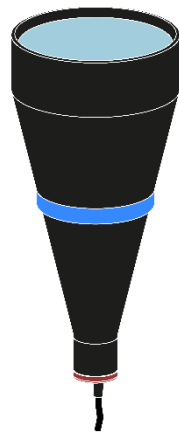
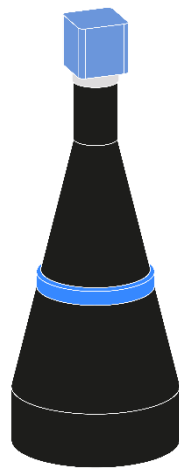




OPTO ENGINEERING

SOFTWARE LIBRARY & STAND-ALONE TOOLS FOR THE OPTIMIZATION OF TELECENTRIC SETUPS

TCLIB Suite



INSTALLATION MANUAL,
GUI REFERENCE AND
SETUP PROCEDURE



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1 • GENERAL INFORMATION

1.1 Description

TCLIB Suite is a C++ based set of computer vision tools dedicated to the optimization of telecentric setups. This software package is made of a .dll library that contains a complete collection of data types, structures and procedures for telecentric setup optimization and utilization, made for integration in any system or software of sorts, and of a graphical user interface that can serve both as a demo of the TCLIB software and as a walkthrough tool for the optimization proceeding.

A valid alignment of a telecentric setup is of paramount importance in the metrology field, where the total accuracy of the measure is not only correlated to the quality of the lens but it is due to combined effects of all optical elements in the system, that are camera, optics, telecentric lighting, inspected object and so on. A perfect alignment and setup of the system is fundamental to achieve best accuracy and to ensure repeatability of the measurement in the whole field of view.

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1.3 Installation instructions

When a license is purchased, a short URL for the download of the software will be contained in the License Key packaging. The software can be also downloaded from Opto Engineering website www.opto-e.com.

The downloaded file is a compressed zip containing this manual and the setup executable. In order to install, double-click on the setup file, insert your administrator credentials and follow the on-screen wizard.

During installation, the user will be prompted for the installation of Visual C++ Redistributable runtime. If the user is sure that this component is already installed in the PC, it is possible to cancel the runtime installation. In any other case, the runtime is strictly needed for the execution.

The installer will install the software in the PC, will create a start menu shortcut to the TCLIB APP executable and will prepare the environment for the integration of the library in your code.

In particular, two environmental variables will be created:

- TCLIB_LIB: path to the .lib files for binaries reference.
- TCLIB_INCLUDE: path to the library header files.

For the deployment of a software that integrates the TCLIB it is necessary to operate a fresh installation of the TCLIB Suite on every machine that will be built. Doing so will install and add to the system PATH the needed DLL binaries for runtime execution.

During installation both release and debug builds of the library are installed. The libraries with the "_d" suffix are debug builds.

1.4 Minimum requirements

TCLIB Suite requires a Windows based PC with the following:

- Intel® Core™ i3 Dual Core (4th gen) or AMD Ryzen™ 3 Processor (*Minimum*)
- Intel® Core™ i5 Quad Core (4th gen) or AMD Ryzen™ 5 Processor (*Suggested*)
- Windows 7 64 bit or later
- Color WXGA-H monitor (1280 x 720 resolution)
- 4GB (*or more*) RAM
- At least 150MB free hard disk space (*for installation*)
- An internet connection (*for installation download*)
- Available USB port (*for USB License Dongle*)
- Visual C++ runtime version 2015 or later
- .NET framework 4.5.2 or later
- Administrative privileges (*for installation*)

For the development of software using the TCLIB Suite Visual Studio 2015 is highly recommended. The installation of OpenCV 3.4.0 or higher is also needed. In order to use TCLIB Suite, an explicit

reference to the core header of OpenCV library is needed (see example at section 2.2 of this manual).

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NOTE: *Although the software is designed to work with the Windows Operating Systems listed above, Opto Engineering s.r.l. cannot guarantee operation on OSs no longer supported by Microsoft Support Life Cycle Policy.)*

TCLIB APP is a full GenTL compliant software. Any GenTL compliant camera device can be used with this software. Camera manufacturer drivers need anyway to be installed in order for the program to operate correctly.

