Post-scan or thermal correction

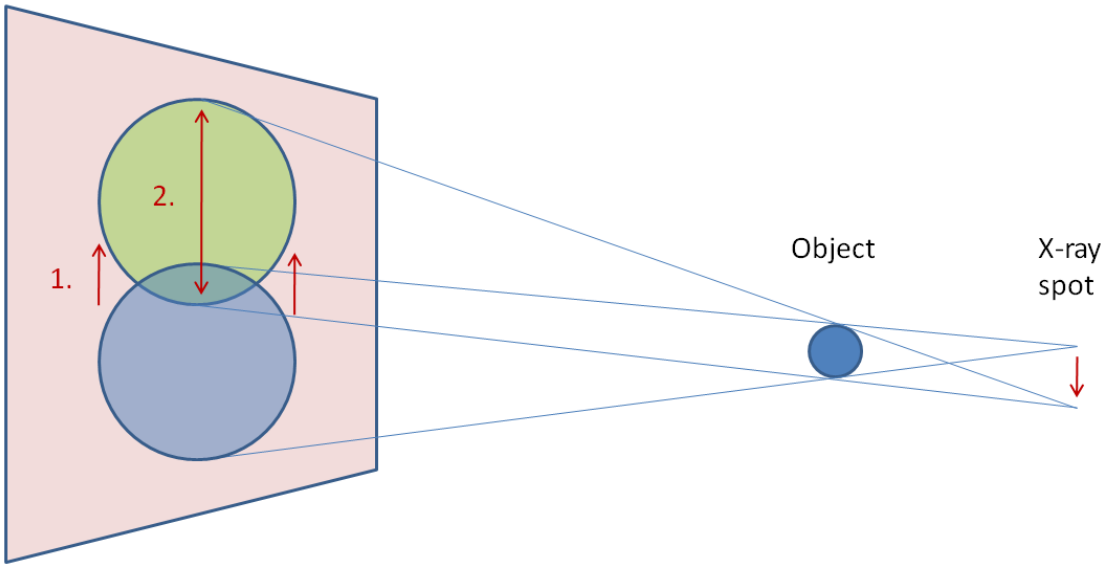
Method note

MCT-013

1. Introduction

1.1. The x-ray spot in a micro-focus source is subject to small thermal movements, while on and emitting x-rays; these can become significant with long scans of more than an hour duration.

1.2. These thermal spot movements can cause shifts in the projection image especially at the highest magnifications, when the x-ray spot and the scanned object are close together, and far from the camera (see image below)



1.3. The projection pixel shift correction method employs a short “post-scan” to measure these spot movement-related projection shifts, and to apply an appropriate correction to the projection images during reconstruction.
This method is applicable to slow, continuous movements or changes of geometry during a scan, and is thus particularly appropriate for correcting artefacts of thermal instability for instance of the x-ray source emission spot during long scans at high magnification.

However other kinds of movement can also be corrected, if they are slow and uni-directional.

2. Method: adding the reference post-scan

2.1 At the end of a scan in the SkyScan1172, SkyScan1272, SkyScan1173 and SkyScan2211 scanners[1], using current control software, post-scan images will automatically be acquired. These images are taken with a large rotation step (e.g. 10-45 degrees) that is calculated on the basis of the scan duration. These post-scan images are saved with the modified extension “iif”. An associated log file for the post-scan is saved in the scan directory with the modified extension “oog”. Do not delete or move these files.

2.2 In these scanners there is a preference menu option concerning the post-scan, including the option to turn it off if you prefer not to use it. You can opt to activate the post-scan for scans above a certain length such as 15-30 minutes.

