Flexible Optical B.V.

Adaptive Optics • Optical Microsystems • Wavefront Sensors

Adaptive optical system based on 79-channel MMDM: technical passport

OKO Technologies,

OKO Technologies is the trade name of Flexible Optical BV

1 Installation of FrontSurfer software

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 could be connected.

3. To be able to operate deformable mirrors, you need to install "DLPortIO" library. Go to the directory "DLPortIO" and run the setup program "port95nt.exe". Please reboot after the installation.

4. Attach the FrontSurfer dongle to a free USB port. The system will recognize the device. Choose for automatic installation of the driver.

5. Start "FrontSurfer" from the Start menu.

2 Interfacing of a wavefront sensor

1. Go to the directory "basler". Start the setup program and install drivers and applications for Basler A601f/A602f camera. Attach the camera to a Firewire port of your computer only when the program will request it. Please note that 12 V DC voltage should be supplied to the camera via the Firewire port. When using a notebook, you should connect an external adaptor to "+12 V" connector on the Firewire interface card.

2. Start "BCAM Viewer" and make sure that you can see the image from the camera.

3. Configure frame grabber type in FrontSurfer. For this purpose go to the menu "Options ⇒ Parameters". In the dialog box "Camera interface" check "Plugin" option. After that, load plugin for the Basler camera by pressing "Load" button and selecting "BCAM1_8.dll" file in the FrontSurfer installation directory. Press "OK".

4. Set camera viewer type through the menu command "Preview ⇒ Configuration". Select the option "internal viewer" and press "OK". Now you may check whether FrontSurfer can capture images from the wavefront sensor.

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.

For Basler A602f you may achieve faster closed-loop operation by enabling a partial scanning mode. For this purpose go to the menu “Options ⇒ Camera”. In the dialog box “Camera interface” press “Properties” button. Unselect the option “maximize” and adjust the fields “Left”, “Width”, “Top” and “Height” to reduce the area of interest. You need to reduce dark space at the periphery of the frame, keeping the whole hexagonal pattern of spots visible.

The sensor has a microlens array with orthogonal arrangement of microlenses, and is aperture is mostly limited by the image sensor size. You can use it only 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.

3 Interfacing of a deformable mirror

1. Connect the USB hub enclosed to a USB port of your computer. Power the USB hub using the power supply enclosed, then connect DAC40USB units to it. Drivers for these units can be found in “DAC40USB/Driver” directory of the installation CD. Install the drivers. Start “DAC40USB / Program_win2000 / TEST_DAC40.exe” to make sure that the units are recognized by the system.

2. Load configuration of channels for the deformable mirror. With this purpose go to the menu command “Mirror ⇒ Configuration”, then press “Configure”. In the dialog box “Deformable mirror configuration” press the “Load” button and load the file “mmdm79_50usb.txt” from the CD “fsurfer” directory. Press “OK” twice to complete configuration.

3. Connect the amplifier units to DAC40USB units using four 20 pins-to-26 pins cables, observing the order of numbering (see labels next to the sockets).

4. Connect the mirror to the amplifier units using four 20 pins-to-20 pins cables, observing the order of numbering. Fix the cables to the optical table.

4 Assembling and running of the adaptive optical system

1. Place the mirror and the wavefront sensor into an optical setup. The optical scheme should satisfy the following conditions.

   a) The optics should re-image the plane of the mirror to the plane of the Hartmann mask (or microlens array).

