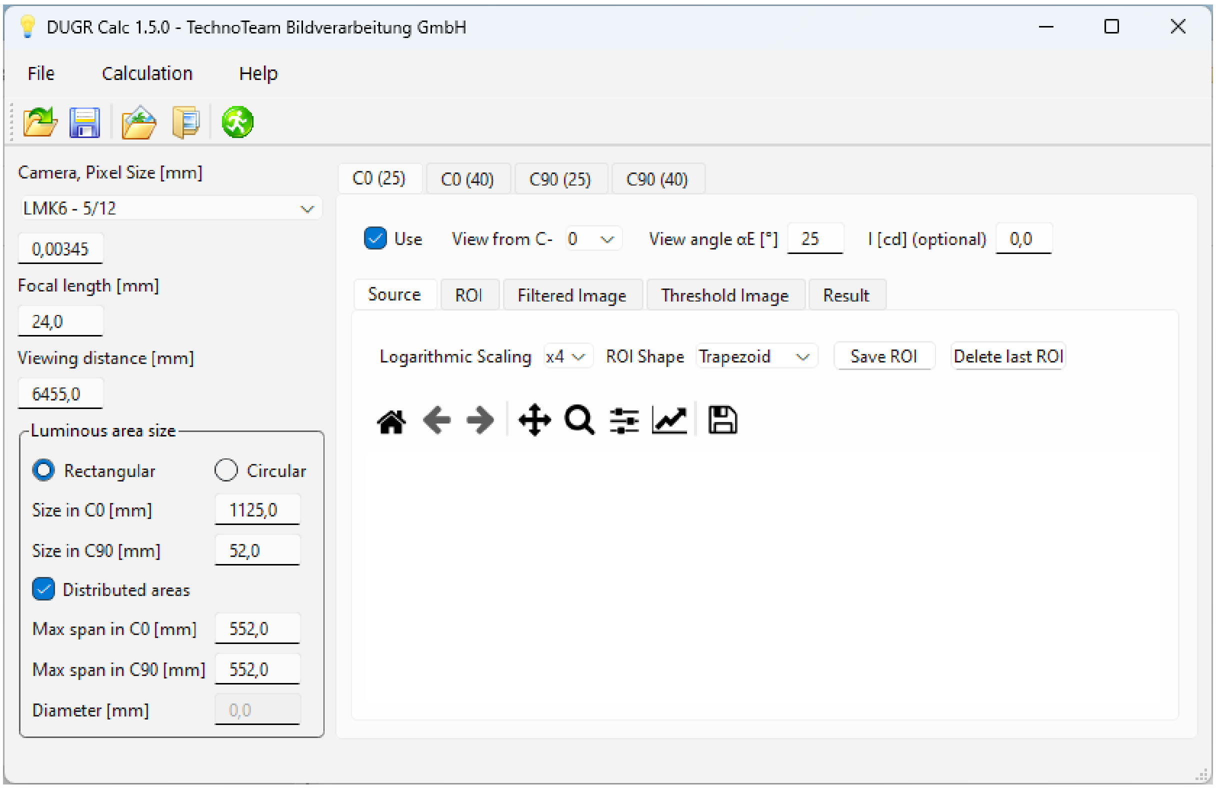


Figure 4: Program interface after starting (standard mode without rectification)

This is the standard mode in which the luminance images are not rectified. You can switch to the variant with perspective image rectification via the C*alculation - Projective rectification mode* menu item (see Figure 5). This mode has not been revised for a long time and is still at an experimental stage. In the following, we will therefore mainly focus on the standard mode.

The standard view is divided into two areas. The left-hand area contains the general information on the evaluation project and the right-hand area contains 4 tabs with their own evaluation areas for the camera orientations used.

