Welcome to Bruker micro-CT Academy!

Welcome to the first issue of the Bruker micro-CT Academy newsletter. Our goal is to keep users informed and involved in our micro-CT technologies and applications on a monthly basis. In every issue, we will discuss a topic about SkyScan systems and their extended applications; meanwhile, we will also update you on new available application software and our participation in conferences and exhibitions. Subscribe at http://partners.bruker-microct.com/subscribe and get Bruker micro-CT Academy every month!

Visualization of Local Thickness in 3D

This month’s technical focus is on visualization of thickness measurement in SkyScan analysis software by the color-coding of thickness. Thickness measurement in 3D reveals one of the biggest advantages of analyzing objects in 3D, that is, the making of true 3D measurement independent of the orientation of the object. The 3D thickness measurement method is referred to as “sphere-fitting” – thickness is defined locally as the diameter of the largest enclosed sphere.

A method note, “MN025_Color_coded_3D_size_distribution CTVox” shows how to perform the two necessary steps:

1) binarize the scanned object in CTAn, perform 3D analysis and create a thickness color-coded dataset, and
2) load and view this 3D thickness map in CTVox, using the powerful transfer function editor for fast and flexible creation of vivid and revealing color and texture to best visualize thickness in 3D.
SkyScan1172 Advanced Setup and Customization

The SkyScan1172 high-resolution desktop micro-CT scanner is becoming a benchmark world-wide in an ever-expanding range of applications. This popularity comes from the combination of high resolution with flexibility to image a broad range of sample sizes and densities with fast scans that can be done in automated batches.

In order to take advantage of the full possibilities with this scanner, a thorough working knowledge of the instrument is needed including some advanced functions such as setting up nonstandard external filters, adjusting voltage, batch and oversize scans, as well as essentials such as flat field corrections and the alignment test. All of these are covered in a comprehensive instruction document entitled "MN029 Method Notes 1172" which is a supplement to the manual of this scanner.

Bruker micro-CT News

An important update of CTVox is released: CTVox version 2.7. A major new feature is the ability to magnify or "stretch" the transfer function window, making it much easier to finely control the color channel curves at any narrow range. This is necessary with color coded thickness images where the number of used grey levels may be very limited. Also new in CTVox 2.7 is adding a color bar legend to an image to link values to colors, and adding of a customizable annotation to a displayed image. Other recent enhancements to CTVox include handling of DICOM, RAW and ISQ formats and export of data to mobile volume rendering apps created by Bruker microCT and freely available on the AppStore and GooglePlay (search for CTVox).

Image of the Month

3D reconstruction of the internal structure of a rose flower scanned in SkyScan1172. Volume rendering with virtually removed front top part using CTVox program.

Upcoming Events

Bruker microCT will participate with an exhibit in the forthcoming conferences. Please click the link below for more information. We hope to see you there!

- AACR April 6-9, San Diego, USA
- ATS May 16-21, San Diego, USA
- ECTS May 17-20, Prague, Czech Rep.
- INTERPORE May 27-30, Milwaukee, USA
- ESMI conference June 4-6, Antwerp, Belgium
- TERMIS EU June 10-13, Genova, Italy
- BRS June 25-26, Sheffield, UK
- 3D Materials Science June 29-July 2, Annecy, France
In this issue:
- Welcome to Bruker micro-CT Academy
- Application note: How to make and open surface rendered 3D models
- Application note: Drift compensation
- Introduction of SkyScan2211 Multiscale High-Resolution X-Ray Nanotomograph
- Image of the month
- Upcoming events

Welcome to Bruker micro-CT Academy!

We would like to thank all our readers for the positive feedback we received on our first Bruker micro-CT Academy newsletter. In the second issue we delve deeper into micro-CT technology, this time exploring the generation of surface rendered models using CTAn and we demonstrate how to compensate for the drift of the emission point inside an X-ray source. Also in this issue we are proud to present the SkyScan2211 Multiscale High-Resolution X-Ray Nanotomograph.

To receive your monthly copy of the Bruker micro-CT Academy newsletter subscribe at [http://partners.bruker-microct.com/subscribe](http://partners.bruker-microct.com/subscribe). After registration you will also be able to download the method notes of previous issues.

How to Make and Open Surface Rendered 3D models

Surface rendered models are the basis for numerous software technologies, including visualization, CAD, rapid prototyping (3D printing) and modeling software. CTAn offers possibilities for the creation of models in terms of meshing algorithms and output format. CTVol allows for realistic 3D visualization of such models, including the generation of movies.

In the method note "MN017_Basic 3D surface rendering" the essentials of model generation using CTAn are described. By use of the custom processing and batch manager functions this can be done in an efficient manner.

