ClariFast™ version 1.2.3
Install / Startup Guide / Description of Operations

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Introduction:

ClariFast^{TM} is a closed loop system which corrects optical aberrations by combining an intelligent camera, PC computing power, and AgilOptics' unique deformable mirrors. The primary goal of the system is to bring together all these units into an inexpensive yet powerful system to correct all sorts of optical aberrations. ClariFast^{TM} combines advanced algorithms to compute Zernike, Fourier, or Legendre fits of the optical aberrations and impose the inverse operations with the Unifi mirror to correct the beam or optical imperfections.

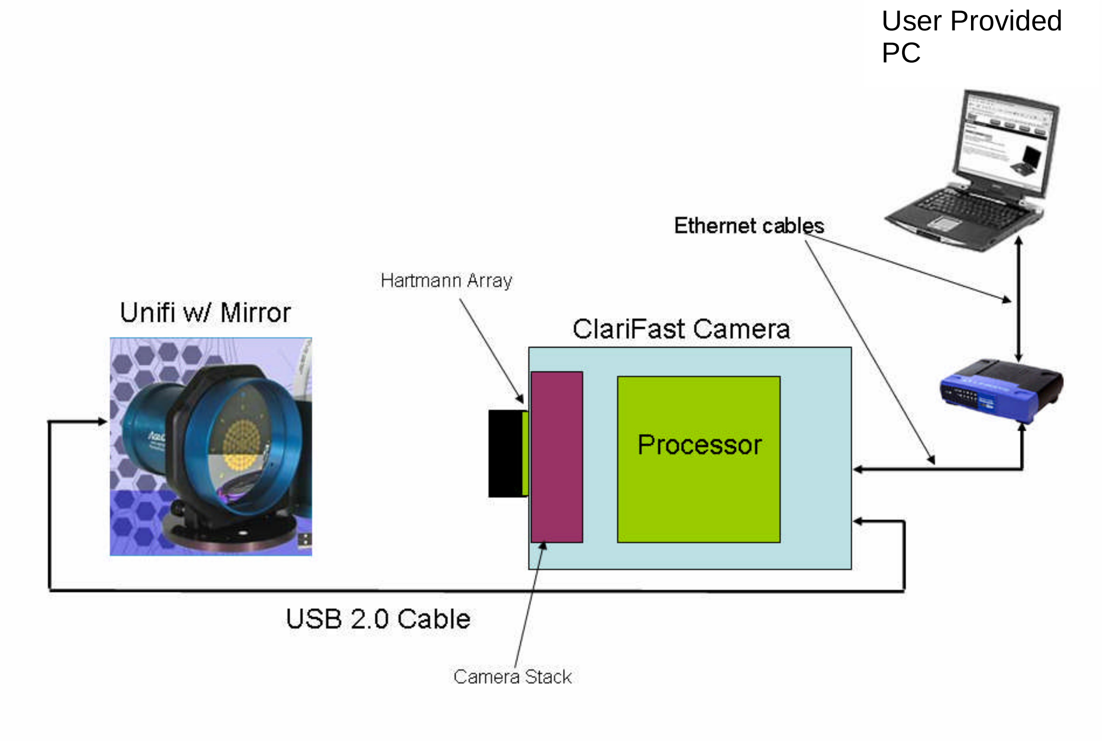


Figure 1. Basic Hardware Setup

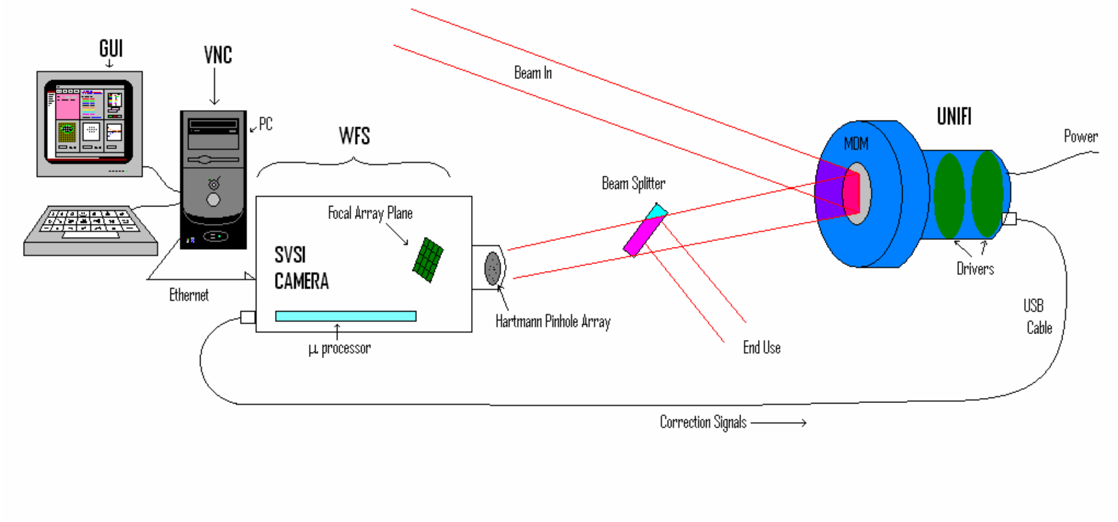


Figure 2. ClariFast™ and VNC setup.

ClariFast™ and VNC Overview:

ClariFast™ is a quick closed-loop laser aberration correction program. The closed loop consists of ClariFast™ software on the WaveFront Sensor Camera (WFS) camera (made by SVSI, Inc.), a deformable mirror (Unifi™), and a laser bouncing off that mirror into the WFS lens. ClariFast™ uses a Hartmann array to measure various aberrations in a laser. Using these measured aberrations, it communicates with Unifi, telling the deformable mirror how to correct these aberrations.

ClariFast™ runs in the Linux environment on the WFS. To view ClariFast™ from the Windows environment, an X-Windows emulator is required. X-Windows is the primary window/graphics system Linux machines use. VNC is a free X-Windows emulator that will enable the user to access ClariFast™ from a Windows machine through a standard computer network port from anywhere on the network. We provide a user-loadable copy of VNC on the enclosed CD along with the ClariFast™ software. Operation of ClariFast™ does not rely on the ethernet connection to the PC, and it will operate autonomously if the connection is lost!

Introduction to ClarifFast™

This section will introduce the first time user of ClariFast™ to its general optical operation and setup.

ClariFast™ is a system of two optical components that allow an optical engineer to correct aberrations in their laser beam. The first unit, is a wavefront sensor (WFS) based on a CMOS camera with an integrated microprocessor computer that reads a sample of the system's optical beam, performs an analysis of the beam aberrations, and commands the membrane deformable mirror to assume a conjugate shape which corrects for the beam aberrations.

The second unit is a membrane deformable mirror (MDM) with the trade name "Unifi", which takes the correction signal over a USB cable from the camera/microprocessor and applies a set of high voltages to the actuators on the DM causing it to deform the membrane mirror and cancel or correct the beam aberrations. Unifi™ is a stand alone MDM and high voltage driver with a USB connection and an external, 5v DC power supply input.

Most laser-based optical systems use a laser beam to conduct some particular application: marking, designating, cutting, carrying free space communication signals, etc. Frequently in high power laser systems, as the power increases or the beam is reflected from redirection mirrors, thermal distortions become significant and beam aberration correction is desired. Many times, lasers are plagued by distortions inside the laser cavity which limit the beam quality and correction of aberrations from the cavity gain media is necessary to restore diffraction limited performance.

The optimum optical layout should allow the distorted beam to reflect off the Unifi MDM assembly first, and then be directed into the wavefront sensor (WFS) later in the system.

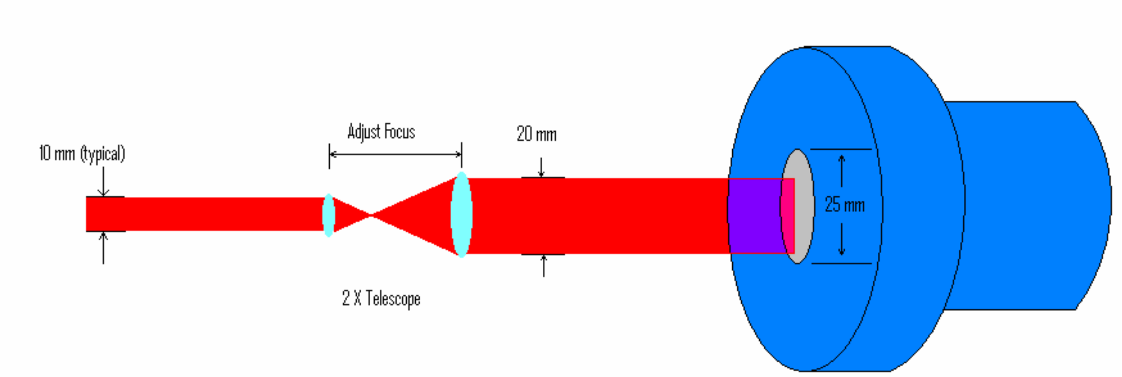


Figure 3. Beam re-sizing to match MDM useable diameter.

First we will discuss the general setup of the Unifi MDM. To optimally use the 16mm, 25mm or 50mm MDM, the beam should be a significant fraction of the mirror diameter (over 50%) and yet less than the full mirror size to minimize edge effects. If possible, the user should plan to use only 80% of the mirror diameter for the beam correction (13mm for the 16mm, 20mm for the 25mm and 40mm for the 50mm MDMs.)

This usually requires installing a beam resizing telescope ahead of the MDM. Generally, the telescope should also be capable of focus adjustment, so that the input beam can be adjusted to a slightly divergent condition. This allows the MDM to be set up and used in the mid-range of its throw and will permit the system to correct both divergent and convergent beam errors. (Relaxing the voltages will cause the beam to become more divergent, increasing the voltages will cause the beam to become more convergent.) Remember, one salient feature of a MDM is that its electrostatic actuators can only pull, making the mirror concave or more concave, but never convex.

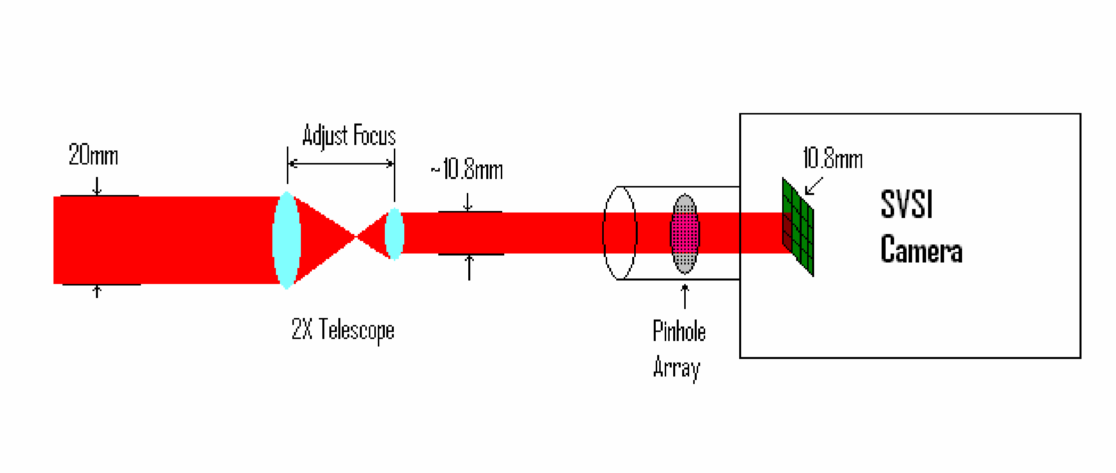


Figure 4. Beam resizing to match pixel array in WFS camera.

The optical system needs to be arranged to provide a sample of the final output beam to the wavefront sensor (WFS). Most designers use wedged beam splitters or beam attenuators. In most systems, the best quality output beam is one that is collimated, and the ClariFast™ assumes that the user will want to have a beam with the best collimation possible. Beams that are well corrected and collimated can be focused to the smallest possible focus (approaching the diffraction limit) and can be propagated long distances with minimum beam spreading.

