Keyence VK-X 3000: Imaging and Processing Protocol

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Step 0: Before You Start

1. Check to see if you have booked a time slot through "Clustermarket" and log into your "Clustermarket" account on the Keyence Computer.
2. Password to Keyence computer is written on the monitor.
3. Check to see if the plate is clean and clear of contaminants.
4. Make sure the plate is levelled and centered on the Keyence stage.
    a. On the first drawer to the left, there is a bubble. You can use that to verify whether the stage is level. Most times it is.
    b. Important: Do not forget to lower the stage when you complete your experiments.
5. Make sure your plates are labeled and organized to avoid accidental switching or incorrect naming of files.
6. Create folders and sub-folders on hard drive with the different names and save directly into them during the scanning and imaging process.
    a. Connect the hard drive to the PC behind the monitor.

Step 1: Identifying Regions of Interest

In most cases, the whole plate will serve as the region of interest with the fabrication process involving all parts of the plate. On some occasions, some areas of the plate are better excluded from imaging. These areas are often also excluded from testing. Some reasons for exclusions could be:

1. Non-uniformity in fabrication resulting from:
    a. Unevenness in applying coating.
    b. Incorrect or excessive etching on a certain location of the plate.
    c. Inherent plate non-uniformness (bulging, bending, break).
2. Surface Damage:
    a. Scratch on coating.
    b. Visible discoloration or wear.
3. Contamination due to:
    a. Embedded particles within surface.
    b. Adhesive residue.
    c. Dust particles (user unable to dislodge using air).

It is recommended that the user identifies up to 5 regions of interest (R.O.I.s) that correspond to the center and each of the 4 corners of the plate. This ensures that the measurements are not skewed to one section of the plate. This is especially important when the tests are being done on all regions of the plate. The results of the measurements will be averaged after processing.

Step 2: Obtaining Optical Images

Before commencing the scanning process, optical images of the surface should be taken. This serves several general purposes:

1. Identifying the best magnification for surface scanning.
2. Documenting the “look” and color intensity of the surface structure and microstructure.
3. Obtaining useful data on how effective the fabrication process was in terms of coverage and uniformity of coating or etching.
4. Using the obtained images for comparison and presentation in papers and presentations.

One extremely important reason why the optical images are taken before scanning is that the obtained optical image will be compared with the obtained scanned image under “Optical” view. This image will immediately appear on the Keyence software screen after the scan has been processed and before the user saves it. As such, the user should compare the “Optical” view of the scanned area to the actual optical images the user has taken. How close or far the resemblance will determine whether the scan is good or bad in quality.

<u>Note:</u> The user does not have to compare the scanned image with an optical image of the same area. While this is ideal, it is not necessary. It is simply required that the user be able to compare the color intensity, the sharpness of the structure of the image, and how distinct the roughness elements look. A bad scan would smoothen the elements together and badly represent the peaks and valleys.

How to Obtain and Name (OPTIONAL) Optical Images:

1. Upon opening of Keyence software, press yes when prompted to move the stage to the origin.
2. Set the selected plate **(PlateX_FabX)** in the center of the stage.
3. Starting with 2.5x Mag **(Magx = 2.5x)**, use knobs to bring the surface into focus *(fig.1)*.
4. Click Autofocus. You will notice that the lens will move a bit and the Z height shown on the screen will change.
   <u>Note:</u> Always click on autofocus before any imaging to allow the software to properly calculate the height of the lens relative to the stage. The use of knobs to focus will lead to incorrect values for the relative height and hence incorrect values of the upper and lower limit *(fig.2)*.

5. Most often, it's best to take an image with the ***Ring light*** on and shining from the top left position **(Light = RingTL)**. At 20x Mag and beyond, the lighting automatically switches to Coaxial **(Light = Coaxial)**.
6. If possible, take additional images with no light **(Light = NOLIGHT)**. The lack of glare allows the elements to appear clearer. This is not always viable as the surface may appear too dim.
7. Once the surface focus and lighting are set, decide on the scale bar length. For 2.5x, set the scale bar length to be between 500 µm - 600 µm. Set the scale bar to appear on the bottom right corner, and if necessary, align the value with the bar itself by moving it using the mouse.
8. Take an image with the scale **(ScaleXX = ScaleON)** and another without the scale **(ScaleXX = ScaleOFF)**.
9. For every magnification and selected light (or no light) source, you should save two images, one with the scale and one without.
10. Save the images as: **PlateX_FabX_Optical_Magx_Light_ScaleXX**
11. Move on to the next Magnification factor and repeat steps 4-9. As the magnification doubles, you should half the length of the scale bar, to prevent it from taking up too much space on the image. Make sure the scale bar and scale value are centered w.r.t. each other.
12. At some point, most of the image will appear out of focus as the magnification is increased. Once that happens, there is no need to continue imaging as the results would be of little value.

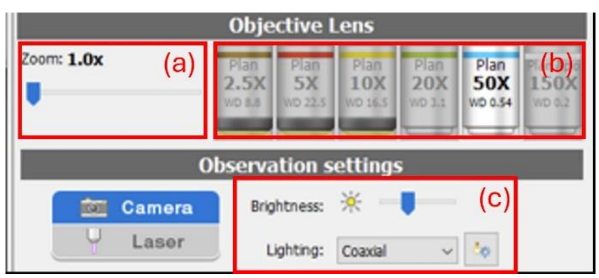


Figure 1: Magnification and lighting options where (a) controls viewing zoom, (b) controls actual lens zoom, and (c) controls the lighting source and brightness.

Figure 2: Imaging Panel Control Options

Step 3: Scanning

The most important step during the surface analysis process is to correctly scan the image. This requires the user to select the optimal scanning technique and assess the quality of the scanning process before deciding to proceed with the analysis of the scanned image.

