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Feasibility study for image reconstruction in circular digital tomosynthesis (CDTS) from limited-scan angle data based on compressed-sensing theory

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ABSTRACT

In this work, we performed a feasibility study for image reconstruction in a circular digital tomosynthesis (CDTS) from limited-scan angle data based on compressed-sensing (CS) theory. Here, the X-ray source moves along an arc within a limited-scan angle ($\leq 180^{\circ}$) on a circular path set perpendicularly to the axial direction during the image acquisition. This geometry, compared to full-angle (360°) scan geometry, allows imaging system to be designed more compactly and gives better tomographic quality than conventional linear digital tomosynthesis (DTS). We implemented an efficient CS-based reconstruction algorithm for the proposed geometry and performed systematic simulations to investigate the image characteristics. We successfully reconstructed CDTS images with incomplete projections acquired at several selected limited-scan angles of 45°, 90°, 135°, and 180° for a given tomographic angle of 80° and evaluated the reconstruction quality. Our simulation results indicate that the proposed method can provide superior tomographic quality for axial view and even for the other views (*i.e.*, sagittal and coronal), as in computed tomography, to conventional DTS.

1. Introduction

Digital tomosynthesis (DTS) is currently considered in clinic as a standard or the next-generation X-ray imaging modality since it yields a three-dimensional (3D) image with imaging doses comparable to conventional radiography [1–5]. In current DTS, the X-ray source typically moves along a line segments or a circular arc set in a longitudinal plane around the object during the projection acquisition, and a computationally-efficient filtered-backprojection (FBP) method is often used for image reconstruction. Typical examination protocols, for example, in digital breast tomosynthesis, acquire only 10–30 projections over a tomographic angle range of 15°–60° with a stationary detector. Thus, it results in tomographic quality only in axial view; the reconstruction quality in the other views (*i.e.*, sagittal and coronal) is usually inferior to that in the axial view due to the missing data in the scan direction on the Radon space [6].

To overcome these difficulties, Pelc et al. recently revisited the circular source trajectory in DTS with an experimental system by mounting a flat-panel detector onto a mobile C-arm system [7–9]. In addition, Thran et al. proposed a new concept of X-ray tube geometry, the so-called *circular* X-ray tube, which is equipped with a series of cathodes distributed around a rotating anode, enabling a *circular* DTS (CDTS) geometry [10]. Fig. 1 shows schematic illustrations of a CDTS geometry (*not to scale*): (a) side view and (b) top view. Here, the X-ray source moves along a circular path set perpendicularly to the axial direction at a given tomographic angle while the detector remains stationary during the projection acquisition. In this study, for considerations of practical uses, we limited the scan angle below 180° to allow imaging system to be designed more compactly, compared to full-angle (360°) scan geometry. However, in this case, the projection data are theoretically insufficient for exact image reconstruction, giving algorithmic challenges for accurate reconstruction. In recent years, with amazing advances in foundational mathematical theory, the-so-called *compressed-sensing* (*CS*), the development of reconstruction algorithms from incomplete data has received growing attention during the last decade [11]. In the following sections, we briefly describe the implementation of the CS-based algorithm for CDTS reconstruction and we present the simulation results.

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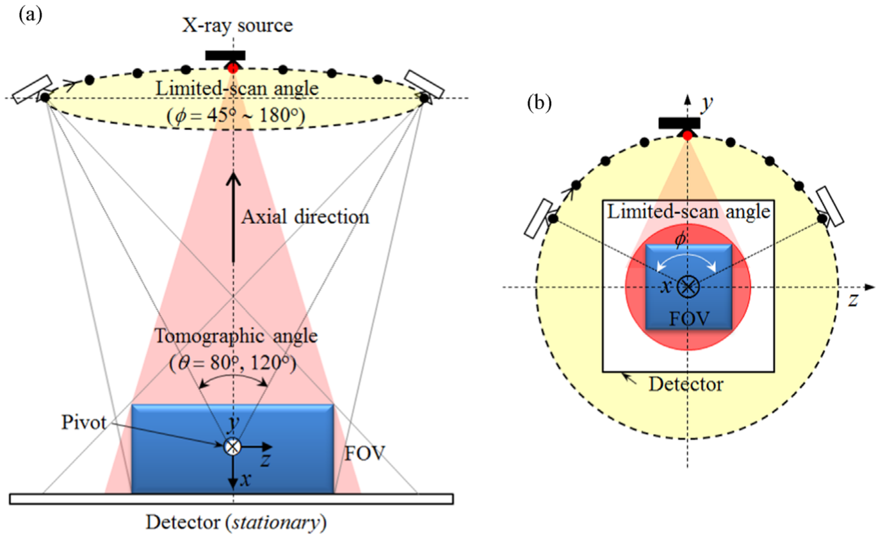

