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X-ray computed tomography system for laboratory small-object imaging: Enhanced tomography solutions

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HIGHLIGHTS

- Characterization of an X-ray tomograph.
- Determination of spatial resolution limit by the MTF.
- Demonstration of 3D examination capability.
- Enhancement of projections by super resolution POCS algorithm.
- Enhancement of 3D image reconstruction by projections sets reorganization.

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ABSTRACT

A portable X-ray tomography system has been installed and actually being tested at our medical imaging laboratory. This tomography system employs a combination of scintillator screen and CCD camera as image detector. The limit of spatial resolution of 290 μm of this imaging system is determined by the establishment of its modulation transfer function (MTF). In this work, we present attempts to address some issues such as limited resolution and low contrast through the development of affordable post-acquisition solutions based on the application of super-resolution method (projection onto convex sets, POCS) to create new projections set enabling the reconstruction of an improved 3D image in terms of contrast, resolution and noise. In addition to small-object examination, this tomography system is used for hands-on training activities involving students and scientists.

1. Introduction

The history of tomography began in 1917 with Radon's work on the determination of mathematical functions from their integrals according to different directions (Radon, 1917). In 1963 and 1964, Allan Cormack published a theory of computed tomography (CT) in the Journal of Applied Physics (Cormack, 1963, 1964). In 1972, the first X-ray scanner was developed by Godfrey Hounsfield and Allan Cormack, both of whom won the Nobel Prize for Medicine in 1979 (Hounsfield, 1973). Computed tomography is currently a well-established technique that enables the 3D examination of an object internal structure by collecting projections over 360° at a constant angular step. Our medical imaging laboratory established an X-ray tomography program for small biological and anatomical specimens to visualize internal structures in 2 and 3 dimensions. A LEYBOLD X-ray tomography system (554821) was recently acquired for such investigations. The first objective of this work is the description and characterization of this tomography system and presentation of the first images obtained. It is well established that the high cost, complexity, and technology (soft and hard) of professional X-ray tomography systems act as a barrier to the adaption of their real-time solutions to small-sized and low-cost tomography systems (such as ours). In this work, we present attempts to address some of these issues, such as limited resolution, through the development of affordable post-acquisition solutions based on the application of POCS super-resolution method to create a new set of projections enabling the reconstruction of an improved 3D image.

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2. Materials and methods

This tomography system records X-ray-illuminated 2D projections of an object over the span of a few minutes. The acquisition and processing of projections are ensured by the software provided with the tomography system (Tomodensitométrie, Version 1.12.4693, LEYBOLD GmbH, Germany). After a scan, the complete 3D object image is automatically reconstructed and can be slightly improved using certain filtering and image processing functions. This 3D image can also be analyzed using different tools, such as through varying the transparency and intensity, in addition to virtual color mapping and image illumination from different angles. Relatively resolved and contrasted images of various small objects can be obtained with this tomography system but these images cannot be compared with those obtained using professional medical tomography systems. Post-acquisition processing methods are proposed to enhance the quality of these images in terms of resolution and contrast and to overcome limitations due to the simple measurement method and the low X-ray radiation energy (35 kV). These methods enable qualitative and quantitative evaluation of the reconstructed images.

2.1. Hardware

As shown in Fig. 1, the used tomography system consists of two juxtaposed modules (an X-ray source and object holder module and a detector module) with a nominal spatial resolution of ~250 μm and an angular resolution of up to 0.5°. The X-ray source is a commercially available 35 W Tungsten anode tube with a thin beryllium window, a maximum voltage of 35 kVp and a maximum anode current of 1 mA. The X-ray tube is mounted on a stable table for vibration isolation and housed in a tin-doped Plexiglas radiation enclosure. The scanning process and data acquisition are controlled via a Windows XP workstation.

A scintillator screen and CCD based detection system are used for projection capturing. The detection system employs an ENEO VKC-1376 CCD array (12 bits) with an active area of 350 × 350 pixel elements and a pixel size of 23 × 23 μm^2. The detector provides a spatial sampling of ~25 μm in the center of the field of view (FOV) due to the cone-beam configuration of the system. Although the CCD-based detector does not measure individual X-ray energy, it provides substantially improved statistics due to its charge integration mode of operation. With the CCD-based detector, a projection is acquired in 0.5–1 s. For low-resolution tomography (~180 projections), a data set is acquired in ~3 min; higher resolution data sets (~360 projections) are acquired in ~6 min. The tomography system's spatial resolution is limited by the pixel sampling rate, the X-ray source size, the source-to-scintillator screen distance, and blurring due to the thickness of the scintillator-screen (Jespers et al., 1976; Samei et al., 2005). In this work the spatial resolution limit is determined through the establishment of the MTF of the system according to the ISO 12233 standard which presents the general methodology for performing MTF measurements based on the slanted-edge method (Kharfi et al., 2012). Fig. 2 shows the calculated contribution of the above mentioned components to the MTF of the system. The limit of

