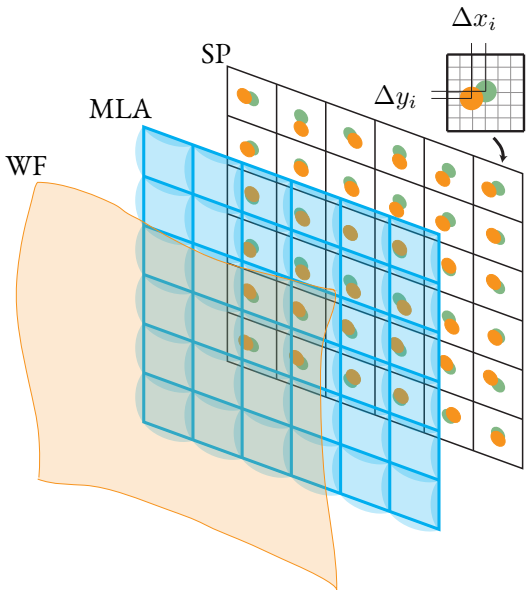
Flexible Optical B.V.

Adaptive Optics • Optical Microsystems • Wavefront Sensors

Shack-Hartmann wavefront sensor: technical passport



OKO Technologies,

OKO Technologies is the trade name of Flexible Optical BV

1 Parameters of the wavefront sensor

The Shack-Hartmann wavefront sensor consist of digital camera and a microlens array (MLA) in front of it. The specifications of the camera and the MLA used in this model are given below.

Parameter	Value
Serial number	FS3370-O-P300-F18.6-16.04
Camera model	IDS UI-3370CP-NIR
Camera type	digital CMOS
Camera interface	USB 3.0
Array geometry	orthogonal
Array pitch	300 m
Array nominal focal distance	18.6 mm
Clear aperture	$\leq$9.5 mm
Subapertures	$\leq$900
Angular range	$\pm$ 0.388 ° = $\pm$ 6.77 mrad
Tilt range	$\pm$ 64.4 μm
Minimum focal distance	$\pm$ 700 mm
Defocus range	$\pm$ 16.1 μm
Spherical aberration	$\pm$ 2.7 mic
Wavefront measurement precision	0.0034 λ
Full spot size	95.7 μm
Minimum distance between spots	47.8 μm
Repeatability, RMS	$\lambda/150$[1]
Repeatability, PV	$\lambda/20$[1]
Acquisition rate	$\geq$60 fps
Processing rate, fast mode	$\sim$35 fps[2]
Recommended Zernike terms	$\leq$300
Wavelength	400…1000 nm[3], see Fig. 1
Mechanical dimensions	See Fig. 2 and 3

[1] For λ = 633 nm
The repeatability figures can be further improved by averaging over multiple frames. To enable averaging, go to menu "Options ⇒ Camera", press button "Properties" and correct the field "Average over …frames".

[2] For low-order aberration analysis on a PC with AMD Athlon XP1800+ processor and 256 MB RAM