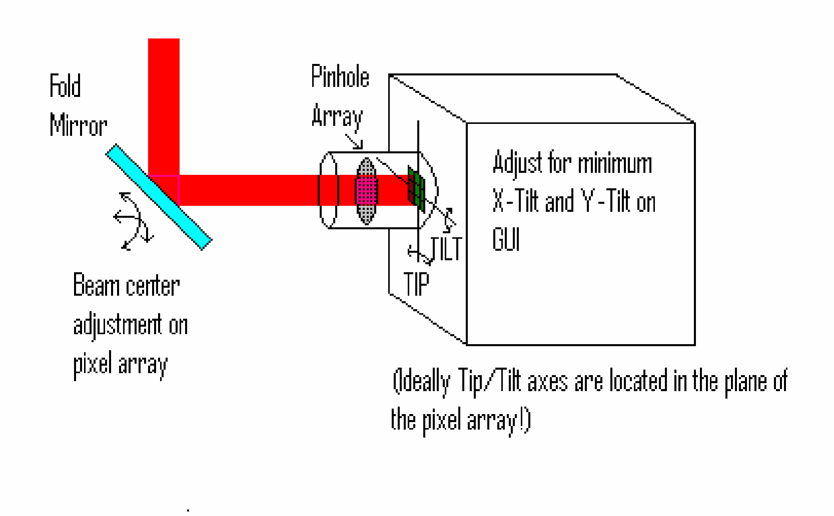


Figure 5. Alignment of the WFS camera

Consequently, for the WFS to operate correctly, the beam delivered to the WFS must be 1) as well collimated as possible and 2) closely match the size of the CMOS pixel array at the input to the camera. Since the camera uses a 900 by 900 array of 12 micron square pixels, the optimal beam size would be 10.8 mm by 10.8mm. The WFS can accommodate a slightly smaller beam, so to use a reasonable portion of the sensor format, the beam should be greater than about 7mm and yet less than 10.8mm. You will want to adjust the beam position to center it on the camera's pixel array, usually using a folding mirror ahead of the camera. Once centered on the camera pixel array, you will also want to adjust the camera's tip and tilt to zero out the x-tilt and y-tilt components at the start of the operation, so plan ahead to provide a special mount under the camera to provide accurate x-tilt and y-tilt adjustments.

We suggest that the optical design should arrange to beam split a sample portion of the master output beam into a simple telescope that will expand or contract the beam to between 7mm and 10.8mm. The beam power should be on the order of 1mW total, and it may need to adjusted slightly once the system is made operational based on the WFS performance. We suggest a set of high-quality crossed polarizers to allow continuous reduction of the power to an acceptable value. Ideally, the telescope should be arranged to allow adjustment of the spacing of the components so that the beam collimation can be varied to minimize the focus component. Once set up as described, the WFS will provide a continuous assessment of the beam errors in terms of Zernikes, Fourier terms or Legendre polynomial coefficients (user selectable). The experienced user will watch the graphical user interface (GUI) and will "tweak" the system performance (such as x-tilt, y-tilt and focus) to achieve the best starting position.

Once the WFS is operational, the experienced operator will check the beam sizes and collimations at each point in the system to be sure the set up is correct. Then, using the ClariFast^{TM} software, we suggest putting a fixed DC voltage on the mirror (or equivalently on all of the actuators) to set the membrane mid-range in its throw and pull the mirror concave. Watching the ClariFast™ GUIs, one can adjust the x-tilt and y-tilt of the WFS to minimum values, and then adjust the focus in one of the system telescopes to minimize the system focus. Depending on the precision of the system alignment and set up, there may be some crosstalk and a second round of tweaking may be necessary. This will be covered in more detail in steps 6 and 7.

After all of the external optical alignments are complete, the ClariFast™ can be directed through the calibration routines and the system can be sent into full operation.

The first step when initially operating ClariFast™ is to install VNC on your PC. VNC allows the user to communicate over an Ethernet connection between an external PC and ClariFast.

Step 1: Installing VNC

On the CD that came with ClariFast, you will find the file vnc-4_1_1-x86_win32.exe. This file is the installation file for an X-Windows emulator for Windows. With this program you will be able to run ClariFast™ from the SVSI camera, and view ClariFast™ on your Windows machine. The VNC install executable is under the GNU General Public License and may be downloaded from www.realvnc.com.

To install VNC, first run vnc-4_1_1-x86_win32.exe on the computer from which you wish to view ClariFast™ from. Read over the license agreement and accept.

The program will now prompt you for an install directory. Choose an appropriate directory for your computer and select Next.

You will then be prompted for which components to install. You only need to install VNC Viewer, so select it.

The rest of the options are 1) to input a Start Menu file name and 2) whether you want to place a shortcut on the desktop. We suggest you place a shortcut on the desktop so you may find the viewer quickly.

Congratulations! You now have VNC installed and may use it to log on to your ClariFast™ camera.

Step 2: Setup and Powering up/Powering down your ClariFast™ camera:

To properly setup your ClariFast™ WFS, make sure it is connected to your local network, via a standard network cable and make sure it is plugged in to your deformable mirror via a standard USB cable.

Your ClariFast™ camera has some requirements for powering it up and shutting it off. On power-up, your camera will take about 5 minutes until it is ready to communicate with the computer network. During this time, the computer in the camera is booting up. The computer does not have a lot of memory, so it takes a little while.

When shutting down your camera, you should right-click outside of the GUI windows in the VNC window and select shutdown, or you may type “shutdown –h now” to shutdown the camera. Once the shutdown command has been given, give the camera three minutes before unplugging the power. If you unplug the power too soon, your camera computer may be damaged. Test to see if you can still communicate with it and run ClariFast™ properly. If not, you will need to send the camera back to AgilOptics for repairs.

If you don’t enter the shutdown command properly, the camera may enter a single-user mode and be unreachable through the network. If this is the case, the camera is NOT shutdown. Wait 30 minutes before unplugging the power.

Step 3: Logging on to your ClariFast™ camera

Start up the VNC viewer. It will prompt you for an IP address. The default address for your specific ClariFast™ camera is 192.168.0.13:5901. We provide instructions later on how to change this IP address.

Once you enter the IP address, you will be prompted to enter a password. The default password for the ClariFast™ camera is AO followed by the SVSI serial number. The SVSI serial number can be found on the SVSI camera, on a sticker on top of the camera. The password, too, can be changed.

After successfully entering the password, you will be greeted with a text window inside a larger VNC window.

Remember that if you change the password and IP address, and return the camera to us for any reason, we will need the new IP address and password to be able to log on to the machine, so keep that information with or near the camera. We suggest adding a label to the camera with this information.

Also note that you cannot log on to the ClariFast™ camera unless the camera is powered up and connected to your computer network.

Step 4: Running ClariFast

There are two methods you can use to run ClariFast. The first is to type the following series of commands:

```
cd   /root/clarifast
clarifast
```

The second method is to right-click inside the VNC window, but outside of the text window in VNC, and choose **clarifast** from the options.

Now ClariFast™ should be running and attempting to connect to the Unifi mirror. Make sure the camera is connected to the mirror via USB. If the camera is not initially connected to the mirror via USB, you can connect it after ClariFast™ has started, simply select the “Voltage Settings” tab, and select “Init USB” to attempt to connect to the mirror.

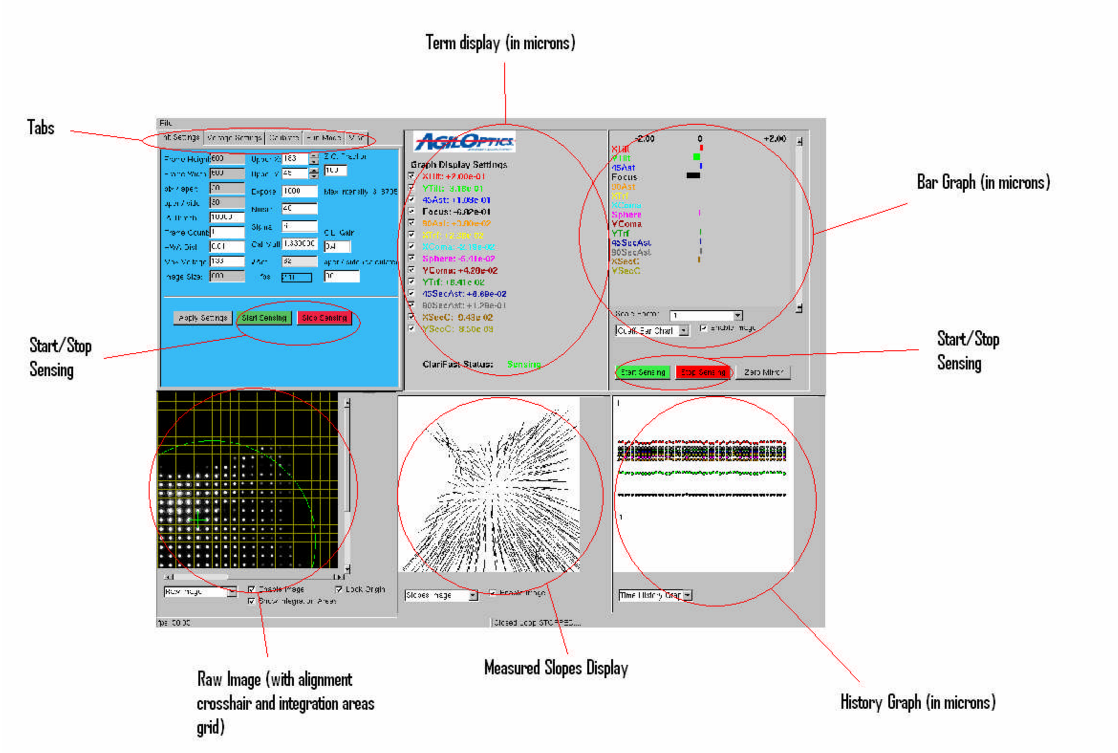


Figure 6. ClariFast™ Main Interface

Step 5: Initial ClariFast™ settings/checkup

These initial settings require that the deformable mirror be powered on by plugging in the connections to the back of the Unifi case, and that ClariFast™ could connect to it.

Before introducing an aberration into your laser, you need to make sure your laser setup is properly aligned. Press the "Start Sensing" button on the middle-right of the ClariFast™ GUI. ClariFast™ will now connect to the camera and display what the camera is seeing. In the lower-left window (showing a Raw Image) you should see a golden grid with a green cross on it.

If the laser is aligned properly, there should be white dots in the grid. These dots are an array of beamlets from the Hartmann array, converted into a pixel map by the camera. If the dots are dim or not apparent, the first thing you should try is increasing the exposure time. Under the "Init Settings" tab, select the number just to the right of the label "Expose" (second column of labels, third label from the top), and increase it by 250. Once the value is changed, press the "Apply Settings" button. This will apply all your settings in the "Init Settings" tab, and should update your Raw Image window.

If the increased exposure doesn't allow you to see white dots on the Raw Image window, there are two options: 1) Increase the exposure to 100,000 (equivalent to 200,000 microseconds of exposure and the maximum exposure we recommend) to see if they appear. If they do, decrease the exposure until about half the dots are dim. (Note that high exposure values are the main cause of ClariFast™ running slow. If your exposure value ends up at more than 1000, you will get less than 50 frames per second.) If this does not solve the problem, then use option 2. 2) Make sure your laser is properly aligned and not blocked on it's path to the camera. This may require adjusting the X and Y tilt of mirrors leading to the camera.

Once white dots are showing up properly on your Raw Image screen, we need to make sure they are properly aligned with the calibration file. This is usually accomplished by lining up the back reflection from the glass plate holding the pinhole array onto the center of the MDM (you may have to trace the back reflection, lining it up until it reaches the MDM, first).

To see if your white dots line up properly, make sure first that your white dots surround the green crosshairs in the Raw Image window. There should be one location where a white dot doesn't show up. This location is an occluded spot on the Hartmann array designed precisely for alignment. The green crosshair should be exactly centered on that location. If the crosshair isn't centered, then there are two steps you should perform.

First, make sure the base reference file is being used. To do this, select Read Absolute Reference from the File menu in the upper-left of the ClariFast^{TM} GUI. This loads the base reference file used by ClariFast^{TM} and created by us. This reference file should align your camera perfectly with it's Hartmann array. This reference file is called ".baseref" and should never be altered. This base file was generated by aligning the camera and the Hartmann array, using a Zygot Interferometer. If this does not align the green crosshair with the occluded spot in the Hartmann array, then the reference file isn't the problem, and we go to the second step.

The reference file is an array of (X, Y) coordinate pairs, one for each sample area (about 30 x 30 pixels). These coordinates are the precise initial positions of a calibration beam provided at the factory. These represent the baseline condition of each beamlet, from which the tilted beamlets are referenced. Comparing the baseline condition of each beamlet to their current condition gives us the slopes of each beamlet, based on the movement of the centroids.

Second, adjust your X and Y tilt of your camera until the green crosshair is centered on the occluded spot in the Hartmann array. If you can see that it isn't aligned, it will take some huge adjustments of the X and Y tilt to align it.

The final test is to see if your laser covers enough actuators for the mirror to be useful. Go to "Voltage Settings" and press the "Zero Mirror" button. This should zero-out your mirror's voltages. Now we need to test the center actuators of the mirror to make sure they are properly aligned.