2 • TCLIB REFERENCE

2.1 Interactive documentation

At the act of installation, the library documentation is copied in the *doc* folder inside the installation directory. A simple double click on the *index.html* file will open a web browser at the index of the interactive documentation.

The documentation is a web-based manual containing all information regarding the integration of the library, the classes and the function calls necessary to operate correctly the software library.

2.2 Application example in C++

```

#include "Calibration.h"
#include "OEStructConverter.h"
#include <iostream>
#include <opencv2\core\core.hpp>

int main(int argc, char** argv)
{
    // Calibration object instantiation
    Calibration cal;

    ////////////////////////////////////////////////////
    // Image loading:
    // "inputPattern.bmp" is the pattern image
    // "inputImage.bmp" is the image to be remapped
    ////////////////////////////////////////////////////

    cv::Mat inputPattern = cv::imread("inputPattern.bmp", 0);
    cv::Mat inputImage = cv::imread("inputImage.bmp", 0);

    // Load the pattern image in the calibration object
    cal.setPatternImage(cvtFromMat(inputPattern));

    // Run the calibration
    cal.createRemappingRecipe();

    // Load the image to be remapped in the calibration object
    cal.loadImage(cvtFromMat(inputImage));

    // Extract the undistorted image from the calibration object
    OEImage remappedImage = ...
        c.getUndistortedImage(REMAPPINGMODE::PRECISE);

    // Save the remapped image
    cv::imwrite("remappedImage.bmp", cftToMap(remappedImage));

    return 0;
}

```

This integration example makes use of OpenCV library for image loading and saving. Ensure that the library is correctly referenced in your project to use this example as-is.

NOTE: The libraries of the TCLIB are native C++ dynamic libraries and as such they are fully based on unmanaged code. In order to use it in .NET based applications, a wrapper implementation is needed.






3 • TCLIB APP

3.1 General overview

The TCLIB APP is a full featured deploy of the TCLIB. It serves both as a demonstration and as a guided tool for the purpose of optimizing telecentric setups. All functions reported in the TCLIB APP are available in the TCLIB library.

At the startup it presents three main sections: a top bar with 5 buttons, a left panel that will host the camera stream, and a right panel that contains the parameter inspector.

The 5 buttons at the top activate 5 different control panels listed below:

Icon	Title	Parameters
	Camera	<ul style="list-style-type: none"> - Camera selection (CTI and device) - Acquisition settings (exposure/gain) - Image format settings (sensor crop)
	Light-Lens Alignment	<ul style="list-style-type: none"> - Standard deviation tolerance on homogeneity of illumination - Image histogram - Gray level average and standard deviation
	Object Plane Alignment	<ul style="list-style-type: none"> - Pre-procedure (model acquisition) - Iterative procedure (measure start and acquisition) - Measure results
	Focus Estimation	<ul style="list-style-type: none"> - Algorithm selection - Focus estimation result - Back focal adjustment calculator
	Calibration	<ul style="list-style-type: none"> - Calibration recipe creation and selection - Calibration mode - Calibration algorithm

3.2 Control panels

3.2.1 Camera

The CAMERA control panel is used to select the camera source and to adjust acquisition parameters, through the access to the GenICam tree.

In the first sub-panel, the first operation is selecting the desired CTI¹ file. This allows the selection of different camera manufacturer interfaces of the GenTL protocol. Once the CTI is selected it is possible to click on the SEARCH button in order to scan the system for GenTL compliant cameras. At the end of the scan all connected and compatible devices will be added in the drop-down menu at the left of the button. They will be visualized as GenTL addresses. Refer to the camera manufacturer manual in order to associate GenTL names to devices.

In order to open a connection with the camera, select the desired device from the drop-down menu and click on the OPEN button. In order to close the connection just click on the CLOSE button.

¹ CTI: Common Transport Interface. Dedicated dynamic library that defines the manufacturer specification of communication through the GenICam Transport Layer (GenTL)

Once connected, the camera will run in free run mode with default on-camera settings. In order to change Camera settings, click on the GENICAM TREE button. A window with a tree view will open. In this window, all camera settings listed on the tree are editable.