[3] https://github.com/TechnoTeam-Bildverarbeitung-GmbH/DUGR_GUI

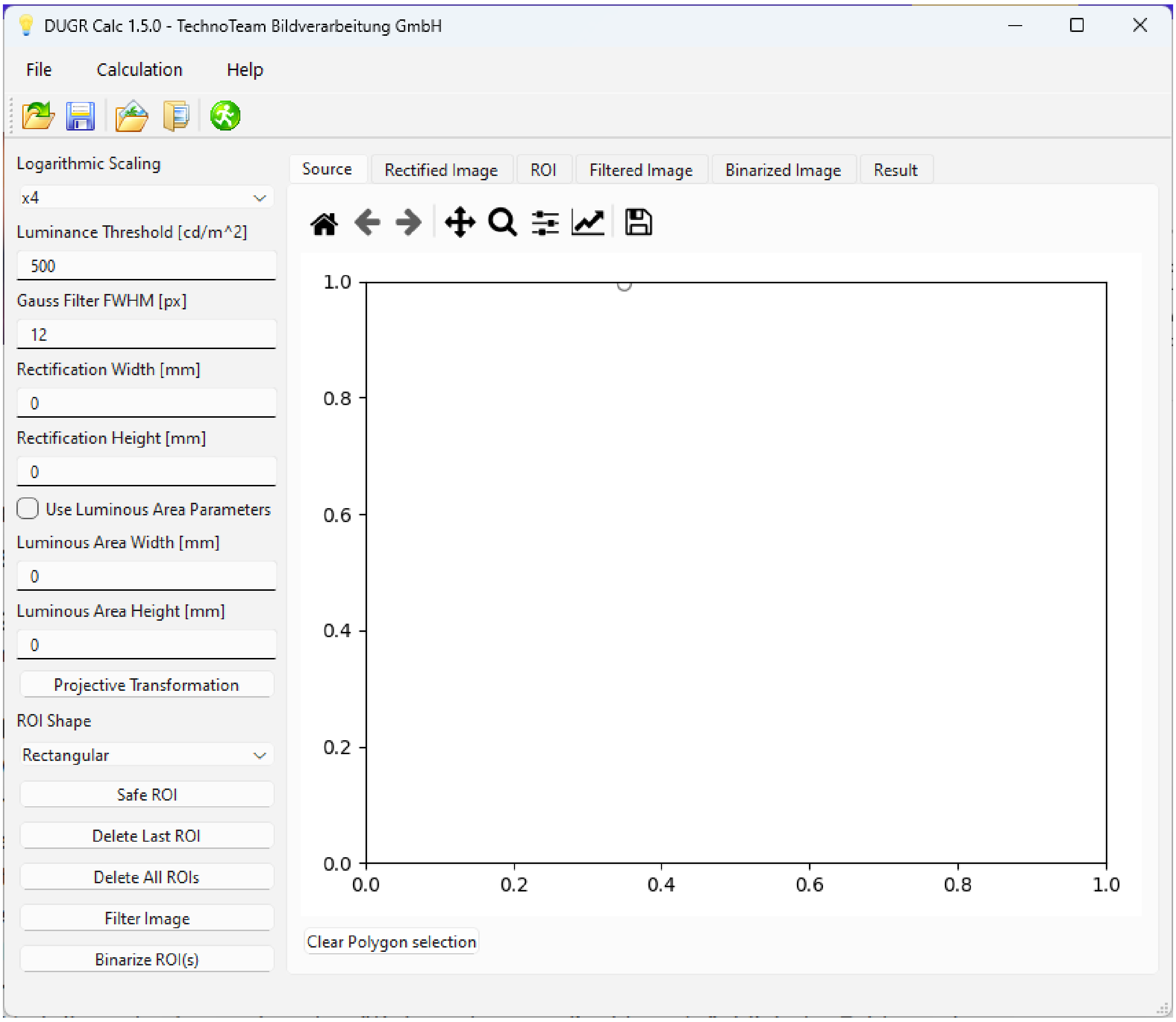


Figure 5: Program interface for the image rectification mode

5.2 Basic settings

The basic settings can be accessed via the *File - Settings ...* menu item. So far, these are the luminance threshold (default is 500 cd/m²), the eye resolution as parameter *d [mm]* (default is 12 mm, see 4.1) and the option *Evaluation only inside ROI*. This option makes it possible to consider two views of the evaluation of the filtered luminance images. For the evaluation of the light emission regions, these regions are outlined (see 5.8.1). After filtering, luminances may be present outside these boundaries. The question now arises as to whether the evaluation should only be carried out within the boundaries or whether the luminance components outside the boundaries should also be taken into account. The *DUGR Calculator* assumes that the human eye also has a "filtering" beyond the limits of the light-emitting surface and switches this option off by default. As not everyone may be of this opinion and interpret the CIE232:2019 differently, the option can be activated in this case.