For instance the 1172 preferences are shown to the right – they include the

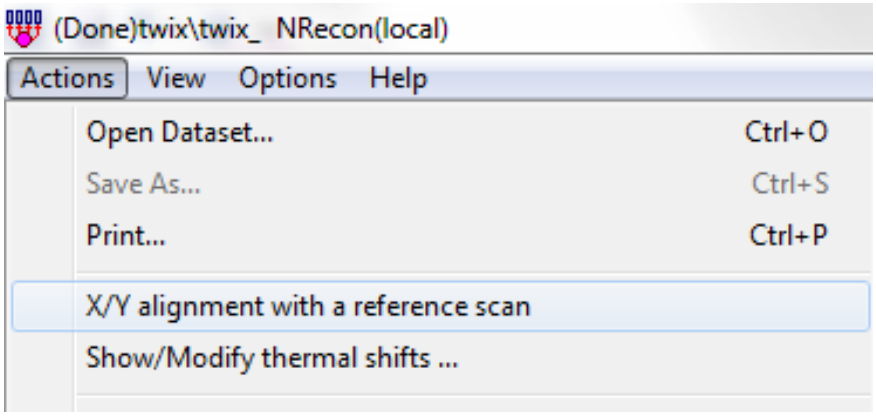
[1] Note that the post-scan correction is also a scan option in the SkyScan1176 *in-vivo* scanner under the advanced “more >>” scan options – here it serves to correct small slippage movement of a rodent limb.

option to “skip the reference post-scan”.

3. Reconstructing a scan with a post-scan movement correction

3.1. Use NRecon version 1.6.0.3 or higher

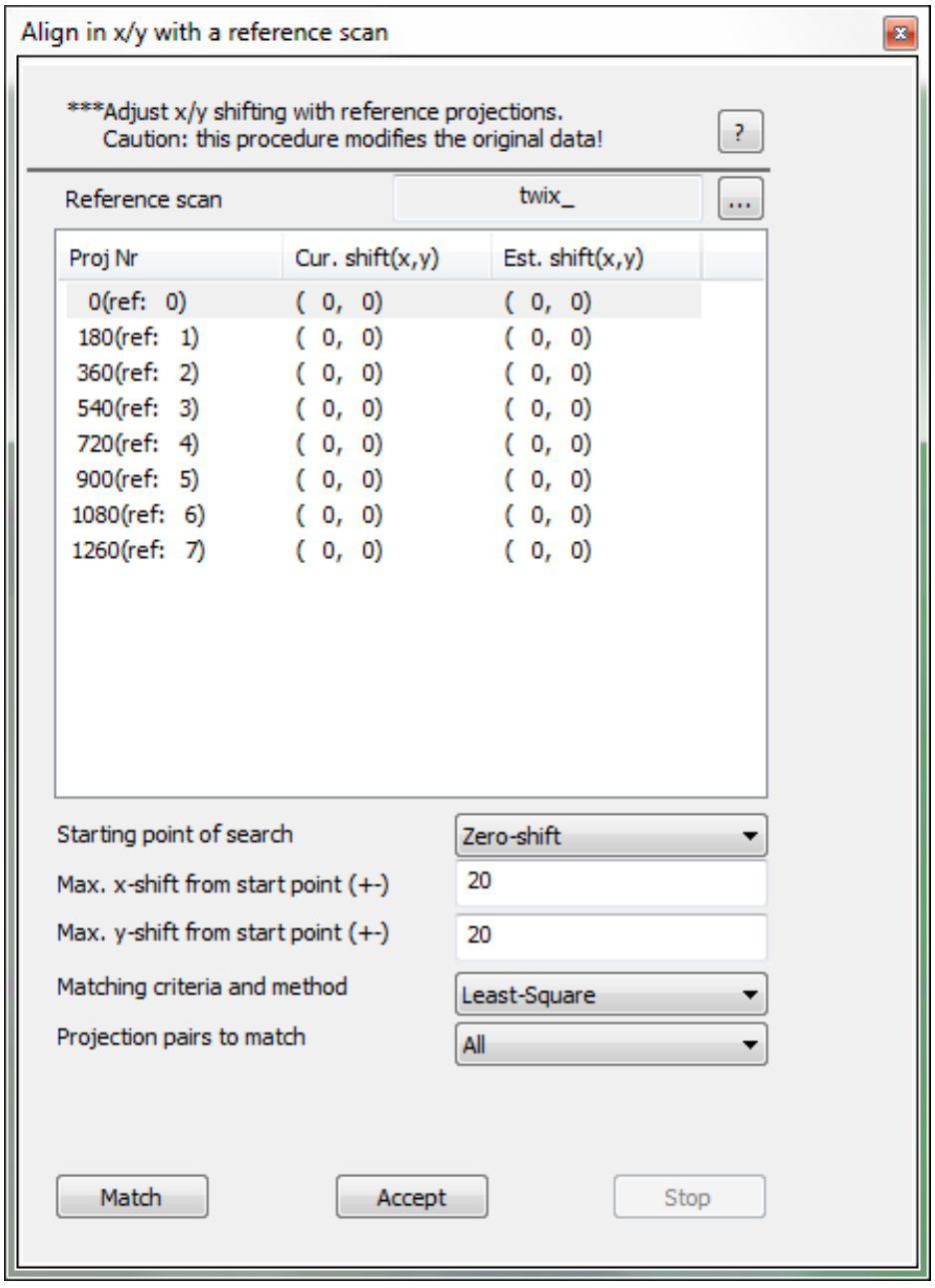
3.2. Open the projection dataset of the scan to be corrected – for instance “twix_”. Note that a delay will occur on opening the dataset as NRecon checks the projections for thermal shifts; this process is shown to the left of the status bar at the bottom of the program window.