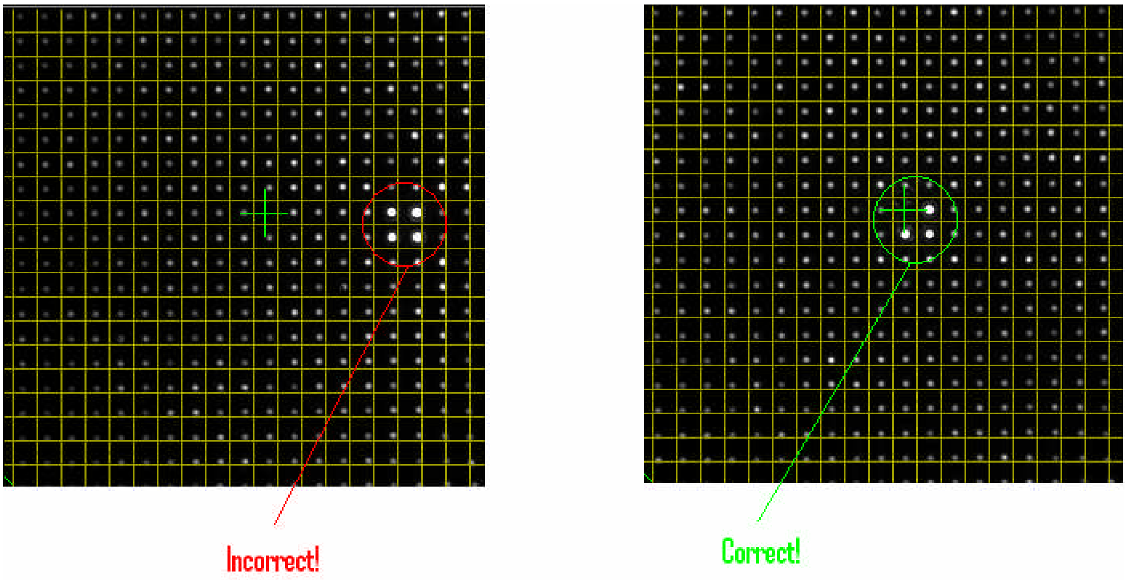


Figure 7. Incorrect and Correct center-actuator position in the Raw Image window.

The MDMs consist of an array of actuators. Most of these actuator arrays are circularly symmetric, and label their center actuator as the first actuator. Rectangular mirrors have the first actuator on one side of the circle instead of the center. Their center actuator is actually half-way through their list of actuators. So, if they have a 60 actuator mirror, the center actuator is actuator 30, whereas non-rectangular MDMs have their center actuator as actuator 0. Set the value to the left of channel to the center actuator number for your mirror. Next, set the number next to the “Write Voltage to All” button to 300. Now select “Write Voltage to Current Channel”. We are now writing 300 volts to the center actuator. This creates a concave distortion at the exact mirror center, which will show up as a brighter group of beamlets at the mirror center on the Raw Image grid. Four especially white points should appear just slightly offset from your green crosshair. They should be centered on the grid intersection just down and to the right of the green crosshair. If this is not the case, either the laser isn’t centered on the mirror, or the laser isn’t centered on the camera. To correct this, center the bright points on the grid location down and to the right of the green crosshair, using X and Y tilt on the camera.

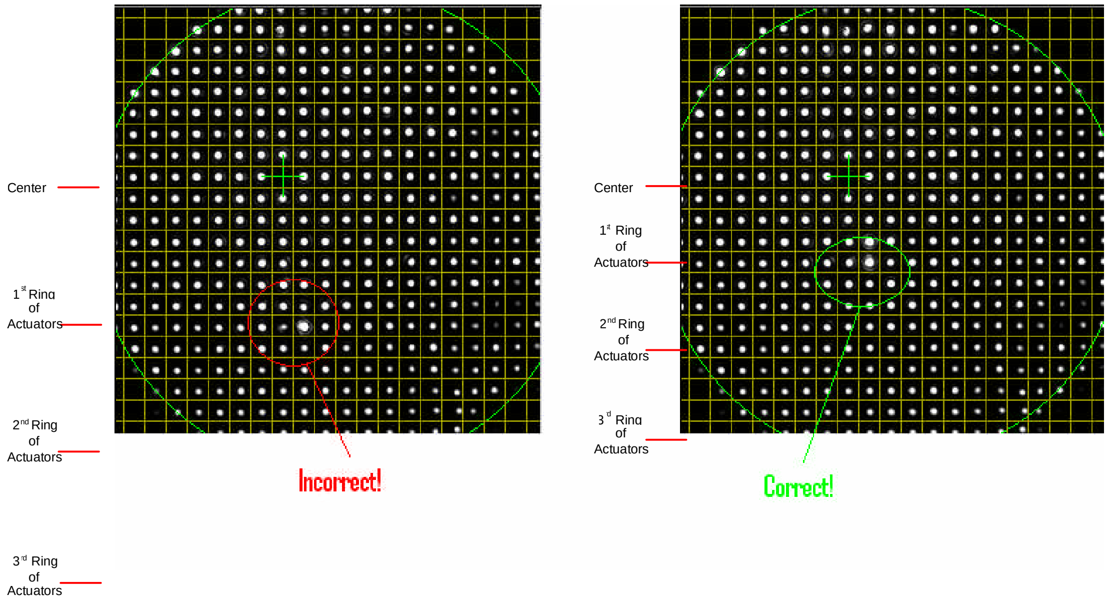


Figure 8. Incorrect and Correct next actuator positions in the Raw Image window.

Next, we need to make sure your laser covers enough actuators. Select "Zero Mirror" to zero all voltages on your mirror again. Now, press the up arrow to the left of the Channel label. This should increment the channel value by 1. Now select "Write Voltage to Current Channel". Once again, a small group of white dots should appear. However, they should be offset from the green crosshair. For the best results with your mirror, these new dots should not be more than two to three dots (integration areas) away from the center. If they are further than that, your laser beam is too small when it reaches the mirror. The mirror will not be able to apply many actuators to fixing your laser's aberrations. Make sure the laser covers at least ¾ of the mirror area when it hits the mirror.

The mirror has rings of actuators around the center actuator. The more rings that are within the beam size, the more control the mirror will have over the beam. The less rings that are within the beam size, the less control the mirror will have over the beam. However, if the actuators are all inside the beam, the mirror will only be able to control the center of the beam. It is best if the outer-most ring of actuators are just outside of the edge of the beam.

After you have finished these steps, once again press the "Zero Mirror" button to zero-out your mirror's voltages.

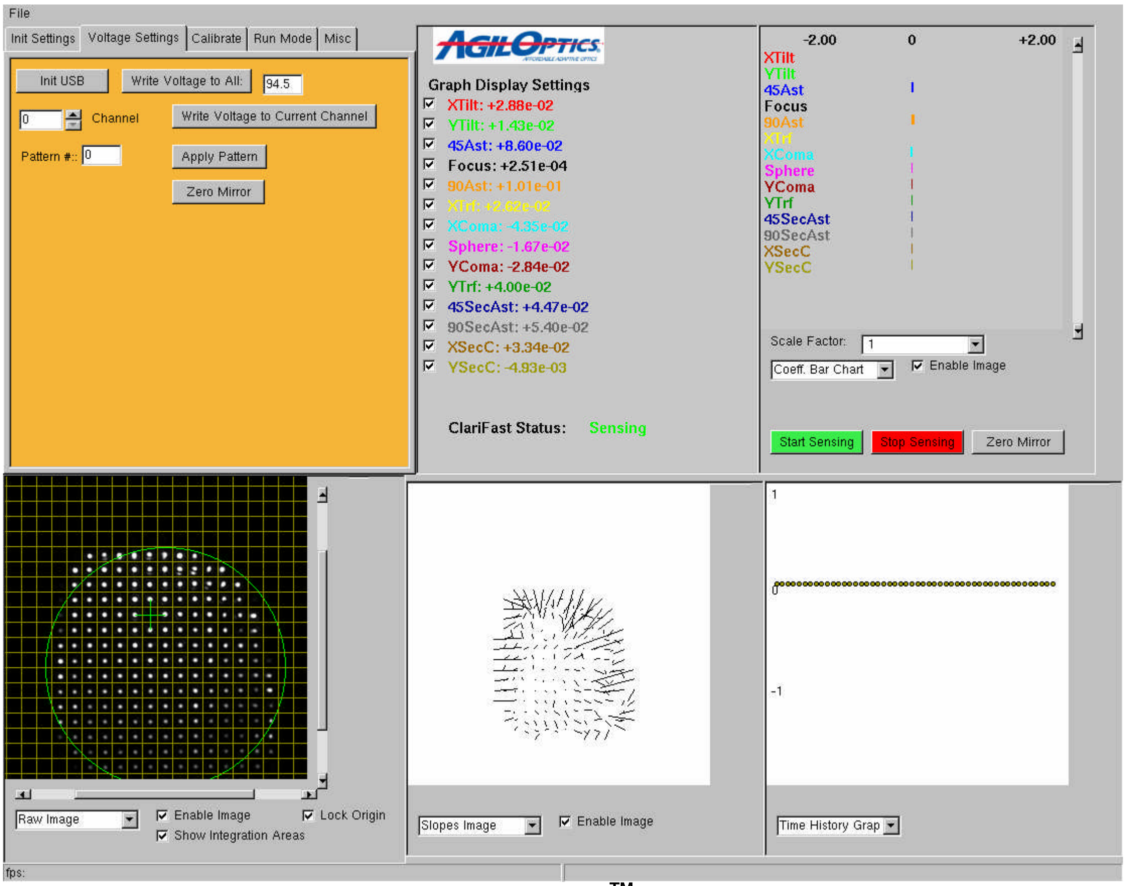


Figure 9. Optimal tuning for ClariFast™ with a 135 max volts mirror.

Step 6: Fine-tuning your ClariFast™ setup

Now for the fine-tuning. This step can be done with or without an aberration in the laser. Under "Init Settings", find the Max Voltage value for your mirror. Figure out what 70% of that value is and remember it. Go to the "Voltage Settings" tab and select the number to the right of the "Write Voltage to All" button. Set this value to 70% of your Max Voltage value.

The image in the upper-right of the ClariFast™ GUI should show a series of colored bars. This is the Coefficient Bar Graph. These bars represent how much of the Zernike, Fourier, or Legendre values the ClariFast™ sensor is detecting on the laser. Bars going to the left represent negative values, and bars going to the right represent positive values. There are three bars here we want to reduce in size as much as possible. They are the X-Tilt, Y-Tilt, and Focus.

First, change the Focus on the laser so the Focus bar on the Coefficient Bar Graph is really small, or disappears. With the voltage set at 70% of the mirror's max voltage, setting the focus to near zero allows the mirror to deal with both focus and defocus aberrations.

Now that the focus is correct, try to minimize the X and Y tilt detected by the camera by mechanically altering the camera's X and Y tilt. These values may jump a bit. If that is the case, try to make them jump between positive and negative values, instead of jumping around in just positive values or just negative values.

Calibration:

Now we are ready to calibrate ClariFast. Calibration runs ClariFast^{TM} and the MDM through a series of patterns. Each of these patterns deal with a different type of aberration. Once the calibration routine is finished, and the closed loop correction is started, the alterations recorded by the patterns will be used to correct the aberrations detected in the laser.

To calibrate ClariFast, select the "Calibrate" tab, and choose "Fast Calibrate". Fast Calibrate calibrates ClariFast^{TM} as quickly as possible, while Calibrate shows the pattern changes ClariFast^{TM} goes through for calibration.

Once the fast calibrate is done, you are ready to go. You may introduce an aberration to the laser and get ClariFast^{TM} to correct it.

Introducing and Correcting Aberrations using ClariFast:

When introducing an aberration to the laser and correcting it with ClariFast, there are some procedures you must accomplish. First, introduce an aberration to the system. This may not be easy! It may mean adding an aberrated lens to the system, or activating some aberration-causing device. Make sure that the aberration still allows the laser to reach the deformable mirror in the center, and the laser reaches the WFS in the center.

ClariFast^{TM} can correct for Focus, but at the cost of not being able to correct for other aberrations. To compensate for this, go to the "Init Settings" tab and calculate 70% of the Max Voltage value shown. Go to the "Voltage Settings" tab and put 70% of the Max Voltage value as the value to the right of "Write Voltage to All". Since the mirror responds proportionate to the square of the voltage, a 70% setting places the membrane at approximately the center of it's range. Press the "Write Voltage to All" button. Now, focus or defocus the laser input beam so that the Focus value in the Zernike Bar Graph is minimized.