Fig. 1. Schematic illustrations of a CDTS geometry (*not to scale*): (a) side view and (b) top view. Here, the X-ray source moves along an arc within a limited-scan angle ($\phi \le 180^\circ$) on a circular path set perpendicularly to the rotational axis at a given tomographic angle.

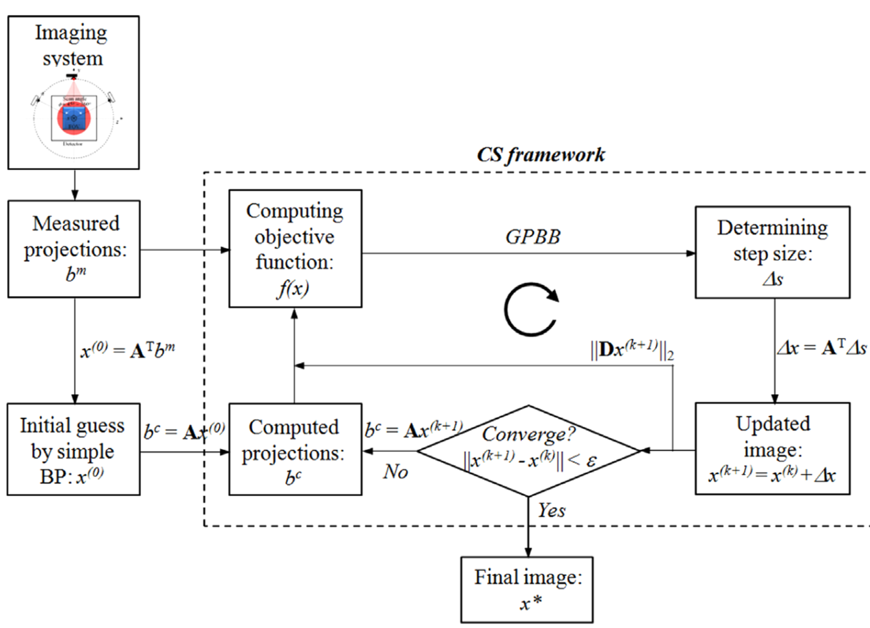

Fig. 2. Simplified flowchart of the CS-based image reconstruction procedure. This shows the simplified flowchart.

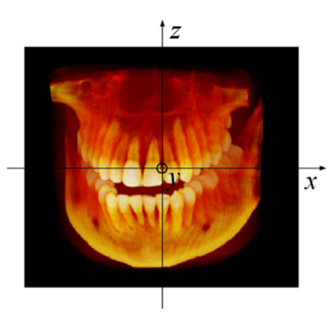

Fig. 3. A numerical mouth phantom used in the simulation. The voxel dimension of $100 \times 100 \times 100$ was selected for saving reconstruction time.

2. Materials and methods

The physical formation of X-ray projections can be modeled approximately by a discrete linear system as follows:

$$\mathbf{A}x = b, \tag{1}$$

where x is the original image vector to be reconstructed, b is the measured projection vector, and $\mathbf{A}$ is the system matrix, relating x and b. In the CS framework, x is normally recovered as an optimal solution, x^*, by minimizing the following convex objective function, $f(x)$, assuming that most components of derivative images are