Drift Compensation

Micro-CT and especially nano-CT scanning require very high stability to reach optimum resolution. Drifting of the emission point inside an X-ray source can contribute to geometrical inaccuracies, effectively reducing the achievable spatial resolution. Aligning projection images with a short post-scan can significantly increase image quality.

NRecon allows for linear distortions to be partially compensated by rigid X/Y shifting of projection images in this manner. In the method note "MN013_Thermal_correction" we show how to perform this operation in detail.

Surface rendered 3D model of a hydroxyapatite scaffold showing high dense particles distributed inside the matrix.

Cross-section through a toothpick showing movement artifacts (left) and the corrected image (right).
Introduction of SkyScan2211 – Multiscale High-Resolution X-Ray Nanotomograph

Bruker microCT introduces the new multiscale X-ray nanotomograph SkyScan2211, a new high-resolution X-ray nano-CT system with the widest available range of object sizes and spatial resolutions in one single instrument. It opens unique possibilities for 3D imaging and exact modeling of geological materials in oil and gas exploration, composite materials, fuel cells, electronic assemblies, etc. The system contains an X-ray source with submicron spot size and two X-ray detectors: flat-panel for large objects and 11 Mp cooled CCD for scanning at the highest resolution. Up to 8000x8000x2300 pixels can be reconstructed after a single scan. The smallest detectable detail (smallest pixel size) is 100nm.

Upcoming Events

Bruker microCT will participate with an exhibit in the forthcoming conferences. You are more than welcome to stop by at our booth to discuss the latest developments with the application scientists. We hope to see you there!

- **ATS** May 16-21, San Diego, USA
- **ECTS** May 17-20, Prague, Czech Rep.
- **INTERPORE** May 27-30, Milwaukee, USA
- **ESMI conference** June 04-06, Antwerp, Belgium
- **TERMIS EU** June 10-13, Genova, Italy
- **BRS** June 25-26, Sheffield, UK
- **3D Materials Science** June 29-July 2, Annecy, France
- **EORS** July 02-04, Nantes, France
Welcome

This third issue will focus on the scanner settings and the analysis of a live mouse lung. We will discuss the different synchronization strategies and how this can overcome movement artifacts. In the method note we explain in detail how custom processing can be applied to successfully analyze the lung volumes at different stages of the breathing cycle.

We organize on a regular basis 5-day User Training courses at Bruker microCT headquarter, Kontich, Belgium. We invite you to check the course program at: http://www.bruker-microct.com/company/training.htm

Gated Lung Imaging and Analysis

Keeping the object stable during the scan is one of the crucial requirements to obtain images without movement artifacts. However, when scanning the chest area of live animals this is of course not possible. In order to compensate for movement artifacts using synchronization strategies, care must be taken to optimize the anesthesia, resulting in a continuous breathing pattern throughout the scan.

Synchronizing image acquisition with breathing movement can be done in two ways: pro-spective and retro-spective synchronization. Both types of synchronization are possible with the SkyScan in vivo scanners. When aiming for the optimal image quality, a pro-spective synchronized scan, combined with intubating the animals and ventilating them using a small animal ventilator will result in optimal stability of the chest during image acquisition. Although this will result in the best image quality, it is also an invasive and time consuming procedure.

As an alternative, retro-spective synchronization can be applied. This synchronization strategy acquires multiple projection images at every rotation step. In addition, a time stamp of both the breathing pattern and the image acquisition is logged, allowing a post-scan sorting of the images into a number of bins in which the breathing cycle is divided. The advantage of the retro-spective synchronization is that it compensates for irregular breathing patterns throughout the scan. The output is a 4-dimensional dataset: 3D at multiple phases of the breathing pattern, allowing functional analysis of lung parameters such as tidal volume, and functional residual capacity. The method note "MN005_Lung analysis in vivo after synchronized scanning" describes in detail the scanning parameters, the sorting of the data into the different phases of the breathing cycle and a step by step analysis of the datasets resulting in the quantitative result of the air volume in the lungs at different phases of the breathing cycle.