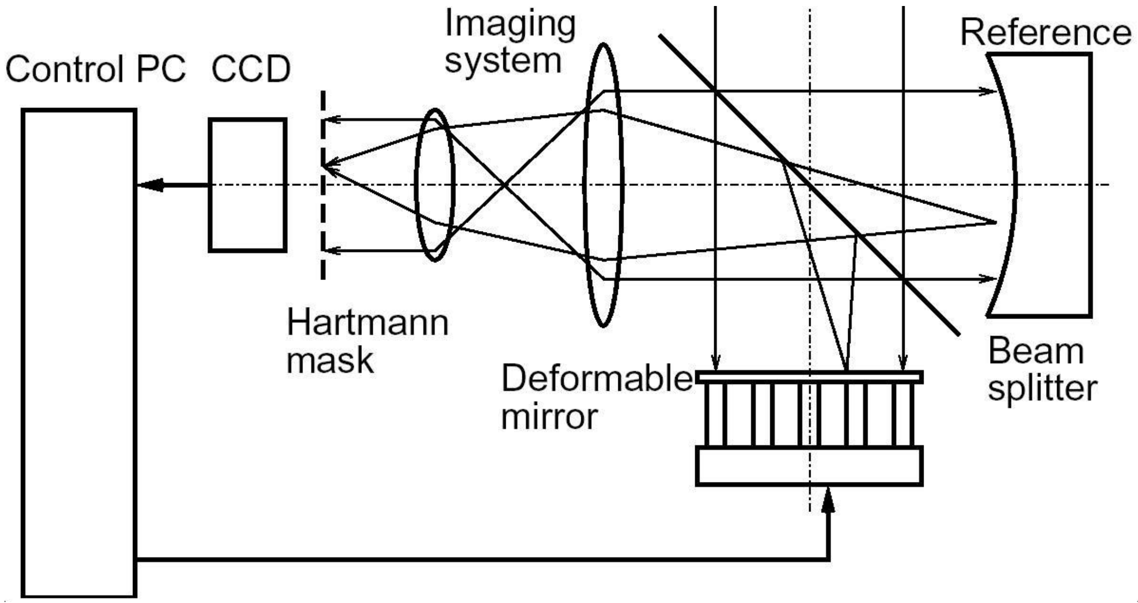

Figure 1: *Scheme of typical adaptive optics setup.*

b) The scheme should scale the beam in such a way that the working aperture of the mirror (about 35 mm) should be re-imaged to the working area of the Hartmann mask/microlens array (about 4.5 mm).

c) The optics should allow for calibration. In the general case, it consists of separate measurement of the complete setup aberration with ideal object or a source of ideal wavefront, replacing the one to be tested.

The typical setup for functional feedback loop is shown in the Figure 1. Flat or concave spherical mirror can be used as a reference.

2. Connect the wavefront sensor and the deformable mirror; turn on the power supplies.

3. Start FrontSurfer. Turn on the preview mode in FrontSurfer and check the Shack-Hartmann pattern from both the calibration beam and those reflected from the mirror. It is highly desirable to provide that no spots are missing.

4. Go to the menu command "Mirror → Set values". Now you may start to use the mirror by applying different control voltages to the actuators. See FrontSurfer manual for instructions on using of the feedback loop operation mode.

5 Mirror testing

The mirror was calibrated and tested in feedback loop operation mode before shipping. The results of its testing at a wavelength of 633 nm (He-Ne laser) are presented below.

FrontSurfer perform wavefront correction in a series of iterations. If the residual aberration ϕ_n at the n-th iteration corresponds to the set of actuator signals $\mathbf{X}_n$ then the actuator signals at the next step $\mathbf{X}_{n+1}$ will be determined by expression

$$\mathbf{X}_{n+1} = \mathbf{X}_n - g\mathbf{A}^{-1}\phi_n,$$

where g is the feedback coefficient with value in the range (0..1], $\mathbf{A}$ is the influence matrix of the mirror, $\mathbf{A}^{-1}$ is its pseudo-inverse given by

$$\mathbf{A}^{-1}=\mathbf{V}\mathbf{S}^{-1}\mathbf{U}^T,$$

$\mathbf{U}$, $\mathbf{S}$ and $\mathbf{V}$ are the singular value decomposition (SVD) of $\mathbf{A}$ which is $\mathbf{A}=\mathbf{U}\mathbf{S}\mathbf{V}^T$ [1]. The columns of the matrix $\mathbf{U}$ make up orthonormal set of the mirror deformations (modes), and the values of the diagonal matrix $\mathbf{S}$ represent the gains of these modes. Discarding those modes having small singular values may improve controllability of the system.