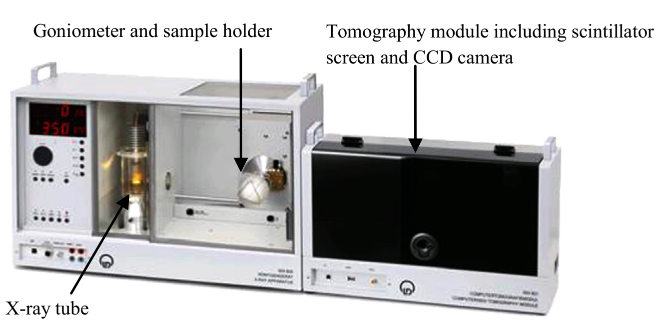

Fig. 1. X-ray tomography system.

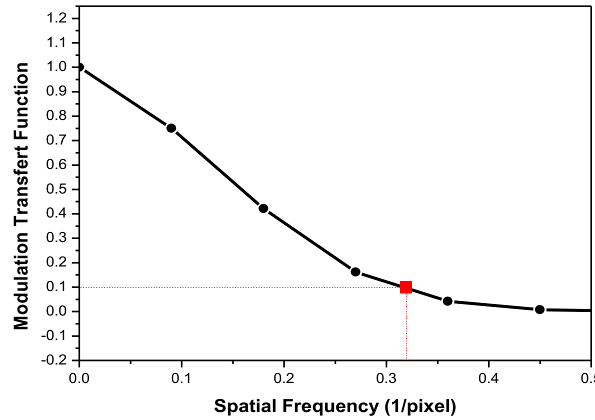

Fig. 2. Modulation transfer function of the scintillator screen/CCD detector.

Table 1
Main technical data of the tomograph.

Characteristics	Main values
Maximum object size	8 × 8 × 8 cm^3
Optimal object resolution	~250 μm (for best exposure conditions)
Angular resolution	1–720 2D projections per computed tomogram
Size of the computed tomogram	350 × 350 pixels per projection
Separate video output	Cinch (CCIR)
Pixel physical size	~23 × 23 μm^2
Focal spot size	2 mm^2
Minimum incremental step of the goniometer	0.1°

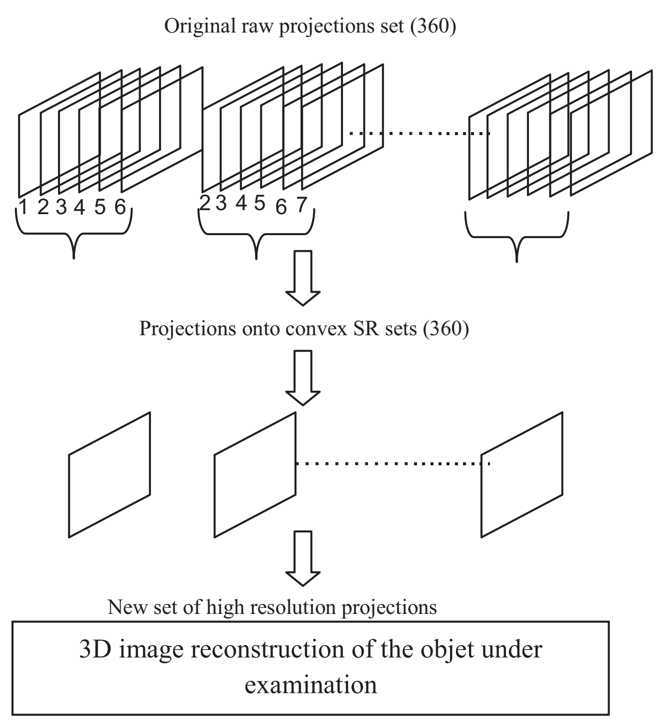

Fig. 3. Diagram of the super resolution reconstruction algorithm which include raw projections subsets creation, convex onto convex sets, creation of new SR projections set and reconstruction of 3D volume of the object under examination.