Cross-section through the mouse thorax of a mouse scanned without (left) and with (right) pro-spective synchronization using a SkyScan1076, pixel size 35µm.
**Bruker micro-CT News**

Last week we held our annual microCT User Meeting in Ostend, Belgium. With over 90 users participating from 23 different countries, and more than 60 scientific contributions, this event turned out to be a great success. We sincerely thank all the authors for submitting their scientific abstracts! The beautiful location in the historical royal Thermae Palace at the Belgian coast combined with the nice weather allowed for the perfect networking opportunity! All abstracts can be freely downloaded from our website at: [http://www.bruker-microct.com/company/usersmeeting2014a.htm](http://www.bruker-microct.com/company/usersmeeting2014a.htm)

Winners of the year:

- **Best oral presentation**: Gregory Pyka, KU Leuven, Belgium, *“Evaluation of Credibility and Limitations of the Non-Rigid Registration of Micro-CT Images as a Tool for Local Strain Analysis”*
- **Best poster**: Bartosz Leszczynski, Jagellonian University, Poland, *“3D visualization of the air within macerated human temporal bone”*
- **Best movie**: Javier Alba-Tercedor, University of Granada, Spain, *“Anatomy (Head) of the Glassy-Winged Sharpshooter”*
- **Best picture**: María Candás, Universidad de Santiago de Compostela, Spain, *“Doris”*

We hope to welcome you once again next year!

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**Image of the Month**

Cross-section through mouse lung; SkyScan 1172, 1µm pixel size + insert to show details

**Upcoming Events**

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- **INTERPORE** May 27-30, Milwaukee, USA
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- **BRS** June 25-26, Sheffield, UK
- **3D Materials Science** June 29-July 2, Annecy, France

Click the image for downloading the full-size format.
Welcome

This fourth issue of the Bruker micro-CT Academy will focus on porosity analysis. We will discuss the difference between open and closed porosity and how to visualize and quantify this. The method notes which registered users can download (registration: http://partners.bruker-microct.com/subscribe) will explain in detail how to calculate a pore size distribution and how to extract a list of all pores and their respective 2D and 3D characteristic properties such as size, volume, and location. The second method note will describe how the visualization of open and closed pore networks can aid in the interpretation of the data.

How to Generate Pore Size Distribution and Characterize Open Versus Closed Pore Networks

Porosity analysis refers to the measure of “void fraction” and the characterization of the empty space. There are numerous application fields for which the analysis of pores is crucial in the understanding of the 3D structure and its mechanical properties. For example, in the field of bone research porosity is a parameter for the overall mechanical strength of the bone, while petroleum engineers are interested in the pore network connectivity to allow for transportation of liquids in oil & gas applications. Porosity analysis refers to the counting of empty space and characterization of their connections. Empty space is either fully surrounded by material on all sides, making it a closed pore, or if the empty space is not fully enclosed but at some point in 3D it can find a connection to the space outside of the object, it is defined as an open pore. The method note MN059_PorosityAnalysis explains why the conventional 2D analysis is very different from the 3D analysis where the values are obtained from the entire dataset. In addition, it describes in detail how to quantify the porosity in a dataset, both for open and closed porosity, and how to obtain a size distribution of the pores, as well as a list of all pores and their surface, volume, centroid location,…The method note also demonstrates how to use custom processing for noise removal functions as well as for automatic data analysis in a batch.

Visualization of Open and Closed Pore Networks

Visualization of open and closed porosity is very important when interpreting the data. 3D visualization is a lot more than “pretty pictures” and it is worthwhile to explore the techniques and tools available in the SkyScan software. A visual representation of the calculated characteristic properties can put new insights to the meaning of the numbers that were generated when performing porosity analysis as described in previous section. The image below nicely illustrates how the
open porosity (shown in green color) for the sample on the right is a measure of the sample itself, while the reported value for the open porosity for the rock on the left is artificial and is due to the sample drilling or the VOI selection. In fact, the rock on the left actually contains a closed pore structure and no gas or liquid transportation is possible.

CTVox (volume rendering) is by far the easiest and hence most used, well known visualization tool of the SkyScan software package. On the other hand, CTVol (surface rendering), being slightly more challenging, opens up opportunities for visualization which are not possible in CTVox. After calculating a pore size distribution, the techniques discussed in the first Micro-CT academy Newsletter can be applied to generate color-coded images for size using CTVox. In this issue of the Bruker micro-CT Newsletter CTVol is used to visualize color-coded image for open and closed pore networks. The techniques mentioned in the previous section will be very useful when generating surface meshes for the different types of pore network for surface rendering. Even more, they allow restricting analysis to either the open or closed porosity characteristic. A detailed step by step procedure on how to obtain these results is described in MN060 Extracting open and closed pore networks for analysis and visualisation.

- **Image of the Month:** Which is it: a piece of scourer or tagliatelle? Find out in our next newsletter!

- **Bruker micro-CT News**

  Bruker microCT is proud to announce the first Asia Pacific User Meeting on November 18 & 19, 2014. This two-day event will take place in Taipei, Taiwan, and will be a combination of user presentations and workshops showing the latest developments in hardware and software as well as training sessions covering both life science and material science applications with hands-on exercises. Registration through our website will be available soon. Please reserve the dates in your calendar!