Go to the “Actions” menu and choose the fourth option from the top, “X/Y alignment with a reference scan”. The window shown above will open.

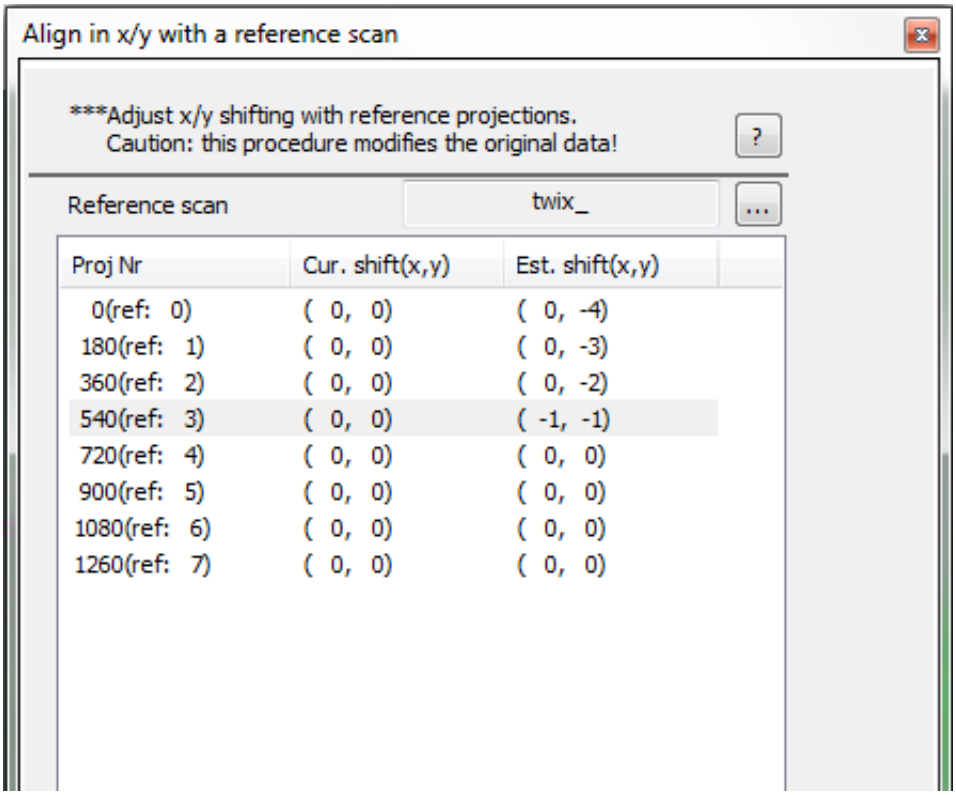
3.3. The filename of the post-scan should appear after “reference scan”. This will be displayed either if your scanner has generated automatically acquired post-scan images (“iif” extension), or if you have manually created post-scan images with the word “post” (or “post_”) at the end of the filename prefix. However if your post-scan images have been acquired with a different name, then select these images after clicking on the ... button to the right of “reference scan” item.