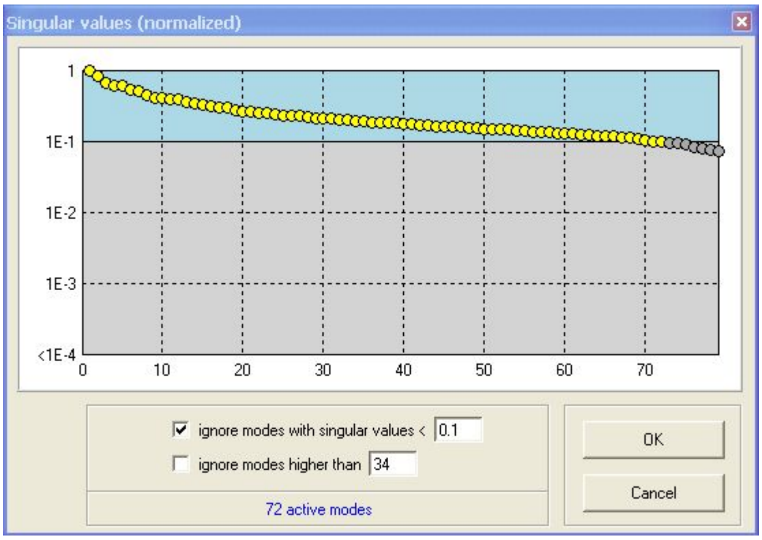

Figure 2: *Singular values of the 79-channel mirror.*

Experimental singular values for the deformable mirror are given in Figure 2; first 20 SVD modes are shown in Figure 3.

A flat mirror was used as a reference. Optimization started from the initial shape of the mirror, which was produced by setting all mirror values to -0.5; this shape is shown in Figure 4. As the mirror can be operated only in biased mode, we introduced a bias curvature relative to the reference by adding the Zernike term Z[2,0] with -1.5 μm amplitude to the target function.

In the first test we generated the spherical wavefront corresponding to the bias curvature - see Figure 5. The residual aberrations are shown in Figure 6. In the following tests we generated various Zernike aberrations in addition to the bias curvature; the results are shown in Figures 7-12. Figure 13 shows the settings of the "Feedback parameters" dialog box used throughout the tests.