  New version of DataViewer (ver.1.5.1) can now be downloaded at [www.bruker-microct.com/products/downloads.htm](http://www.bruker-microct.com/products/downloads.htm)

- **Upcoming Events**

  Bruker microCT will participate with an exhibit in the forthcoming conferences. Please click the link below for more information. We hope to see you there!

  - **BRS** June 25-26, Sheffield, UK
  - **3D Materials Science** June 29-July 2, Annecy, France
  - **FORS** July 2-4, Nantes, France
  - **ESB** Aug 31- Sep 3, Liverpool, UK
  - **IMA** Sep 1-5, Gauteng, South Africa
  - **IMC** Sep 7-12, Prague, Czech Rep.
  - **ASBMR** Sep 12-15, Houston, USA
Welcome

Have you ever tried to find identical slices in different scans where you want to compare the effect of a treatment or the evolution over time, to obtain ‘matching’ pictures for your publication or to save datasets in the same orientation for generating identical movies? Image registration using SkyScan DataViewer software provides the solution. This fifth issue of the Bruker micro-CT Academy explains in detail how to perform dataset registration in multiple application areas.

Basic and advanced image and dataset registration

Image registration is the process of transforming different datasets into one coordinate system. Image registration algorithms can be classified into intensity-based (comparing intensity patterns) and feature-based (comparing points, lines, and contours) algorithms. Depending on the transformation model they apply, both rigid (linear transformations) and non-rigid transformation (elastic transformations) exist. DataViewer (version 1.5.0.0 onwards) provides tools for rigid intensity-based image registration both in 2D and 3D. How to perform this image registration in DataViewer is explained step by step in “MN063 Image and dataset registration in DataViewer - Expanded clay” and “MN044 Image and dataset registration in DataViewer – Tooth”. The first method note makes use of a granule of expanded clay before and after moistening while the second method note uses a tooth before and after root canal treatment.

As the registration algorithm in DataViewer is rigid and intensity-based, one might experience that the registration of objects with big changes in internal morphology is less accurate. For example the morphology of the trabecular network inside long bones changes significantly upon pharmaceutical treatment.

Matching 2D pseudo-colored reconstructed images of dry (left) and moistened (right) expanded clay after registration showing part of the pores being filled with water (❄) in contrast to others (#).
possibly precluding accurate intensity-based registration of these scans. However, the outside anatomy of these bones does not change (that's why we can recognize all bones in the body based on their specific shape), making feature-based registration a more appropriate registration algorithm. “MN048 Advanced image registration in DataViewer” illustrates how rigid intensity-based registration can still be used to mimic feature-based registration. This protocol uses a binary mask of the sample to match and copies these transformation parameters to the original dataset.

- **Upcoming Events**

Bruker microCT will participate with an exhibit in the forthcoming conferences. Please click the link below for more information. We hope to see you there!

- ESB Aug 31-Sep 3 Liverpool, UK
- IMA Sep 1-5, Gauteng, South Africa
- IMC Sep 7-12 Prague, Czech Rep.
- ASBMR Sep 12-15 Houston, USA
- WMIC Sep 17-20 Seoul, South Korea
- IMPC Oct 20-24 Santiago, Chile
- XRM Oct 26-31 Melbourne, Australia

- **Image of the Month**

Surface rendered 3D models of a tooth before (left) and after (middle) root canal treatment. The right panel shows an overlay with the material removed upon root canal treatment. This model was generated from the different dataset after registration. White: enamel, Orange: dentin, blue: material that was drilled out.

- **Bruker micro-CT News**

Bruker microCT is proud to announce the first Asia-Pacific User Meeting on Nov. 18-19 in Taipei, Taiwan. The program includes user presentations, workshops and hands-on training sessions covering both life science and material science applications. Register here! We hope to welcome you there!

A dedicated U.S. user meeting will be held by our local partner, Micro Photonics, Inc., on Sep 10-11 in Houston, TX. Click here for more information!

- **Answer to the last issue’s image of the month**

Piece of scourer (stainless steel cleaning sponge) scanned in the SkyScan1172 at 80kV/ 100µA, 0.5mm Al filter, 4µm pixel size.
Welcome

What is “density” in microCT? In this newsletter we look how “density” is derived from attenuation of x-rays, introduce method notes on calibration for BMD and Hounsfield units, and discuss context sensitivity and artefacts of densitometry.

Image of the Month:

A microCT cross-section of an archeological sample of human femoral bone (SkyScan1172). The effect on bone mineralisation near surfaces of contact with soil (diagenesis) is visible at the endosteum. Multiscale porosity is also evident.