A. *How does the scanning process work?*

The Keyence takes hundreds of images and stiches them together to form a 3D scan of the surface. As the lens moves from one height to the other, an image is taken. The software stiches the images together by identifying the points in each image that are in focus and adding them to the final image. Essentially, as the lens moves from the lower bound to the upper bound, different points on the surface come into and out of focus. While the scanning is progressing, you will see the in-focus points starting to show on the screen while everything else remains dark. By the end of the scanning process no part of the screen should still be dark.

There are various scanning methods that the user can select. Depending on each method, it may be the role of the user to select the lower and upper bounds of the scan. How to select these bounds will be explained. Below is a brief description of each of the scanning methods.

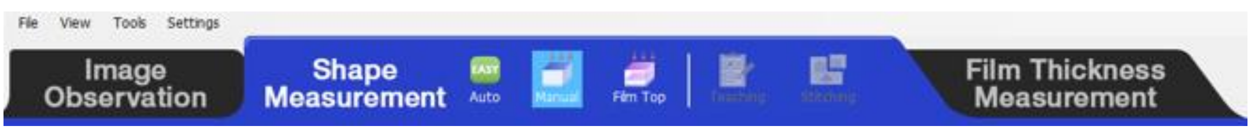


Figure 3: Control bar showing the 3 main scanning options.

1. **Manual Mode: Auto Range:** User autofocuses. System selects the upper and lower bound.
2. **Manual Mode: User Range:** User selects the upper and lower bound.
3. **Manual Mode: User Range Double Scan:** User selects the upper and lower bound. System scans twice for a clearer image.
4. **Manual Mode: User Range ND filter = 1%:** Like manual user range, but the system blocks more light from entering the lens. By default, ND filter = 100%.
5. **Top Film Mode:** User Range: Like Manual but focuses more on the top of the surface. Tests show it's better to use Manual mode for more clarity.
6. **Easy Mode: Auto:** System does everything automatically. No need to autofocus first.
7. **Easy Mode: Auto Focus Variation:** Like Easy Auto, but the system also varies the focus while scanning.

C. Scanning Procedure: Auto (Easy)

1. Select the Auto (Easy) shape measurement *(fig. 3)*. Once the desired zoom is set using the objective lens bring the surface of your material in focus by adjusting the stage height.
2. This method works best if the material does not have a huge range between the upper and lower limits of focus.
3. As shown in *Figure 4.* the user can select between optical and laser scan modes and it is always best to try both the methods to determine what works best in your case. (e.g.: Sometimes for materials that are transparent or white, the laser confocal works the best)
4. Once the desired area is in focus the user can click 'Start measurement' to start the scanning procedure.
5. The Keyence automatically scans and stacks the images to give you a depth composition image. Further analysis is done in the VK-X Analyzer software.

B. Scanning Procedure: Pre-Scan (Manual Method)

1. Select the preferred scanning mode *(fig. 3)*. Depending on the selection the following steps may or may not apply. See *fig. 4*.
2. On the Brightness section, click Auto.
3. Select the Upper Limit and Lower Limit:
    a. Click Auto Focus. If Auto Focus fails, try to manually focus by either moving the knobs or clicking on the single/double arrow up/down *(fig.2)*. The lens will move up or down. Once the object is in focus, click Auto Focus again. The lens will focus, and the current Z height will be updated. The Upper and Lower limit values use the current Z height as reference.
    b. Determining Upper Limit: Click on the single or double up arrows until the whole image is completely out of focus. Do not let leave any part of it in focus. Overdoing this will not alter the imaging, but just make the scanning process longer. Once the image is out of focus, click on "Upper Limit". The value will be updated.
    c. Determining Lower Limit: Same process as above but using the down arrows.
4. Select scanning quality:
    a. Resolution: Can be partial, Standard (1024*1024) or Super Fine (2048*1536).

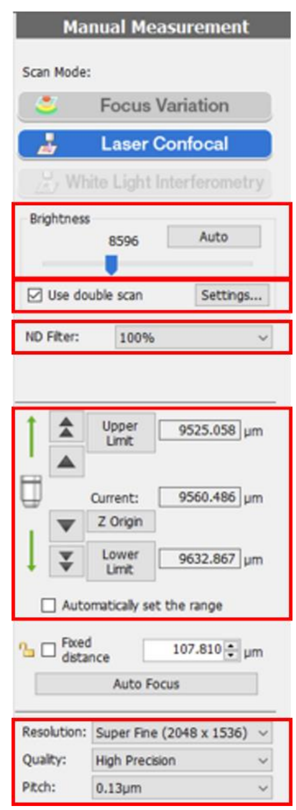


Figure 4: Scanning control panel.

b. Quality: Can be set to High Precision, or High Speed.
c. Pitch: Automatically calculated. Can not be changed. The lower the pitch, the less the tilt in the image and the higher the quality of the measurement.

5. Select whether to double scan. Double scanning means another laser will scan along with the first, obtaining (in theory) a higher quality image. Even after selecting "Use double scan", the user must still go to the settings and select whether double scanning is applied automatically or always applied.
6. Select the ND Filter percentage. ND filter controls how much light enters the lens. Value varies between 1% →100%. The value is 100% by default and should usually be kept so.
7. Select whether to let the system "Automatically set the range". Usually not advisable, as the user may be better suited to correctly identify the upper and lower limit but can be used for cases where low magnifications are employed (2.5x-5x) as system error in identifying the upper and lower limit will be minimal.