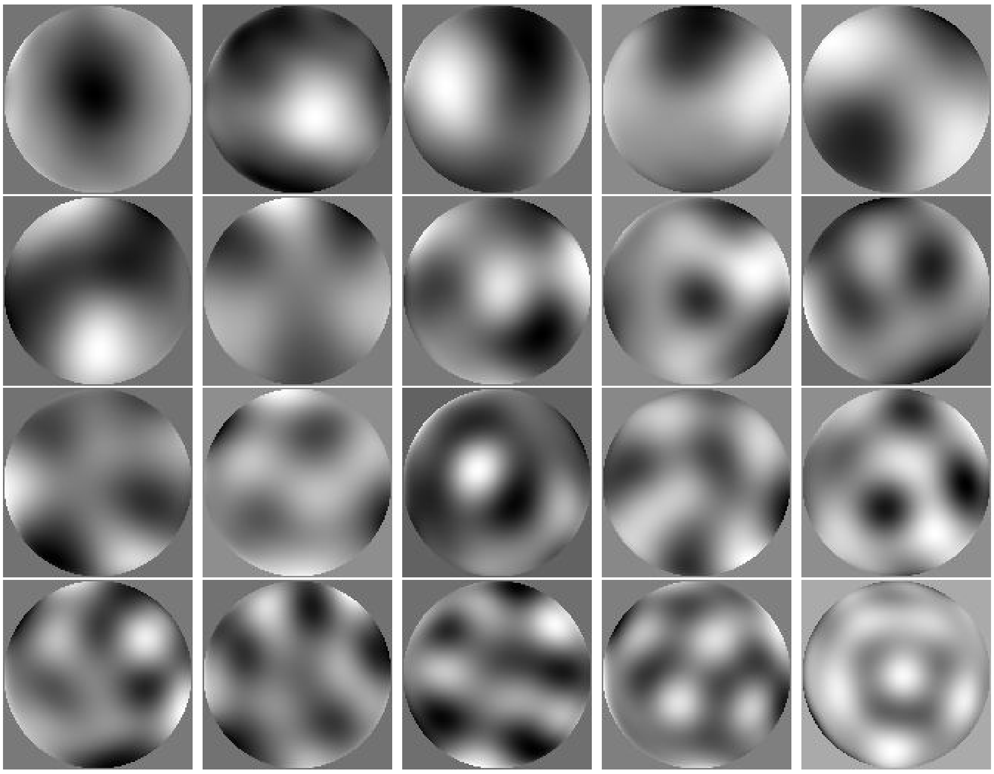

Figure 3: *First 20 modes of the 79-channel mirror.*

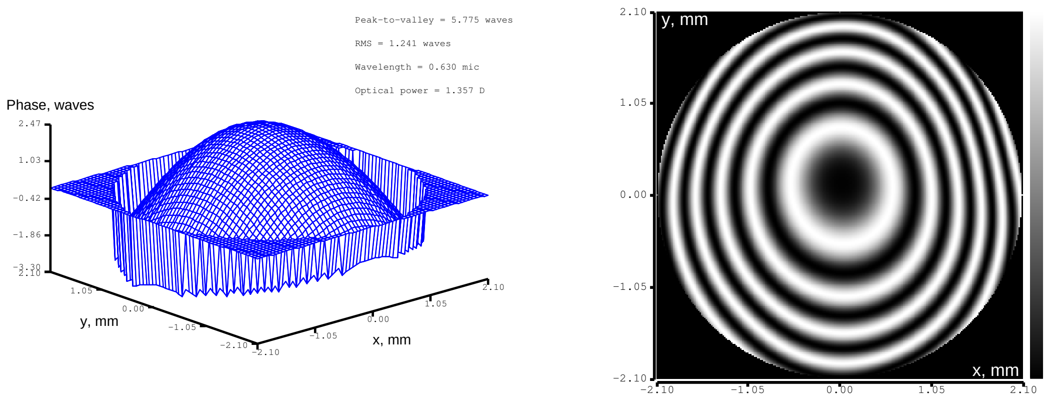

Figure 4: *Initial shape of the mirror, which was produced by setting all mirror values to 0.*