Density Measurement by MicroCT

Microdensitometry in 3D is important in microCT applications including bone and dental research, geology, material science and others. What does “density” mean for microCT? What it does not mean is simply mass density, i.e. the g/cm$^3$ of the material. “Density” instead means x-ray opacity, the strength of x-ray attenuation within a scanned material. Due to its strong dependence on atomic number “Z” (mass attenuation follows $Z^2$) x-ray attenuation is sensitive to elemental composition, as well as to physical density, of the scanned material. How much x-ray attenuation happened within each voxel during a CT scan? That is what is expressed by the reconstructed grey scale of each microCT image voxel.

Attenuation coefficient is converted to the image greyscale (8-16 bit) by reference to the intensity window set by the user during reconstruction in NRecon. Reconstructed greyscale can be calibrated by comparison with reference materials, into bone mineral density (BMD) and Hounsfield units (HU).

The principle of density calibration in microCT is equivalence of x-ray absorption relative to a reference material. For BMD the material is calcium hydroxyapatite, and for HU air and water. If a bone or tooth volume is found to have a certain BMD value, it means that this is the concentration of calcium hydroxyapatite (g.cm$^{-3}$) which would give the same x-ray absorption (with the same x-ray settings and in the same scanner) as the measured calcified tissue. If a selected tissue in a mouse or rat scanned in vivo is found to have a certain HU value, this expresses how different the attenuation of that tissue is from that of pure water (the HU of water is zero).
Method of density calibration and measurement by microCT

CT-Analyzer ("CTAn", Bruker-microCT) provides calibration of greyscale or "density" into BMD and HU. The full methods for measurement of BMD and of HU are described in the following two method notes:

- MN009 BMD calibration in CTAn
- MN039 HU calibration in CTAn

Once the appropriate calibration has been performed, the method for density measurement is similar to any other quantitative measurement in that it begins with the selection of the appropriate region or volume of interest (VOI). With this done, the mean density value of all voxels within the VOI can be reported in units of greyscale, attenuation coefficient, HU or BMD. As always in microCT measurement, the meaning of the measured value is determined by the VOI. For instance, if the VOI is a bone medulla containing trabecular bone and marrow, then the measured value is called trabecular "BMD". However if a binarised image of cortical bone is set as the VOI, excluding soft tissue, then the measured value should instead be called “TMD” meaning tissue mineral density. Distinguishing “BMD” (bone and soft tissue averaged density) from “TMD” (density of mineralized tissue only) is a useful distinction introduced by Bouxsein et al. (JBMR 25(7): 1468-86, 2010).

Context sensitivity of microCT density due to beam hardening and other artefacts

It would be conveniently simple if the greyscale of every voxel was in direct proportion to the composition and consequent attenuation of the material in that voxel, as expected in theory. However three artefacts can break this direct proportionality – these are (a) the partial volume effect, (b) beam hardening and (c) truncation. Understanding these artefacts helps both to plan and to interpret microCT imaging studies.

(a) **The partial volume effect**: voxel attenuation near an object surface follows a sigmoid gradient from low to high intensity (normal to the surface). With thin objects near to the resolution limit, all voxels are near a surface and thus can have their density artificially reduced. Figure 1 shows a scan of four aluminum foils of different thickness, all with the same actual material density. The density profile across all four foils at high resolution shows similar density for all foils; however in the lower resolution scan images the density of the thinnest foil is artificially reduced. This is a demonstration of the partial volume effect.

Practical implication: an object should have a thickness of about 10 pixels or more for density measurement free of partial volume effect.

(b) **Beam hardening**: Laboratory microCT x-ray sources are polychromatic – they emit a wide range of x-ray energies. Passing through scanned objects, low energy x-rays are attenuated faster than high energy photons. So more photons are absorbed near outer surfaces than deeper in the scanned volume. This causes an artefact of apparently elevated attenuation at outer surfaces of scanned objects (where real density is in fact uniform).

Software correction of beam hardening is available in Bruker-microCT NRecon software. This can effectively remove the artificial surface-to-depth density gradient from beam hardening provided that most of the x-ray absorption is from material of a similar x-ray attenuation (opacity).

Figure 1. (a) Thick and thin aluminum foils. (b) The attenuation profile across the foils from a high resolution scan. X axis is distance; y axis is attenuation as greyscale. (c) The attenuation profile across the foils from a lower resolution scan. The thinnest foil has its attenuation artificially reduced as all voxels are affected by the surface intensity gradient.

