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Keywords

synchrotron, station, radiation, esrf, tomography, biomedical, beamline, computed

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Synchrotron Radiation Computed Tomography Station at the ESRF Biomedical Beamline

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Abstract. The different tomography imaging modalities of the ESRF Medical Beamline are described and research applications are presented

Keywords: Medical, Imaging, Tomography

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INTRODUCTION

Synchrotron radiation is now applied to virtually all areas of biomedical sciences using ionizing radiation. The availability of intense monochromatic X-ray beams over a wide energy range differentiates these sources from standard clinical and research tools and gives access to *in vivo* and *in vitro* research not possible otherwise. At the European Synchrotron Radiation Facility (ESRF) a dedicated biomedical beamline (ID17) has been built to perform coronary angiography clinical trials [1]. The protocols took place between years 2000 and 2003. In the meantime, a powerful Synchrotron Radiation Computed Tomography (SRCT) system has been developed. Thanks to the availability of different monochromators and detectors, the system can be used either for *in vivo* high temporal resolution experiments or *static* high spatial resolution experiments. SRCT was then one of the main activities of the beamline during 2002-2005. Other activities are radiotherapy and planar imaging.

The main SRCT scientific topics addressed are Brain Imaging (25 % of SRCT beam time), Mammography and Cartilage imaging with Diffraction Enhanced Imaging (DEI) (25 %), Bronchography in Lungs Physiology Research (20 %), Fossils Imaging in Paleontology (15 %) and Cerebral Angiography (10 %).

BEAMLINE COMPONENTS

The complete beamline design can be found in [2]. The X-ray beam produced by the wiggler (typically: 0.7 T, gap: 50 mm - critical energy: 16.5 keV) travel across slits and attenuators before impinging on the monochromator systems located 150 m from the source. This long distance permits to obtain a wide fan beam (up to 150 mm width, 5 mm height). Then the monochromatized beam delivered in the imaging hutch cross the sample located on a rotating stage and the attenuation profiles are recorded by the detector systems.

Monochromator Systems

The optics hutch is equipped with two monochromator systems.

The first one called TOMO is based on double-crystal bent Laue scheme and provides a fixed-exit beam over an energy range from 17 keV to about 90 keV. This monochromator has two advantages for *in vivo* tomography: the produced beam is horizontal in such a way the sample rotates in a horizontal plane, and changing beam energy is very fast (< 2 minutes). Typical photon flux is $4 \cdot 10^8$ photons/s/mm².

The second system, ANGIO (it has been originally developed for the planar coronary angiography imaging protocols) is a single crystal monochromator, operated in the bent Laue transmission mode. It can provide two separated inclined beams with respective energy bracketing the K-edge absorbing threshold of a contrast agent and is used for the K-Edge Digital Subtraction method (KEDS). The energy can be selected in the range 17 to 80 keV. Typical photon flux is $6 \cdot 10^{11}$ photons/s/mm². As the ANGIO system is non standard, it is displayed on Fig 1.

FIGURE 1. Experimental setup in K-edge mode with the ANGIO monochromator and the Germanium detector

Detector Systems

The imaging hutch is equipped with two detectors which can be chosen according to the experimental needs.

The first one (Germanium) is a high purity solid-state detector (Eurisy Mesures). It is a monolithic germanium crystal 150 mm long with two rows of 432 parallel strips, having a pitch of 350 μ m. Each row can be acquired simultaneously in KEDS mode. The minimum time between two projections recording is 1 ms, so the typical time between two images can be less than 0.5 s. In computed tomography, angular projections acquisitions during 180° rotation is enough. However, by shifting the rotation center near the side of the detector and by doing acquisition on 360°, the field-of-view can reach 300 mm.

The other detector (FReLoN, for Fast REadout LOW Noise) is a Peltier-cooled 2048x2048 pixel CCD-based camera, developed at the ESRF [3]. It is coupled, via tapered fiber optics, to an exchangeable fluorescent screen from different thickness (40-200 μ m). The field-of-view of the taper optics is 94x94mm² with a corresponding pixel size of 46x46 μ m². As in the previous case, by redundant acquisition the field-of-view can be increased up to 180 mm. Because the incident beam is 1D-like, only a horizontal region of interest is readout. As the data transfer across the CCD dominates the readout time, it has been necessary to synchronize the acquisition with a beam chopper [4] also developed at ESRF to avoid beam exposure and to save dose during readout. This chopper consists in 12 planetary stainless-steel blades mounted on two large discs. The blades are kept permanently parallel between them by a series of gears, which also allow changing the orientation of the blades, and thus allow changing the duty cycle.

