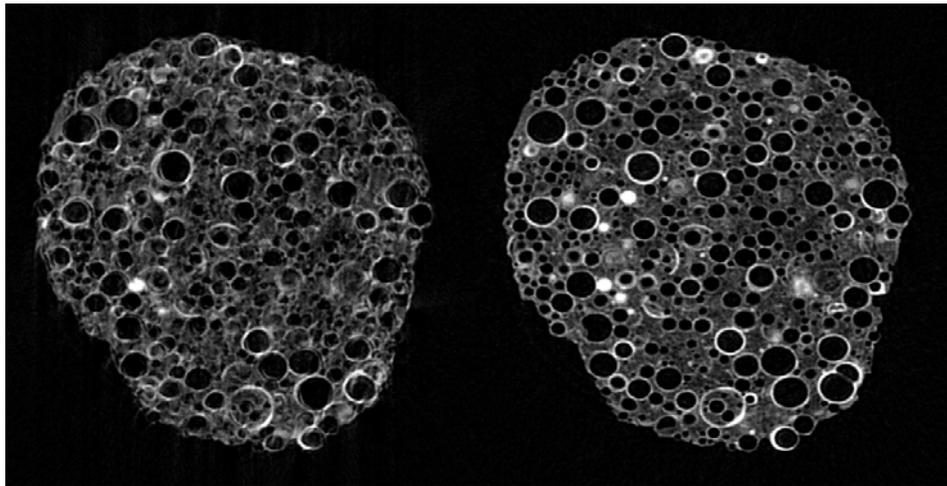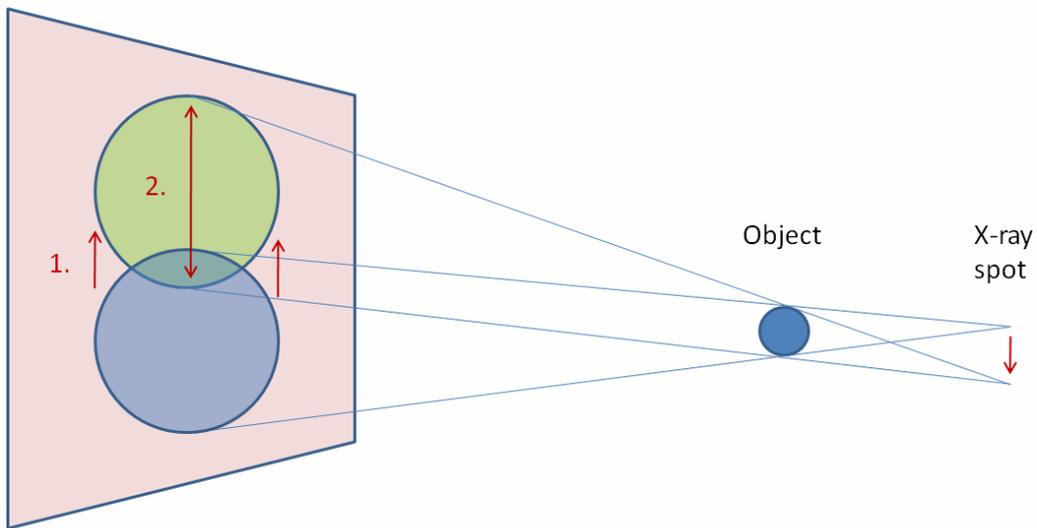# Projection pixel shift correction for high resolution micro/nano-CT scans

Method note

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 shift 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.

2.   Method: adding the reference post-scan

2.1   At the end of a scan in the SkyScan 1172 (control program starting from ver. 1.5.8) and SkyScan 2011 (control program starting from ver.2.6.5) scanners, post-scan images will automatically be acquired (for 2011 - checkbox in the Scanning Options). These images are taken with a rotation step 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.