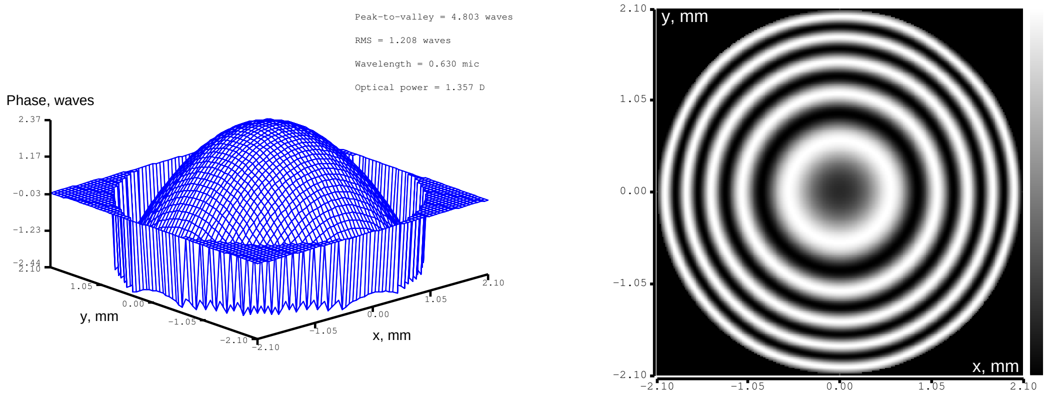

Figure 5: *Generated bias curvature (Zernike term Z[2,0]=-1.5 μm).*

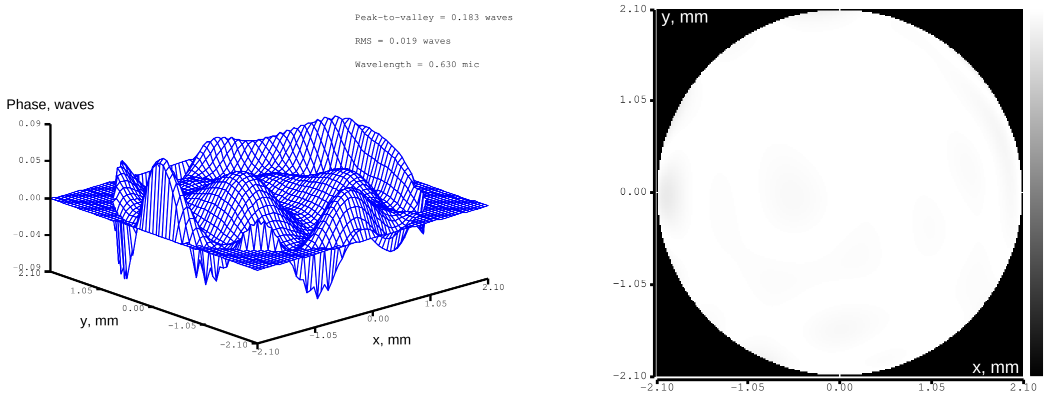

Figure 6: *Optimization with respect to the bias curvature (Zernike term Z[2,0]=-1.5 μm); residual aberrations.*

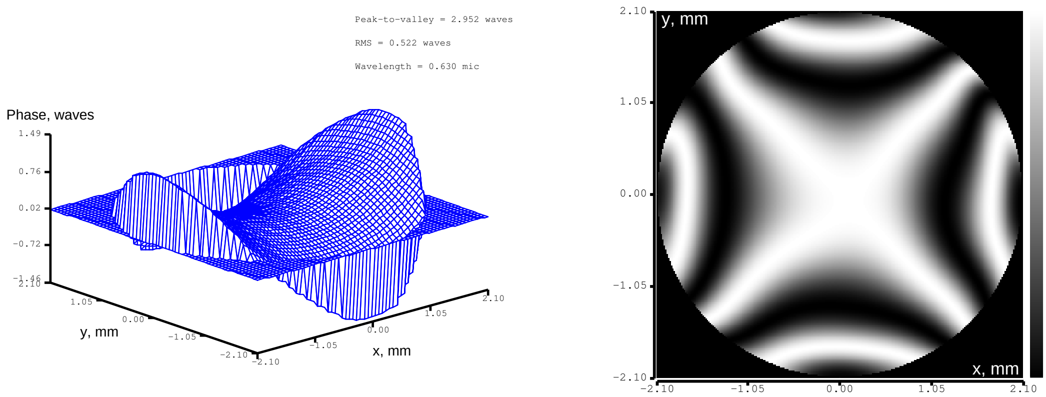

Figure 7: *Generated astigmatism (with respect to the bias curvature), Zernike term Z[2,2], amplitude 1 μm.*

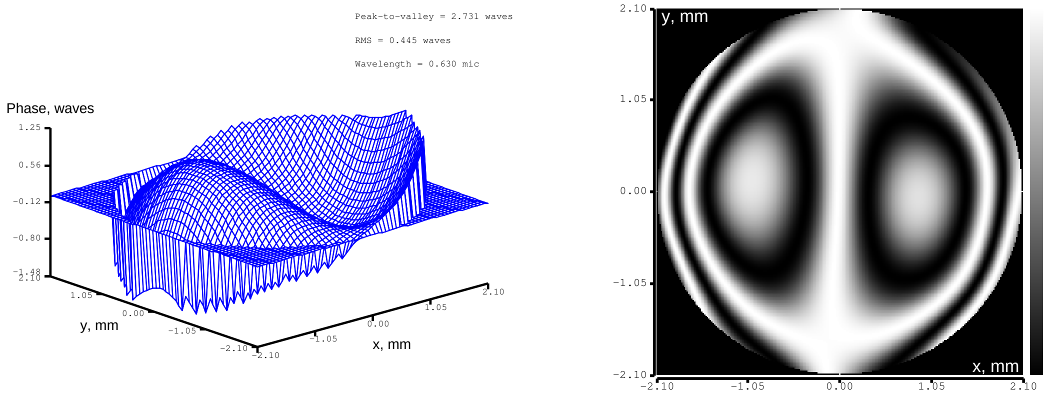

Figure 8: *Generated coma aberration (with respect to the bias curvature), Zernike term Z[3,1], amplitude 1 μm.*

