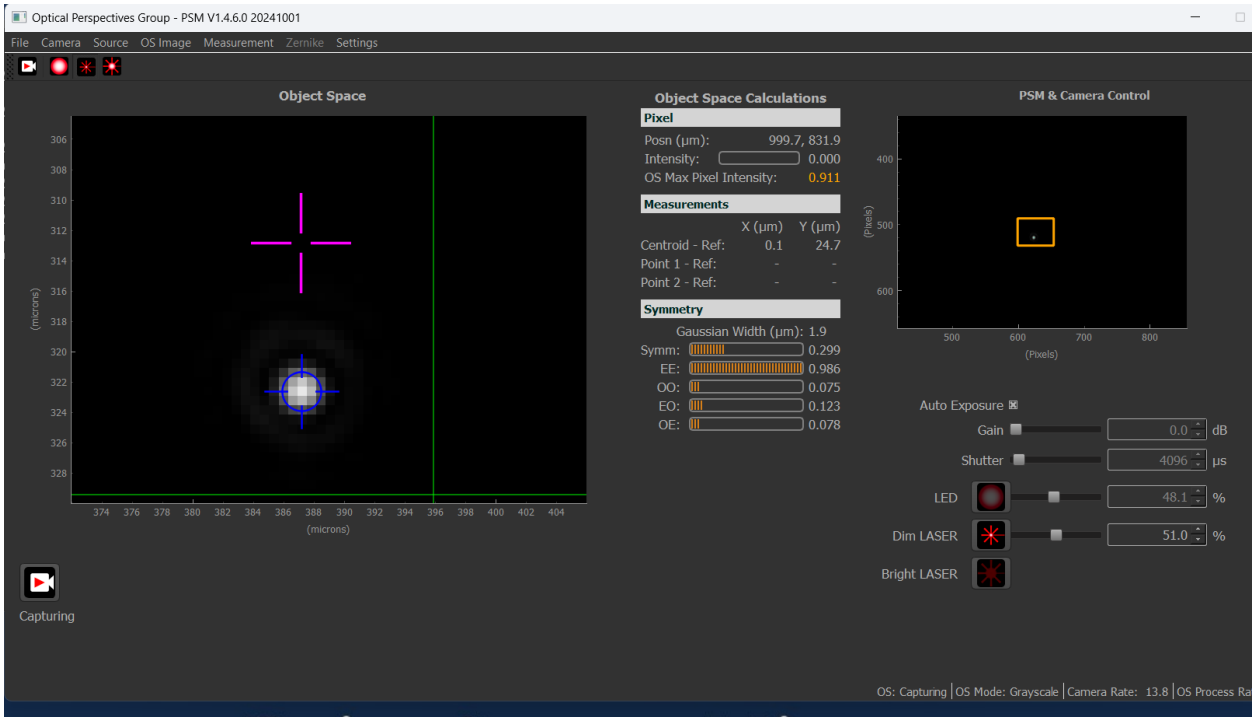
Guide to Python-based PSM Align software for alignment and Zernike coefficient determination

Background: The Python-based PSM Align software replaces the LabView version that was the standard issue. The PSM Align keeps the same functionality but adds more features and flexibility. It is specifically designed to support the PSM's main purpose, optical alignment, making this feature easier to use while keeping all the other functions of the LabView version and adding more functions, such as Zernike coefficient determination (available for an additional fee).

Main features: The new GUI, shown below, was designed with alignment in mind. The software's version number is in the top line of the window and is a helpful clue when troubleshooting.



There are two windows with a column of measurement values separating them. Under the smaller "PSM & Camera Control" window are controls for the camera Gain and Shutter speed and controls for the light sources. The Camera Control window shows what the full camera detector array sees and has scales around the edges in units of kilo pixels starting in the upper lefthand corner. The "Object Space" window is what the PSM "sees" in object space at the PSM objective focus and is scaled in µm with the origin in the upper lefthand corner of the fully zoomed-out window independent of the zoom setting. The scaling is user-set depending on the objective and camera pixel size in the last line of the Settings\OS Image dropdown tab. (For the 10x objective supplied and camera with 3.45 um pixels, the scale factor is 0.69 um/pixel.) The windows zoom via the scroll wheel when the cursor is in the window.

Object Space window: The rectangular box in the Camera Control window shows the size of the Object Space window on the camera sensor. Even when zoomed in on the Object Space window, the reflected light spot is always visible in the zoomed-out Camera Control window, provided the spot is in the camera's field of view. The blue circle with a cross indicates the centroid of the intensities of all the pixels within the Object Space window. Holding the left mouse key allows you to pan in the window.