***D.* Navigation Image**

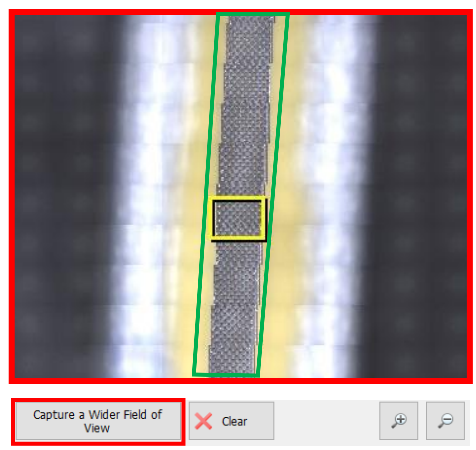


Figure 5: Navigation image of a rough surface

1. This is a pre-step before implementing two powerful steps using Keyence VK-X 3000 (Teaching and Stitching).
2. We strongly recommend the user to do atleast one scan using Auto (easy) and analyze the quality of the result before registering a Navigation image.
3. Align the center of your sample in the focus area and click on 'Capture Navigation Image'.
4. The system automatically creates a bigger image of your sample.
5. In *Figure 5*, the rough surface shown within the green box and the current focus location is shown in the yellow box.
6. If you need a much wider image the system can go one step further and capture a bigger area of your sample when you click on '*Capture a Wider Navigation Image' (fig. 5).*
7. Now when you double click on a location on your Navigation image the machine will automatically move its focus to that area highlighted in yellow.
8. You can also click and drag this yellow rectangular box to another location and the system will move its focus automatically to that location.

E. <u>Scanning Procedure:</u> Teaching

1. We strongly recommend the user to do atleast one scan using Auto (easy) and analyze the quality of the result before registering a Navigation image and proceeding with teaching. This method is useful if you would like specific areas of your profile.
2. Now register the Navigation image as shown in *(fig. 5).*
3. Select the Teaching shape measurement *(fig. 3)*. Now, more options are shown in the space below the navigation image.
4. Move to the desired location in your navigation image and then click on '*Add Current Location*' to add that location as a scan location *(fig. 6).*
5. You can also edit your scan locations using the '*edit*' button under the Teaching menu.
6. Once you are satisfied with your locations click on '*execute scanning'*, the system will automatically scan and save these teaching files in your 'save location'.

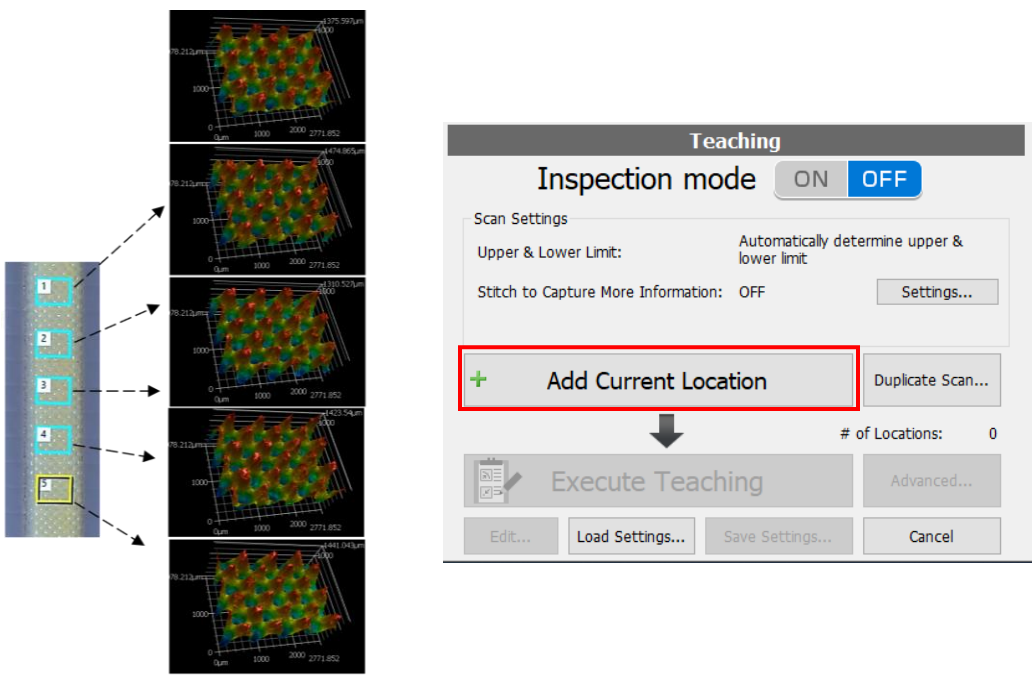
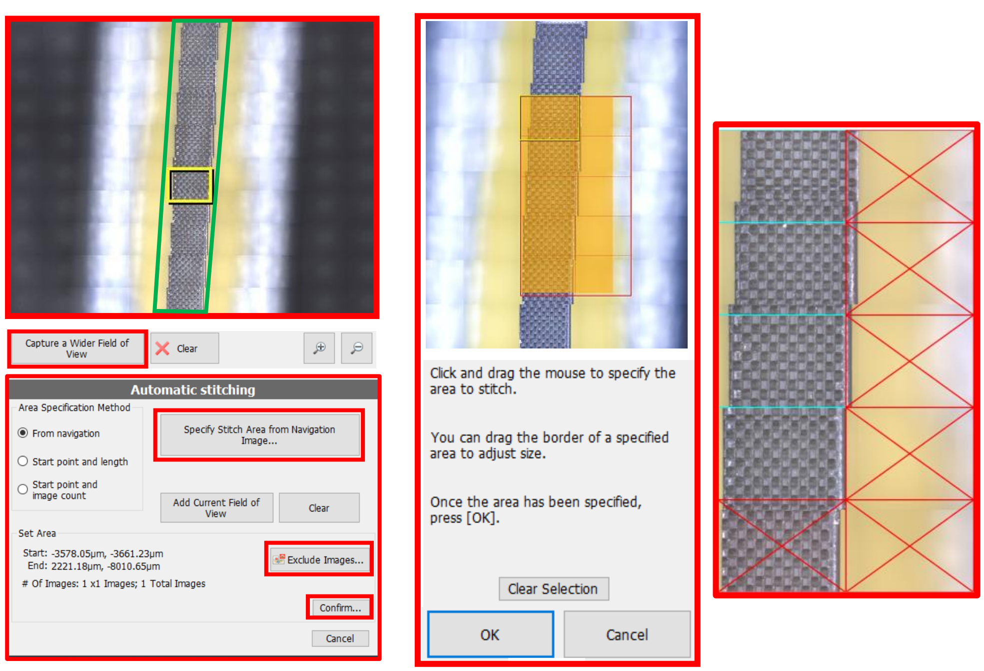


Figure 6: Five different scan locations captured using the teaching method and the teaching menu is shown on the right.