ClariFast^{TM} can correct for X and Y tilt, but at the cost of not being able to correct for other aberrations as well. Remove all the X and Y tilt you can.

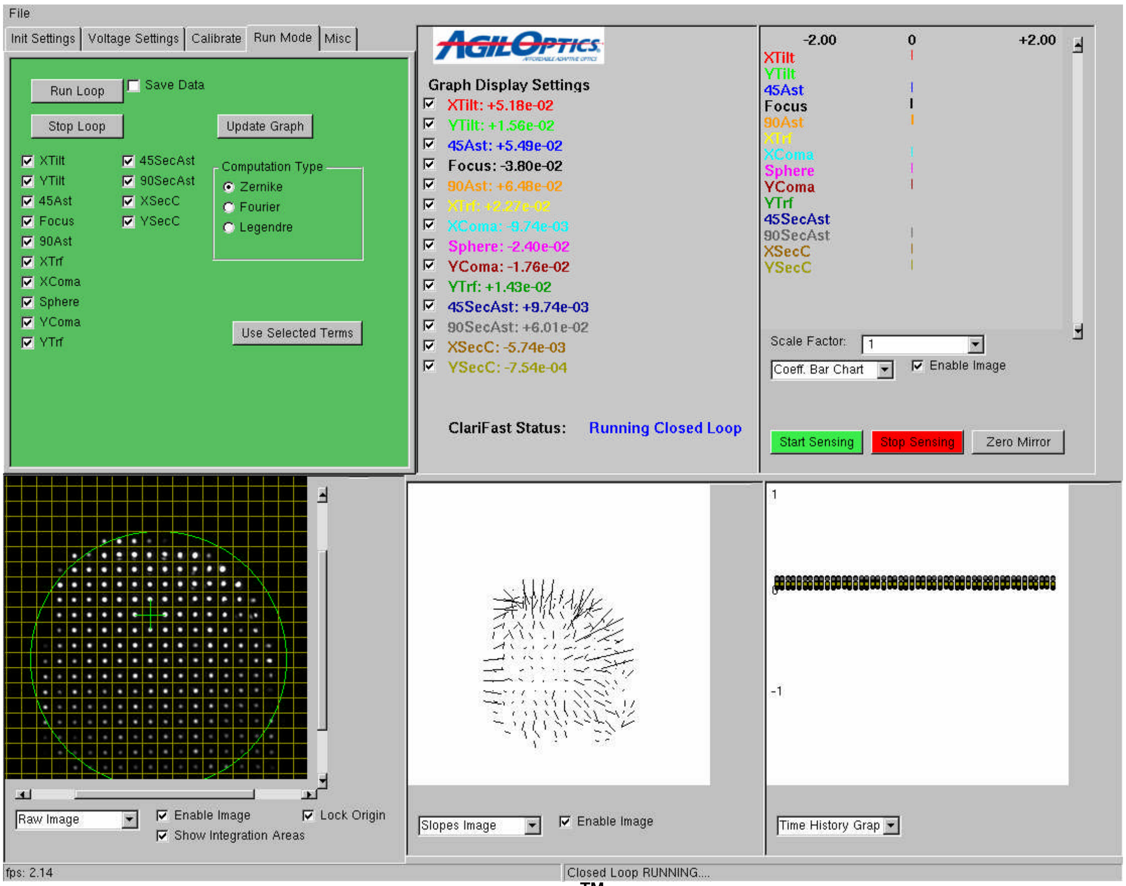


Figure 10. ClariFast™ Closed Loop Running.

You are now ready to correct your aberrations using ClariFast. Under the "Run Mode" tab, select the button "Run Loop" to start the ClariFast™ closed loop process. The closed loop process is where ClariFast™ starts detecting and correcting your aberration. If "Run Loop" is grayed out, you haven't run a proper calibrate. Go back to Step 7 to correct this.

To get the closed loop to run as fast as possible, make sure all "Enable Image" checkboxes are unchecked. Each image drawn slows down ClariFast. The fewer images ClariFast™ needs to draw, the faster it will run. (See the frames per second (fps) data in the lower left corner of the GUI). If you would still like to see some update of how the correction is going, there are a few options:

1) Press the "Update Graph" button under the "Run Mode" tab. This will update the Zernike Graph in the lower-right corner after 50 measurements have been taken from the instant the button is pressed. This allows you to visualize the convergence process.

2) Check the "Enable Image" checkbox for the Zernike Bar Chart.

3) Check the "Enable Image" checkbox for the Slopes Image.

You may choose to display any one or all three of these, but remember that each one slows down ClariFast™ by a few frames per second. The Raw Image window is the worst culprit for slowing down ClariFast, so it is recommended that the user keeps it's "Enable Image" checkbox unchecked during the closed loop. You may also increase the frame rate while still displaying images by altering the “Frame Count” value under the “Init Settings” tab. Frame rates are dependent on exposure values (“Expose” under “Init Settings”). At 1000 exposure, the preferred exposure rate, with all “Enable Image” checkboxes unchecked, the frame rate should be about 50 frames per second or above. This is considered the top speed of ClariFast. With a high exposure of 100,000, the highest exposure we recommend ever using, and all “Enable Image” checkboxes unchecked the frame rate drops to .24 frames per second. Typically, with all “Enable Image” checkboxes checked, an exposure of 1000, and a Frame Count of 1, the frame rate will be 1 to 2 frames per second. By changing the Frame Count to 10, the frame rate will increase to about 13 frames per second, with all images displaying. With a Frame Count of 1, and only the Raw Image disabled, the frame rate should be around 6 frames per second. Note that Frame Count does not increase the frame rate if all the images are disabled.

The run loop runs until you stop it. If the laser is turned off and turned back on, as long as no other light source is detected by ClariFast, the run loop will not be interrupted or affected, and should continue properly correcting the laser.

Mirror Installation:

To install your Unifi mirror, simply plug in the power and connect a USB cable from the mirror to the ClariFast™ camera.

Changing the ClariFast™ password:

At some point the user or system administrator may wish to change the ClariFast™ password. This may be for security reasons or to better fit with the password scheme of their place of business.

There are two places you need to change the ClariFast™ password. To start, you should have VNC running so that you are logged on to the ClariFast™ camera.

To change the normal login password (non-VNC), type “passwd”. It will prompt you to enter the new password, and a verification of the new password. Once done, a normal secure shell connection (ssh) to the ClariFast™ camera will require the new password. This password only changes the password needed to connect to the camera’s computer using ssh. It does not affect the password needed to connect using VNC.

To change the VNC password, type “vncpasswd”. Make sure you are in the VNC xterm window for this, by first left-clicking on the white text window in VNC. Once again, you will be prompted for a password and a verification of the password. Once done, all VNC connections to the camera will require the new VNC password. Write down the new password and re-label the WFS camera with it.

Changing the ClariFast™ IP address and Server Name:

WARNING!: Errors made while attempting the following changes can make your camera unreachable permanently!

The system administrator may wish to change the IP address for the WFS for your particular network. To change the IP address itself (not the server name), you must edit "/etc/rc.d/rc.inet1.conf" and change the IPADDR[0] variable from "192.168.0.13" to your new IP address. If you don't know what IP address to assign, consult with your network administrator.

To change the server name, edit "/etc/HOSTNAME" and change the server name to "yournewservername.localdomain".

Zernike vs. Fourier vs. Legendre

In evaluating the wavefront, the controller first generates an approximation of the wavefront by fitting the measured slopes to a series of polynomial expressions. The polynomial expansions available in the ClariFast™ software are: the Zernike Polynomials, which are defined on a circular aperture and are commonly used in modeling optical systems; the Fourier Series, which consist of sine and cosine functions of increasing frequency, and are evaluated in the X- and the Y-directions; and the Legendre Polynomials, also evaluated in the X- and Y-directions, and which are a series of exponentials of increasing order.