When a parameter is chosen from the tree view, on the right of the tree will be available the name, a description, the type and the actual editable value of the parameter. In order to apply edits to a parameter it is necessary to click on the SAVE button.

3.2.2 Light-Lens Alignment

The LIGHT-LENS ALIGNMENT control panel is used to optimize the optical axis alignment between optics and lighting.

When this panel is opened, the left panel hosting the streamed image from the camera will change and will present some colored rectangles. Those rectangles are regions where light homogeneity is computed and analyzed.

The panel allows to change one parameter called STD DEV TOLERANCE. This parameter is a threshold on the actual standard deviation of grayscale values on the whole image and on single regions highlighted on the image box.

The alignment has to be conducted with two different aims:

- Image regions homogeneity through visual color feedback
- Overall image homogeneity and luminance through image histogram

On the image box, the regions will color red if the region is strongly inhomogeneous, yellow if near to homogeneity and green when homogeneous, always with respect to the standard deviation chosen in the inspector panel.

On the inspector panel, the average will color red if too low or too high. If such, adjust exposure time and/or illumination intensity accordingly. The standard deviation will color red if too high, yellow if near to threshold and green if under threshold set by the user. If such, act on the alignment of the lens/light system as explained in Section 4.3 of this manual.

Standard deviation computed under the histogram is not the full image standard deviation but it's computed only on pixels that are above 50 gray level (8-bit image depth). It is an indicator of the histogram curve width.

A good alignment is achieved when all image regions and inspector parameters are green (with respect to the desired tolerance).

The procedure for a correct optical axis alignment is reported in Section 4.3 of this manual.

3.2.3 Object plane alignment

The OBJECT PLANE ALIGNMENT control panel is used to execute the procedures for the object plane alignment.

It presents three sections:

- Pre-procedure: preliminary model acquisition
- Main procedure: data acquisition buttons
- Result: data captured by the acquisition routine

The plane alignment procedure is based on the observation of a gauge block. In order to execute correctly this step, a smaller than the field of view gauge block must be used in the procedure.

The SET MODEL button starts the search for the gauge block profile in the image. Once found, The start button will activate and the procedure will become available. If not found, an according error message box will be shown.

The START button is active only when a model is set. Clicking on it will make a shape appear on the image box, indicating the direction and position in which the gauge block must be placed. Note that the shape has one red side. Make sure that the gauge block has the same side always facing to the red line.

The NEXT button iterates through the eight steps needed for data acquisition. After data acquisition is complete, the maximum difference between acquisitions is computed and on the image box a rectangular shape will be drawn. This is the orientation in which the gauge block must be oriented. There will also be two red arrows, indicating the direction perpendicular to the axis of rotation of the needed plane tilt.

On the top left corner of the image box a live measurement is visualized. This will aid the alignment in the procedure explained in Section 4.4 of this manual.

3.2.4 Focus estimation

The FOCUS ESTIMATION control panel is used to check the focus of the image and to compute the best spacer thickness for back focal adjustment of telecentric lenses.

The focus estimation can be executed with two different estimators. LAPLACE and TRANSITION. LAPLACE is based on derivative methods and TRANSITION is based on transition slope. The focus estimator result is shown live on the VALUE text box. LAPLACE is more repeatable/stable but sometimes can be not very sensitive. TRANSITION is a little bit noisier but could give best result in finer tuning.

Under the focus estimation result, a simple back focal adjustment calculator is available². Inputs are nominal magnification, nominal working distance, and measured working distance. By pressing compute, the software automatically returns the back focal spacer adjustment in mm. The value

² In order for the calculator to work properly, the system decimal separator must be set to "." (dot).

will be positive if more spacers are needed and it will be negative instead if spacer removal is necessary.

3.2.4 Calibration

The CALIBRATION control panel is used to prepare the calibration recipe and to get a live remapped preview. It is also possible to save remapped images from this panel.

In order to execute the calibration, press the NEW RECIPE button. A *Save file...* prompt will open, asking for the recipe destination path. When confirmed, the calibration is executed. At the end of the calibration, the name of the recipe is shown on the inspector panel. If needed, the recipe can be reloaded by clicking on the LOAD RECIPE button. The click on the button will open an *Open file...* prompt. Chose a recipe .bin file from the prompt.