F. Scanning Procedure: Stitching

1. We strongly recommend the user to do atleast one scan using Auto (easy) and analyze the quality of the result before registering a Navigation image and proceeding with stitching. This method is useful if you would like a continuous and wider scan of your profile.
2. Now register a Navigation image as shown in *(fig. 5).*
3. Select the Stitching shape measurement *(fig. 3).* More options are shown in the space below the navigation image *(fig. 7a).*
4. Click on '*Specify Stitch Area from Navigation Image…*' (fig. 7). A new window opens up with the navigation image.
5. Now click and drag the area that you would like to scan, the borders of your stitch area is highlighted, if you like your selection then click '*OK*' or click on '*clear selection' and start again*.
6. As seen in *(fig. 7b)* some of the boxes are outside the region of interest, these areas can be de-selected using the 'Exclude Images' option in *(fig. 7a).*
7. A window pops up with your selection area. Now, click on the boxes that you would like to de-select *(fig. 7c).* The images that you de-selected will be crossed out and would be avoided while scanning, saving you time and memory.
8. Now click on '*confirm'* and then proceed with 'Start Measurement'. The system will automatically scan and save these stitching files in your 'save location'.



(a) (b) (c)

Figure 7: Stitching procedure on a rough surface (a) Stitching menu (b) Specifying stitching area from the navigation Image (c) Excluding images from the Stitching area.

G. <u>Scanning Procedure:</u> Post-Scan

Once the scan is complete, the user will have to determine whether the scan was satisfactory. Often it can be obvious whether the scan failed or not. *Figure 5* shows a comparison between the optical image and 2 scans, the first with ND filter = 1% and the second with the single scan Manual mode. *Figure 5.b* shows extreme surface smoothing, while *fig.5.c* shows minor surface smoothing that can only be detected if the user takes a good look at the roughness features. *Figure 5.c* is of good quality, but the quality could be improved by using “double scan” instead of “single scan”.

Note: Smooth structures can exist in general, but not for the application represented in *fig.5*. Moreover, the user, when obtaining the optical image and when setting the upper and lower limit during scanning would notice whether a smooth section of the surface exists.

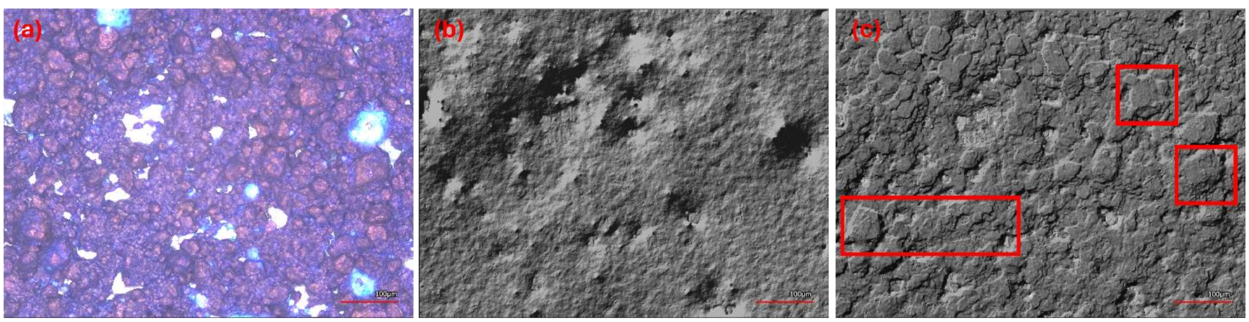


Figure 8: Comparison of (a) optical image, and scanned image using (b) ND filter = 1%, and (c) Manual User Range single scan with the highlighted areas showing inaccurate surface smoothing. Both scanned images are not of adequate quality.

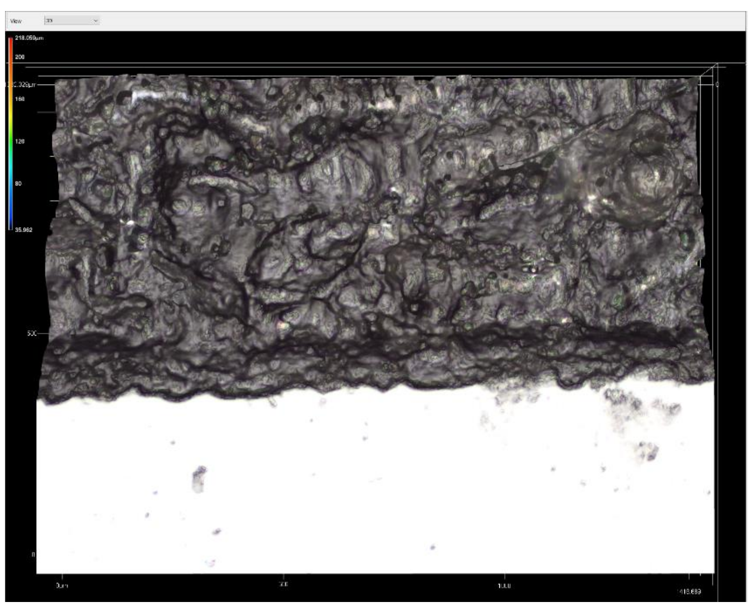


Figure 9: Software output upon immediate completion of scan. 3D top view of scanned surface.

Figure 6 shows the immediate result shown after the scan is complete. In this case, a plate was imaged at the point where the surface meets the smooth section. This was done to create a reference plane for the roughness (see *fig. 7*).

