Scientific Report of the MI-999 experiment

Experiment Title: Development of a detector for high spatial resolution computed tomography of a phantom simulating the human ears

Keywords: High resolution CT, CT of human ear, X-ray detector

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Research Area of the proposal
MD - Medicine, MI - Methods and Instrumentation

Beamline: ID17

Number of shifts applied: 6

Beam requirements 16 bunch
Monochromatic beam, Tunable energy [keV] from: 30 to: 140

Laboratory Support Facility: no

Items not supplied by ESRF: proprietary FO linear array detector with a CCD camera (model APOGEE – ALTA-U9000, with 3056 x 3056 pixels). Motorized turntable and vertical axis. Computer with frame grabber.

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Experimental Session:

Beamline	Allocated shifts	Start Date	Finish Date	Local Contact
ID17	6	02 December 2009 08:00	04 December 2009 08:00	Thierry Brochard (email: brochard@esrf.fr)

Scientific background and state of art

Inner ear diseases include not only hearing loss but also equilibrium disorders. In these cases the normal life is seriously affected and simple actions like walking and moving are seriously impaired by the appearing of symptoms like dizziness, nausea, vomit. Imaging the inner ear is a very interesting radiological challenge. Present medical CT scanners are able to give images with a minimum voxel of 0.5×0.5×0.5 mm^3. Thus some anatomical details like semicircular channels (diameter ~1 mm) and the otoliths, having dimension of few tens of microns are not observable (see Figure 1). Given the fact that inner ear diseases are often treated surgically, the physician has to proceed to the operation without any trustable image guidance. In addition, without good imaging, it is not possible to follow up the therapeutical effects of medications. A dedicated and performing CT system for the inner ear would allow avoiding several useless surgical operations.

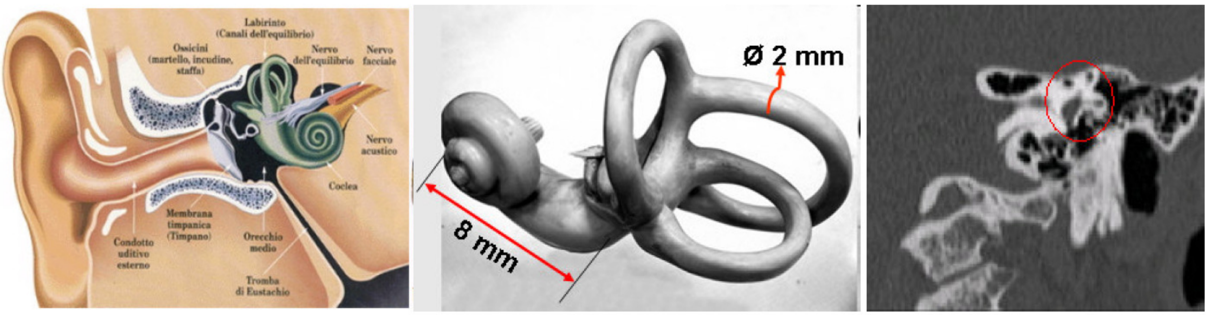

Figure 1. Scheme of ear anatomy (left), scheme of inner ear (centre), CT image by standard medical scanner (right) with a red circle to highlight inner ear with the three semicircular ducts.

Worldwide, preclinical developments of high resolution inner ear CT imaging have been done on small animals (i.e. mice). In human being, the accurate detection of anatomical details like semicircular channels and the otoliths is made particularly difficult because they are relatively small and contoured by the skull and the petromastoid bone which are very radio opaque to X-rays. For that reason, the proposed experiment can be considered a “reference benchmark” of human ear CT imaging, a target to which the modern tomographic equipments should move towards. For obtaining the required precision, a new high efficient and high resolution detector, adapted for high energies, should be employed. In the last ten years the Department of Physics of the University of Bologna has developed X-ray detectors for applications concerning digital radiography and computed tomography [1], [2], [3]. Particular attention was devoted to the development of high spatial resolution multi-slice detectors. The major aim was to develop detector systems for CT of large objects (more than 120 mm wide) with voxels of about 25 microns.

Experimental set-up

The used instrumentation was composed by:

- Proprietary Fiber Optical linear array detector with a CCD camera (model APOGEE –ALTA-U9000, with 3056×3056 pixels);
- Motorized turntable and vertical axis;
- Computer and connecting cables;
- Proprietary software.

