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UGCT: New X-ray radiography and tomography facility

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Abstract

The UGCT (University Gent Computer Tomography) facility, a cooperation between the Radiation Physics research group and the Sedimentary Geology and Engineering Geology research group is a new CT facility providing a large range of scanning possibilities. Formerly a Skyscan 1072 was used to perform X-ray micro-CT scans at the UGCT facility and although this is a very powerful instrument, there were needs for a higher resolution and more flexibility. Therefore, the UCGT facility started the construction of a multidisciplinary micro-CT scanner inside a shielded room with a maximum flexibility of the set-up. The X-ray tube of this high-resolution CT scanner is a state-of-the-art open-type device with dual head: one head for high power micro-CT and one for sub-micro- or also called nano-CT. An important advantage of this scanner is that different detectors can be used to optimize the scanning conditions of the objects under investigation. The entire set-up is built on a large optical table to obtain the highest possible stability. Due to the flexible set-up and the powerful CT reconstruction software "Octopus", it is possible to obtain the highest quality and the best signal-to-noise of the reconstructed images for each type of sample.

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1. Introduction

Microtomography is a technique that allows scientists to investigate the structure of their samples with high spatial resolution without actually opening or cutting them. Without any form of sample preparation, it is possible to obtain a 3D computer model of the sample within 1–2 h of X-ray scanning and data reconstruction. The physical parameter which is providing the information about the structure is the X-ray linear attenuation coefficient μ. This coefficient is function of the electron density of the sample.

X-ray detectors are used to record the attenuation information along lines through the object. To detect the transmitted X-rays, they have to be converted to visible light with scintillation materials like GadoliniumOxysulphide (GdOS:Tb) or CsI crystals. The visible light from the scintillator is in turn registered by CCD camera's, CMOS-flat panels or amorphous Si-flat panels. Direct conversion detectors, like photon counting solid state arrays or amorphous Se, are still not used often but could be the future for microtomography.

Digital radiographs of the sample are made from different orientations by rotating the sample along the scan axis from 0° to 360° (full cone beam scan). Theoretically, the number of projections or radiographs necessary to reconstruct the internal structure of the object, is the product of the number of horizontal detector pixels and π [2].

2. Facility

The CT facility houses three different systems. The newest device is the high-resolution CT scanner. This is

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why we will only briefly present the two other systems. More detailed information can be found on the website of the facility [3].

2.1. Micro-CT and nano-CT scanner

The main components of the new CT scanner are the X-ray tube, the sample manipulator and the X-ray detectors. Further, we have some extra components to facilitate the sample centering (Tables 1 and 2).

The X-ray tube is a state-of-the-art FXE-160.50 dual head open type source from Feinfocus. Open type means that one can open the tube to clean it or to replace filaments or targets. The dual head means that we have two tube heads, a high power directional head and a "nano" transmission head. The system has one high voltage unit and one vacuum system to evacuate the air. The X-ray source is mounted on a rotating platform. The reason is that the X-rays are emitted in the forward direction for the transmission tube and under 60° with respect of the tube axis for the directional head. When we change from one to tube to the other, we need to rotate the X-ray system by 60°.

2.1.1. X-ray imaging detectors

Since the ideal imaging detector does not exist, one should try to use different detectors to match the right detector to the right scanning conditions. For low-energy CT scans, we are using a Photonic Science VHR and a Rad-icon CMOS RadEyeHR. For medium energy scans, we use a RadEye CMOS flat panel and for the high-energy scans, we use an image intensifier coupled to an optical CCD camera or a "scintillator/mirror/lens/CCD" detector (also called camera box). The VARIAN Paxscan 2520 V with 14 bit dynamic range and CsI scintillator is used for the entire tube voltage range up to 160 kV.

Table 1
Properties for the directional head

Property Directional Head	Value
Voltage (kV)	20–160
Power (W)	Micro-focus: max. 10 High power: max. 320
Feature recognition (μm)	2 (defined by manufacturer)
Min. sample distance (mm)	4
Cone angle (°)	40

Table 2
Properties for the transmission head

Property Transmission Head	Value
Voltage (kV)	20–160
Power (W)	Nano-focus: max. 1 Micro-focus: max. 3 High-power: max. 10
Feature recognition (μm)	0.3 (defined by manufacturer)
Min. sample distance (mm)	0.2
Cone angle (°)	170

2.1.2. Low energy

Biological samples and polymers are typically scanned at low kV settings to obtain high contrast projections. For these type of samples, we use a Photonic Science cooled CCD detector with a thin scintillator coupled to the sensor with an optical plate (taper ratio 1:1). The scintillator is 5 mg/cm^2 Gadolinium Oxysulphide. The sensor is 36 mm × 24 mm and consists of 4008 × 2672 pixels of 9 μm × 9 μm. For distortion free images, we are using a RadEyeHR CMOS flat panel with 1600 × 1200, 22 μm pixels.

2.1.3. Medium energy

Denser samples, like geological objects, are scanned with a remote Rad-eye EV detector from Rad-icon. It is a CMOS sensor with 1024 × 512 pixels of 48 μm × 48 μm. The scintillator is a Lanex Fine with a thickness of 34 mg/cm^2 which is pressed onto a FOP (Fiber Optic Plate). The resolution is 48 μm (10 lp/mm). EV stands for extended voltage, which makes it possible to use the detector up to a tube voltage of 160 kV. The entrance window of the detector is 1 mm graphite. The dynamic range of the sensor is 4000:1, approximately 12 bit. The linearity is poor but correction methods do exist. Although the RadEye detector should allow us to work at 160 kV, it is not recommended. The dark current in the CMOS sensor increases quickly and damage has been observed. It is possible to replace the sensor in the case of radiation damage.