Calibration can be executed in two modes:

- FULL FOV: the image is not cropped and on the borders could be present some aberrations due to missing corners.
- CROPPED: the image is cropped in order to remove aberrations due to missing corners. The FoV could be reduced a little bit.

Remapping algorithm can be run with two different solvers:

- FAST: solving is less accurate but remapping is faster.
- PRECISE: solving is slower but highly accurate.

By clicking on the LIVE REMAP button, the preview on the left will show live stream from the camera, remapped with the active calibration recipe. Clicking again on the button will deactivate live remapping and the original image will be shown. Clicking on EXPORT IMAGE will open a *Save File...* prompt that will save the current frame with and without calibration applied on two accordingly named files.

NOTE: Each binary map is strictly bound and encrypted with the license key that was plugged on the machine whilst calibration was executed. At the loading of a calibration binary map, the presence of the specific license key is needed. If the incorrect license key is plugged when a map is loaded, a "Calibration recipe file is corrupted" message is shown, due to failed map decryption.

4 • ALIGNMENT PROCEDURE WITH TCLIB APP

4.1 Preliminary operations

Before starting the alignment procedure ensure the followings:

- Camera is connected to the PC
- Collimated backlight is turned on

As a starting point, execute an alignment based on a spirit level. All the components of the setup (lens, object plane and illuminator) should be levelled vertically with respect to the floor. Use the cylindrical parts of the lens as a reference plane or, where available, the mounting flange.

Once that these first steps are cleared, it is possible to open the TCLIB APP and proceed to the next step.

4.2 Camera selection

The TCLIB APP starts by default with the camera selection panel opened. Please ensure the camera is connected to the PC and is available (i.e. not used by any other application). Click on the REFRESH button and wait until the drop-down menu updates. Select the desired device from the menu and click OPEN.

An image should appear on the left side of the interface. If preliminary operations were executed correctly, an image should be visible. If not, check again the alignment with a level and check the status of the illuminator.

The image obtained should be more or less of this kind.



Image example of a good starting point for alignment

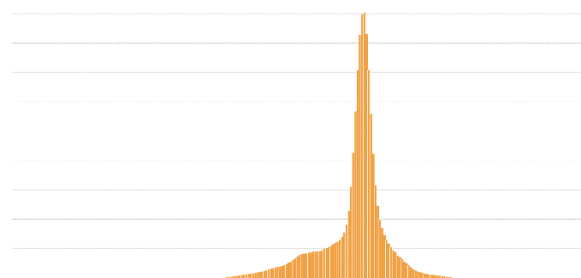


Image histogram

4.3 Lens-Light Alignment

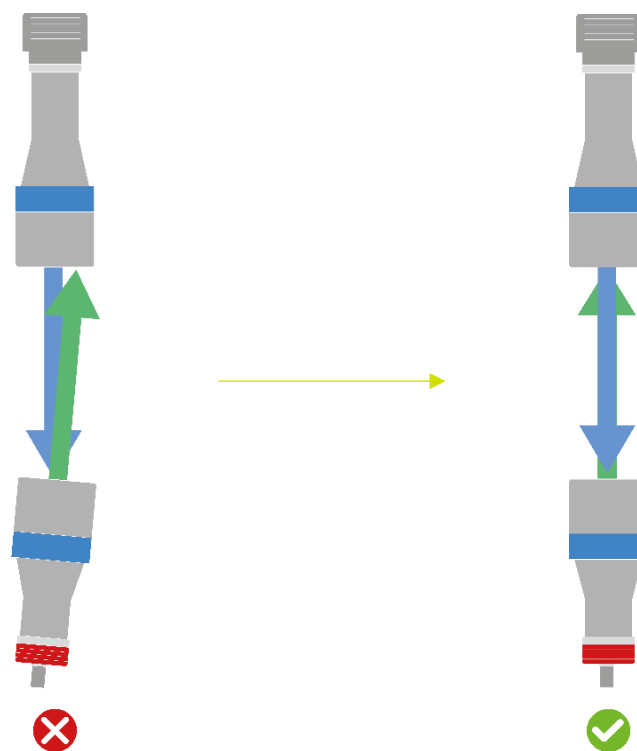
The next step is the optimization of the light homogeneity in the field of view. This procedure consists of two main tasks:

- Optical axis alignment
- LED source depth adjustment

First of all, it is necessary to have a correct gray level on the overall image. Best performances of telecentric setups are achieved when working with high contrast not-saturated images. To achieve optimal illumination, change the exposure time on the camera panel and/or light intensity on the collimated backlight. A good exposure value is set when the average indicator on the LENS-LIGHT ALIGNMENT panel is green

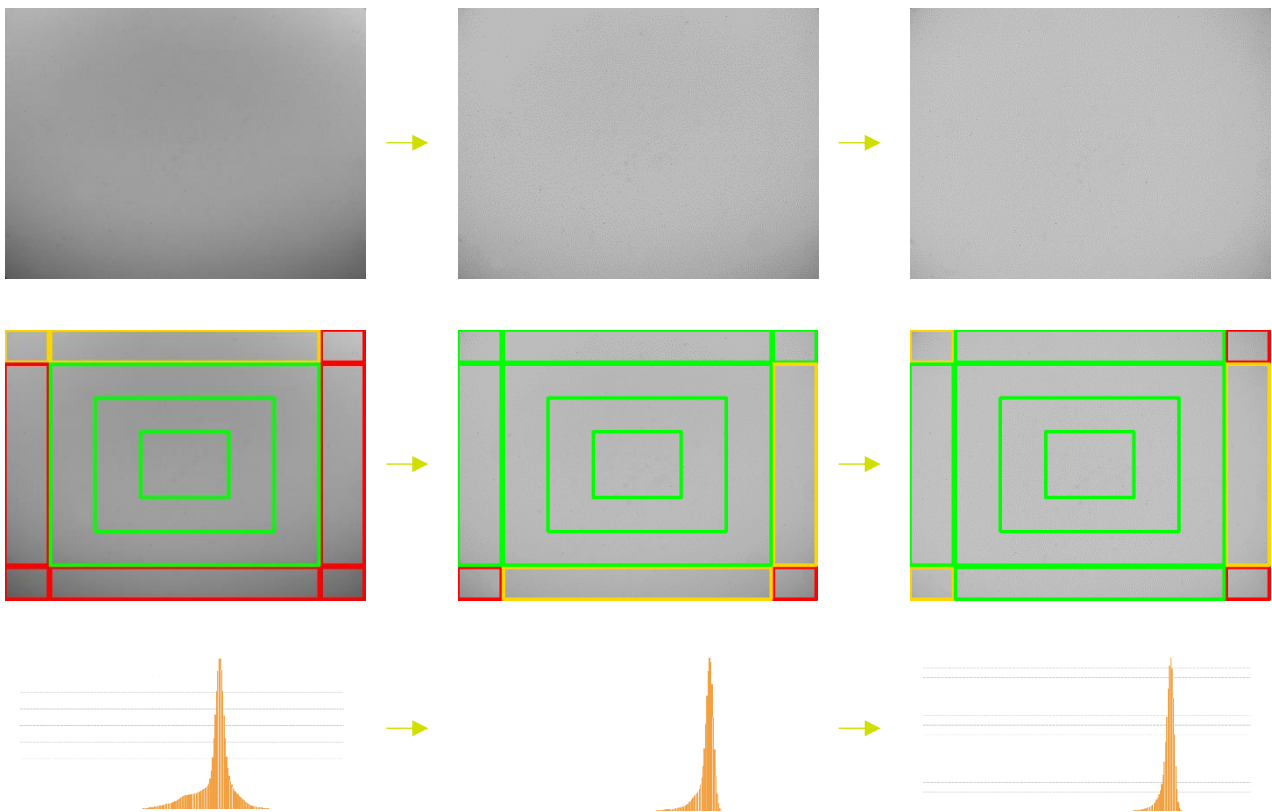
4.3.1 Optical axis alignment

The first task of the lens-light alignment is conducted by tilting the illuminator lens around the X and Y axis, assumed the optical axis corresponds with the Z axis. A scheme of the tilt is represented in the image below.