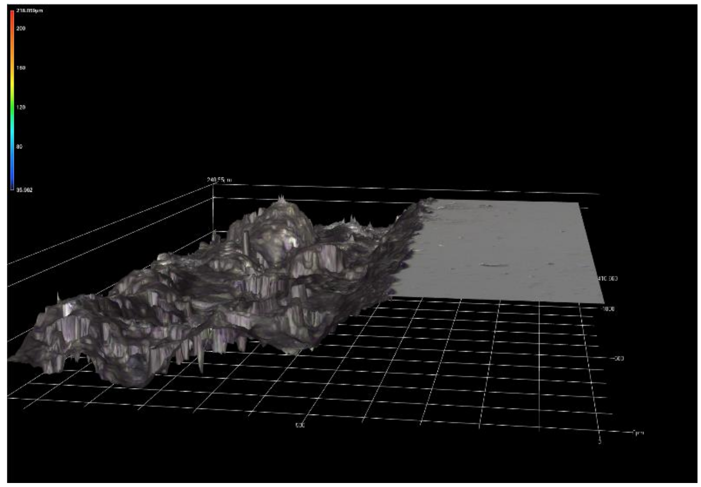


Figure 10: 3D Isometric view of scanned surface.

Figure 6 & 7 can both be visualized under different optical conditions. *Figure 8* shows the different image adjustments that can be done to vary the viewed scan. The main ones are presented below.

- View: The default view is 3D, but the user can select "Optical", "CDIC", "Laser + Optical" or "Height" as the viewing option. Selection of "Optical" allows for best comparison with the previously obtained optical images. Selection of "Height" applies color to the image based on the color range for each roughness values.
- Height Magnification: The default is 100%. Can be increased to amplify small roughness structures.
- Data Quality: Conter-intuitively, the data quality is set to only 50% by default. The user can increase it to 100% to improve the visualization of the small roughness structures and giving the image more "texture". However, setting it to 100% also makes the software slow as it tries to render the image.

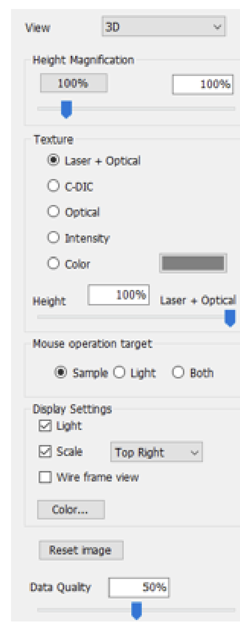


Figure 11: Post-scanning control panel.

Note: Regardless of the changes made while viewing the processed image, the scanned image won't be altered, and the R.O.I. will remain the same.

H. <u>Saving:</u>

Once all is done, save the measurement. There are two ways to do this. Either click the save measurement button or click the analyze button. If you do the latter, then you will be automatically asked to save the measurement. Additionally, the analyzer software will open, and the R.O.I. measurement will be added to it.

Note: Keep the analyzer software open to have the next R.O.I. added to it.

Step 4: Processing

Processing is done using the VK-X3000 MultiFileAnalyzer software. The saved R.O.I. measurements can be either uploaded to the analyzer or be directly added to it during the scanning process.

Upon opening the analyzer your screen should resemble what is seen in *fig. 10*. The main page will contain your different R.O.I.s. It will display them in 3 forms, Laser+Optical, Height, and 3D Image along with a Height color bar, and a column showing the date and time of the measurement.

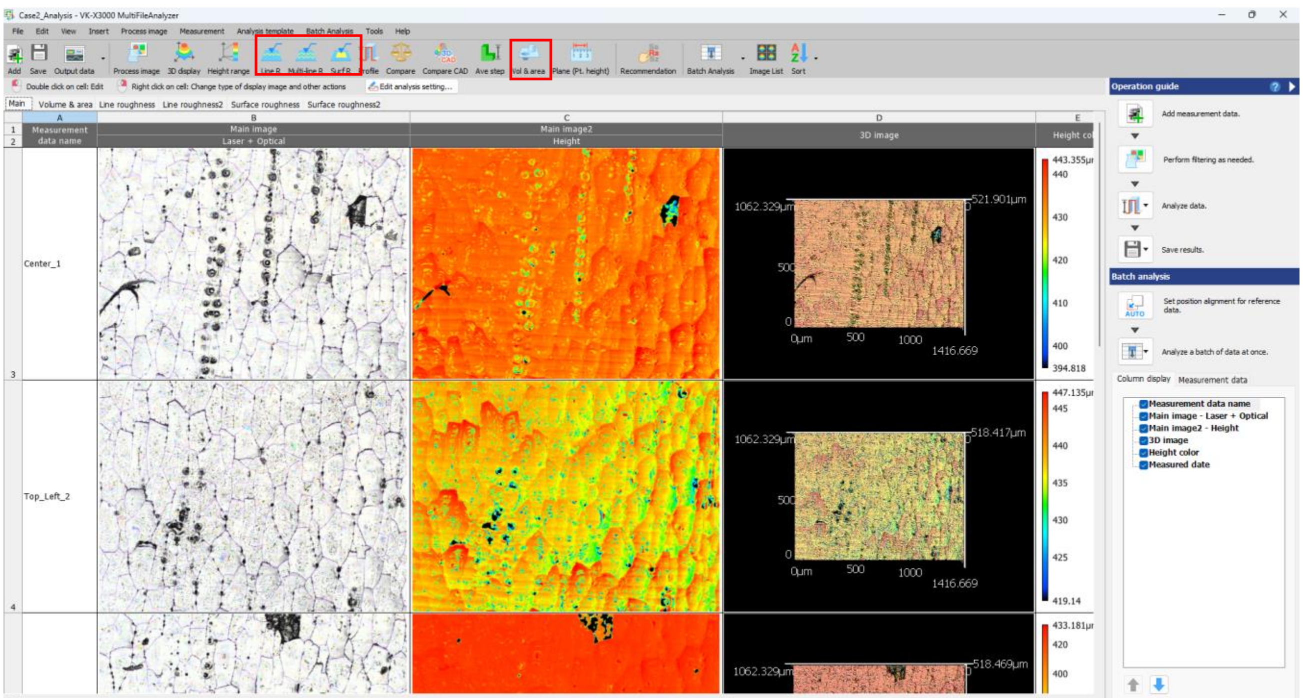


Figure 12: VK-X3000 MultiFileAnalyzer main page.