3.4. Below the line showing the name of the reference scan, two lines show the maximum horizontal and vertical shifts in pixels. By default this value will be 20. Increase this to a higher value if you believe that the calculated shifts are likely to be larger than this – otherwise leave the values unchanged.

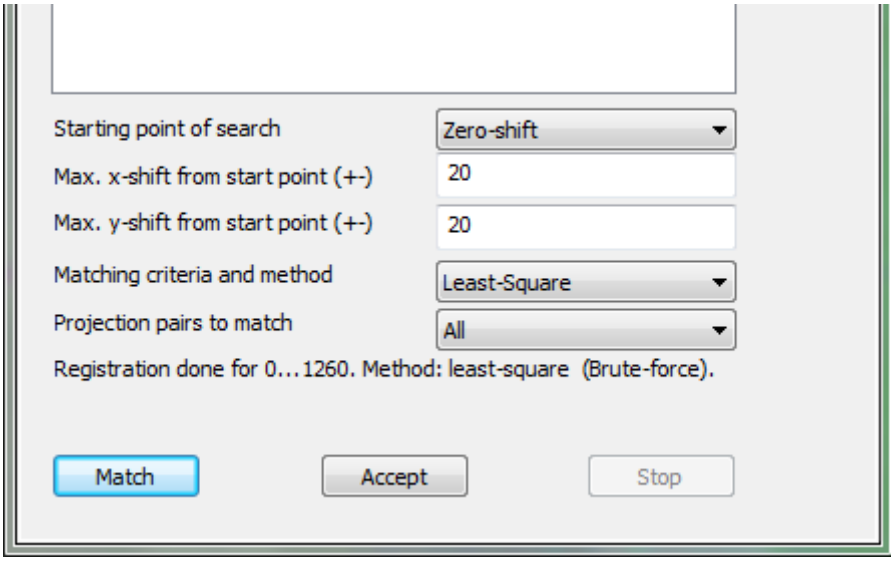


3.5. To start automatic calculation of image pixel shifts by image registration, click on “Match”. Note that “Projection pairs to match” is by default set to “All”.

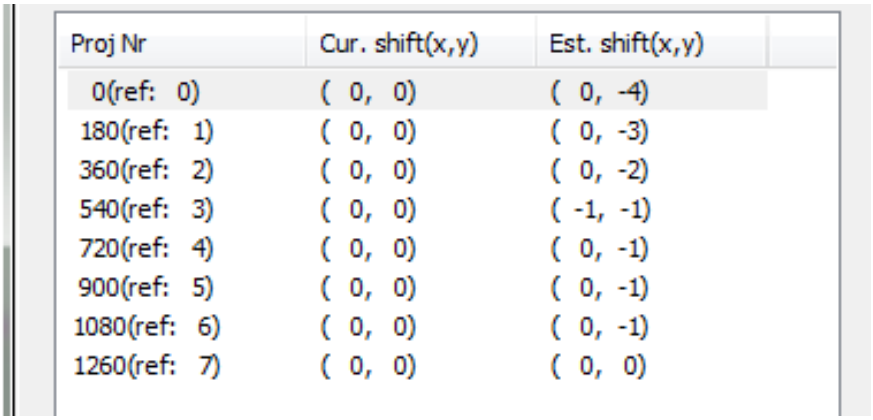
3.6. After clicking on “Match” NRecon will proceed to calculate the XY shifts between the reference images and corresponding main scan images, one at a time from the top down. During this process, a line of text below the table will show which projection number is currently being calculated and the percent progress of this calculation (see image below). The line most recently calculated is highlighted in grey.



3.7. When the matching calculations are complete, the line of progress text will disappear and the “accept” button, up to now greyed out, will become active – see the second image below.



3.8. Inspect the calculated values. If correctly calculated they are likely to show fluent trends in a positive or negative direction, sometimes oscillating both ways but in a gradual wavelike manner (see the values below for example). The X and Y shift values should tend toward zero towards the end. If the values look OK, then click on the “accept” button.