Scheme of the lens-light alignment procedure

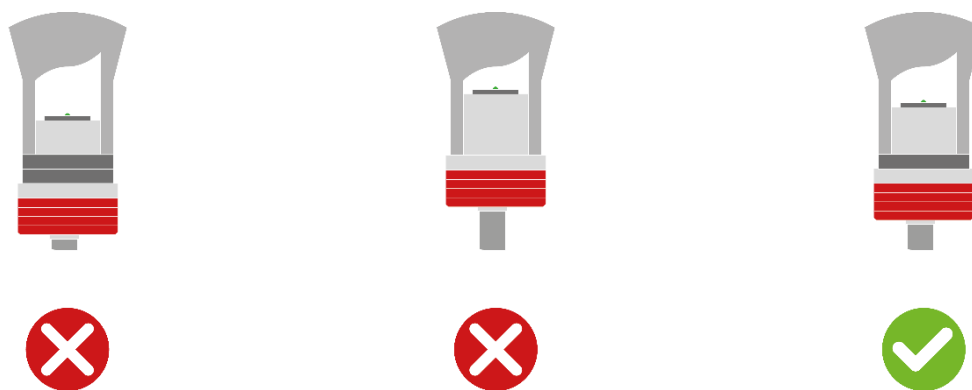
The procedure will raise image homogeneity. Use the interface response in order to follow image improvement. Best tilt position is achieved when most of the region rectangles are green. At the end of the tilt procedure a residual inhomogeneity could remain on the image in the form of corner vignetting or ring-shaped vignetting. This is due to LED source depth inside of the collimated backlight. In the next step this depth will be adjusted in order to obtain maximum homogeneity.



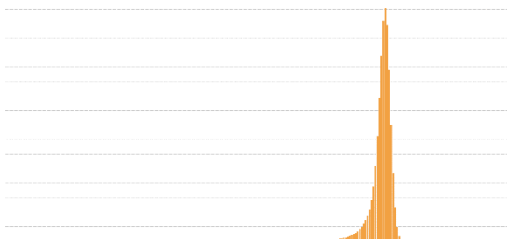
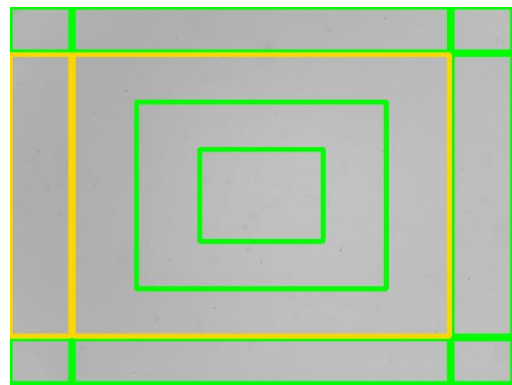
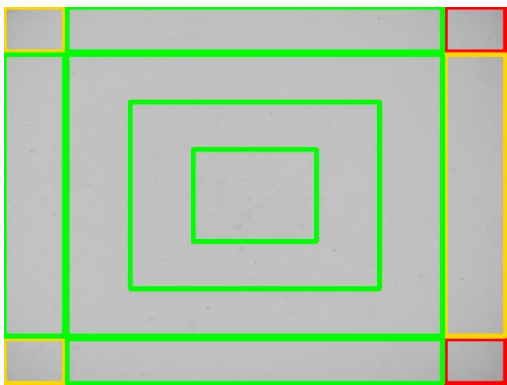
Demonstration images and relative histograms of the tilt procedure

4.3.2 LED source depth adjustment

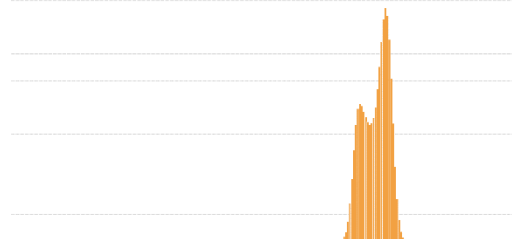
In order to achieve maximum homogeneity it is necessary to adjust carefully the depth of the LED source. The effect of a unoptimized LED depth can be a corner vignetting or a so-called ring-shaped vignetting. The two phenomena are very weak and faint but in some cases they interfere a lot with the quality of the measurements. In our workshop the optimization is conducted with our standard lenses, but the LED depth necessary for a good homogeneity could vary with lens formats and eyepieces. On the next page are reported two images of unoptimized LED source.



