1.9.25. DESIGN AND OPTIMIZATION OF A TOMOSYNTHESIS SYSTEM USING A MULTIPLE X-RAY SOURCE BASED ON CARBON NANOTUBES

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1. Introduction. Tomosynthesis is an X-ray technique that is increasingly used in both NDT and security applications. Despite the poor depth resolution, this technique provides 3D information for configurations where conventional computerized tomography can not be applied. It is the case of the inspection of an abandoned luggage. The objective is the detection of illicit materials – explosive or chemical hazards – in the luggage, using a portable, fast, and reliable system. This inspection is currently performed by radiography. Standard tomography is not possible due to the lack of place around the luggage – moreover, mechanical motion close to unknown content luggage should be avoided, and of course motion of the luggage itself is forbidden.

Through a French collaborative project, we are developing a new concept of portable X-ray system for the inspection of abandoned luggage. Innovation relies on the combined use of two complementary imaging X-ray techniques, transmission and diffraction. In this paper we present the system functionality based on transmission X-ray technique in a tomosynthesis geometry. The system benefits from new technological developments in the domain of X-ray emission devices. We investigate the use of a multiple X-ray source with several emission spots distributed over a large area. This source, under development at Thales, is based on a new beam type composed of carbon nanotubes photocathodes controlled by laser diode. The major difference with a conventional X-ray tube is the possibility of a multiple source without mechanical motion – allowing a tomosynthesis system particularly convenient in the case of a suspicious abandoned luggage. Such a multiple source offers new possibilities but implies new constraints. These aspects have to be considered for the optimisation of the system geometry. This paper focuses on two aspects: system design, and dedicated algorithm development. The different source spots are distributed in a plane parallel to the detector. The corresponding radiographs are combined within a tomosynthesis algorithm that provides a 3D reconstructed volume. The algorithm used is based on a standard shift-and-add step for initialization, followed by a Simultaneous Algebraic Reconstruction Technique (SART). On the reconstructed volume, several figures of merit are evaluated. First, in order to characterize image quality, two criteria are proposed: a depth resolution measurement, and a quantifier of the artifacts induced by the structures outside the focal plane. Second, noise in the final volume is estimated, for a given global acquisition time. Contrary to standard tomosynthesis systems, the transition time from one source location to the successive one can be neglected. Finally, processing time is considered. Using these criteria, the system configuration is optimized in terms of number and location of sources. Then, for the chosen configuration, a dedicated algorithm is implemented. All these studies are done with the help of a simulation software tool developed in our laboratory, able to provide realistic radiographs in any acquisition geometry.

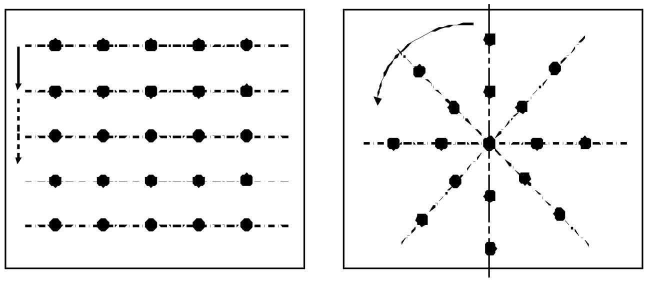

Fig. 1. Optimized geometries for the X-ray source spots: lanetwork" and "star"

2. Tomosynthesis System design. The detector used is typically a flat panel, with approximate dimension 30×40cm. The different source locations are distributed over a plane with a maximum relative distance of 50 cm. The image quality criteria lead us to prefer the "network" shape of source locations – though standard tomosynthesis geometry corresponds to line, cross, or circular trajectories. The number of sources results from the compromise between reconstruction quality and processing time – independently of noise, that depends on the global acquisition time only.

The regular "network" (fig. 1, left) can be achieved with a linear array of carbon nanotubes cathodes under translation motion. The "star" geometry (right) is slightly not as good, but may be of great interest because it presents a static point for power cable. All these configurations are evaluated and compared using our figures of merit. For the "network" geometry, the compromise between quality criteria and calculation time lead to ~ 40 – 50 sources.

3. Dedicated reconstruction algorithm development. First we optimize the reconstruction volume in order to avoid truncature artifacts due to partially imaged large objects. Notice the huge problem size: a luggage of dimensions $600 \times 400 \times 300$ mm^3 corresponds to more than 10 voxels of 0.8 mm size (expected accuracy). Thus we propose a multi-resolution approach to speed up the reconstruction; that consists on a coarse initialization of the reconstruction, then successive iterations from the coarsest scale to the finest scale. A gain in time of a factor five can be reached, with a comparable reconstruction quality. For the considered volume size, the multi-resolution technique finally provides a sufficiently fine result after some minutes; furthermore, the initial coarse result is available very quickly to start the human inspection process while waiting the fine result.

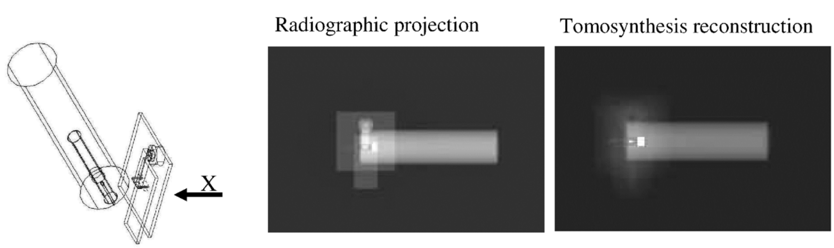

Fig. 2. Example of reconstruction of a hidden detonator (simulation)

4. Results – Summary. The figure 2 illustrates the case of a detonator hidden behind a structured object. On the radiograph, all the internal structures are superimposed. On the reconstructed volume, the detonator is visible. Only one plane is shown, though the result is a volume generally visualized by successive planes parallel to the detector (results at the conference will be presented as films).

In the paper we detail the figures of merit used for the tomosynthesis system design. The different source spots configurations are evaluated and compared taking into account both the capabilities and limits of our emission system. For the optimal configuration, the reconstruction algorithm has been optimized, essentially by implementing a multi-resolution framework to speed up the processing time. Examples will be presented – from simulation and true experiments (a mock-p should be available in 2010).