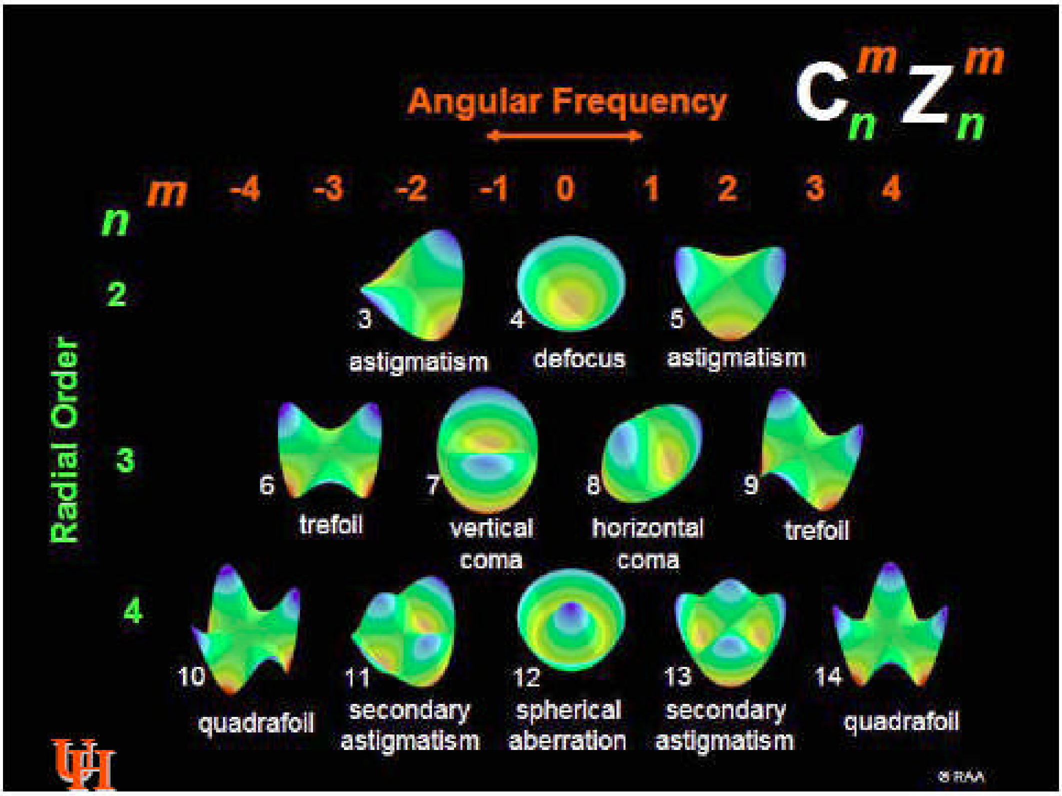


Figure 11-1. Zernike Polynomials

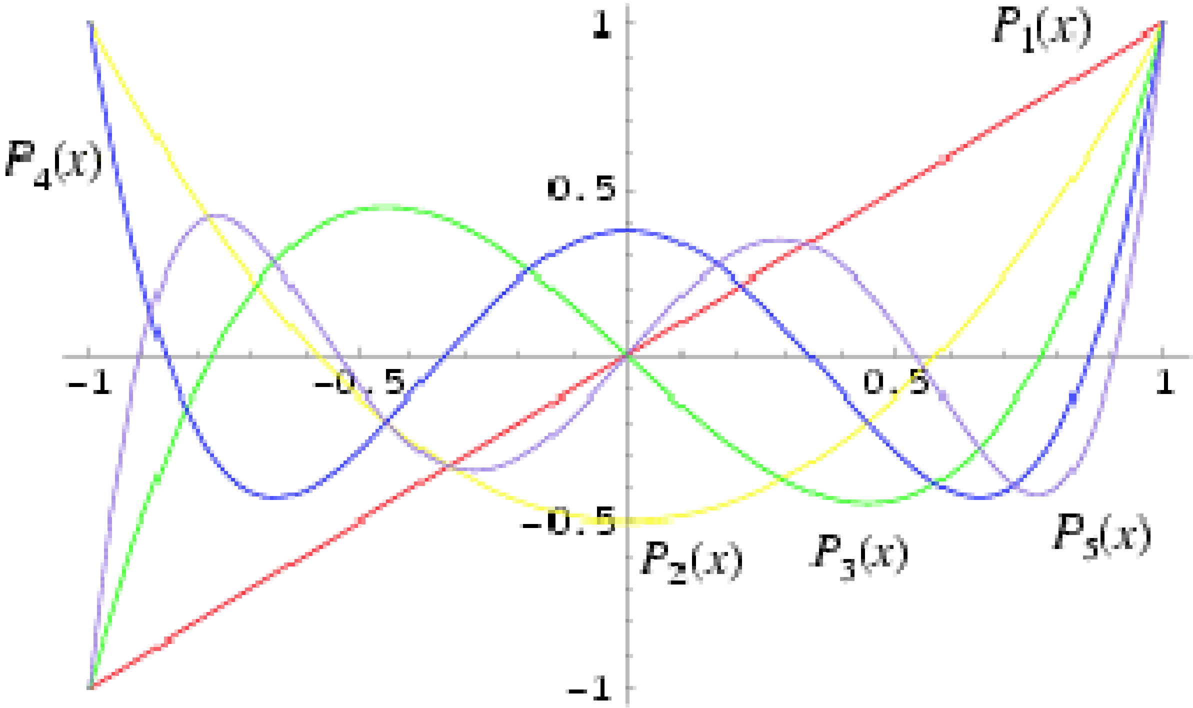


Figure 11-2. Legendre Polynomials

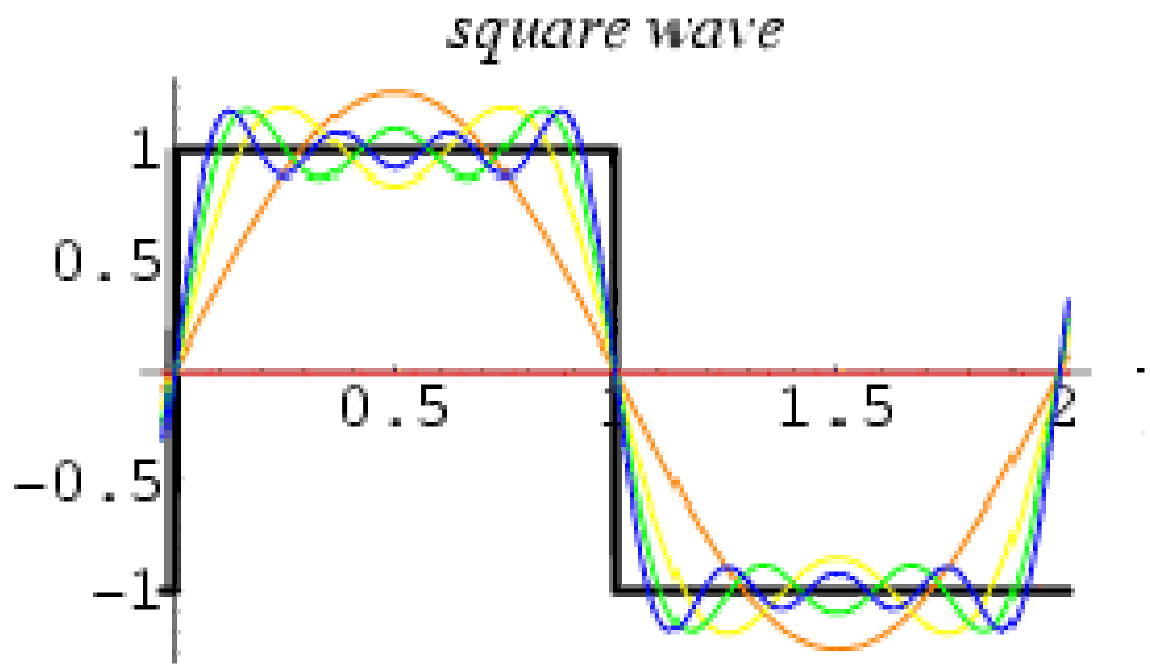


Figure 11-3. Fourier Series: Example of Square Wave Approximation using several Fourier terms

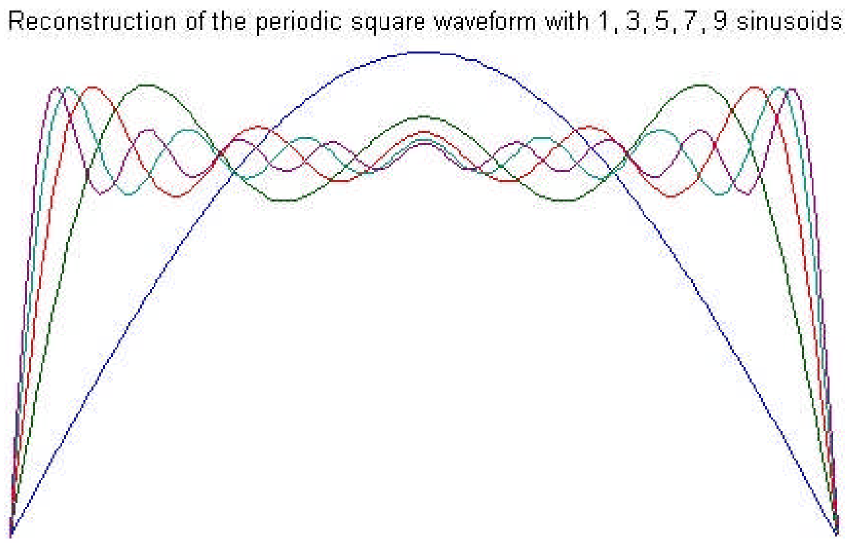


Figure 11-4. Half-Cycle Fourier Series

The ClariFast system fits the measured wavefront to a half-cycle of the sinusoids being used to fit the wavefront. This means the frequencies being used in the decomposition are w/2, w, and 3w/2, where w is the spatial frequency equal to 1/(beam width).

Contacting Us:

For technical support, please call (505) 268-4742 or e-mail us at support@agiloptics.com.

ClariFast™ version 1.2.3
Appendices: "Details of GUI Controls"

AgilOptics
1717 Louisiana NE
Suite 202
Albuquerque, NM 87110
(505) 268-4742
support@agiloptics.com

Table of Contents:

Section 1: The Big Picture:

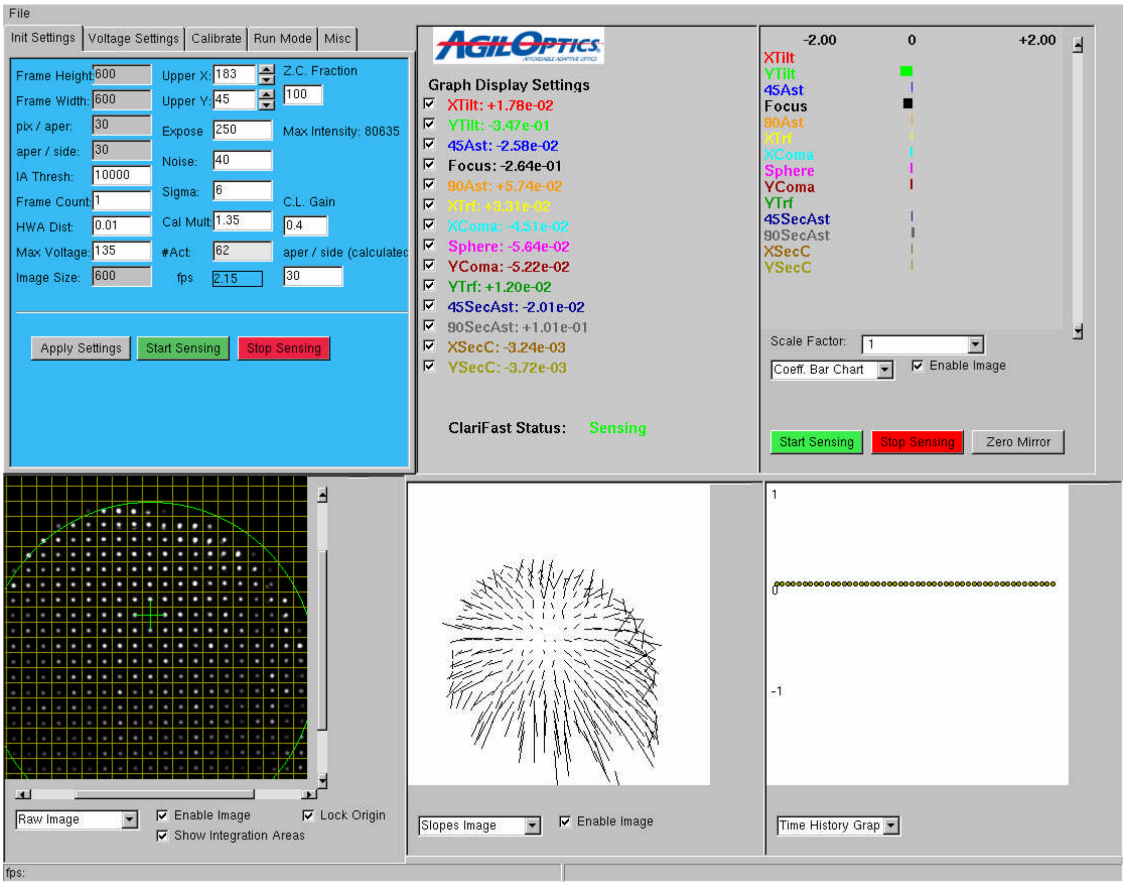


Figure 12.

Upper Left: Control Panels
Upper Middle: Coefficient Terms output box, color-coded for the various graphs
Upper Right: Bar Chart showing the coefficient magnitudes
Bottom Left: Raw intensity image of the Hartmann sensor
Bottom Middle: Slopes image showing the slopes relative to the reference.
Bottom Right: Time History Chart of all selected coefficient terms.

This is the ClariFast main window. Most of the user input is done in the Control Panel. The rest of ClariFast™ is data displays providing the user with ClariFast™'s current status and the status of the laser beam it detects.

Buttons:
See the sections on the pertinent tabs for descriptions of buttons in the upper left. The upper right buttons can be used for immediate actions.

- ***Start Sensing*** (green button) will start the Hartmann sensor.
- ***Stop Sensing*** (red button) will stop both the sensing operations as well as closed loop operations. It will also stop any currently running closed loop.

- ***Zero Mirror*** will immediately write all zero voltages to the mirror. These values remain until changed by the user by running calibrate or closed loop. If the closed loop is currently running then ClariFast™ will continue updating the voltages; so please hit "Stop Sensing" if you really want ClariFast™ to stop all operations.

Windows:

The four main windows (lower left, lower center, lower right, and upper right) are multi-windows and can change what they display. With the exception of the Time History Graph, each of these windows can be disabled to speed up ClariFast.

Raw Image:

The Raw Image window displays the current 900 x 900 region read by the camera's sensor. This view has two scroll bars (X-axis and Y-axis) and a Lock Origin checkbox. By default the Lock Origin checkbox is on. This allows you to freely view the 900 x 900 region of the graph without altering the Upper X and Upper Y position for the camera.

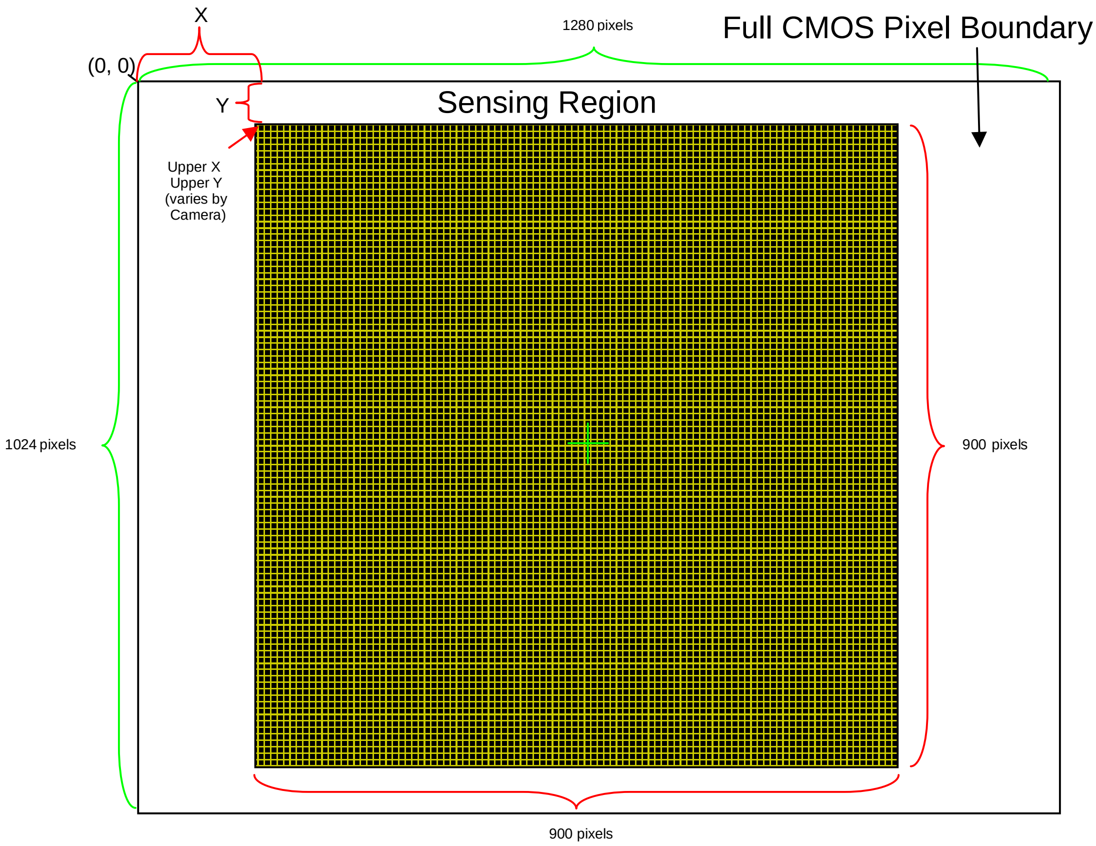
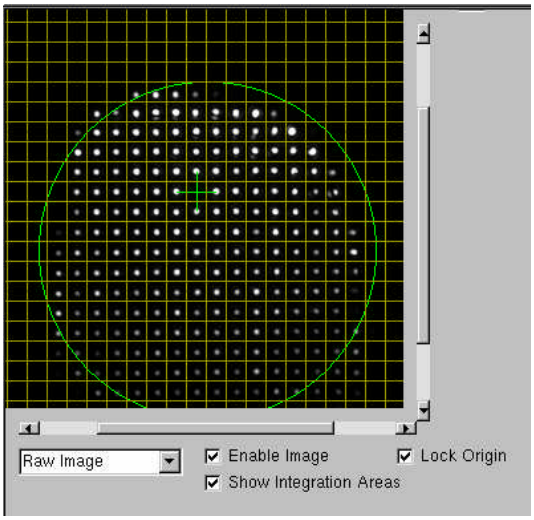