However if you wish to perform a post-scan with your own selected rotation step (or if you are using a version of the control software that does not generate the "iif" or "oog" files) then follow

the steps 2.2. Otherwise, go straight to section 3.

2.2. **Making a manual post-scan.**
To take a manual post-scan at the end of your scan with your own selected rotation step, follow these steps:

(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-res. 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 a 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 may have the "iif" projections and "oog" log file created with them (if you have a recent version of the control software).

2.3. Please note: a "post-scan" can be a pre-scan. If you need to add a post-scan manually (e.g. appropriate software 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.

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

3.1.   Use NRecon version 1.6 or higher

3.2.   Open the dataset of the corrected scan – for instance object_highres_" (see section 1). Note that a delay will occur on opening the dataset as the program checks the projections for thermal shifts – this process is shown to the left of the status bar at the bottom of the program window.
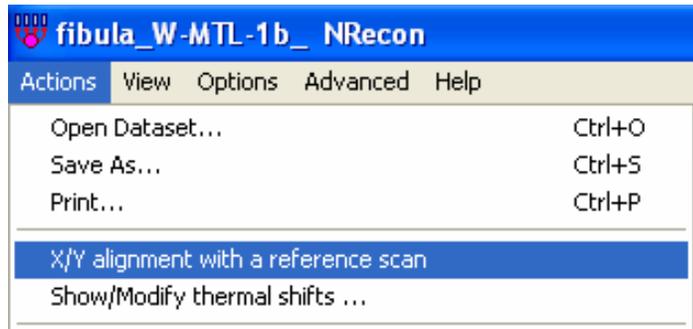
Go to the "Actions" menu and choose the fourth option from the top, "X/Y alignment with a reference scan". The window shown below will open.
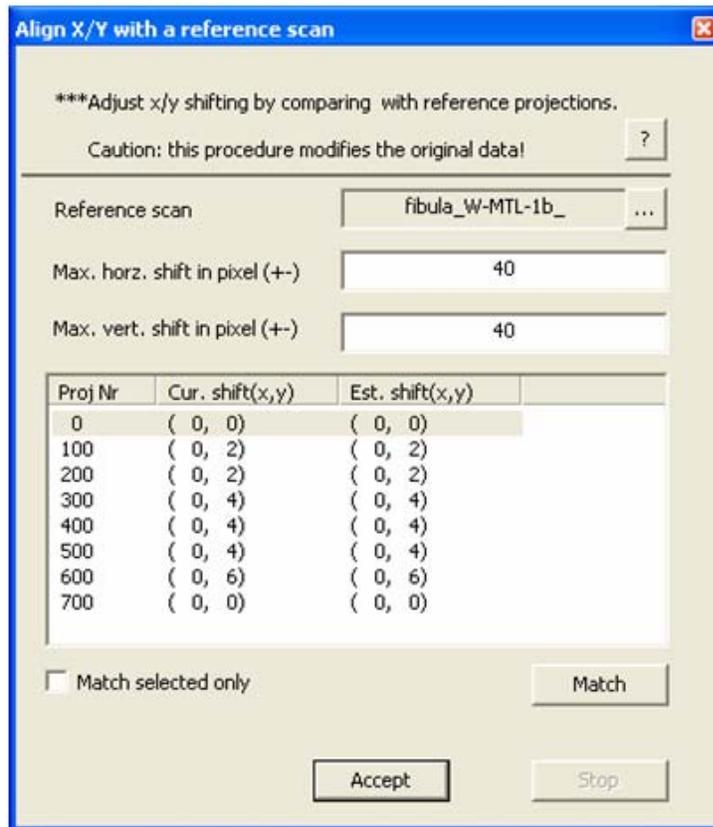
3.3. The filename of the post-scan should appear after "reference scan". This will be displayed either if your scanner has generated automatically acquired post-scan images ("iif" extension), or if you have manually created post-scan images with the string "post" (or "post_" at the end of the filename prefix. However you 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. Please note that in the SkyScan 2011 scanner, the "current shift (x, y)" images may initially have non-zero y values. These will not affect the calculation of the thermal correction based on the reference post-scan images.