Rotating Devices

The Medical Beamline was designed to permit clinical trials in such a way a Patient Positioning System (PPS) has been built to vertically scan the patient chest for angiography protocol planar imaging. The PPS is also able to rotate the Patient for tomography or tomotherapy purposes. This rotation can handle heavy sample and is very precise at 180°/s speed. However it cannot be inclined and so it cannot be used with the ANGIO monochromator. As this rotation is reliable at high speed due to position and speed feedback regulation, this system cannot be used with the FReLoN camera too. Thus K-edge or FReLoN camera acquisitions are based on small stepper motor rotating stages.

CONTROL AND ANALYSIS SOFTWARE

The combinations of these beamline components require that the control system and the reconstruction software's are very flexible. The control system has to handle the detectors and the rotating motors in such a way a very precise synchronization between the data acquisition and the angular rotation can be achieved. The synchronization is even more challenging when the chopper, the contrast agent injector or the vertical movement must be included in the chain. The control system is built on a client-server basis using SPEC (Certified Scientific Software) as the client and Linux drivers running the equipment as servers. The sinogram treatment is handled with IDL (Research Systems) software. This software is parameterized in function of the imaging modality to permit image subtraction either in KEDS, temporal or DEI mode. Some tools to define rotation center, to filter and clean the sinograms have been included. The tomography back-projection reconstruction algorithm is either Snark (Pennsylvania University) or HST, developed at ESRF.

RESULTS AND DISCUSSION

Avoiding beam-hardening effects, absolute concentration measurements of a contrast agent are achievable with an optimal combination of signal to noise ratio and X-ray dose parameters. Regarding the broad variety of applications by combining the different beamline components as summarized in Table 1, the achievements of the ID17 experimental tomography station are numerous and challenging. For some applications the system must be as fast as possible in order to achieve dynamic studies as Cerebral Blood Volume (CBV) and Cerebral Blood Flow (CBF) assessment in Cancer Research, and Bronchography, whereas high-spatial resolution is more important in DEI and Paleontology. The rotating devices permit SRCT imaging of a large variety of samples, ranging from small rodents to pigs. In combination with the precise vertical motion of the PPS, fast helical tomography can be achieved to record volumes.

The image acquisition is very flexible. It can be operated in the KEDS mode where the two beams with slightly different energies tuned around the K-edge of the contrast agent are recorded at the same time. This mode is mandatory for moving objects like lungs. On the other hand, the temporal digital subtraction mode, which quickly records images before and after contrast agent injection, will provide better quantitative results but is applicable only for static objects like a rodent brain.

Figures 2 and 3 illustrate the very different types of results one can obtain with this system. Figure 2 shows a typical image of a rat brain where the tumor is perfused by some contrast agent (1 s data acquisition) whereas Fig. 3 shows the volume reconstruction of a precious fossil (24 h data acquisition). Images acquired with the ANGIO mono in KEDS mode may be found in [5].

TABLE 1. Typical Tomography Imaging Modalities

Monochromator \ Detector	Germanium	FReLoN
TOMO monochromator	Low spatial resolution, fast acquisition	high spatial resolution, slow acquisition
	<i>In vivo</i>	Volume reconstruction
	temporal subtraction	
	possible to use PPS rotation brain perfusion imaging	Diffraction Enhanced Imaging Paleontology
ANGIO monochromator	Low spatial resolution, fast acquisition	high spatial resolution, slow acquisition
	<i>In vivo</i>	<i>In vivo</i>
	K-edge subtraction lungs imaging	K-edge subtraction cerebral angiography

FIGURE 2. Tomographic slice of a rat bearing a brain tumor highlighted here by some iodinated contrast agent

FIGURE 3. Mandible of an ancestor of modern orang-utans from Thailand. Right teeth have been virtually pulled off.

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REFERENCES

1. B. Bertrand et al, Comparison of synchrotron radiation angiography with conventional angiography for the diagnosis of in-stent restenosis after percutaneous transluminal coronary angioplasty - *European Heart Journal* - Vol.26 - pp.1284-1291 - 2005
2. H. Elleaume et al, Instrumentation of the ESRF medical imaging facility. *Nucl Instr and Meth A* 428, 513-527, 1999
3. P. Coan et al, Evaluation of image performance of a taper optics CCD FReLoN camera designed for medical imaging. *Journal of Synchrotron Radiation* **13**, 260-270 (2006).
4. M. Renier et al, A mechanical chopper with continuously adjustable duty cycle for a wide X-ray beam, *MARS 2004 Proceedings, Nucl Instr and Meth A* 548, 111-115, 2005
5. S. Monfraix et al, Quantitative measurement of regional lung gas volume by Synchrotron Radiation Computed Tomography – *Phys. Med. Biol* **50**, 1-11 (2005)

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