Each component is showed in the following figures:

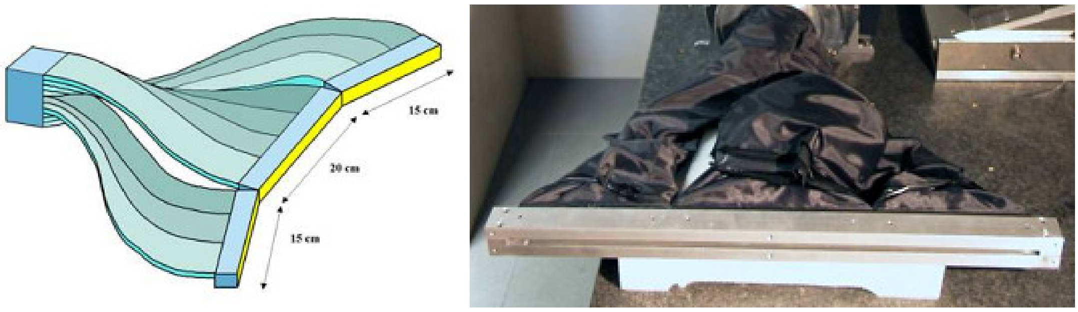

Figure 2 – Scheme and picture of the fiber optics fan. [1]

Figure 3 – Pictures of the M-038 Precision Rotation Stage, the turnable axis, (left) and M-511 Heavy-Duty Micropositioning Stage, the vertical axis (middle), both by Physik Instrumente, Picture of the Apogee Camera (right).

The linear detector used, see Fig.4, is done by FO ribbons that overlap like in a fan. This fan is a coherent image light guide made of thin glass fibers. Over the input face of the “fan” there will be a GOS screen scintillating under X-ray irradiation. The rectangular face of the output face of the fan will be seen by a CCD camera.

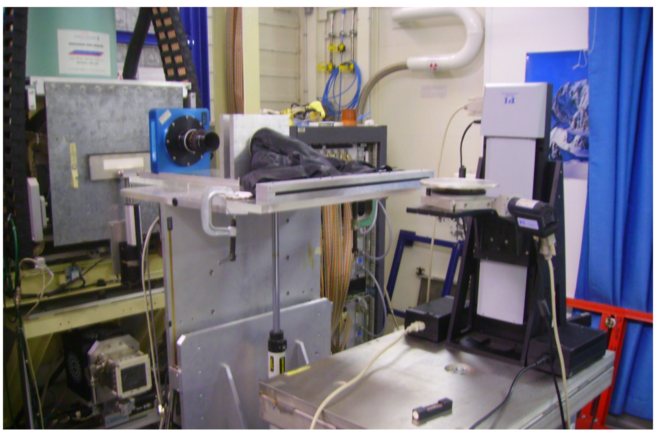
Figure 4 - Picture of the detector during the CT analysis at the ESRF

We used, as CCD camera, an APOGEE, model ALTA-U9000, with 3056 $\times$ 3056 pixels of 12 micron size. With the FO fan, which can be intended as a "geometry transducer", it is possible to change the CCD matrix 3000×3000 in an equivalent one, about 20,000 × 400, that is 400 slices of 20,000 pixels. In Figure 5 a radiographic image is shown, it should be point out the order for which the blocks (named from 1 to 6) must be collated to obtain a single multislice projection.

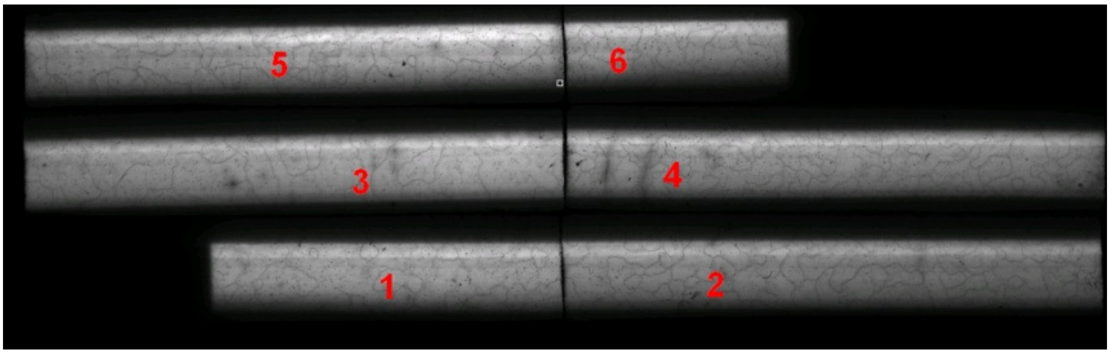

Figure 5 - Acquired radiography by the CCD camera. The six blocks to be collated are shown.