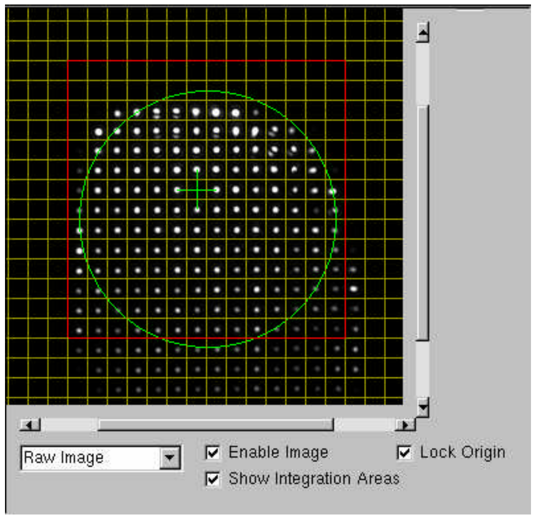
Figure 13. CMOS total boundary region vs. 900x900 sensing region

The camera has an upper X and Y position to show where in it's 1280 x 1024 total view to detect sensor data. The maximum size of this region is 900 x 900. The origin is positioned based on the Hartmann Pinhole Array, using a collumnated laser beam. Unlocking the origin makes the scroll bars change the starting X and Y position of the 900 x 900 region inside the total 1280 x 1024 view.

There is a crosshair in the center of the 900 x 900 region (offset by half an integration area up and to the left) that, when properly aligned, is centered on the blank spot on the Hartmann array, with it's crosshairs ending at the center of the adjacent Hartmann spots. Altering the starting X and Y position of the 900 x 900 area will move this crosshair.



Aper / side (calculated) = 30 (aper / side default)
Zernike Radius unchanged



Aper / side (calculated) = 16
Zernike Radius reduced

Figure 14. Reducing the region ClariFast™ calculates on reduces the Zernike Circle size.

ClariFast™ may calculate on a smaller region than the 900 x 900 region. This region is shown as a red square in the Raw Image picture. No integration areas outside of the red box will be used, and the Zernike circle will never be larger across than the integration areas surrounded by this box. The Zernike circle is not used for Fourier or Legendre calculations. This red box's scale can be changed by altering the aper / side (calculated) value on the Init Settings tab. If this value matches the aper / side value in the upper-left of the Init Settings tab, no red box will be displayed, as it contains the whole image.

The gold grid in the Raw Image file shows the integration areas ClariFast™ is using. This grid may be turned off by unchecking "Show Integration Areas".

Slopes Image:

The Slopes Image window displays all the points inside the red box region of the Raw Image window. These points are drawn with lines from their reference position to the position where they are detected due to movement by the local slopes of the aberrations.

Zernike Graph:

The Zernike graph shows the last 50 points of calculated offset for each of the Zernike, Fourier, or Legendre terms. Each term is color-coded for easy recognition, and can be turned off by deselecting their check-box in the upper-center window. This graph is only updated during the first 50 steps of the Closed Loop cycle (see the Run Mode tab), or 50 steps after the instant the Update Graph button on the Run Mode tab is pressed.

Coefficient Bar Chart:

The Coefficient Bar Chart shows the current amount each Zernike, Fourier, or Legendre term is detected by the camera, in microns. Bars going left are negative. Bars going right are positive. Each bar is color-coded with it's term to make recognition easy. Bars can be hidden by deselecting their term in the upper-center window.

The Coefficient Bar Chart window has a pull-down menu allowing you to select a different scale with which to view the Coefficient Bar Chart. The default scale is 2 microns. The pull-down menu allows you to go to up to 8 times that size, to 16 microns, or to $1/8^{th}$ the size, or .25 microns. This can allow you to better correct for X and Y axis tilt in your optics setup. The values of the bars are relative to the reference file used.

Section 2: ClariFast^{TM} GUI overview.

The ClariFast^{TM} GUI (graphical user interface) provides full control of the system. Please see the enclosed installation guide to install the proper software on your Windows XP PC, and for tips on the opto-mechanical setups required. Once you have the software installed refer back to this manual for the proper usage of the GUI. The next few sections will introduce you to the operation of ClariFast. Please read these sections in order as they represent the general flow of procedures from setup and initialization to actual closed loop operation of ClariFast.

Section 2.1: File Menu (on header)

The file menu allows you to save settings for future use as well as load different mirrors and pattern files. However, the default settings should get you started as they are suitable default values to begin with. If you want to return to default settings you can always select "Default Settings" from the file menu to return to defaults. If you should ever accidentally write over your default settings, please contact AgilOptics for a replacement file.

Menu Options

Load Default Settings:

This option will reset your ClariFast^{TM} system to the default values it was shipped with.

Load Settings:

This option will allow you to load settings that you have saved previously

Load Pattern:

This option will allow you to load custom pattern files that AgilOptics may provide for you in the future.

Load Mirror File:

This option will allow you to load custom mirror mapping files that AgilOptics may provide for you in the future.

Load Array Voltages:

This option will allow you to load custom array voltage patterns. Most users will not need this option. Please contact AgilOptics if you need to load static voltage patterns to the deformable mirror.

Load Reference:

This option will allow you to load custom reference points. Custom reference files make all the aberrations your laser might show become your basis. This means all deviations from that recorded aberration pattern will be measured, instead of the AgilOptics reference pattern.

Read Absolute Reference:

This option will allow you to load the reference file AgilOptics provided you with. On initialization, ClariFast™ loads the last loaded reference file. If you created a new reference file, you may wish to go back to the original your system came with. This selection loads that original.

Save Settings:

This option will save your current settings as set in the initial stage of setup. This is particularly useful once you have found an ideal set of values.

Save Reference:

This option will save your current aberrations (or lack of aberrations) as a new reference for ClariFast™ to measure all other aberrations by. This file is then immediately loaded as your current reference file, effectively zeroing your slopes. The default reference file name is “relative.ref”. The reference file used on initial startup of ClariFast™ was initially produced by AgilOptics at the factory, using an accurate, uniform calibrated beam. The reference file is filed as “.baseref”, and should not be altered.

Exit Program:

Close the program immediately. All settings you are currently using will be saved, to be loaded the next time you start ClariFast.

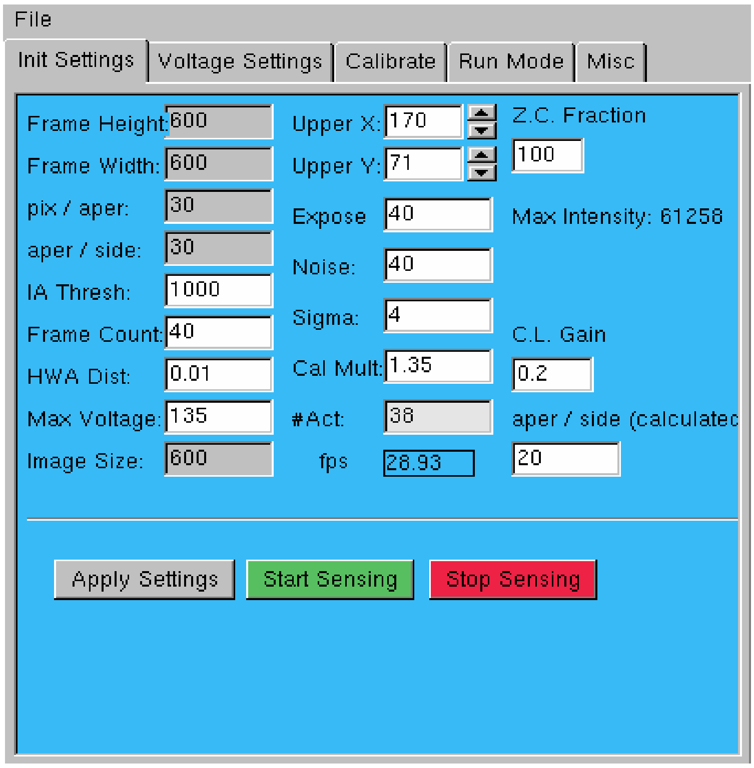


Figure 15.

Section 2.2: Init Settings Tab:

Initial settings are shown in figure 3. Notice that you can only edit those boxes which are in white. These boxes will be described below. Please note that the Hartmann array is aligned at AgilOptics and the user should not under normal circumstance change the "Upper Y" or "Upper X" settings as this will affect the alignment and computations, most likely resulting in errors.

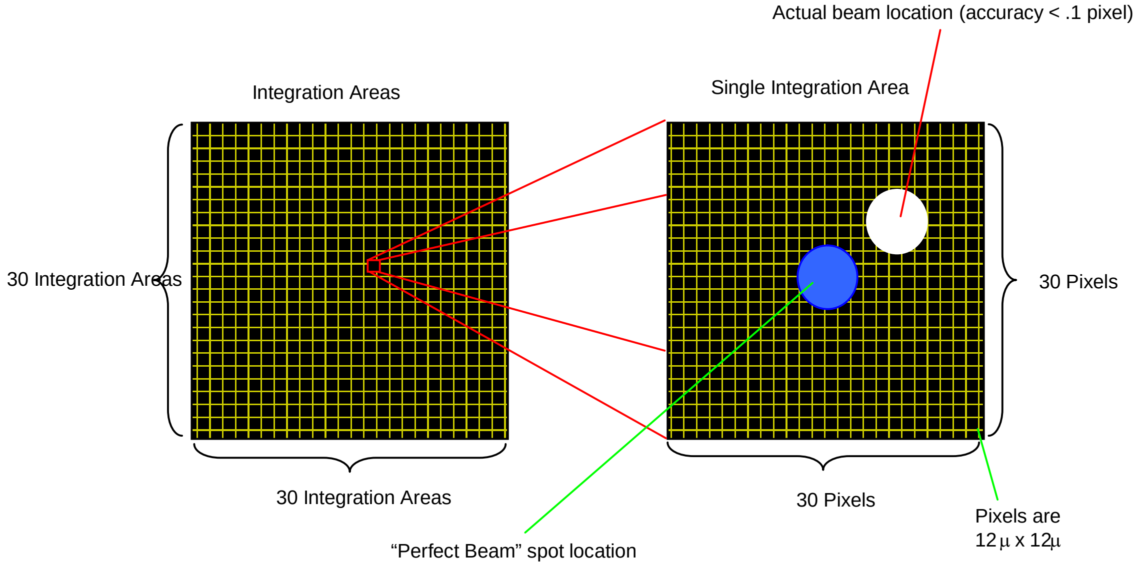


Figure 16. Sensing region integration area, scaled to pixel size.

IA Thresh (Integration Area Threshold):

This number represents the actual sum of all the pixels in an integration area on the Hartmann array (the 30x30 area of pinholes, which are 30 camera pixels each on a side). If the sum of the intensities of the pixels in an integration area is less than this number then that integration will be ignored in computations for Zernike and Fourier decompositions. You can see which integration areas are currently being ignored by looking at the slopes image for missing vectors. Normal increments to this values would be 5000 to 10000. Pixel intensities vary on a scale of 0 to 255.