2.1.4. High energy

For the high-energy applications, we are using an image intensifier coupled to Sensicam PCO camera. The dual field image intensifier was bought from Precise Optics and has a circular field of view of 6″ in low-resolution mode. The gain of the intensifier is fixed and it is important to optimize the ratio X-rays at the input to electrons in the CCD camera. We use an optical filter in front of the CCD lens to reduce the visible light intensity. The distortion inside the intensifier is considerable. For CT scanning, the distortion has to be corrected by a grid image and a calibration algorithm. The radiation damage is negligible at 160 kV. Cupper beam hardening filters are placed in front of the detector to remove the low-energy X-rays. The pixel size is 136 μm in 6″ mode or low-resolution mode.

A second detector is a camera box. Inside the box, the Sensicam CCD camera is observing the light from a scintillator. Since not all X-rays are stopped inside the scintillator we are using a surface coated mirror to deflect the light over 90°. The optical lens is a NIKKOR 50 mm f/1.4 MF lens.

2.1.5. Sample manipulator

The sample manipulator is an XYZ-theta CT system. The linear spindle modules are using Berger-Lahr Intelligent Compact Drives (IcIA IFA). The controller is integrated inside the stepper motor housing.

The rotation motor is ultra precision rotation stage from MICOS (UPR-160F AIR). To reach sub-micron resolution CT scans, the rotation stage requires a low wobble ($<2.5\,\mu$rad) and eccentricity ($<0.1\,\mu$m) which can be guaranteed by high precision toroid air bearings. The load capacity is 5 kg. The air pressure is 4.5 bar and is filtered for oil, particles and humidity.

For nanotomography, it is almost impossible to place the samples exactly on the rotation axis. To facilitate this process, we use a PI miniature XY piezo stage M-662.470. This XY stage has remarkable features. The resolution is 50 nm, the travel range 20 mm, the acceleration 20 g and the load capacity is 5 N or 500 g.

2.2. Electron accelerator

The electron linac is a high power machine with a maximum electron energy of 15 MeV and a maximum beam power of 10 kW. It can be used for scanning large dense objects after conversion of the electrons to X-rays (100–15,000 keV). The X-ray camera is a camera box with thick scintillator. To reduce the contribution of scattered X-rays to the images, the sample is placed 1.5 m from the detector. The source–detector distance is 7 m. The resolution is about 1 mm.

2.3. Medical CT scanner

The medical CT scanner is a 10-year old Philips SR5000. The scanner will mainly be used for scanning cultural objects, e.g. panel paintings. The focal spot size is $0.6\,\text{mm} \times 0.75\,\text{mm}$. There are 768 detector elements with a centre spacing of 1.16 mm. The maximum voltage is 130 kV and the maximum current 350 mA (Fig. 1).

Fig. 1. The "Dual head X-ray source" is mounted on a rotating platform.

3. Results

We will show one result of the nanotomography scanner since this is the newest instrument at the UGCT facility. The sample is a planktic foraminifera of Karibik (depth: 2900 m). Foraminifera (forams for short) are single-celled protists with shells. The shells are commonly divided into chambers which are added during growth, though the simplest forms are open tubes or hollow spheres. Depending on the species, the shell may be made of organic compounds, sand grains and other particles cemented together, or crystalline calcite. In Fig. 2, we show the result of a nanotomography scan with a voxel size of 880 nm. The 800 projections, 20 flat field images and 10 dark current images were processed into a stack of CT-slices with the Octopus package [1]. The 3D rendering was realized with VGstudioMAX. The voltage on the FXE-160.51 X-ray tube was 40 kV and the detector was the Photonic Science VHR in binning 4 mode.

4. Conclusion

The UGCT facility is able to make tomographic scans of a wide range of object going from biological to geological samples and from cultural heritage to industrial objects. The nanotomography scanner is flexible multidisciplinary device with a spatial resolution just below 1 μm. In 1–2 h scan time, it is possible to obtain high contrast 3D volumes. The system is build inside a bunker on a large granite table. This approach allows us to adapt the system easily to the experiment. The facility is much easier accessible to scientist from universities, institutes and industry compared to synchrotron beam lines.

The big advantage compared to the commercially available CT scanners is that the whole system control

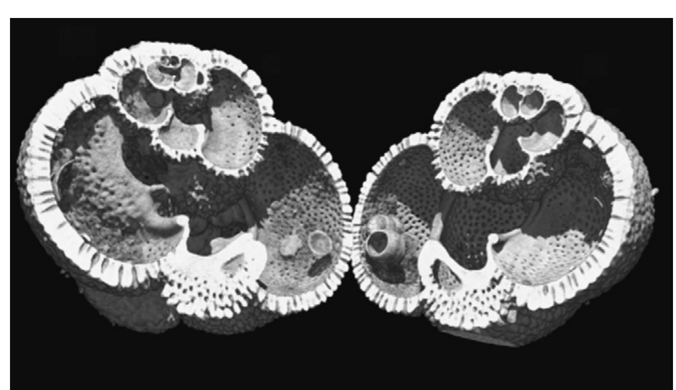

Fig. 2. 3D rendering of a 500 μm large Foram.

and the cone beam reconstruction process was developed by the UGCT team. The integration of new detectors or algorithms is relatively easy which makes the facility very flexible.

References

[1] Octopus, CT reconstruction software from XRayLab.com. ⟨http://www.xraylab.com⟩.

[2] A.C. Kak, M. Slaney, Principles of Computerized Tomographic Imaging, Society of Industrial and Applied Mathematics, 2001.

[3] UGCT, X-ray tomography facility: ⟨http://www.ugct.ugent.be⟩.