Right-clicking within the OS window brings up a menu box with the first entry of View All; in other words, fully zoom out. Next is Set Ref Point. Clicking this option sets a magenta crosshair at the current location of the blue fiducial that shows the centroid location of all the pixels within the OS window. This function sets the PSM origin when a Cat's eye image of a specular surface is in good focus. Setting the Ref Point should be done before aligning an optical system to zero the origin of the PSM.

Set Ref Point 1 puts a crosshair at the origin of the cursor, as does Set Ref Point 2. This gives a way to determine the x, y distance from the reference point 1 or 2 to the PSM origin indicated by the magenta crosshair. Set pixel lock monitors the intensity of a particular pixel in the Intensity box independent of other actions within the window.

Clear All removes all reference points except the blue centroid fiducial of the intensity of all pixels. This should be used with caution since it removes the Ref Point, which is the origin, as well as other fiducials. It is better to use Clear Point >, and remove only those desired points rather than all. Finally, Save Image saves the pixels in the OS window as a csv or png file. Since most operations, when doing alignment, use only a limited array of all the camera pixels, this save option produces a small file the size of the window without any fiducial information, that is, it is just the raw 16-bit pixel intensity map.

PSM & Camera Control Window: When zoomed out, this window shows the entire camera sensor array with a scale in kilo pixels around the edge. The rectangular window and pixel colors indicate the normalized relative intensities: red for saturated or > 1.0, orange for 1.0-. 85, green for .85- .75, and blue for the .75 to pixel threshold which is set in the Settings\OS Image dropdown tab. The pixel threshold is typically set at 50% of the maximum intensity range. Intensity values are only calculated for pixels within the rectangle and when the intensity drops below the pixel threshold, measurements stop. Right-clicking in the window allows one to zoom out to the full window.

Object Space Calculations\Pixel: Between the two windows is the display of the results of quantitative measurements of the images in the OS window. When the cursor is in the Object Space window, the first entry in the Pixel box, *Posn (um),* is the x, y location of the cursor cross origin, or intersection in µm. The *Intensity* entry is the pixel's relative intensity at the cursor's origin. The OS *Image Max Pixel Intensity* is the relative intensity of the brightest pixel in the Object Space window. These intensity values are useful in setting the *Dim LASER* slider and camera *Gain and Shutter* sliders to avoid saturated pixels where a normalized intensity of 1.0 indicates saturation of the 16-bit camera resolution.

Measurements: *Centroid – Ref.* gives the x, y distance between the intensity centroid (blue circle) and the magenta cross reference point. Two other reference points, set using Set Measure Point -1 and 2, show the x, y distance between these reference points and the magenta cross.

Symmetry or Zernike: Image symmetry values and the Gaussian image width are given under this heading, or Zernike coefficients, depending on whether the Zernike module is enabled under the Settings/General tab. This differentiates two different modes of using the software depending on whether it is desired to look at the reflected image directly (Zernike module not enabled) or a defocused image used to calculate Zernike coefficients. With the supplied 10x objective, moving the PSM about 0.33 mm inside the best focus is the correct defocus for using the Zernike option. This option is discussed further in a separate section below.

When using the Symmetry option, the first entry gives the Full Width Half Max (FWHM) of the Gaussian fit to the intensity map of the focused spot on the screen. This value is useful in determining the best

focus and the percentage of energy falling within a certain diameter circle. The remaining 5 entries relate to the 5 symmetries of an image, namely rotationally symmetric and 4 symmetries in the x-y plane. These values are useful when aligning an optical system because they indicate which adjustment must be made to improve the image quality, that is, to make it as symmetric as possible. (The even-even component will always be large relative to the other components for a small, symmetric image because of an artifact due to the discrete sampling of the small number of pixels arrayed on a square grid. To prove this, rotate the camera 45°. This should make the Odd-odd component large, but it doesn't.)

Camera and source controls: A check box for Auto Exposure is under the Camera window. This feature is very useful during initial searches for reflections from surfaces and centers of curvature, for it increases the exposure when the PSM focus is far from a surface and then reduces the exposure as the PSM comes to the best focus position. If at best focus there are still saturated pixels it is necessary to reduce the intensity of the laser source.

Under Auto Exposure are sliders for manual control of Gain and Shutter. When more exposure is required, increase the Shutter first, then the Gain because increased Gain will increase the noise in the measurement. The sliders are controlled by Auto exposure when that box is checked and cannot be controlled manually in this mode.

The maximum settings of the Gain and Shutter slides are reset using the Settings\Camera dropdown. A combination of the Shutter, Gain and Dim laser sliders permits great flexibility depending on a particular test setup, but this also means that suitable ranges of use must be found for particular applications. The best ranges of settings can by 3 orders of magnitude between looking at a well-focused image and the optimum settings for using the Zernike module. Overall, this combination of settings gives a range of useful intensities on the order of $1{:}10^7$.