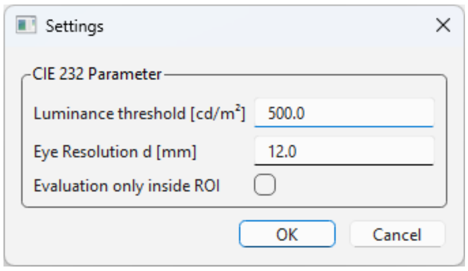


Figure 6: Dialog with basic settings

5.3 Project files

The ability to save and reload complete projects (menu *File load/save project ....*) makes using the *DUGR Calculator* much easier. All data belonging to the project, i.e. settings, luminance images and evaluation regions, are compiled into a TAR file. This means that the raw data can also be viewed independently of the *DUGR Calculator* if required.

5.3.1 *Parameter*

The parameters are stored in JSON files. There are general parameters (*common_param.json*), parameters for the 4 evaluations (({*image index*}*_param.json*) and for each evaluation the parameters of the ROI (Region of Interest) areas used *({image index}_roi{roi index}.json*).

```
"common": {
    "camera_id": "LMK6",
    "focal_length": 24.0,
    "lum_area_C0": 250.0,
    "lum_area_C90": 250.0,
    "lum_area_d": 0.0,
    "lum_area_distributed": true,
    "lum_area_span_C0": 290.0,
    "lum_area_span_C90": 290.0,
    "lum_area_type": 0,
    "pixel_size": 0.00345,
    "viewing_distance": 1800.0
}
```

common_param.json

```
"eval": {
    "c_angle": 0,
    "luminous_intensity": 0.0,
    "use_flag": true,
    "viewing_angle": 25
}
```

{image idx}_param.json

```
"roi": {
    "id": "TrapezoidRoi",
    "num_vertices": 4,
    "v0_x": 1613,
    "v0_y": 1363,
    "v1_x": 2659,
    "v1_y": 1365,
    "v2_x": 2748,
    "v2_y": 1838,
    "v3_x": 1542,
    "v3_y": 1842
}
```

({image idx}_roi{roi index}.json

5.3.2 *Source images*

The luminance source images are saved as Numpy arrays in *.npy* format. An associated parameter file (*{image idx}_srcimg _param.json*) is stored.

```
"img": {
    "columns": 4089,
    "first_column": 8,
    "first_line": 16,
    "lines": 2998
}
```

5.4 General project parameters

Die Eingabefelder der allgemeinen Projektparameter befinden sich im linken Bereich des Programmfensters. Im oberen Bereich erfolgen die Angaben zur Kamera und zum Messabstand und im unteren Bereich sind die geometrischen Parameter zur Leuchte bzw. zur Lichtaustrittsfläche anzugeben.

5.5 Image capture parameters

The *DUGR Calculator* requires precise information on the camera model (see 4.2) and the measuring distance. First, the pixel distance must be specified in mm. For simplification, the input area contains a predefined list of cameras and corresponding pixel distances. For cameras not listed, select "Custom camera" and then enter the corresponding pixel pitch.

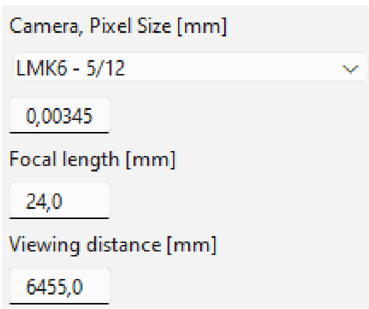


Figure 7: Camera parameters

For the measuring distance, select the distance between the entrance pupil of the lens and the center of rotation of the light (see 4.1).

5.6 Light-emitting surface

The dimensions of the light-emitting surface are used to calculate A (see equation (4)) but also to calculate the filter size (see 4.3). Now there are luminaires with distributed light-emitting surfaces for which normally only the sum of the individual surfaces and not the total surrounding area is specified for the classic UGR calculation (Eulumdat / IES files). These surface areas must be selected as they were used for the UGR table method so that the calculated DUGR value has a correct reference.