3.6. To start automatic calculation of image pixel shifts by image registration, click on "match". Note that a tick box gives you the option of testing a alignment of a single post-scan reference image only and its corresponding main scan image. With the "match selected only" box unchecked, all image pairs will be matched, by least-squares rigid XY registration.


3.7. After clicking on "match" (with "match selected only" unchecked) 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.
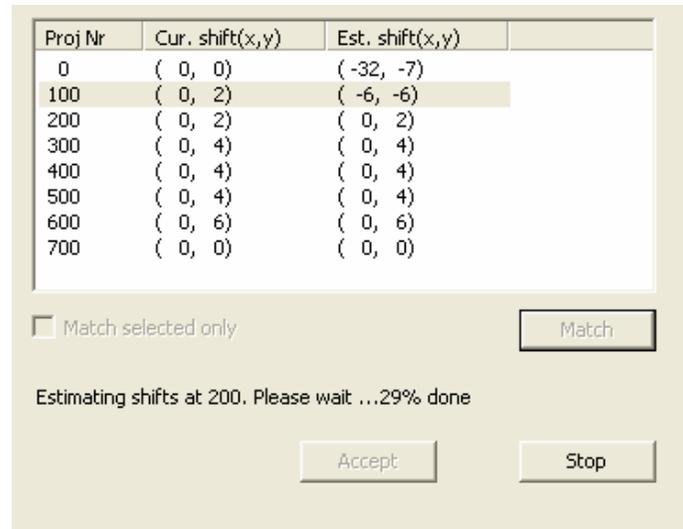
3.8. When the matching calculations are complete, the line of progress text will disappear and the "accept" button, up to now greyed out, will become active – see image below. (Note that occasionally at the very last projection line, an error message will appear concerning a missing reference image – this can be disregarded as it will not significantly affect the correction.)
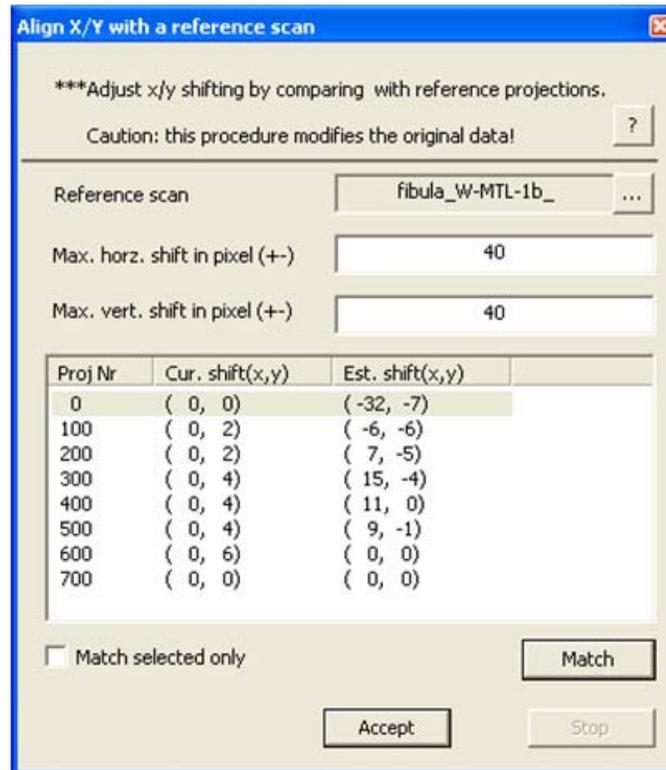
3.9. Inspect the calculated values. If correctly calculated they are likely to show fluent trends in a positive or negative direction, sometimes oscillating both ways but in a gradual wavelike manner

(see the values above 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.

3.10. However if any values are unusually large and equal to the maximum accepted shift or marked by following star (*), 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.