The LED slider controls the LED source used for full-field illumination when the PSM is used as a video inspection microscope. The Dim Laser slider controls the laser diode point source used for alignment. Since Auto Exposure uses all the pixels in the OS window, the Dim laser intensity must be reduced or turned off to see an in-focus view of a surface due to the Cat's eye reflection from the surface. Conversely, the Cat's eye reflection is a great way to locate a surface reflection.

When the laser is in the Dim mode, it is not lasing but producing light by spontaneous emission. The Bright LASER button powers the laser diode so that it is lasing and bright enough to see the focused beam under most ambient lighting situations. Even in the Bright mode, the laser produces less than 1 mW at the end of the fiber, so the PSM is a Class 1 laser device. (Even so, do not look directly into the PSM objective or objective aperture.)

Tabs: *File**Save ROI* saves the region of interest, which is the contents of the OS window less the fiducials. If Excel is installed, an RSV contour map of the intensities is produced by going to Insert\Recommended Charts\All charts\Surface\3D or Contour. Once a PNG file is saved, it can be viewed by double-clicking on the saved file. *Exit* saves all the settings made during the measurement session. If you exit by clicking the X in the upper right corner, the program will open to default settings.

Camera: If *Auto* exposure is checked, Auto exposure starts when the program opens. *Average* frames performs a running average on the number of frames set in Setting\camera. Averaging may make the measurement data seem less noisy depending on the environment.

Source: These 3 buttons turn on the sources the same as clicking the source buttons under the Camera Control window.

OS Image: This tab stands for Object Space Image and controls features in that window. *Pause* freezes the window when the button is clicked, which is helpful in saving a particular instance of an image. The other three buttons control the window's coloration. Binary mimics the green pixels in the camera control window because it only shows the pixels above the pixel threshold, the pixels on which the calculations are based. (The *Capturing* icon below the Object Space window also pauses the image.)

Measurement: These options are apparent.

Zernike: Greyed out. The PSM alignment-only version of this software does not offer an option to obtain Zernike coefficients from an out-of-focus image of a point source. A license to use this software is available from innovationsforesight.com.

Settings: *General**Zernike Module enabled*. Click this to enable the Zernike coefficient calculation module, or wavefront sensor software, for the PSM. A license from innovationsforesight.com is necessary to use this feature.

SettingsPSM\The light sources turn on when the software boots.

*Settings**Camera**Exposure time min* sets the minimum value of exposure time on the Exposure slider

*Settings**Camera**Exposure time max* sets the maximum value of exposure time on the Exposure slider

*Settings**Camera**Exposure time (Zernike) max* sets the maximum value of exposure time on the Exposure slider when using the Zernike module because the image is out of focus and requires more intensity

*Settings**Auto-exposure set point* The set point for the brightest pixel to keep all pixels in an image below saturation. The default value of 0.8 is generally good, but the better the image quality the lower this must be to assure all pixels stay below saturation. This is the case when the Gaussian image width approaches 2 µm.

*Settings**Auto-exposure Gain* Use the default value when using the PSM for alignment and the return spot is well focused

*Settings**Auto-exposure Gain (Zernike)* As in the Exposure time, this setting is different when using the Zernike module because of the defocused image

*Settings**Frames to average* Can be set from 2 to 16. Depending on the measurement and the environment this may make the data less noisy

*Settings**OS Fiducials**Centroid**Width**height, Gap size, Circle radius, Line thickness* User editable blue centroid fiducial

*Settings**OS Fiducials**Reference**Width**height, Gap size, Line thickness* User editable magenta Reference fiducial

Settings\OS Fiducials\Point 1\Width\height, Gap size, Line thickness User editable light blue Measurement Point 1 fiducial

Settings\OS Fiducials\Point 2\Width\height, Gap size, Line thickness User editable yellow Measurement Point 2 fiducial

Settings\OS Fiducials\Pixel loock\Width\height, Gap size, Circle radius, Line thickness User editable geen Pixel lock fiducial

Addendum: Ignore the MS warning about an unknown publisher when installing the program.

Updates for PSM Align will be via an MS Installer and available from the OPG website

We use the new software daily in our own lab and keep a list of bugs and desired improvements that will be incorporated in new releases. Please let us know of bugs or fixes you would like to see.

One of the first major changes will be to have the software continuously track measured parameters in the Symmetry/alignment mode. This will make it possible to do drift tests, or to monitor changes against a time base.

The source code will soon be available so that you can customize the software for your applications and integrate it into existing test routines.