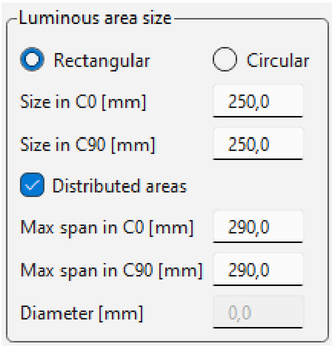


Figure 8: Information on the light-emitting surface

As the evaluations can be carried out automatically for all camera orientations and the algorithm must know the dimensions seen in each case, a distinction is made between the length of the (net) light emission surface in C0 and in C90 when specifying the dimensions. If there is only one light-emitting surface, this information is relevant for the calculation of $r_{B\min}$ (see 4.3). For distributed light-emitting surfaces, the *Distributed areas* option must be activated and the enclosing maximum external dimensions of the light-emitting surfaces must be specified in the *Max span* fields. In this case, A is calculated from the upper specifications and $r_{B\min}$ is calculated from the lower specifications.

For circular light-emitting surfaces, there is currently no provision for distributed surfaces. Only the circular diameter can be specified here. If there are nevertheless distributed circular areas, you can make do by specifying equivalent rectangular areas.

5.7 Loading luminance images

There are two options for loading luminance images in the *File* menu. *Open image ...* loads an image into the current evaluation tab. The *Open TT image series ...* function allows to load *TechnoTeam* luminance image series and automatically select the images of the standard positions (25° and 40° in C0 and C90) and transfer them to the associated evaluations. These image series are generated position-controlled with the *LMK LabSoft*[4] software.

Supported file formats are the TechnoTeam .pf image format and a .txt format, which is read in as a *Numpy* array with the following program lines:

```
    with open(image_file, 'r') as file_object:
        pixel_values = file_object.read().replace(',', '.').split('\n')[2:-1]

    image_array = np.genfromtxt(pixel_values,
dtype=np.float32, delimiter='\t')
```

It is therefore an ASCII file in which the first two lines and the last line are ignored. The luminance values must be separated by a tab. Values with commas as decimal separators are replaced by dots so that they are read in correctly by *Numpy*.

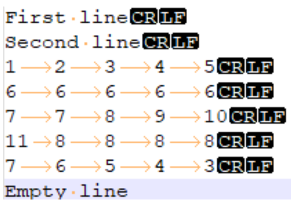


Figure 9: Example TXT image file

[4] https://www.technoteam.de/products/software__add_ons/lmk_labsoft/index_eng.html

5.8 Evaluation

The *DUGR Calculator* provides 4 evaluation windows in tabs. In the upper area of an evaluation window there is the option *Use*, which determines whether this evaluation area should be used, the specification of the C-plane and the recording angle (see Figure 1 in Section 3.2). The optional specification of the light intensity must be done with care (see section 4.4). If a luminous intensity is specified here, the average luminance is calculated from the luminous intensity and not from the image.

Below these input fields there are several tabs with the source image (*Source*), the selected light emission areas (*ROI*), the filtered image (*Filtered Image*), the threshold image (*Threshold Image*) and finally the result page (*Result*).

5.8.1 *Source image and ROI definition*

A luminance image is displayed in the source image view after loading. Here it is possible to switch the scaling of the color palette between logarithmic 2 and 7.

An icon bar is displayed to control the view. These functions as well as the image display are provided by the Python library *Matplotlib* and have a behavior that takes some getting used to. The magnifying glass icon is used for zooming. A click on the icon activates the zoom mode, which is signaled by a cross mouse cursor. You can now hold down the left mouse button and drag a region to zoom in on. Use the arrow icons to switch between the views. To exit zoom mode, click on the magnifying glass again. The house icon resets the view. The remaining icons with settings for the view and axes should not be used.