3.11. **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.

3.12. After clicking on "accept", the following "attention" message will appear. Read the message and respond accordingly. Clicking yes will start the updating of the thermal tags of all the projection images.
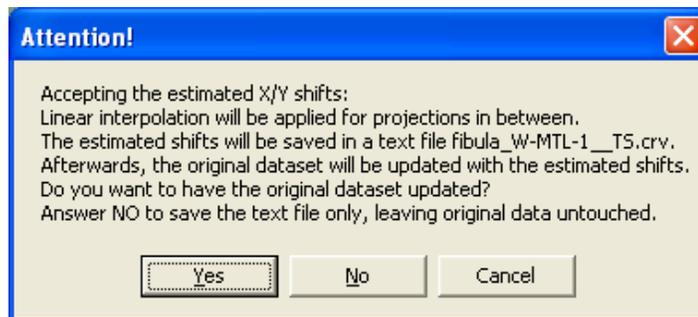
A progress bar will indicate the thermal tag updating process:
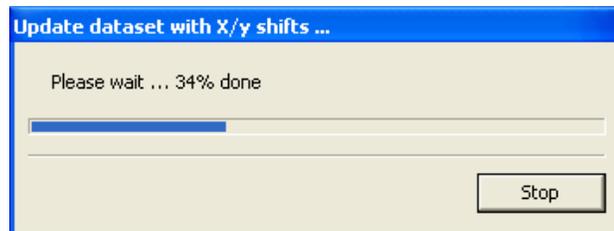
3.13. Please note: if the projection images from your scanner do not have the appropriate format to support thermal correction, a dialog will appear asking you to make a duplicate copy of the projections. Make the copy as requested. It will appear in a subdirectory "TScopy". The duplication may take some time especially with 4k or larger 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.


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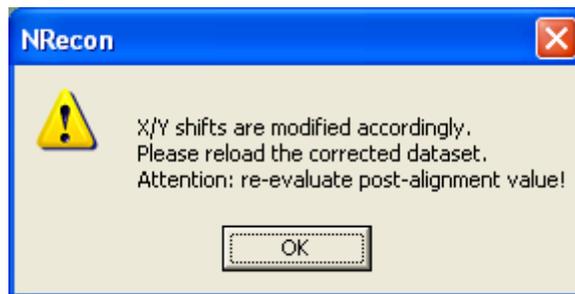

3.15. Click on OK, then reload the dataset. Note that a new post-alignment value will be calculated usually different from the previous value.

3.16. Go to the settings tab, and click on the post-alignment value. Check that the displayed value is the same as the default ("def") value. If not, then click on the "use default value" tick-box to apply the default value, which is the new calculated value. (If the displayed value is different from the default value, then it is probably the previous uncorrected value.)
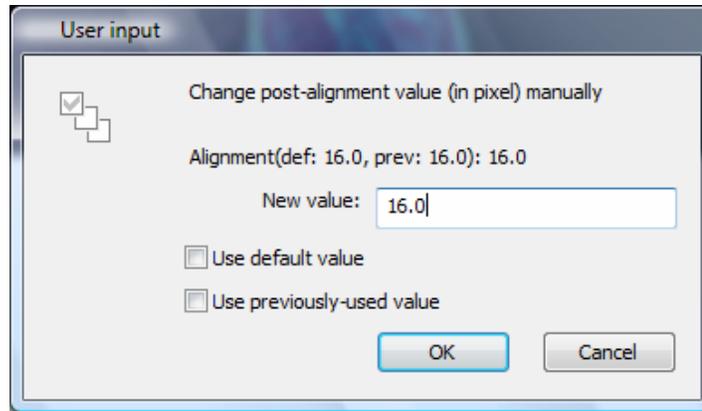
3.17. Now proceed to do the reconstruction, which will now be corrected.