As you start analyzing your data, additional tabs will show up, each representing the different analysis you have done so far. The three main types are:

1. Volume & Area
2. Surface Roughness
3. Line/Multi-Line Roughness

<u>Volume & Area:</u>

It is the simplest analysis to perform. Just click on “Vol & Area” on the main page (*fig.9*), then click “OK” on the screen that pops up (*fig.10*). The software will calculate the following and automatically apply it to all R.O.I.s:

- Volume [μm^3]
- C.S. area [μm^2]
- Surface area [μm^2]
- Surface area/C.S. area []
- Area ratio [%]
- Average height [μm]
- Max height [μm]

Figure 11 shows the resulting "Volume & Area" tab on the main window. Note that the data can be saved as a .csv file or be copied directly into another file.

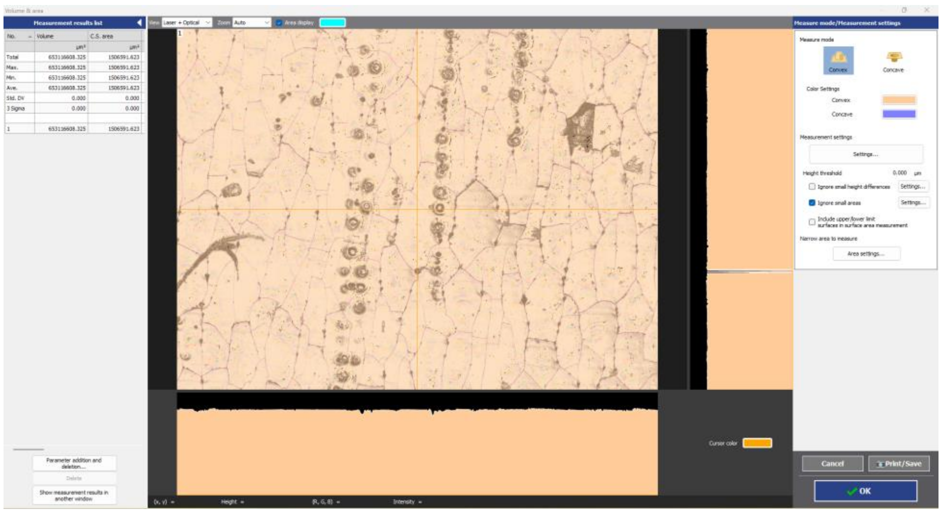


Figure 13: Volume & Area analysis window.

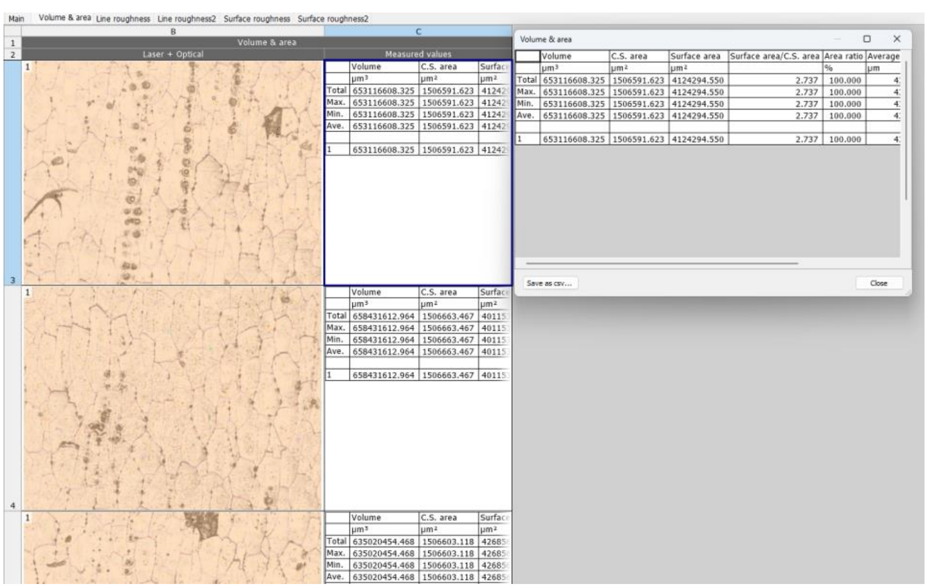


Figure 14: Resulting Volume & Area analysis. The data can be directly copied or saved as .csv

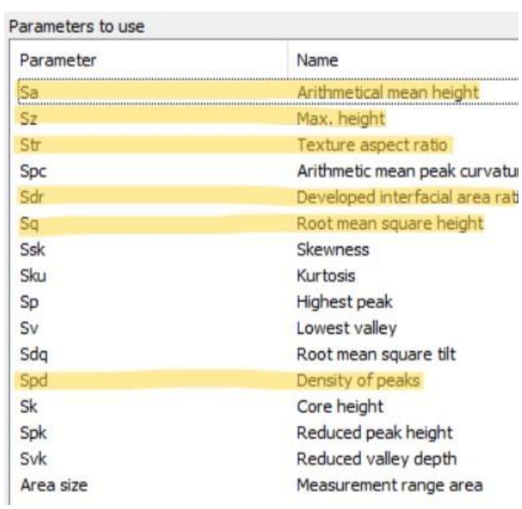
<u>Surface Roughness:</u>

There are several steps to conduct a surface roughness analysis:

1. Click on the R.O.I. to analyze.
2. Click on “Surface Roughness” from the main window (*fig.9*).
3. Once the Surface Roughness window pops out, start by clicking on “Add/Remove roughness parameters”. Add or remove the roughness parameters you desire to measure.
4. Once that is done, on the right-hand side of the window, click on “Add an area”. You can add up to 10 areas in one analysis. Your areas can cover the whole surface area or just a part of it. They do not have to be uniform, and they can overlap.
5. The calculated values will appear on the left-hand side of the screen. Click on “Show measurement results in another window” to see the entirety of the results.
6. You will obtain the overall min, max and averaged results as well as the results of each drawn area.