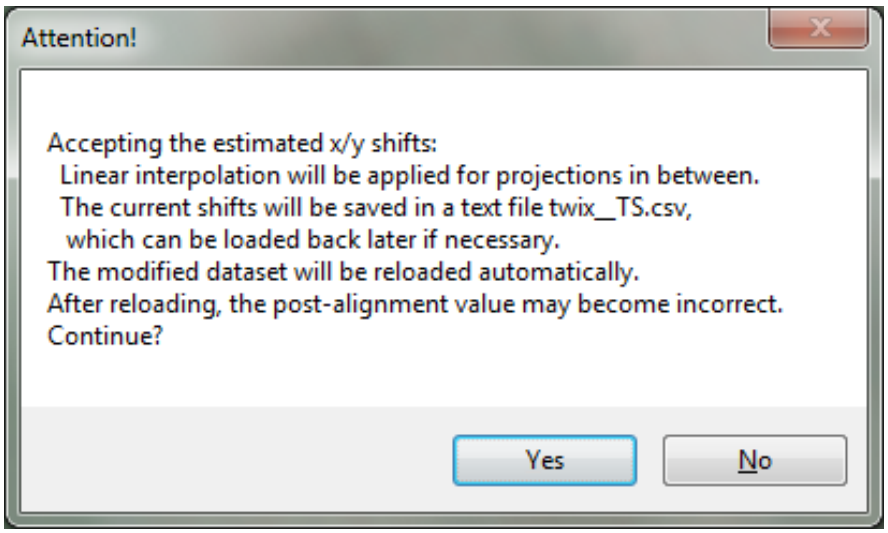
Proj Nr	Cur. shift(x,y)	Est. shift(x,y)
0(ref: 0)	(0, 0)	(0, -4)
180(ref: 1)	(0, 0)	(0, -3)
360(ref: 2)	(0, 0)	(0, -2)
540(ref: 3)	(0, 0)	(-1, -1)
720(ref: 4)	(0, 0)	(0, -1)
900(ref: 5)	(0, 0)	(0, -1)
1080(ref: 6)	(0, 0)	(0, -1)
1260(ref: 7)	(0, 0)	(0, 0)

3.9. However if any values are unusually large and out of sequence, then it is likely that the registration matching has failed for this image pair. In this case, select and highlight the incorrect line. You can then manually adjust the XY shift to a correct value – how to do this is described next.

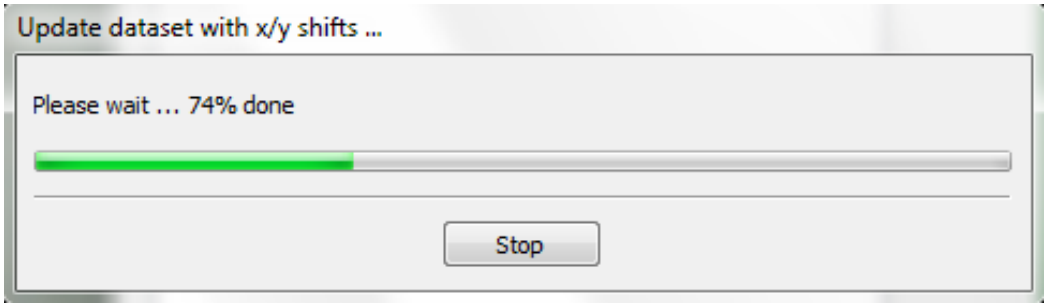
3.10. **Manual adjustment of the XY shift.**

Select (highlight) the projection line you wish to adjust. Hold down the CTRL and SHIFT buttons and hit the up or down keyboard arrows. Doing this toggles between three alternative projection image views, the reference image, the corresponding scan image, and a colour-highlighted merged image from the scan and reference images. Quickly toggling between the reference and scan images shows any mismatch as a movement between the images. Then with the SHIFT button held down (and not CTRL), hitting the left-right arrow buttons changes the X shift and hitting the up-down arrows changes the Y shift. Change the Y and X shifts until toggling between the two images results in zero or negligible movement of the images relative to each other.

3.11. After clicking on “accept”, the following “attention” message will appear. Click **yes** – this will start the updating of the thermal tags of all the projection images and the reload of the dataset.