3.18. Please note: sometimes the calculated X/Y shift values may not be correct. This may occur for example where a long thin object is scanned which is vertically uniform, having few prominent image features in the vertical axis. Here registration measurement of Y shift becomes difficult. In such cases, you should set the correct XY values manually as described in part 2.13.

Examples of image results of thermal correction
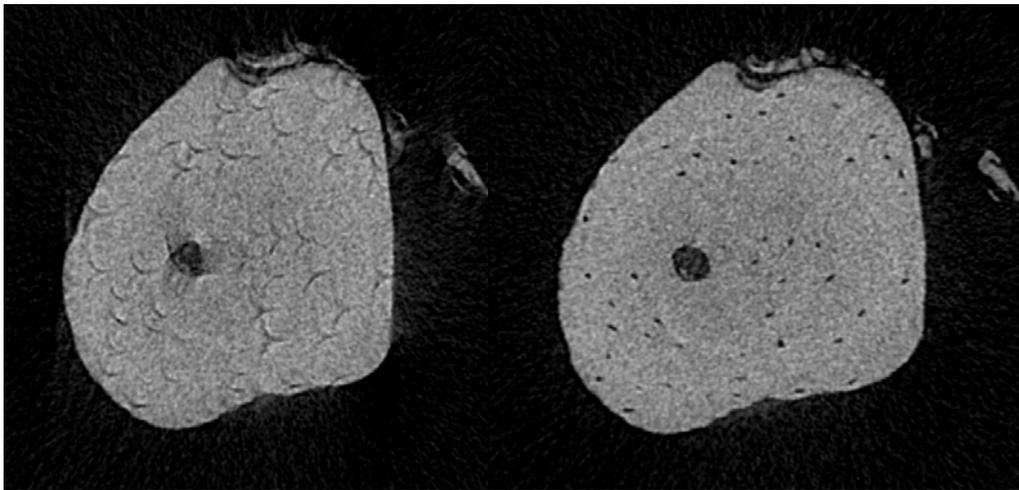
Uncorrected   *Corrected*

The scan of mouse fibula in the SkyScan-2011 nano-CT, voxel size 400 nm, showing movement artefacts and the effects of applying the correction. Note that movement related misalignment resulted not only in distortion of parts of the image such as the canals within the bone, but also a distortion (left-right compression) of the whole shape of the reconstructed image. 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).
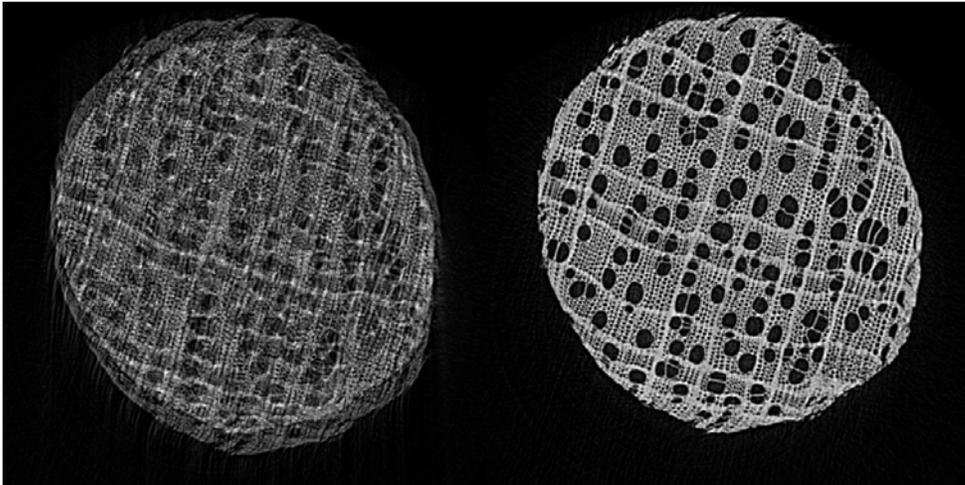
Uncorrected   *Corrected*

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.