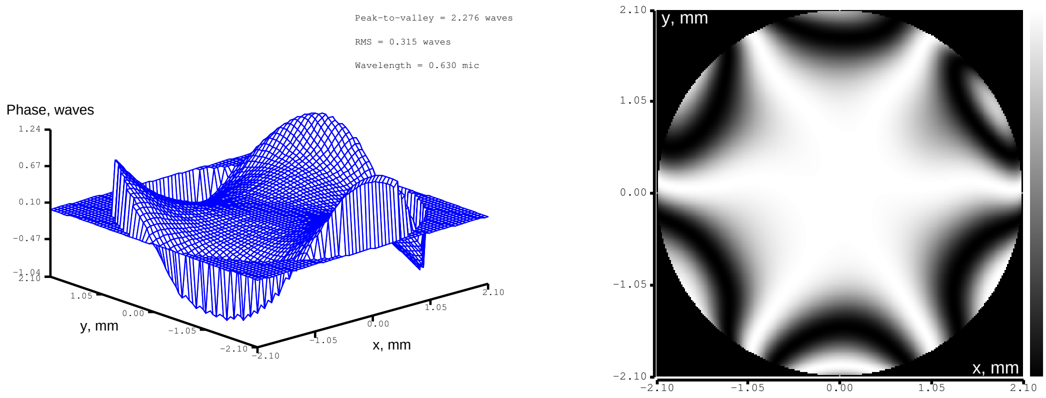

Figure 9: *Generated trifoil aberration (with respect to the bias curvature), Zernike term Z[3,3], amplitude 0.7 μm.*

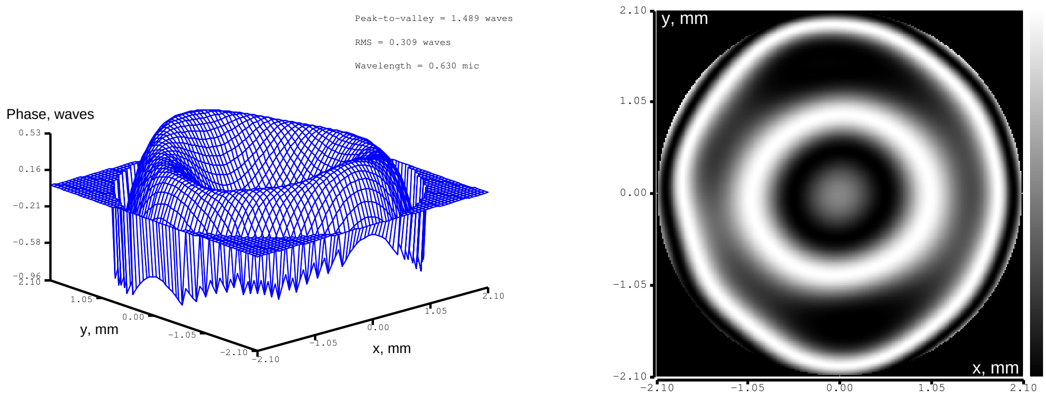

Figure 10: *Generated spherical aberration (with respect to the bias curvature), Zernike term Z[4,0], amplitude 0.5 μm.*