Frame Count:

This number represents the number of frames to skip before an update of Raw Image, Slopes Image, and the Zernike Bars. For example, if the value is set to 5 the output images and boxes will only update every 5 frame grabs of the camera. Computations will still be done for every frame grab but the screen will only update based on this value. Please note that you can speed up the application by setting this to a high number, completely turning off updates in the Misc tab, or disabling all the displays using their Enable Image checkbox. Check the fps display in the GUI lower-left corner for your fps while running closed loop.

HWA Distance

This is the distance from the camera sensor to the Hartmann array in meters. The slope at each integration area (beamlet) is the (reference – actual) / HWA distance. You shouldn't change this value unless indicated by AgilOptics.

Max Voltage:

The maximum voltage that will be applied to any single actuator during calibration or during actual closed loop operation. This number provides an upper bound to prevent the deformable mirror from snapping down. The default setting will have been set for the mirror originally sent to you. You should not need to change this number unless you are experiencing snap down of the mirror or AgilOptics indicates the necessity.

Upper X and Upper Y

These two boxes should not need to be changed from their default settings. And you will probably only need to change them if you are told to during a troubleshooting session with one of AgilOptics technicians or engineers.

Expose:

This text box sets the exposure time of the camera pixels. The exposure time is defined as the amount of time that the camera “exposes” the pixels on the camera before taking an actual data value. The exposure time is in 4 microseconds units. For example if you set the value to 100 the exposure time of the camera would be 4x100 or 400 microseconds. Adjust this value until the spots of the Hartmann array take on a grayish hue rather than a bright white. Note that high exposure values can result in significantly slower performance by ClariFast. High exposure values are in the 10,000 and above range.

Noise:

This box sets a lower bound to the “noise” level of the camera. Ambient light in any given room will always cause the lower “bound” of pixel intensities to hover at 20-50 (on a scale of 0 to 255) so setting this value to near that level will remove large amounts of noise from the calculations. Again values of 20-50 seem to work best.

Sigma:

A figure of merit for the singular value decomposition used to compute linear dependencies in the closed loop calculations. It represents the number of rows to use from the SVD matrix in calculations. 4-8 (out of 12 possible) are often good values with 4 often giving the best results, as higher order rows may only contribute more noise to the calculations. Unlike most other settings, simply pressing return after setting a new Sigma value will cause the program to check the new value. This is to help facilitate quick changes while running the Closed Loop.

Cal Mult:

A multiplication factor used during calibration to determine upper bounds on the voltages being applied to the Unifi mirror. This factor is also used when applying specific patterns to the mirror via the Voltage Settings tab. 1.8 is a good value and probably will not need to be changed unless the mirror seems to be snapping down, at which point it is okay to lower the value to between 1.35 or 1.0.

Z.C. Fraction (Zernike Circle Fraction):

This is the fraction of the Zernike circle to be used when doing calculations. It ranges in value from 0 to 100 (percentage). This value can often be used to calculate over only a portion of the Zernike circle in computations, as often there are edge defects to the beam which only add noise to computations. Values between 80-100 are often the best range. Feel free to experiment The Z.C. Fraction has no effect on Fourier or Legendre calculations.

C.L. Gain (Closed Loop Gain):

This box sets the gain which is used to close the loop. Higher values will result in the closed loop "closing" faster to the optimal value. However setting this value too high will result in instability in the loop. The number of iterations that it will theoretically take to close the loop are based on the ratio of the Calibration Gain to the C.L. Gain. To estimate this divide the Calibration Gain by the C.L. Gain. For example: If Calibration Gain is 4.0 and C.L. Gain is 0.2 then we get 4.0 / 0.2 = 20 iterations.

Aper / Side (calculated):

This value determines how many integration areas across the center of the camera view ClariFast^{TM} will use. When not set to the same value as Aper / Side (another value, this one in the upper left of the Init Settings tab), a red box will be displayed around the used region. Note that odd sizes here will result in a Zernike circle that is offset from center. This should not invalidate the calculations, but even sizes are recommended.

Init Settings Buttons:

Apply Settings:

After changing the setting in a text box you will need to click on apply settings to apply them to the current operation.

Start Sensing:

When this button is clicked the camera will begin taking data and sending it to the processor for computations. This is NOT closed loop operation. In this mode the ClariFast^{TM} system is merely acting as a Hartmann sensor, and not attempting any calculations for the closed loop.

Stop Sensing:

Stop the sensor from operating. This also stops any currently running closed loop operations that might be running.

Section 2.3: Voltage Settings Tab:

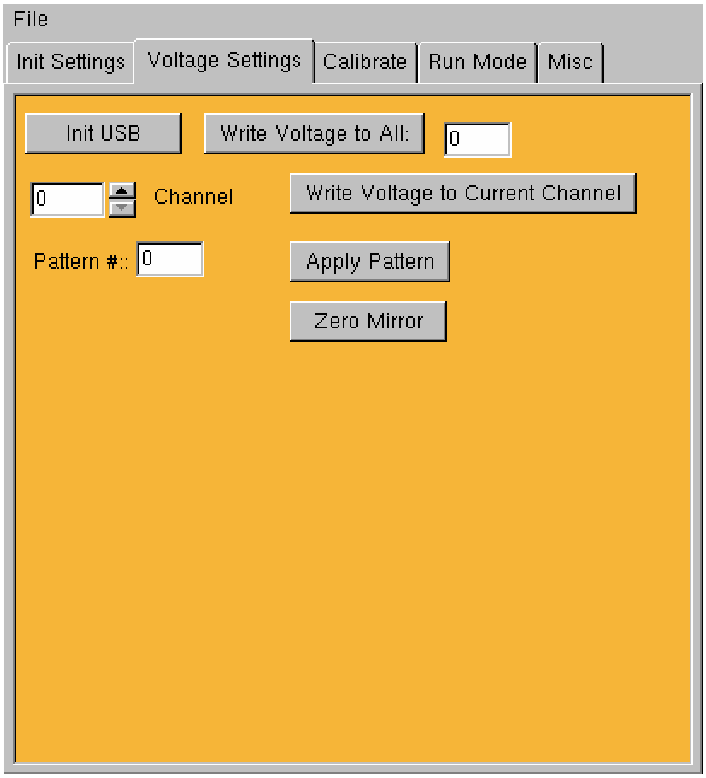


Figure 17.

The voltage settings tab as shown in figure 4. contains various voltage related settings needed for operation of the ClariFast^{TM} System. The following section will describe all the pertinent user information.

Zero Mirror:

When the user clicks on this button all voltages applied to the mirror will immediately go to zero. Upon exiting ClariFast^{TM} (through File->Exit Program or by clicking the "X" in the upper-right of the ClariFast^{TM} window), all voltages are automatically set to zero.

Init USB:

This button can be used to initialize the USB interface on the mirror. Ordinarily the user will not need to do this as the mirror is initialized upon program startup.

Write Voltage to All:

This button will immediately write to all actuators (except the mirror membrane) the voltage value typed in the box to the right of the button. This value is typically set to approximately 70% of the snapdown voltage of the mirror during the manual alignment of the ClariFast^{TM} system. Snapdown voltage on each MDM delivered is provided with each unit and available from the factory upon presentation of the serial number.

Pattern #:

Specify a pattern from the currently loaded pattern file. The default pattern file is a Zernike pattern file with 13 patterns. To load a new pattern, go to File->Load Pattern. Each pattern is named *_Z.pat for Zernike patterns, or _Fourier_ for Fourier patterns. There are currently no Legendre patterns available. However, Zernike patterns have been found to work well for both Fourier and Legendre calculations.

Channel:

Specify a particular actuator on the mirror. When using Write Voltage to Current Channel, this value determines what channel is written to.

Write Voltage to Current Channel:

This button, when pressed, writes the voltage next to Write Voltage to All to only one actuator. That actuator is specified by the Channel value.

Apply Pattern Button:

This button applies the specified pattern next to Pattern # to the actuators, using the Cal. Mult value from the Init. Settings tab. Note that this currently ignores the maximum voltage value, allowing any multiplication, and can easily result in snapdown on the mirror.

Section 2.4: Misc. Settings Tab:

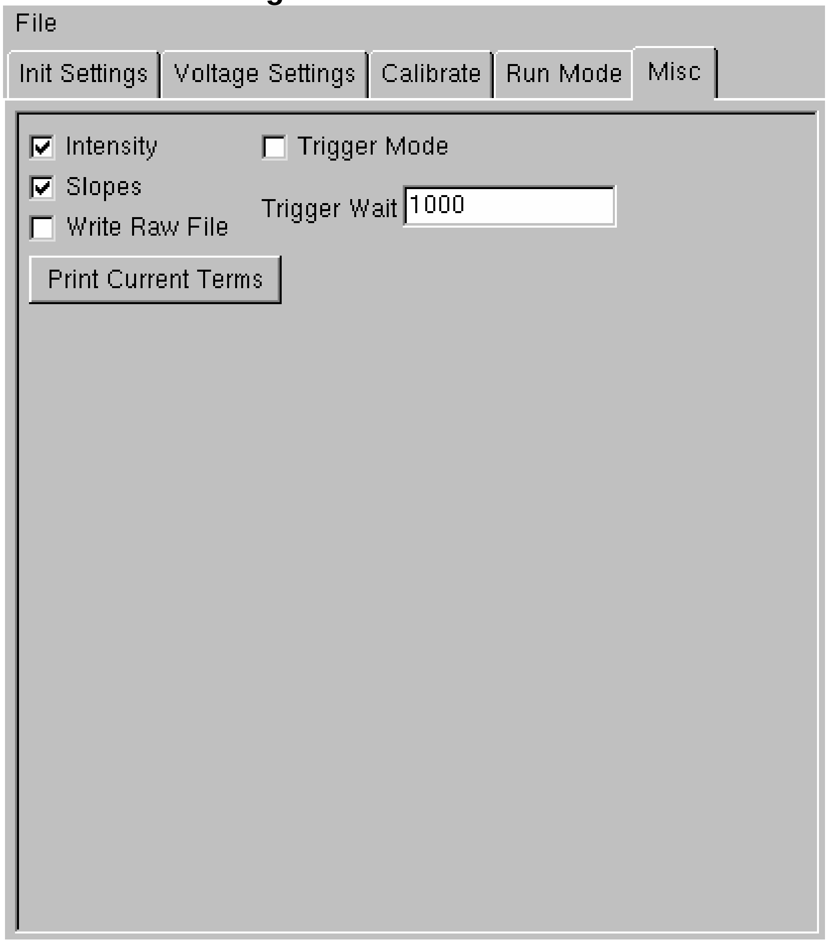


Figure 18.

The miscellaneous settings tab is used to set various miscellaneous, yet very important settings for the ClariFast™ system. Figure 5 show the tab contents. Please refer to the following section for detailed description of these settings.

Intensity:

This checkbox will turn off/on the display of the Intensity (Raw) image in the bottom lower leftmost box. Turning this off will speed up image acquisition and calculations, however the user will be unable to see the raw Hartmann image or the Zernike Bars. These are both particularly useful during initial setup but not necessary once the closed loop is started.

Slopes:

This checkbox turns off/on the display of the slopes image in the bottom center of the GUI. This will speed up closed loop and sensing speed, but the slopes image is often needed during the initial manual setup.

Write Raw File:

This will grab the raw image coming from the Hartmann Array, storing it to a file, and writing the intensity values for the center-most integration area to your terminal window. The user will not need to check this box unless an AgilOptics engineer or technician needs this for troubleshooting purposes.

Trigger Mode:

This will place the unit in trigger mode. Please see the section of this manual pertaining to triggering the ClariFast™ camera with either TTL or CMOS 3.3 to 5 V signals. The trigger input is on the back of the WaveFront Sensor camera, labeled “External Trigger”.

Trigger Wait:

When a trigger signal is received the ClariFast™ closed loops system will immediately begin closed loop operation. The trigger wait period is the period in milliseconds that ClariFast™ will remain operational after a trigger signal is received. For example: Setting the time to 5000 (5 seconds) will force the ClariFast™ to operate for exactly five seconds after the trigger signal is sent. After this time the ClariFast™ will not update the closed loop any longer. Subsequent triggers (TTL and CMOS Highs) will enable the closed loop operation again for the time selected. This could be useful in environments where, when the input beam is off, outside light would affect the ClariFast™ closed loop readings. By setting the timer to the duration of the beam being on, and pulsing the trigger when the beam turns on, the user can guarantee that ClariFast™ is only correcting the beam when the beam is actually on, and not when the outside light is the only reading.

Print Current Terms:

When clicked, Print Current Terms prints the current Zernike, Fourier, or Legendre decomposition values the camera is detecting from the laser. These values are printed to the console and state whether they are Zernike, Fourier, or Legendre terms.