Samples

We brought with us two samples (see Figure 6):

A – Plexiglass Geometrical Phantom with enclosed a geometric hydroxylapatite insert to simulate the skull and the petromastoid bone. Some artificial holes, each one with a diameter of 2 mm, have been drilled in the hydroxylapatite to simulate inner ear. The phantom is entirely realized in plexiglass, divided into 10 slices, simulating the human tissue from the point of view of the x-ray interaction - in which some materials (hydroxyapatite and copper wires) are inserted for reproducing the human ear. IUPAC name: poly(methyl 2-methylpropenoate), other names poly(methyl methacrylate) (PMMA), Chemical Formula: $(C_5O_2H_8)_n$, Density 1.19 g/cm³ , Melting point 130–140 °C (265–285 °F), Boiling point 200.0 °C (392 °F).

B – Alderson-Rando Phantom composed by a material to simulate soft-tissue and a material to simulate skeletons and bones. Soft Tissues simulated are unlimited, small variations in density and absorption throughout the human body. Phantom soft tissue is closely controlled to have the average density of these tissues. The simulated skeletons are highly-detailed polymer moldings which reproduce the shape, mass density and attenuation coefficients of cortical bone and spongiosa. They allow continuous production of phantoms, instead of the sporadic production required by the limited availability, variable size and uncertain chemical composition of human skeletons. These problems, plus loss of marrows in dried natural skeletons, make these skeletons superior to "real bone".

Figure 6 – Pictures of Alderson-Rando Phantom (left) and of the plexiglass phantom (centre) and the modified slice with enclosed a geometric hydroxylapatite insert.

Results

After some tests to choice the best energy (we changed energy and studied the radiographic contrast) we decided for 55 keV and we carried out the experiments summarized in table 1.

Phantom	Positions (vertical steps 2mm)	Energy (keV)	Binning	Projections (angular steps)	Exposition time (sec)	Pixel (single projection)	Voxel side (μm)
Alderson-Rando	5	55	3	900	0.8	1649×1649	69
Plexiglass	6	55	3	900	8.0	1649×1649	69
Plexiglass	2	55	2	720	0.5	537×537	46

Table 1 - Experiments performed

The tomographic analyses have shown that it is really possible to achieve a resolution able to display the inner ear details. In particular the reconstruction of plexiglass phantom with binning 3 shows a very defined imaging of the iron wire inserted in a hole of the plexiglass layer in spite of the strong X-ray attenuation occurring when they gone through the cranium and the plexiglass layers. See Fig. 7.

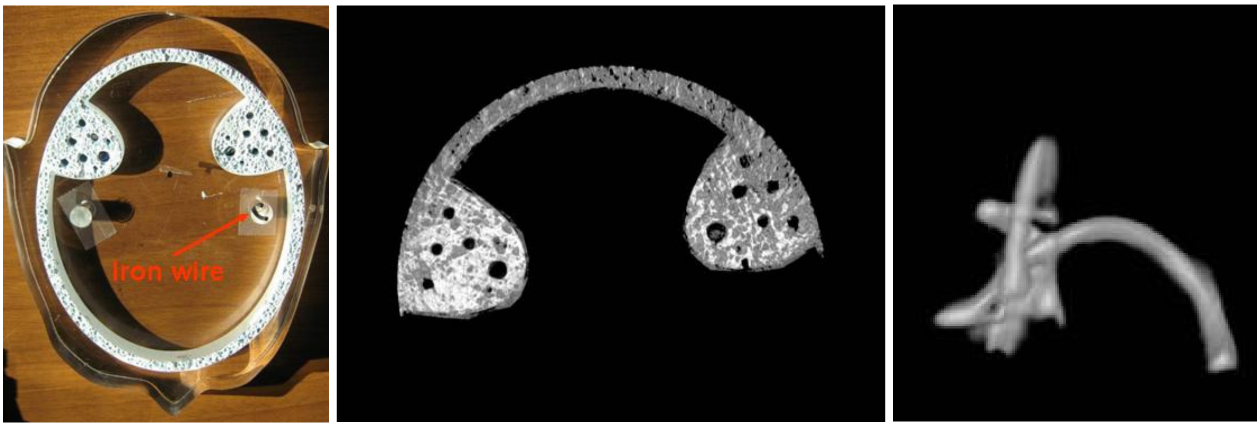

Figure 7. Picture of the plexiglass phantom (left), 3D volume reconstructed with binning 3 (centre), detail of the iron wire (right). This analysis was carried out with beam energy of 55 keV.