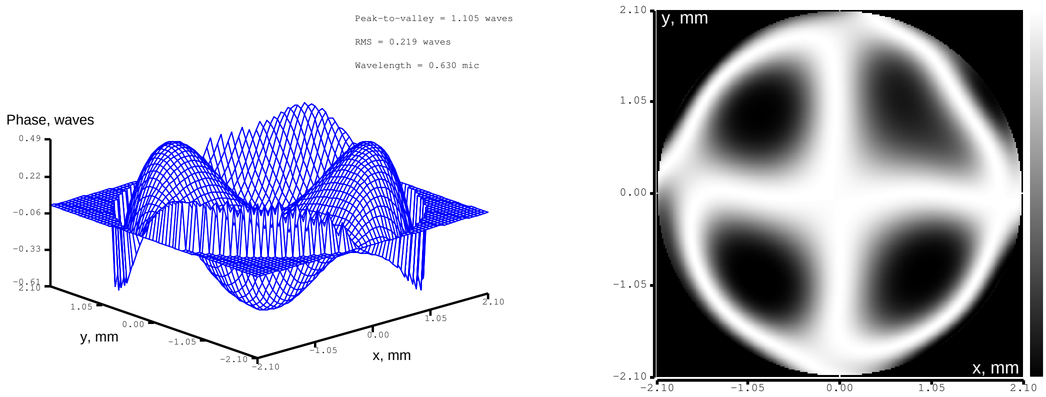

Figure 11: *Generated Zernike aberration Z[4,2] (with respect to the bias curvature), amplitude 0.5 μm.*

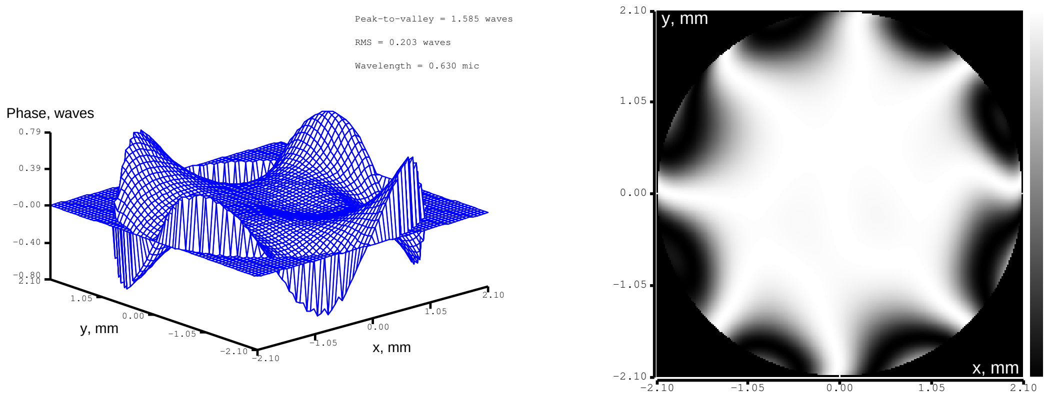

Figure 12: *Generated Zernike aberration Z[4,4] (with respect to the bias curvature), amplitude 0.5 μm.*

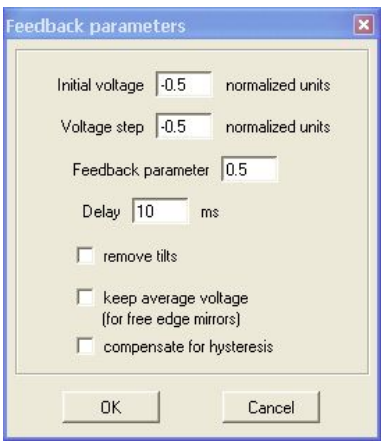

Figure 13: *Settings in the "Feedback parameters" dialog box used throughout the tests.*

Higher stroke and better correction quality can be achieved when the mirror is operated in biased mode (optimization with respect to the initial mirror curvature, which can be achieved by setting 0 to all actuators, which corresponds to half stroke of the mirror). We recommend biasing for practical applications.

6 Contact person

All questions about the technology, quality and applications of adaptive mirror should be addressed to:
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The Netherlands

Date:

Signature:

References

[1] C. Paterson, I. Munro, C. Dainty, A low cost adaptive optics system using a membrane mirror, Optics Express **6**, 175-185 (2000).