Section 2.5: Calibrate Settings Tab:

The calibrate tab allows the user to begin the calibration mode step of setup. Running calibrate applies a series of voltage patterns to the mirror to get the level of responsiveness of the mirror to the various patterns. Figure 6 shows the tab.

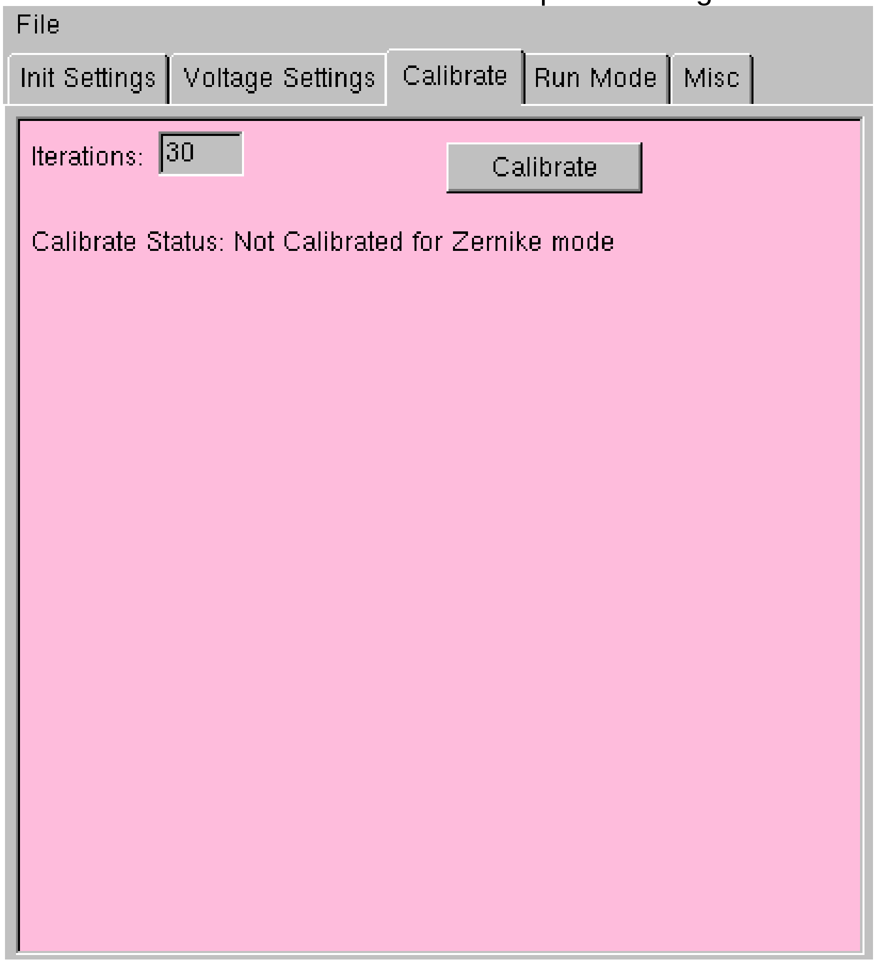


Figure 19.

Calibrate:

This button begins the calibration cycle which lasts ~10-20 seconds. Calibrate runs a series of voltage patterns which are applied to the deformable mirror. The results of these patterns are analyzed by ClariFast™ and used to provide information to the close loop operation calculations for removing optical aberrations. Note that calibration is meaningless unless the optics and the mirror are properly aligned manually first.

Calibrate Status:

This text displays the current status of ClariFast™'s calibration for each mode (Zernike, Fourier, or Legendre). ClariFast™ can only calibrate for one mode at a time.

Section 2.6: Run Mode Tab:

Run Mode is the final and most important stage of ClariFast™ setup. In run mode, the user starts the actual closed loop operation of ClariFast. Figure 7 shows Run Mode tab contents.

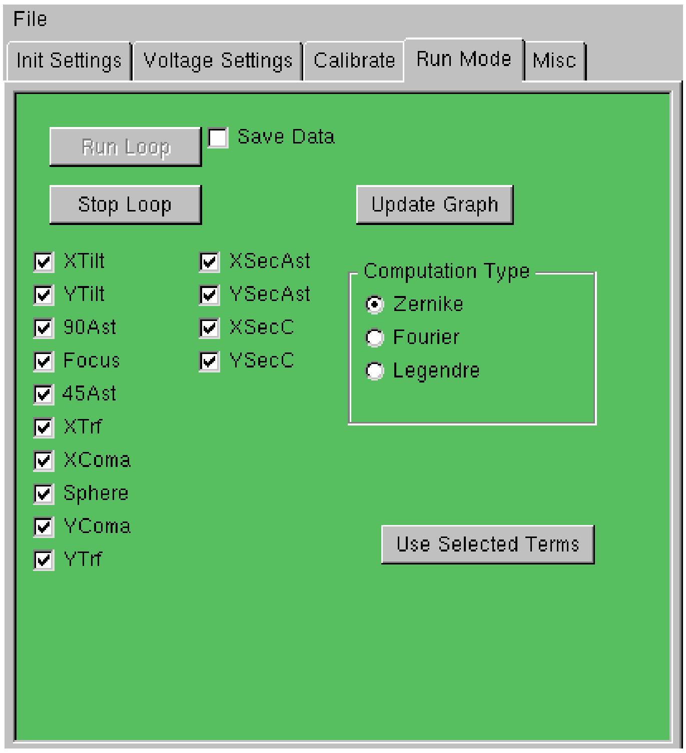


Figure 20.

Run CL:

Run closed loop. This button will begin the closed loop operation of ClariFast. Note that it can not be clicked until the calibration has been done at least one time.

Stop CL:

Stop the closed loop.

Save Data:

Save various computational data. Regular users will not need to select this box, and should not select it unless asked to do so during an AgilOptics troubleshooting session.

Update Graph:

This will force an update of the Zernike Graph (default window in the bottom right) that show the time history of all the terms of the Zernike, Fourier, or Legendre coefficients.

Check Boxes:

The check boxes in this panel are used to force zero contribution from the unchecked coefficient when doing internal calculations for closed loop control.

This can often be used to produce better results, particularly when unchecking higher order coefficients. This tells the calculation algorithm that the particular contribution to this unchecked error term is zero, and hence already “optimized”. You must click “apply selected terms” in order to update the calculations.

Apply Selected Terms:

When this box is clicked the current check boxes in this panel will be applied to the closed loop calculations. Note these can be changed “on the fly” while the closed loop is running.

Section 3: Manual Alignment

1. The camera should be mounted such that the SVSI logo on the side of the camera is "upside down". This will put the camera in proper orientation with regards to the ClariFast^{TM} Software. Double check the system setup by slipping a card in across the beam at the MDM and checking the orientation of the shadowing on the Raw Image display. Do the horizontal and vertical directions separately to ensure that the system does not flip or invert the beam.

2. This section assumes that you have thoroughly read and understood the rest of the manual concerning all GUI controls and information.

3. The user should obtain a good image in the "Raw" image display box which is to the bottom left of the GUI. To make sure you are updating your Raw image, make sure the Enable Image checkbox is checked for your Raw image window, and press "Start Sensing". A good image will have the typical Hartman array of light "blobs": gray near the edges and almost pure white in the middle. You should adjust the exposure (Expose under the "Init" settings tab) to obtain this type of image.

4. Go to the Voltage Settings Tab and set the voltage to ~70% of the snap down voltage of the currently installed deformable mirror. Click on Bar Graph to show the bar graph window. Assuming that the camera is mounted on an X-Y tilt stage or stand, adjust the X tilt until it as near to 0 as possible. Do the same with the Y Tilt control of the stage/stand.

5. Next, adjust the optics so that the focus going to the deformable mirror is also as near to zero as possible. This means that the beam should be slightly diverging as it approaches the mirror so that the mirror can pull focus on the beam.

6. At this point the manual alignment stage is complete.

Section 4: Running ClariFast

You are now ready to use the ClariFast^{TM} closed loop aberration correction system. Please thoroughly read the previous sections which describe all the buttons and controls present in ClariFast, as they are all important to proper operation of the system.

1. If you have already have ClariFast^{TM} running, you may skip this step. You will now need to log in to the ClariFast^{TM} camera processor. Refer to the software installation instructions on how to do this. Once you have the log in screen

right click on the desktop and you will see ClariFast™ in the drop down. Select this and continue.

2. If you are satisfied with the physical alignment of the system, you are ready for Calibration. Simply go to the Calibrate Tab and click "Calibrate". ClariFast™ will do the rest. During this stage ClariFast™ is actually applying known Zernike or Fourier Patterns to the mirror in order to determine the correlation between these known results and actual changes in the mirror surface.

3. Once the calibrate cycle is finished, go to the Run Mode tab and click "Run Closed Loop". You can also try to improve results by un-checking terms in the checkbox list (almost always the higher order terms). Some experimentation will need to be done here, as every system is different.

4. Congratulations, you have run your first ClariFast™ closed loop system.

5. Once you are finished with the ClariFast™ GUI you will need to shutdown the system. Close the ClariFast™ GUI. Right click on the desktop again, Click on **SHUTDOWN** from the menu and **wait at least 3 minutes before powering off the system. Failure to do so may result in file system corruption, and you will have to return the product to AgilOptics to repair the file system.**

Section 5: Multi-System, Single Computer Control

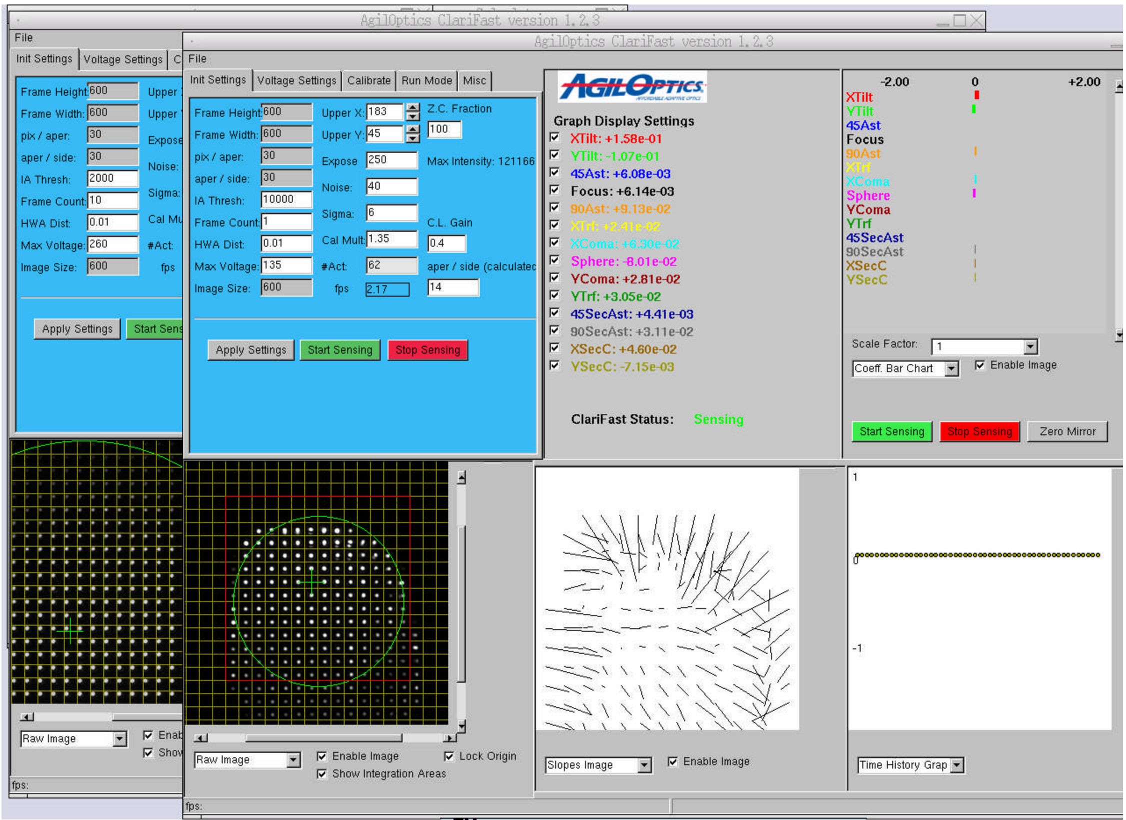


Figure 21. Multiple ClariFast™ systems being controlled by one computer.

The ClariFast™ WaveFront Sensor Camera comes with it's own IP address, allowing multiple cameras to be accessed and controlled simultaneously by one computer. Up to 8 cameras can be controlled by a single computer, ideally on a large screen monitor. Since all computation and calculations take place on the individual cameras, controlling multiple cameras does not result in any loss of computational speed for the ClariFast™ system.