[3] also sensitive up to 1100 nm, but with lower quantum efficiency

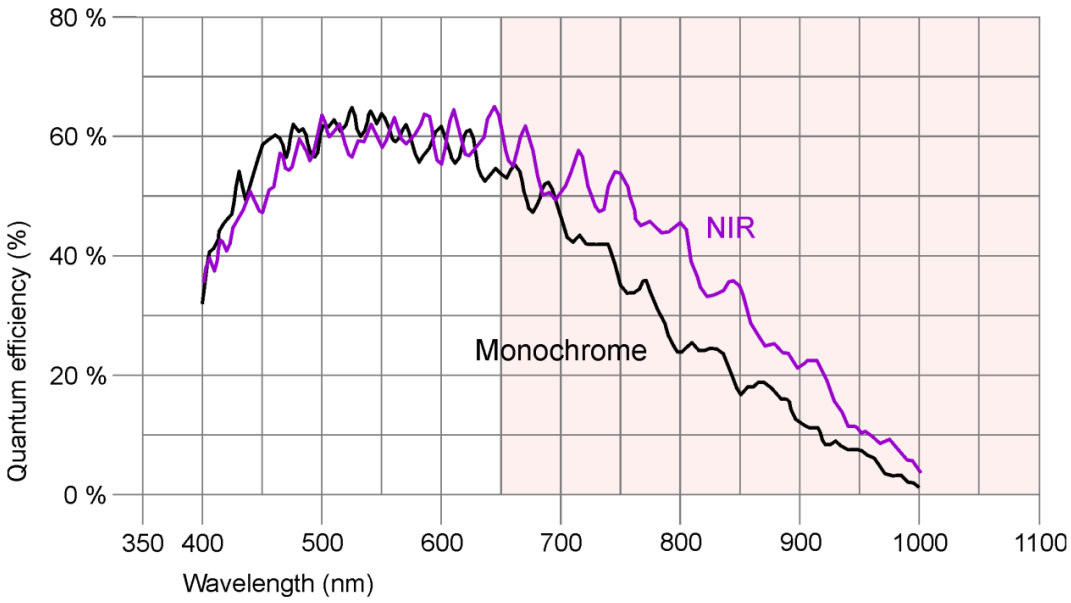


Figure 1: *Quantum efficiency of the camera sensor*

Figure 2: *General view of the sensor*

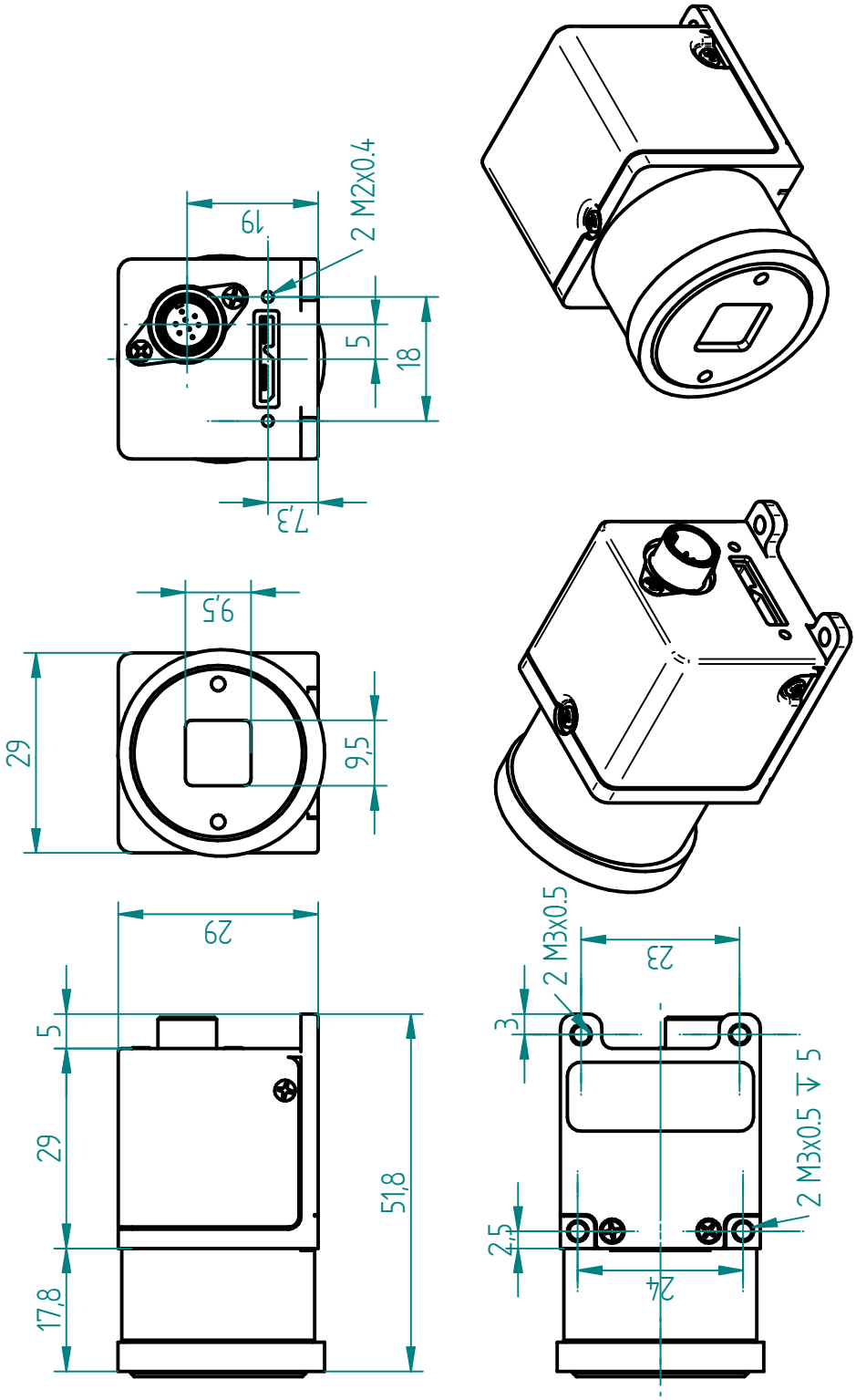


Figure 3: *Mechanical dimensions of the sensor*

2 Installation of FrontSurfer software (Windows 2000/XP/Vista/7)

1. Start `setup.exe` from `fsurfer` directory of the installation CD to install FrontSurfer to your computer. Follow further installation instructions.
2. Start `Install.exe` from `keylok` directory of the installation CD to install drivers for the protection dongle. Select the option "USB dongle". Please note that the installation should be completed BEFORE the dongle is connected.
3. Attach the FrontSurfer dongle to a free USB port. The system will recognize the device. Choose for automatic installation of the driver.
4. Under Windows Vista, 7, 8, and 10, FrontSurfer should be started under administrator access rights and in compatibility mode[1] with Windows XP. To enable them, right-click on "FrontSurfer" shortcut and locate "Compatibility" property sheet. Enable the options "Run this program in compatibility mode for Windows XP (Service Pack 3)" and "Run this program as an administrator" and press OK to confirm.
5. Now you may start "FrontSurfer" from the Start menu.

[1] compatibility mode is optional for the latest operational systems and can be omitted

3 Interfacing of a wavefront sensor

1. Install uEye camera drivers from `uEye` directory of the installation CD. Chose `32bit` or `64bit` subfolder depending on the bitness of your operating system.

2. Connect the wavefront sensor to the computer. The system will recognize the device. Choose for automatic installation of the driver.

3. Start "uEye Cockpit" program and make sure that you can see image from the camera. Close camera (use button) or "uEye Cockpit" before processing to the next step.