An example of how to conduct this analysis is given below.

For the case of a glass surface with a certain roughness, 5 R.O.I.s were taken. R.O.I. Center_1 was selected for surface roughness analysis. The selected roughness parameters are shown highlighted in *fig. 12*.


Parameters to use

Parameter	Name
Sa	Arithmetical mean height
Sz	Max. height
Str	Texture aspect ratio
Spc	Arithmetic mean peak curvatu
Sdr	Developed interfacial area rati
Sq	Root mean square height
Ssk	Skewness
Sku	Kurtosis
Sp	Highest peak
Sv	Lowest valley
Sdq	Root mean square tilt
Spd	Density of peaks
Sk	Core height
Spk	Reduced peak height
Svk	Reduced valley depth
Area size	Measurement range area

Figure 15: Selected (highlighted) roughness parameters for analysis.

Having done that, 9 areas of equal size were added one at a time and were spaced out evenly across R.O.I. Center_1 as seen in *fig. 13*. This was done by specifying the desired width and height of the area during the process described in Step 4. Similarly to “Volume & Area”, a new tab will appear on the main page, and it will show the analysis done on R.O.I.

along with the measured parameters, which can be directly copied or saved as a .csv file. However, unlike "Volume & Area", only R.O.I. Center_1 was analyzed.

To apply the same exact analysis to the rest of the R.O.I.s, on the main page, perform a ***batch analysis*** as follows:

- Click on "Analyze a batch of data at once"→Then select "Unify position alignment."
- *Figure 14* will pop up, showing the Center_1 as the source for the analysis and the rest of the R.O.I.s as the destination. Click "Ok".

Note: Any filtering or image alterations done to R.O.I. Center_1 can be applied at the same time to all other R.O.I.s if the user desires. *Figure 14* shows this process.

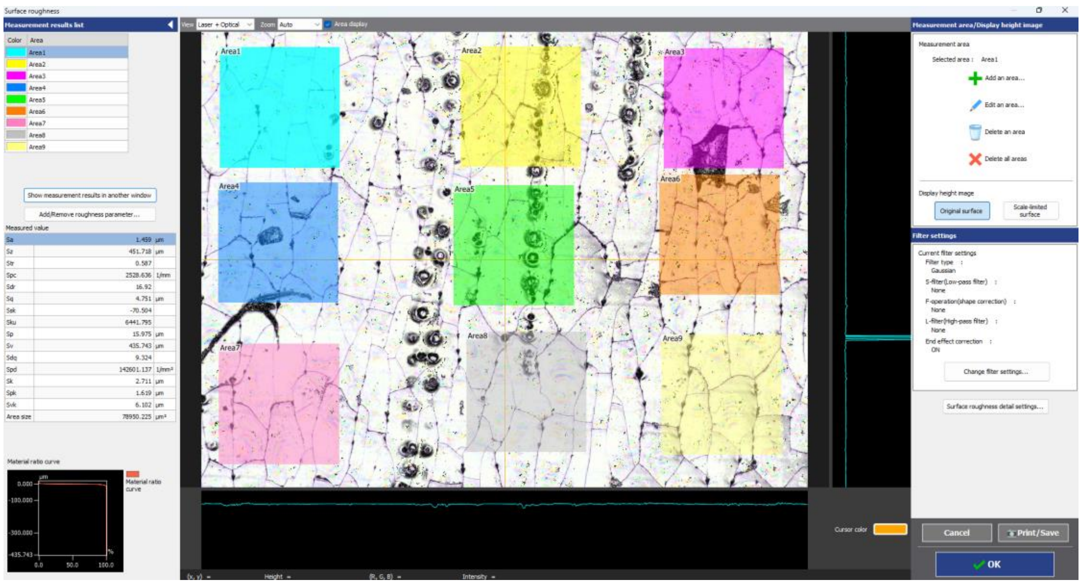


Figure 16: Surface roughness analysis window.

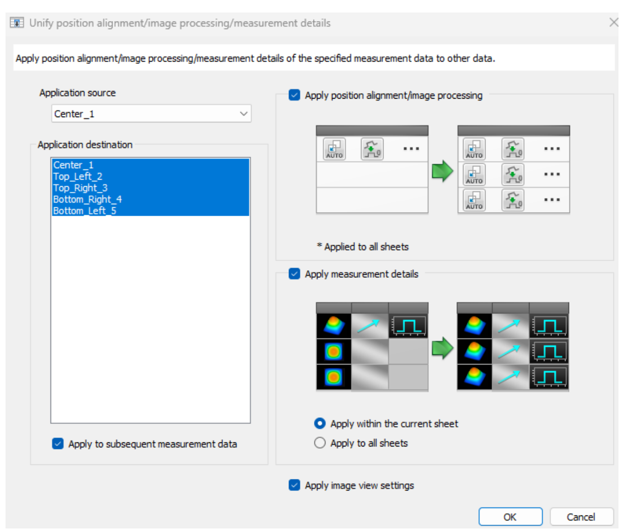


Figure 17: Batch Analysis window.