However if a scanned object is surrounded by a lower density medium, such as liquid around a sample or – in an in vivo scan – soft tissue around bone, the software beam hardening correction is much less effective, since it becomes a more complex two-material scenario.
Figure 2 shows that, with no software beam hardening correction, surrounding medium such as water does reduce the beam hardening gradient; however it prevents further software correction. By contrast in air, software correction is much more effective and can remove beam hardening gradients entirely. Practical implication: When scanning bone ex vivo, reduce the thickness of surrounding material to a thin plastic or moist paper layer. Immersing samples in liquid can make beam hardening uncorrectable. Bear this in mind also when interpreting in vivo scans with surrounding tissue. BMD calibration phantoms should approximately match the diameter of the calibrated bone with surrounding tissue “simulated” by scanning the phantoms in a water-filled plastic tube.

Practical implication: Densitometry requires an FOV wide enough to include the whole sample, ideally with ambient air to the right and left. In highly truncated scans densitometry is compromised. Try to minimize truncation for densitometry.

Figure 3. (a) Truncation means loss of image data outside of the FOV width (not height); (b) A plastic cone was scanned with the base of the cone truncated (dotted blue line); (c) Cross-sectional attenuation plotted with height in the cone. Truncation grossly alters the reconstructed attenuation.

(c) Truncation: This is when the camera field of view (FOV) is too small to contain all the sample or animal width during the scan rotation. Data in figure 3 show the significant, abrupt effect of truncation, which clearly compromises density measurement. Truncation can occur for instance during in vivo scans of bone in scanners with a small camera, where the bone stays within the FOV but a varying amount of surrounding soft tissue rotates outside the FOV. The result is a large artificial “quantum” step change in the reconstructed density of the scanned tissue such as bone (fig. 3c).

Figure 2. Beam hardening (BH) gradients in aluminum scanned in air and 20mm of water. The y axis is the surface gradient in attenuation coefficient (AC) from beam hardening, so zero means no – or corrected – beam hardening. In air, beam hardening correction of 40% fully removes the surface gradient artefact. In 20mm water however, software correction becomes much less effective and cannot remove the surface gradient artefact (all lines stay below zero).

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In this issue:
- Enhanced material contrast by dual-energy microCT imaging
- Advanced reconstruction for SEM-CT
- Introduction of new SkyScan1278 In-Vivo X-Ray Microtomograph
- Upcoming events
- Image of the month

Welcome

In this issue we have a look at a method to potentially improve material contrast by means of dual energy scanning. We also outline two techniques to improve reconstruction results specifically for data acquired with the micro-CT attachment for SEM. Finally we proudly announce the launch of the SkyScan1278 ultra-low dose, high-throughput in-vivo X-ray microtomograph.

Enhanced Material Contrast by Dual-Energy MicroCT Imaging

X-ray microCT provides 3D information about local attenuation within a sample. To visualize and quantify different features of a sample requires a sufficient spatial difference in attenuation – we call this “contrast”. In certain cases different materials, composed of different mixtures of elements, produce highly similar and/or overlapping X-ray attenuation profiles, making segmentation difficult or impossible. X-ray attenuation by a given material is the sum of the attenuation of its constituent elements. However, absorption of X-rays changes with different photon energy in a way that is nonlinear and differs between elements. By scanning an object at two different X-ray energies and combining the information from these, we can take advantage of such differences and nonlinearities in attenuation between different materials, and achieve an improved segmentation between those materials. In this way we can find differences in attenuation that would not appear in a single scan only. We use the Bruker microCT “DEhist” software (short for “Dual Energy histogram”) which plots an X-Y intensity map based on the attenuation values of two reconstructed slices with an identical position in a sample but acquired at different energy. As with all Bruker microCT software the latest version of DEhist can be downloaded from http://www.bruker-microCT.com/products/downloads.htm, together with the method note: "MN038 Enhanced material contrast by dual-energy microCT imaging".

Advanced Reconstruction for SEM-CT

The method note “MN046 Advanced reconstruction for SEM-CT” describes two techniques for improving reconstruction results from the microCT attachment for SEM using that advanced functionality of NRecon. The first part describes a method for compensating possible angular misalignment between the X-ray camera and the object’s rotation axis, which can create difficulties in finding a suitable misalignment value for all slices. NRecon compensates such camera tilt by determining the misalignment near the top and bottom of a projection image, then automatically re-rotates all shadow projections.
The second part describes the possibility to improve sharpness of reconstructions for highest (submicron) spatial resolutions by removing artifacts from random shift of the rotation axis during acquisition. After position adjustments, the second reconstruction produces sharp results not affected by object displacement during rotation.

Example of a reconstruction image before (left) and after (right) the iterative x/y alignment procedure. The sample is a micro-fossil scanned with micro-CT attachment for SEM with an image pixel size of 570nm.