4. Configure frame grabber type in FrontSurfer. For this purpose go to the menu "Options ⇒ Camera". In the dialog box "Camera interface" check "Plugin" option. After that, load plugin for the uEye camera by pressing "Load" button and selecting `uEye.dll` file in the FrontSurfer installation directory (e.g. `C:\Program Files (x86)\FrontSurfer1.4.10.dm\`). Press "OK".

5. Load the wavefront sensor calibration data. For this purpose go to the menu "Options ⇒ Parameters". In the dialog box "Sensor parameters" press "Load" button and load the calibration file `calibration.txt` from the `fsurfer` directory of the CD. Press "OK" to complete. See Fig. 4 for illustration.

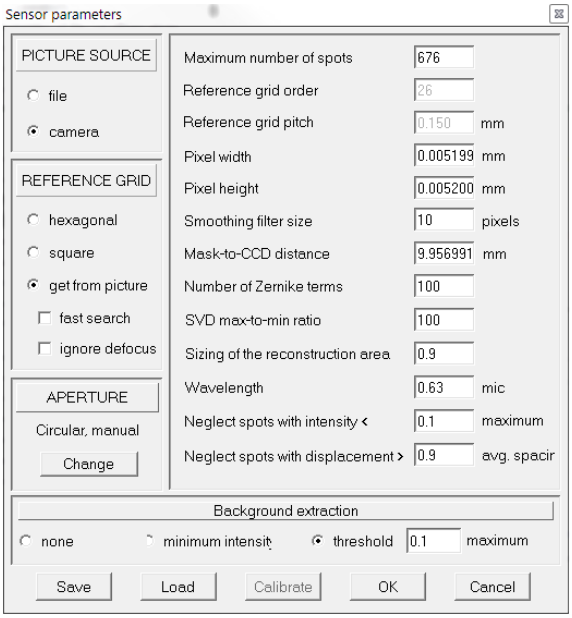


Figure 4: *Sensor parameters window*

4 Camera settings

Camera settings such as exposure, pixel clock, area of interest, *etc.* are available through menu menu "Options ⇒ Parameters". In the dialog box "Camera interface" press "Properties" and set the desired parameters in "uEye device properties" window (Figure 6). The following parameters are important for accurate and fast wavefront measurements and reconstruction.

4.1 Pixel clock

Pixel clock setting affects the minimal possible exposure and maximum possible frame rate, and usually is set to the highest acceptable value. High values, however, might result to unresponsive system. We recommend to set it to the middle value first and increase in small steps until the desired exposure time is achieved.

For USB 3 cameras running on USB 2 bus in compatibility mode, the range of possible pixel clock is very limited. This results in slower performance. Connect USB 3 camera to high-speed USB 3 port for maximum frame rate.

4.2 Setting correct exposure

For proper measurement, adjust the camera exposure and/or measured beam power so that the maximum spot intensity is about 90% of the camera range. Use "Histogram" and "Line view" tools of uEye Cockpit software (see Figure 5) to determine the correct exposure and enter this value in the camera plugin settings.