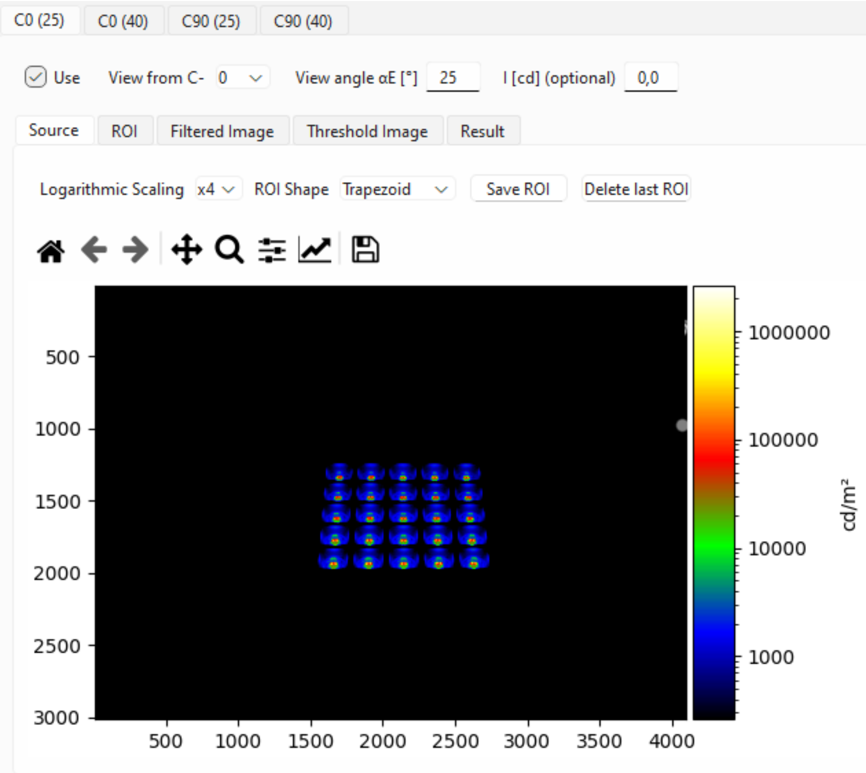


Figure 10: Source image display

The aim is now to define the light emission areas in the source image, which are referred to here as ROI. In this case, there is only one continuous light emission area with small interruptions, so that this area is enlarged accordingly. A larger logarithmic scaling is recommended to see the edges. For rectangular surfaces shown in perspective, it is advisable to select the polygon selection tool, here referred to as "*Trapezoid*", in the *ROI Shape* selection list. The mode for drawing an ROI is indicated by a small round mouse cursor.

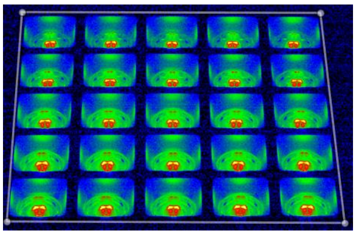


Figure 11: Polygon ROI

First, a polygon is placed approximately around the area by clicking on the 4 corner points. The position can be defined more precisely in enlarged views. When necessary, the ESC key deletes the drawn region completely.

This ROI is now saved using *Save ROI* and transferred to the *ROI* tab (Figure 13). Several ROIs can be saved for distributed light emission areas (Figure 14). The last ROI can be deleted using *Delete last ROI*.

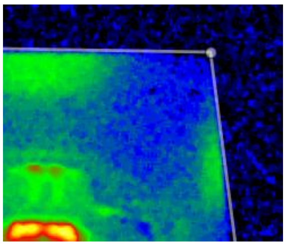


Figure 12: Precise polygon positioning

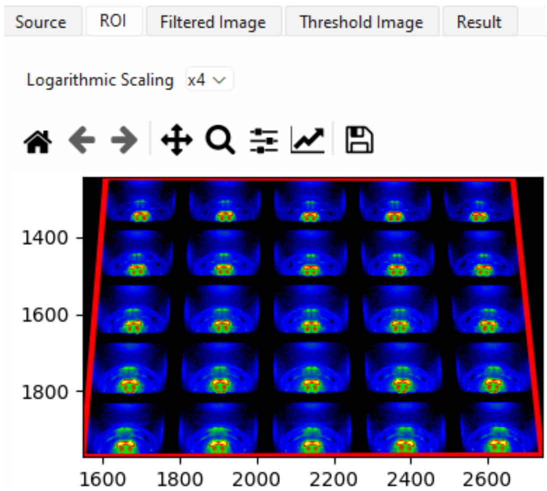


Figure 13: Single ROI in ROI tab

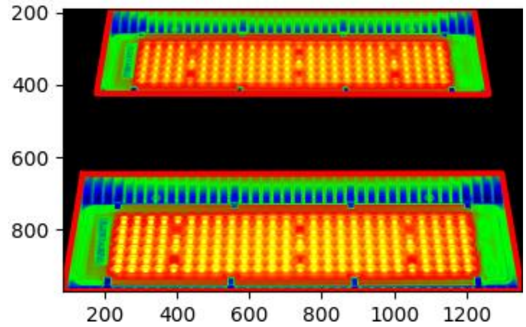


Figure 14: Example with two ROIs

5.8.2 *Determining the luminaire parameters*

Before the DUGR calculation can be carried out, the dimensions of the light-emitting surface must be entered. The luminaire in Figure 13 is a case of distributed light-emitting surfaces. The manufacturer has specified a light-emitting surface of 250 mm x 250 mm in the published data, whereby the outer dimensions are 290 mm x 290 mm. The spaces between the small spotlights were therefore correctly omitted. However, the *DUGR Calculator* must know both sizes, so the input is made according to Figure 8.