Scheme of the LED depth adjustment

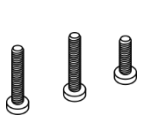


LED is too shallow inside the lens

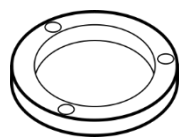


LED is too deep inside the lens

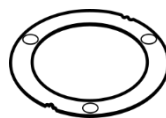
By operating with given LED spacers, move the LED source inwards if corner vignetting is present. Move the LED source outwards if ring-shaped vignetting is present. If there is the need to set the LED deeper than the maximum position achievable with no external spacers, add an internal LED spacer under the LED PCB. Accessories are illustrated in the next image.



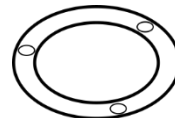
Screws



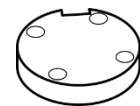
5mm external spacer



2mm external spacer



1mm external spacer



5mm internal spacer

Best homogeneity is achieved following again the response of the interface and when the correct positioning of the LED is complete, all region rectangles should be green. If this condition is impossible to reach raise the tolerance to a higher value (e.g. from 5.5 to 6.5-7).

NOTE: *With non-standard solutions a corner vignetting could persist even at best illumination condition.*

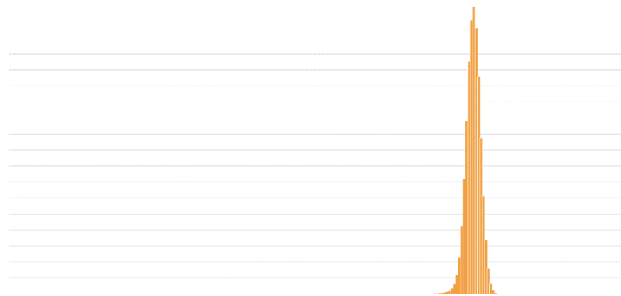
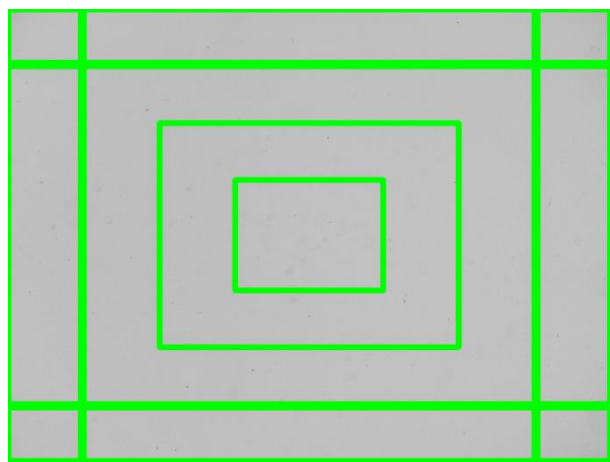


Image and histogram example of a correct lens-light alignment

4.4 Object plane alignment

Object plane alignment is key point for achieving good repeatability of object measurements in all orientations. In this part of the procedure a gauge block smaller than the shorter side of the field of view of the system.

In order to align the plane of measurement, place the gauge block approximatively at the center of the field of view. Then click on the SET MODEL button. After the model of the gauge block is correctly acquired the START button will activate. If the model acquisition fails, a message box will appear.