4.3 Area of Interest (AOI)

To increase the acquisition speed, the sensor can be used with a smaller AOI. To change AOI, unselect the option "maximize" in "Area of interest" section of the camera properties window and adjust the fields "Left", "Width", "Top" and "Height" to set the desired AOI. You need to reduce dark space at the periphery of the frame, keeping the whole pattern of spots visible. A convenient way to set these parameters is to use the Crop tool of uEye Cockpit (see Fig. 5) to chose the desired AOI, jot down the AOI size and coordinates, and insert their values in the FrontSurfer.

4.4 Sub-sampling and binning

To increase the acquisition speed, the sensor can be used either in sub-sampling mode or in binning mode.

4.4.1 Sub-sampling mode

To change the sub-sampling mode, chose the desired sampling mode ("Normal", or "Subsampling x2", or "Subsampling x4") in "Sampling mode" drop-down menu (see Fig. 6). Load the proper calibration file for the chosen sampling mode.

Note that sub-sampling mode reduces the accuracy of the measurements.

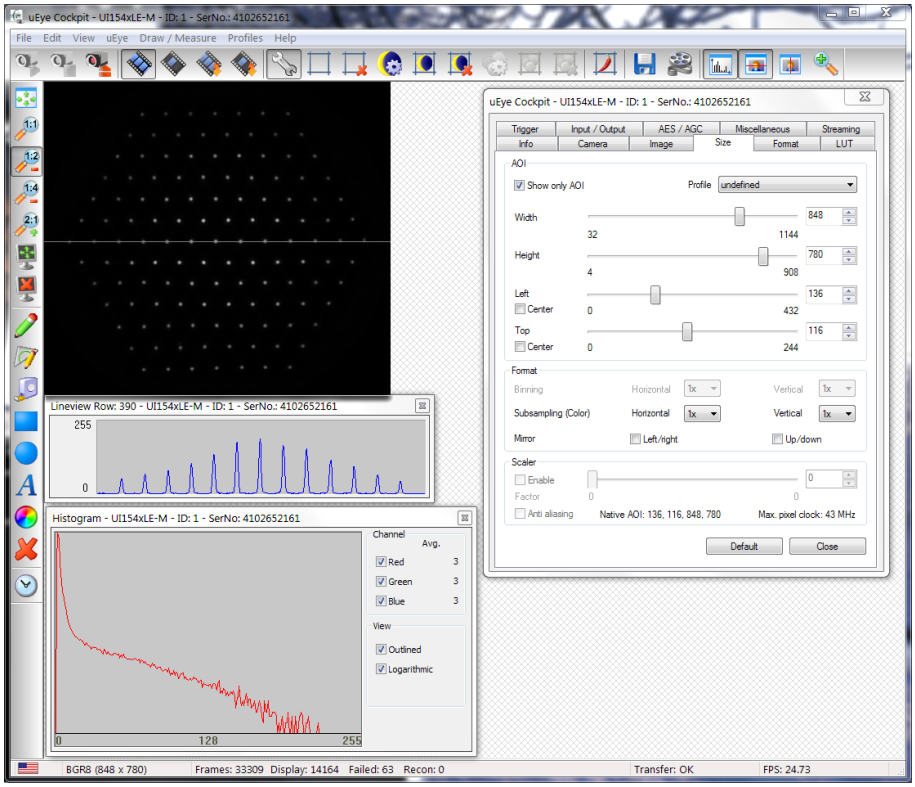


Figure 5: *Choosing correct camera parameters wit uEye Cockpit: the AOI values set by the Crop tool are visible in "Size" tab of camera settings; the hystogram and Line view tools are helpful to set the correct exposure.* NB! *The snapshot was taken with 127-lenses hexagonal array; the pattern taken with other sensor will look, of course, differently.*

4.4.2 Binning mode

To change the sub-sampling mode, chose the desired sampling mode ("Normal", or "Binning x2", or "Binning x4") in "Sampling mode" drop-down menu (see Fig. 6). After that, change the maximum pixel clock frequency to get higher frame rate. Load the proper calibration file for the chosen sampling mode.

2x binning makes the image brighter by a factor of about two. It also reduces image noise.