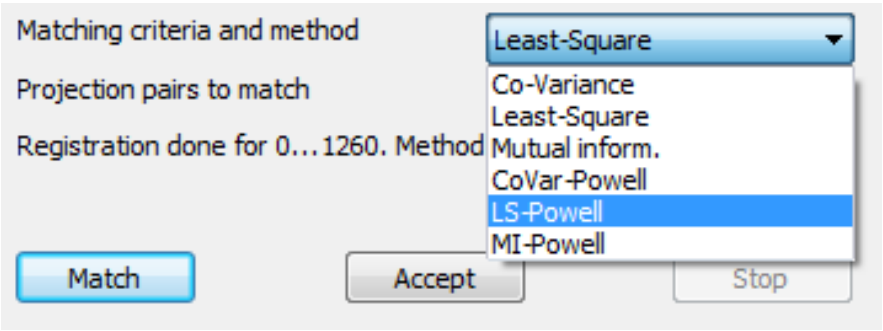


A progress bar will indicate the thermal tag updating process:

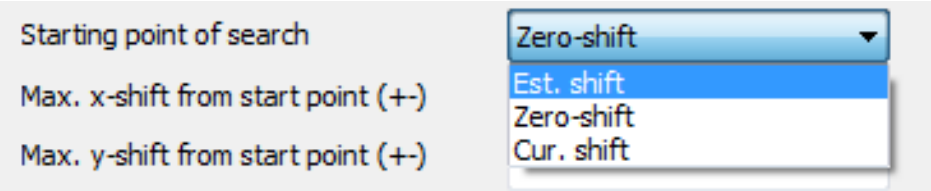


3.12. Algorithms of co-registration. There are three algorithms of coregistration selectable, covariance, least-squares and mutual information. By default, least squares is set. In nearly all cases this is the best so it is not recommended to change it.

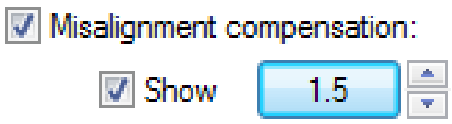
You will see three ”-Powell” versions of these three algorithms. This is a faster way to run co-registration. If your dataset image format is large, or if pixel shifts are large, you can speed up the process by selecting “LS-Powell”.



3.13. Fine-tuning. Note that the first setting beneath the table, “Starting point of search”, is set by default to “Zero-shift”. After running with this, you can optionally change to “Est. shift” (estimated) where the starting point will be the already calculated value. The “Max x and y shifts from start” will be smaller. For this fine-tuning you can use a different algorithm – for instance do the first run from “zero-shift” using the faster LS-Powell, then fine tune from “Est. shift” using the standard “Least squares”.



3.14. When the post-scan corrected projection dataset is reloaded, please check that the post-alignment value is correct:



3.15. Now proceed to do the reconstruction, which will now be corrected.

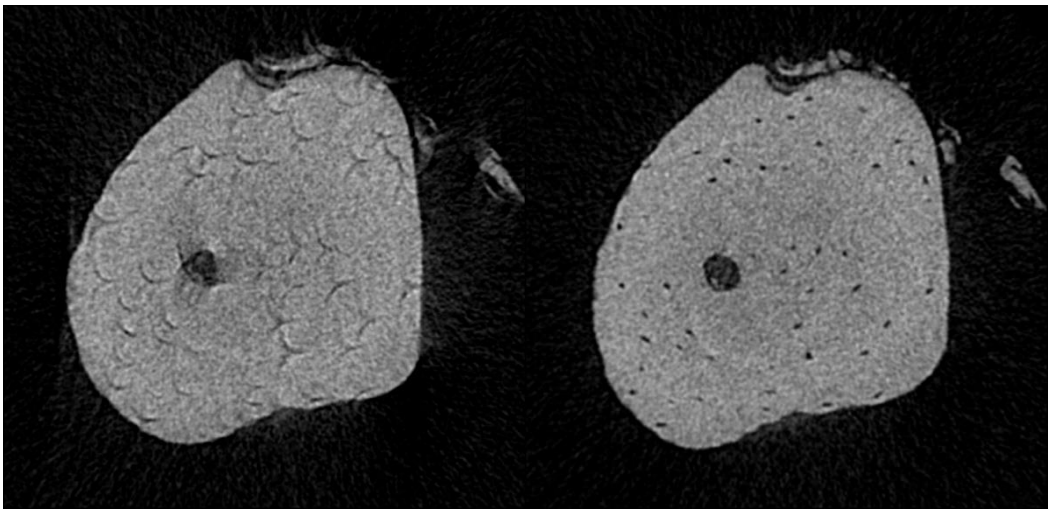
3.16. Please note: sometimes the calculated X/Y shift values may not be correct. If the result of the post-scan suggests that further adjustment is needed, you should set the correct XY values manually as described in section 3.10 above.