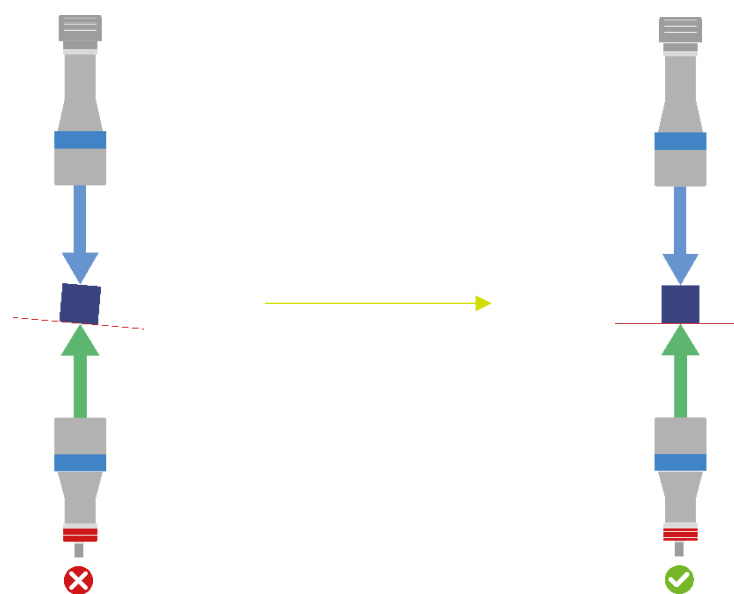
At the press of the START button the main acquisition starts. The interface will guide the user through the placement of the object in the field of view. It is important to note that the positioning mask drawn on the image presents a red side. This side must always stay aligned with the same short side of the gauge block. This is to avoid incoherence in measurements.

When the object is positioned correctly under the mask, press the NEXT button. The mask will rotate and a new measurement can be taken. Iterate the procedure eight times until all text boxes are filled with a measurement.

The measurements are the sub-pixel distances between the two longer sides of the gauge block. One could imagine that if the block is placed on a tilted plane, its vertical sides will be tilted with respect to the optical axis, giving a larger shape on the image taken from above. This is the reason why the alignment is conducted with eight different orientation.

After all measurements are conducted, the software estimates the worst tilt direction and tells the user to place the gauge block on that specific angle and optimize the live measurement tilting the plane along the direction orthogonal to the long side of the block.

The precision of plane alignment that can be achieved with this procedure is of the order of 0.05° , strongly dependent on lens magnification and tilting degrees of freedom sensitivity. The user must take care of eventual dust on the sides of the gauge block. The procedure is very sensitive to dust.



Scheme of the optical plane tilt procedure

4.5 Best focus adjustment

After the object plane alignment is complete, best focus adjustment is necessary. The object suited for best focus estimation in the TCLIB Suite is a chessboard pattern from our PTXXX-XXX-C series.

The best focus adjustment can be executed in two ways, depending on the typology of mounting implemented on the setup. If the setup provides working distance adjustment (in the form of either lens and object plane translation) it is necessary to retrieve the best focus working distance moving relatively lens and object plane and compare the obtained working distance with the one reported on the production test report by the means of the provided calculator. The calculator will return automatically the desired thickness of back focal spacers, given magnification and factory measured working distance of the lens. After spacer insertion/removal, it is necessary to reset the working distance to the factory measured one.

If otherwise the setup has fixed positions for both lens and object plane, the focus adjustment must be conducted directly with provided back focal adjustment spacers.

All estimators give greater values when focus improves. Best focus is achieved at a maximum of the focus estimator value.

4.6 Calibration

In order to obtain the calibration recipe, place the suited chessboard pattern from our calibration pattern range. After the pattern is correctly placed and aligned, possibly with the chessboard aligned to the sensor orientation, simply press on the NEW RECIPE button. At the press of the button, the recipe save prompt opens. Insert a valid name and click SAVE. After the confirmation the calibration will take place. Wait for a message box of completed calibration.

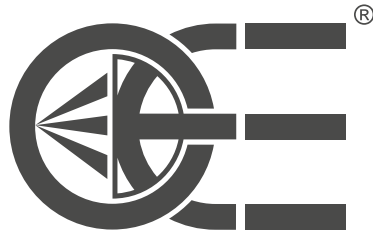
After the calibration is completed, the pression of LIVE REMAP button the image coming from the camera is real time remapped with the loaded calibration recipe.

The recipe computed with this routine is strictly bound to the license key that was plugged in during the calibration routine. If the recipe obtained with this method is loaded on another machine or with another key, a "Calibration recipe file is corrupted" message will be shown. This is due to an encryption check on the recipe.

The recipe can be loaded with the TCLIB.dll library given the condition that the same license key used for recipe preparation is plugged at the time of operation.

DISCLAIMER

Specifications within this document are subject to change without notice. Photos and pictures are for illustration purposes only and may differ from the real product's appearance.



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