5.8.3 *Executing the calculation*

The calculation is started via the *Calculation - Execute* menu item or the icon in accordance with section 4. The filtered image is now displayed in the *Filtered Image* tab. The border has been extended by the filter width so that the luminance values extending beyond the border can also be taken into account (see section 5.2). The image after the threshold operation can be found in the *Threshold Image* tab.

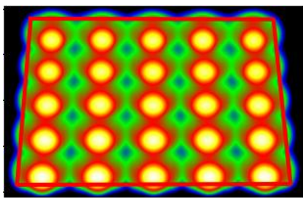


Figure 15: Filtered image

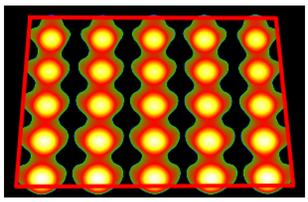


Figure 16: Threshold image

5.8.4 *Results and plausibility test*

The results are output in the *Result* tab (Figure 17). All important calculation results are listed here, whereby the values of or DUGR are mainly of interest. The DUGR designation is provided with the index "_L" or "_I". The method for determining L_s via the luminance image or luminous intensity is characterized here (see section 4.4).

In this example, a DUGR_L value of -0.1 was calculated. The evaluations for the other camera positions result in similarly small values, i.e. there is no need to change the UGR classification of this luminaire.

DUGR_L	-0.1
k^2_L	1.0
A_p_new_L	40764 [mm^2]
A_p	40174 [mm^2]
A_new_L	63417 [mm^2]
A	62500 [mm^2]
A_eff	38517 [mm^2]
Effective luminance (L_eff)	5276.92 [cd/m^2]
Mean Luminaire luminance (L_mean)	5196.04 [cd/m^2]
Effective solid angle (ω_eff)	0.011888 [sr]
Luminaire solid angle (ω_luminaire)	0.012441 [sr]
Measurement angle αE	40 [°]
Viewing distance	1800.0 [mm]
Luminous area size in C0	250.0 [mm]
Luminous area size in C90	250.0 [mm]
lum_th	500.0 [cd/m^2]
d	12.0 [mm]
Calculated optical resolution	0.00822 [°/px]
FWHM	43.74 [px]
Filter width	113 [px]
Filter sigma	18.575 [px]
rb min	1913.35 [mm]
ro min	0.03593 [°/px]

Figure 17: Result table

This raises the question of the plausibility of the results. Since, in addition to high-quality luminance measurements, the exact parameterization of the geometric camera model and the measurement setup are crucial for the accuracy of the results, a plausibility test was integrated into the *DUGR Calculator*. Here, the specified area A or the resulting projected area A_p is compared with the area determined from $A_p = \omega_p \cdot r^2$. For this purpose, the integral of all solid angle components within the ROI(s) is determined using the solid angle components of the pixels obtained from the camera model. The two areas should theoretically be identical. The plausibility test is called up via the *Calculation - Plausibility test* menu item. In this example, there is a difference of 0.3 % (Figure 18).

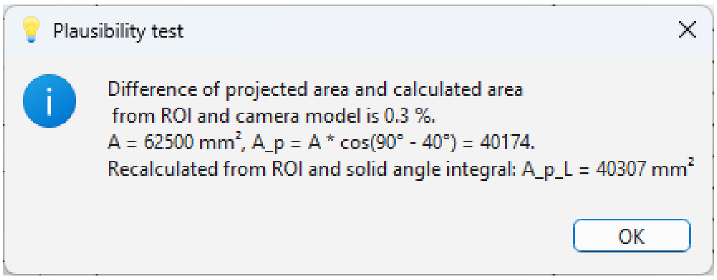


Figure 18: Plausibility test

In the current version, the results are still output separately for each evaluation, i.e. for each camera orientation. An export as PDF is possible with the *Generate PDF report* button. Data can also be exported as a JSON or CSV file.

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