<u>Line or Multi-Line Roughness:</u>

The steps to conduct a line roughness are like those of the surface roughness:

1. Click on the R.O.I to analyze.
2. Click on "Line Roughness" from the main window (*fig.9*).
3. Once the Line Roughness window pops out, start by clicking on "Add/Remove roughness parameters". Add or remove the roughness parameters you desire to measure.
4. Once that is done, on the right-hand side of the window, click on the line adding tools. You can add up to 10 lines in one analysis. Your line can cover any length across the R.O.I. They do not have to be uniform, and they can overlap.
5. The lines can be made to be perfectly horizontal, vertical, diagonal, or parallel.
6. The calculated values will appear on the left-hand side of the screen. Click on "Show measurement results in another window" to see the entirety of the results.
7. You will obtain the overall min, max and averaged results as well as the results of each drawn line.

An example of how to conduct this analysis is given below.

For the case of a glass surface with a certain roughness, 5 R.O.I.s were taken. R.O.I. Center_1 was selected for surface roughness analysis. The selected roughness parameters are shown highlighted in *fig. 15*.

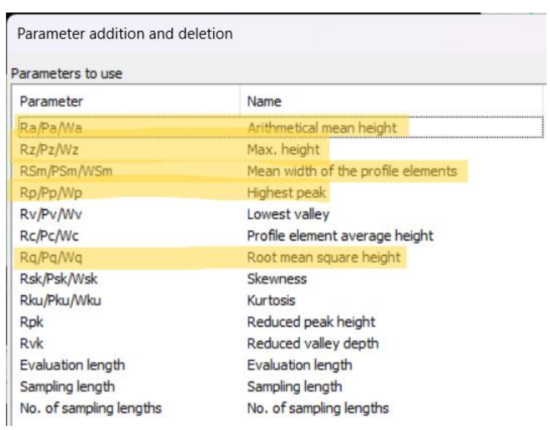


Figure 18: Selected (highlighted) roughness parameters for measurement.

Having done that, 10 lines, 5 vertical and 5 horizontals of equal length were added one at a time and were spaced out evenly across R.O.I. Center_1 as seen in *fig. 16*. This was done by specifying the desired length of the line during the process described in Step 4. Similarly to "Volume & Area", a new tab will appear on the main page, and it will show the analysis done on R.O.I. along with the measured parameters, which can be directly copied or saved as a .csv file. However, unlike "Volume & Area", only R.O.I. Center_1 was analyzed.

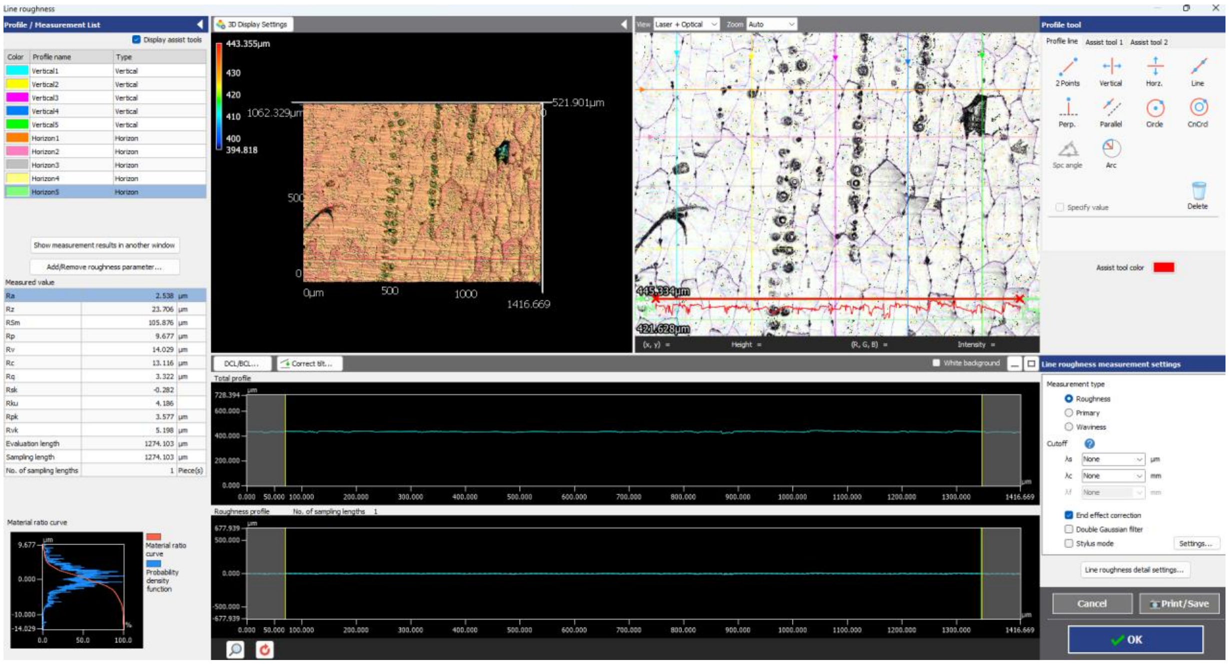


Figure 19: Line roughness analysis window.

To apply the same exact analysis to the rest of the R.O.I.s, on the main page, perform a ***batch analysis*** as described above.

Step 5: Post-Processing

Having completed your desired analysis and applied it to all your R.O.I.s, you can now save your analyzer file as a template. In doing so, you can apply the same exact analysis and filtering to a different set of data located on a different analyzer file. In short, you only need to do one complete analysis, and after that all you do is apply the exact processing template directly to your other sets that are awaiting processing.

Note: This usually only applies when the other data sets are taken at the same magnification. Otherwise, the drawn lines and area will appear shorter or larger than those in the originally processed analyzer file.

The methodology of post-processing is left to the user, but generally it is best to collect your results in excel or .mat files then average those results for each data set.

For example, for a set of glass surfaces with five R.O.I. (each), the results are exported to excel, then using a MATLAB code, the excel files are accessed and the results of the five R.O.I.s for each surface are averaged and then saved into a .mat file. The code can be made to automate the averaging of all the glass surfaces if the user employs a simple naming convention when saving the results.