References

Salmon PL, Liu X, Sasov A, A post-scan method for correcting artefacts of slow geometry changes during micro-tomographic scans. J. X-ray Science Technol. 17(2): 161-174, 2009.

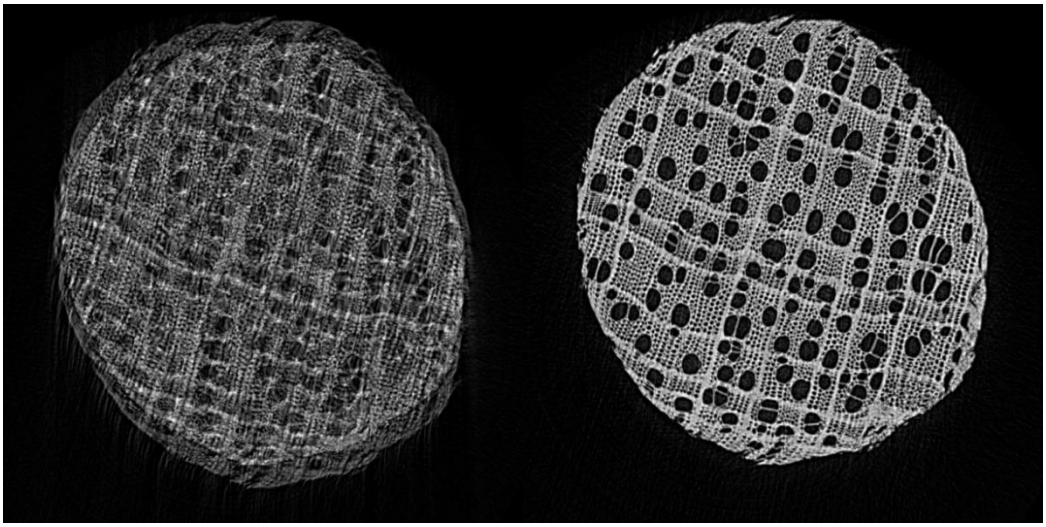
Sasov A, Liu X, Salmon PL, Compensation of mechanical inaccuracies in micro-CT and nano-CT. Proc. SPIE 7078, Developments in X-Ray Tomography VI, 70781C (September 17, 2008); doi:10.1117/12.793212; http://dx.doi.org/10.1117/12.793212

4. Examples of image results of thermal correction



Uncorrected Corrected

The scan of mouse fibula in the 2011 nano-CT, voxel size 400 nm, showing movement artefacts and the effects of applying the correction. The scan was over 180 degrees, so movement in the uncorrected image manifests as “tails” for instance around the holes in the bone (osteocyte lacunae).



Uncorrected Corrected

The scan of a toothpick in the SkyScan 1172, voxel size 0.5 um, showing movement artefacts and the effects of applying the correction. The scan was over 360 degrees so the movement artefacts, from source spot thermal movement, manifest as image doubling.

Appendix 1: doing the post-scan manually

If you wish to perform a post-scan with your own selected rotation step (or if you are using a version of your scanner control software that does not automatically do the post-scan and generate the “iif” or “oog” files) then follow the steps below. Otherwise, go straight to section 2.

(a) Start the scan of your object, for example with the filename prefix “object_highres_”. Make sure that the options to “turn off x-rays after scan” and also “open scanner after scan” are NOT selected – the x-ray source must stay on after the scan.