We are pleased to introduce the SkyScan1278 ultra-low dose, high-throughput in-vivo X-ray microtomograph. It is the world’s fastest low-dose high-resolution in-vivo scanner available. The system was officially launched at the World Molecular Imaging Conference WMIC 2014 this month, with a functional system on display. For detailed information please visit our website.

Upcoming Events
Brucker microCT will participate with an exhibit in the forthcoming conferences. Please click the links for more information. We hope to see you there!

- **WMIC** Sep 17-20, Seoul, South Korea
- **IMPC** Oct 20-24, Santiago, Chile
- **XRM** Oct 26-31, Melbourne, Australia
- **Process Mineralogy** Nov 17-19, Cape Town, South Africa
- **MRS Fall** Nov 30 - Dec 5, Boston, USA

Image of the Month:
Volume rendering from a full body mouse scan with contrast agent injection. The scan was made using the SkyScan1278 with following scanning protocol: 65kV, “low dose” filter, 50µm isotropic pixel size.
Welcome

This eighth issue of the Bruker microCT academy Newsletter gives an overview of the different workflows for each SkyScan system that will guide you through the essential steps on how to setup the appropriate parameters to obtain a high image quality.

SkyScan MicroCT System Workflows

Running microCT scans with not-optimally adjusted acquisition parameters can result in images containing microCT-related artefacts. These artefacts may lead to misinterpretation of the data and even circumvent the analysis. Although a lot of microCT-related artefacts such as post-alignment, ring artefacts and beam hardening can be eliminated during the reconstruction and post-processing of the dataset, there is a limit to how much the software can compensate. Therefore, the correct selection of the scanning settings, such as voltage, filter, exposure time, rotation step, averaging, etc., is crucial in order to obtain good results. The method notes linked to this Bruker microCT academy Newsletter provide a workflow or checklist for each type of SkyScan microCT system, and are intended to be quick-start guides that describe how to set up a good scan step by step, taking into account the common pitfalls. Depending on the application and desired image quality, these parameters may be further optimized and refined.

As a user of our systems you are welcome to download the detailed method notes. Please click on the image of the system that you are using and login to your account. If you haven’t had an account yet, please subscribe at: http://partners.bruker-microct.com/subscribe.
Bruker microCT News

We would like to remind you of our first Asia-Pacific User Meeting which will be held on 18 & 19 November 2014 in Taipei, Taiwan. The program includes user presentations, workshops showing the latest developments in hardware and software and hands-on training sessions covering both life science and material science applications.

Detailed information can be found through our website. Online registration is still possible until October 17th at http://partners.bruker-microct.com/APUM. We hope to welcome you there!

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2014:
- IMPC Oct 20-24, Santiago, Chile
- XRM Oct 26-31, Melbourne, Australia
- Process Mineralogy Nov 17-19, Cape Town, South Africa
- MRS Fall Nov 30-Dec 5, Boston, USA

2015:
- AADR Mar. 11-14, Boston, USA
- EMM Mar. 18-20, Tübingen, Germany
- ORS Mar. 28-31, Las Vegas, USA

Image of the Month:

False color 3D volume rendering of a defect inductor component scanned on the SkyScan1272 at 3 μm pixel size (100 kV, 0.11 mm Cu filter). The defect or shortcut is indicated by an arrow.
In this issue:
- Minimal intensity projection in CTVox
- Bruker microCT news: location and dates for the Bruker microCT User Meeting available!
- Upcoming events
- Image of the month

Welcome
Thank you for joining us again in this ninth issue of the Bruker microCT Academy newsletter. This edition will illustrate a technique to improve visualization of low density phases. Also in this issue you will discover more on the latest update of CTVox v3.0 where multiple volume renderings are now possible. Using this new 3D visualization features we look forward to your contributions for the picture contest at the Bruker microCT User Meeting 2015, which will be held in Bruges!

Minimal Intensity Projection in CTVox
For visualization purposes, the technique of Maximum Intensity Projection (MIP) is becoming increasingly more popular. The MIP projects the highest intensity along the path of projection (which is perpendicular to the screen) and is used to highlight high dense structures. CTVox allows applying this in a straightforward user-friendly way. CTAn requires some intuitive interaction and 3D geometrical thinking while allowing more features, such as generating a stack of MIPs. Several applications are focusing on the lowest density phase, rather than the highest density, for example for the visualization of pore networks in reservoir rocks and food products, or the airways in lung tissue, micro-cracks in geothermal reservoirs, defects in car parts, ... It is desirable to have a similar visualization method to achieve the results as displayed below. To this end, one can generate a Minimal Intensity Projection (MinIP), which projects the lowest intensity along the path of projection. This technique is not widely used. In this method note, we will introduce a way to generate minimal intensity projections in CTVox. Depending on the dataset, this can be achieved in CTVox by well-considered manipulation of the transfer function. For other datasets some processing steps should first be applied in CTAn to allow the use of the MIP option in CTVox as a MinIP. In the method note ‘MN034 Minimal Intensity Projection in CTVox’ you will find a step by step procedure describing the different plugins that are used to generate the MinIP images.