The CT analysis carried out at higher resolution was performed in "local tomography", that is a standard CT acquisitions but obtained framing a little interesting zone into the plexiglass phantom and fixing the rotation centre in a point at the centre of hydroxyapatite region where we would carried out the analysis. The copper wire (diameter of 200 μm) placed in a hole (diameter of 3 mm) bored in the hydroxyapatite layer is well imaged in Fig. 8 and 9.

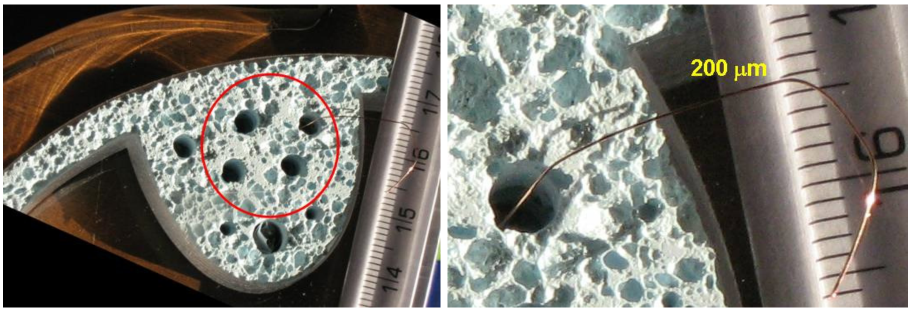

Figure 8 - Pictures of the region of interest studied with high resolution CT analysis (red circle, left), zoom of the hole where the copper wire (200 μm) is placed (right). This analysis was carried out with beam energy of 55 keV.

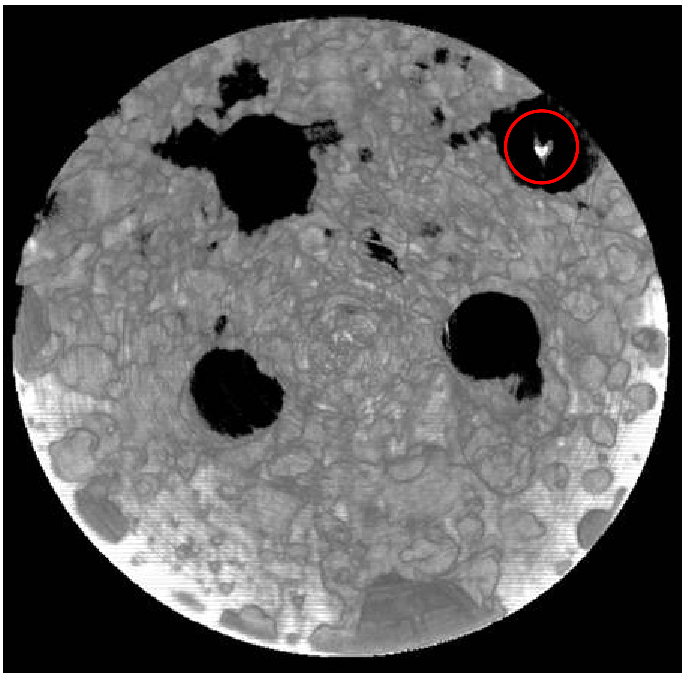

Figure 8. Reconstructed volume in local tomography at high resolution. See the copper wire with a diameter of 200 μm (red circle) in a hole (diameter of 3 mm) bored in the hydroxyapatite layer.

At the end we show the result obtained with the analysis of Alderson-Rando phantom. See Fig. 9.

Figure 9. Picture of the Alderson-Rando Phantom (left), inner reconstructed volume (centre), particular of the reconstructed volume (right). This analysis was carried out with beam energy of 55 keV.

Conclusions

The pioneering results obtained on last year are a very important starting point, because they have demonstrated the very good system resolution at (energy) 55 keV.

The ID17 and ID19 beamlines showed a large interest in our ability of obtaining a linear detector from a square CCD: it can allow to perfectly fitting with the laminar beam of ID17 (15 cm × 4 mm) or of ID19 (within the upgrade program, planning larger beam for palaeontology applications). During our experiment in last December a very important collaboration with the ESRF "Detector & Electronics Group" was established, in particular with the Dr. J.C. Labiche and the Dr. C. Ponchut. The final aim of the collaboration is to merge our developments and skills in fiber optical fan (geometric transducer) with a wide dynamic range camera developed at the ESRF. For these reasons we have planned a new ESRF proposal for 2011.

References

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