(b) Be present at the scanner at the time the scan ends. There must be a maximum delay of less than a minute or so from the end of the high-resolution scan and the start of the post-scan.

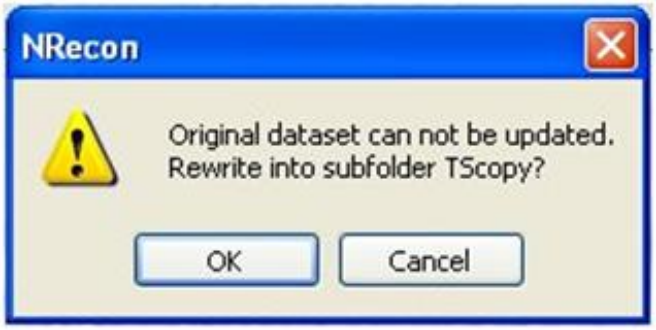
(c) Immediately after the scan ends (with the source still on), click again on the scan button. Go to the box for scan filename prefix which will still show the previous scan prefix; edit this by adding the word “post_” after the prefix. In the present example the new filename prefix will be: “object_highres_post_”. Don’t change the scan directory – the images should be written into the same place (but take care to rename them by adding “post_” so that the main scan images are not deleted!).

(d) Change the rotation step to a selected value such as 20 or 30 degrees. Leave all other parameters such as frame averaging the same. (In the case of very high frame averaging you can reduce it to make the post-scan faster.) **Please note**: it is recommended (but not mandatory) that the rotation step of the main scan is an integer multiple of the rotation step of the post-scan. It is preferable that projection images are present in the main scan dataset with the same rotation step as images in the post-scan. This is not possible for instance if your main scan step is 0.4 degrees and the post-scan step is 45 degrees; but a step of 0.3 degrees in the main scan would be compatible with either 30 or 45 degrees post-scan step. If the projection image with identical rotation to the post-scan image cannot be found, then the image with the nearest rotation angle will be used.

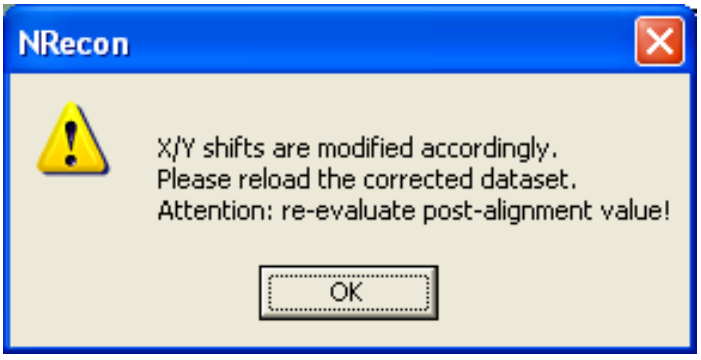
(e) With the post-scan complete the x-ray source can be turned off. Note that both the main scan and the post-scan will have the “iif” projection and “oog” log file created with them (if you have a recent version of the control software).
Please note: a “post-scan” can be a pre-scan. If you need to add a post-scan manually (e.g. appropriate software is not available) but cannot be present at the scanner at the end of the scan, then take the “post-scan” at the beginning rather than at the end of the scan. Make sure the x-ray source is reasonably stabilised before doing the pre-scan, and don’t turn off the x-rays between pre-scan and scan. In general however a post-scan is better since the x-ray source will be more stable.

Appendix 2: Rewriting the projection dataset if your projection image format does not support the “thermal tag”.

Please note: if the projection images from your scanner do not have the appropriate format to support thermal correction, a dialog will appear asking you to make a duplicate copy of the projections. Make the copy as requested. It will appear in a subdirectory “TScopy”. The duplication may take some time especially with 4k resolution scans – also check that disc space is sufficient. Then reconstruct from this copy (you can delete the original projections to save disc space). If this happens, you can download from the SkyScan website a more recent version of your scanner control software (e.g. 1172, 2011) which will write thermal tags in the projection and make this re-writing step unnecessary.



However if the correction is supported by the image format, the images will be updated and the following dialog will appear:



Click on OK, then reload the dataset. Note that a new post-alignment value will be calculated usually different from the previous value.