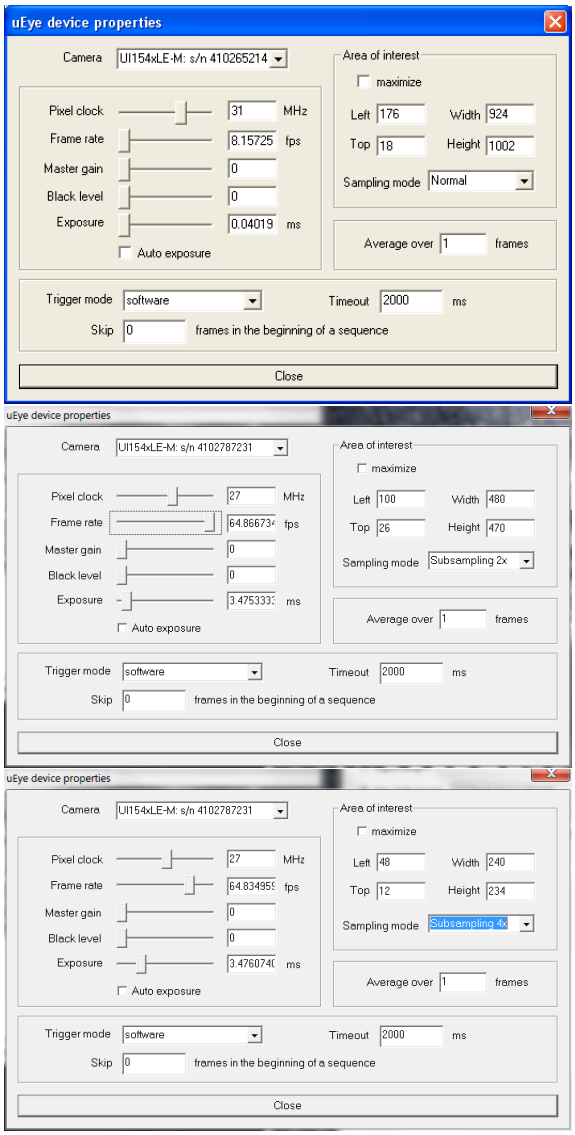


Figure 6: *"uEye" plugin properties; settings for "Normal", "Subsampling x2" and "Subsampling x4" modes (top to bottom).*

5 Sensor settings

The wavefront sensor setting are accessible through menu "Options → Parameters" (Figure 4). Some of the settings (like pixel size, microlens array parameters and the actual distance from the MLA to the camera chip) are obtained during the calibration procedure and should not be changed by the customer[2]. Other setting, like aperture type, measurement mode, *etc.* should be change to match the measuring situation.

The most often changed parameters are described below. For overview of all settings, please refer to FrontSurfer manual.

5.1 Using of the absolute and reference measurement modes

In the reference measurement mode, a reference Hartmann pattern corresponding to the desired wavefront is captured first. The position of the centroids in this pattern will be used by FrontSurfer as reference grid. In result, the difference between the main and referenced wavefronts will be measured.

In the absolute measurement mode, FrontSufer uses an ideal ("absolute") geometrical grid derived from the microlens array and camera specifications.

Please see Section 3.3 "Choosing the measurement mode" of the FrontSurfer manual for more details.

- To switch to the absolute measurement mode, go to the menu "Options → Parameters" and change the "Reference grid" setting to "hexagonal". Press "OK".

  If working with an automatically defined aperture, you can extract the errors resulting from irregularity/misalignment of the microlens array or technical properties of the camera chip, use the menu command "Options → Extract terms" and load the file "extract_terms.txt" from the "fsurfer" directory of the CD. Press "OK" to complete.

- To switch to the reference mode, go to the menu "Options → Parameters" and change the "Reference grid" setting to "get from picture". Press "OK" to complete.

  Please note that in the reference mode extraction of errors is not needed. Use the menu command "Options → Extract terms" and delete all Zernike terms. Press "OK" to complete.

The sensors with "unlimited" MLA (*i.e.* with microlenses filling the whole clear aperture) are recommended to use in the reference mode.

5.2 Manual/Automatic aperture

Sometimes, it is more convenient to use the sensor in the reference mode with manually defined circular aperture. To define the aperture (area of interest), load the reference pattern first, then click on the reference picture and draw the aperture by dragging the cursor. It will be displayed as a red circle. For more information, refer to section 3.6.3 of the FrontSurfer manual.

[2] If, however, they were changed unintentionally, they can be restored by loading the supplied with the sensor ``calibration.txt'' file

6 Warranty

The equipment is covered by a one-year factory-defect warranty.

If the device is damaged during shipping, it will be replaced by a similar device within two months. A photo of the damaged device should be sent to Flexible Optical B.V. (OKO Technologies) within 3 days after the damaged device is received.

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7 Contact

All questions about the technology, quality and applications of the wavefront sensor should be addressed to:

Flexible Optical B.V.
Polakweg 10–11,
2288 GG Rijswijk ZH,
the Netherlands

Date:

Signature:

(Dr. Oleg Soloviev,
Senior Associate)