Minimal Intensity Projection Image (MinIP) of the pore microstructure in a sandstone (left) and a mouse lung visualizing the major airways (right).
• **Bruker microCT News**

We are proud to announce that the **Bruker microCT User Meeting in 2015** will take place in the historical site of Bruges on May 5, 6 and 7, 2015. More information will be announced soon, reserve the dates!

A new release of CTVox 3.0 is now downloadable from our website. The most important novelty from this version onwards is the capability to work with multiple volume renderings simultaneously. Each volume retains its own transfer function; different weights can be assigned to the volumes to produce a combined emission color and opacity. The newly implemented Volume Manager allows for convenient navigation between the different volumes. Taking into account the capacity of the graphical card, multi-volume rendering easily allows overlaying your grey scale images with binarized data without exploiting the GPU memory use too drastically. In addition to the methods described in previous section, this combination of a volume with a binarized dataset in CTVox 3.0 allows for an alternative approach to enhance visibility of airways, pores and other low dense phases. Two datasets can also be displayed, providing a wide range of new opportunities; an example can be found in this Image of the Month.

• **Image of the Month:**

3D volume rendering of a sandstone, showing density information (in grey scale) as well as color-coded morphometric structure thickness information of the pores simultaneously in a single image (image created with CTVox 3.0).

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- **EMIM** Mar. 18-20, Tübingen, Germany
- **ORS** Mar. 28-31, Las Vegas, USA
- **AACR** Apr. 18-22, Philadelphia, USA
- **ECTS + IBMS** Apr. 25-28, Rotterdam, the Netherlands
- **ISBM** Apr. 27-29, Tokyo, Japan
Welcome back to the last issue of the Bruker microCT academy Newsletter for 2014! This edition will focus on the preparation of samples, and discuss in detail a drying technique which can be applied to a variety of samples, resulting in a better overall image quality. We would like to thank all the users who participated in the first Asian Pacific User Meeting for their contributions! The next international Bruker microCT User Meeting will be held in May in the historical city of Bruges, also known as the Venice of the North. More information can be found on our website. We hope to welcome you all!

Sample preparation

Often overlooked, but of great importance is the sample preparation. Not only the positioning of the sample in the microCT scanner, which will allow you to obtain the desired pixel size, but also the stability of the sample throughout the scan is crucial. Samples such as fibers or micro-spheres can be stably mounted on the provided metal sample holders by using a small drop of glue. After the glue is dry, this easy and straightforward technique will enable long scans without sample movement. If the samples are preserved in ethanol of formaldehyde, placing them directly on a stage will allow the liquid to evaporate during the scan, resulting in artefacts in the reconstructed images. Leaving the sample surrounded by liquid will increase the noise in the image and will impact the beam hardening. By wrapping the samples in parafilm or low dense wax, thereby creating a ‘cocoon’, will prevent this.

However, for a wide range of samples the density difference between internal structures is sometimes not enough. For these samples a chemical drying procedure can be useful. In the method note “MN070 chemical drying of specimens to enhance contrast” you can find more information on how this simple technique works. This drying process has been successfully used in a range of biological samples. A nice example of this technique is lungs scanned ex vivo, where without this drying the fixative would limit the contrast. After chemical drying the contrast between the tissue and the air is maximized, resulting in much nicer images. Although maybe not considered straightforward, this procedure can also be applied to soft tissues. The image below shows the result of the chemical drying of a snake, where there is a differential uptake of the chemical allowing visualization of the different soft tissues.
Image of the Month

MicroCT reconstruction of a sheep proximal femur containing two titanium screw implants. The scan was with the SkyScan2211 nanoCT employing 170kV and a molybdenum filter to eliminate metal artefacts allowing detailed imaging of bone in direct contact with the metal implant surface, 71x71 mm cross-section size. The volume rendered visual 3D model was created in CTVox version 3.

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Bruker microCT News

- The first Asia Pacific User Meeting was held in Taipei, Taiwan and was great success thanks to the contributions of the users!
- We are proud to announce that the international Bruker microCT User Meeting in 2015 will take place in the historical site of Bruges from May 4 till 7, 2015. A first glance at the program can be found on our [website](#).