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Feasibility study on low-dosage digital tomosynthesis (DTS) using a multislit collimation technique

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A B S T R A C T

In this study, we investigated an effective low-dose digital tomosynthesis (DTS) where a multislit collimator placed between the X-ray tube and the patient oscillates during projection data acquisition, partially blocking the X-ray beam to the patient thereby reducing the radiation dosage. We performed a simulation using the proposed DTS with two sets of multislit collimators both having a 50% duty cycle and investigated the image characteristics to demonstrate the feasibility of this proposed approach. In the simulation, all projections were taken at a tomographic angle of $\theta = \pm 50^{\circ}$ and an angle step of $\Delta\theta = 2^{\circ}$. We utilized an iterative algorithm based on a compressed-sensing (CS) scheme for more accurate DTS reconstruction. Using the proposed DTS, we successfully obtained CS-reconstructed DTS images with no bright-band artifacts around the multislit edges of the collimator, thus maintaining the image quality. Therefore, the use of multislit collimation in current real-world DTS systems can reduce the radiation dosage to patients.

1. Introduction

Digital tomosynthesis (DTS) is an X-ray imaging method that produces three-dimensional (3D) multiplanar images using limited angular range scanning. This popular technique has been used in a variety clinical applications such as mammographic imaging, chest imaging, and dental imaging due to the fact that it provides computed tomography (CT) benefits at a reduced radiation dose and scan time [1,2]. Digital breast tomosynthesis (DBT), in particular, is becoming a standard mammographic examination protocol, rather than an option, in clinical practice [3,4]. As DBT clinical use grows, radiologists are continuously seeking ways to reduce the radiation dosage to patients. In fact, there is a consensus among radiologists that image quality should not be the only parameter considered when imaging patients and that every imaging technique should be performed at the lowest possible radiation dose [5,6]. In the CT community, numerous methods for radiation dose reduction have been extensively studied, including sparse-view CT [7], region-of-interest (ROI) CT [8], and low-dosage CT [9]. A review of these methods can be found in [10]. Among these reduction methods, sparse-view CT is a promising method that can be directly applied to DTS to reduce patient radiation dosage. In sparse-view CT, fewer projections, typically less than 100, are taken from the CT system due to fast power switching of the X-ray tube. However, the fast power switching technique can be challenging to implement in current CT systems. As an alternative, Cho et al. has recently proposed a multislit collimation technique where a multislit collimator placed between the X-ray tube and the patient oscillates during projection data acquisition, partially blocking the X-ray beam to the patient thereby reducing the radiation dosage [11].

In this study, we employed the multislit collimation technique with sparse-view CT to evaluate its potential in reducing patient radiation dosage. Fig. 1 shows the schematic illustration of the proposed DTS. In the system, a multislit collimator moves back and forth along the scanning direction during projection data acquisition. We performed a systematic simulation using the proposed DTS and investigated the image characteristics to demonstrate the feasibility of the proposed approach. Our simulation results indicate the use of the multislit collimation technique in DTS reduces the radiation dosage to patients.

2. Material and methods

The multislit collimator in the proposed DTS partially samples projection data in the detector array for all the projection angles. Fig. 2

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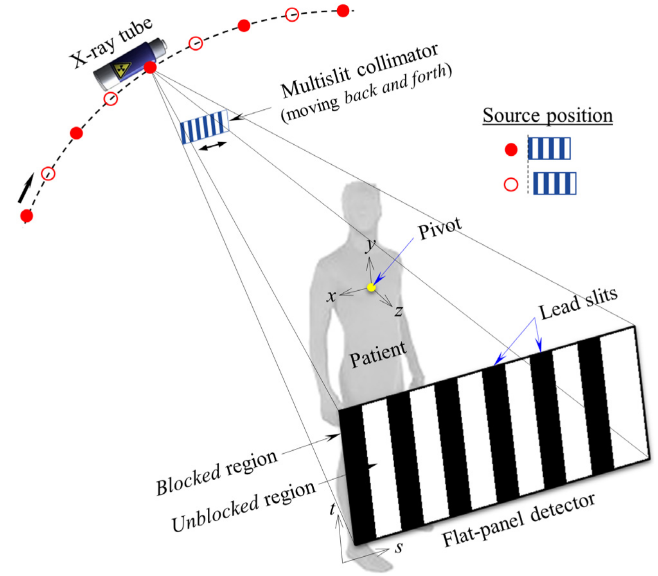

Fig. 1. The schematic illustration of the proposed DTS with a multislit collimator that moves back and forth along the scanning direction during the projection data acquisition, partially blocking the X-ray beam to the patient thereby reducing the radiation dosage.

shows the two sets of multislit collimators designed for the simulation: (a) C(20/20) and (b) C(60/60). Here C(20/20) denotes the collimator layout that blocks the X-ray beam over 20 detector pixels vertically with a 20-pixel interval. The duty cycle of the multislits is 50% (*i.e.*, half opening) for both collimator layouts. Thus, half of the fully sampled data is available for DTS image reconstruction. As indicated in Fig. 2, the width of the multislits, w_{slit}, is designated by

$$w_{slit} = \frac{n_{colli} \cdot d}{M_{colli}}, \tag{1}$$

where n_{colli} is the number of detector pixels blocked by each slit (*e.g.*, n_{colli} = 20 and 60), d is the detector pixel size, and M_{colli} is the collimator magnification. For example, when d = 0.198 mm and M_{colli} = 15, the widths of the multislits for the C(20/20) and C(60/60) collimator layouts are 0.264 mm and 0.792 mm, respectively. The oscillation distance of the multislit collimators is the same as the slit width. The radiation dose required in the proposed DTS scan will be reduced by

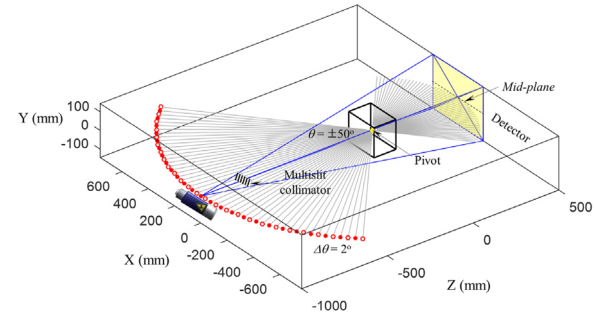

Fig. 3. The actual dimensions of the DTS configuration used in the simulation. The source-to-detector distance (*SDD*) is 1500 mm and the pivot-to-detector (*PDD*) is 500 mm. All projection data was taken at a tomographic angle of $\theta = \pm 5°$ and an angle step of $\Delta\theta = \pm 2°$.

the same duty cycle ratio, compared to that in a full DTS scan with no collimator.

Fig. 3 shows the actual dimensions of the DTS configuration used in the simulation. The source-to-detector distance (*SDD*) is 1500 mm and the pivot-to-detector (*PDD*) is 500 mm. All projection data was taken at a tomographic angle of $\theta = \pm 50°$ and an angle step of $\Delta\theta = 2°$. Fig. 4 shows (a) the 3D numerical chest phantom (128 × 192 × 160) used in the simulation and (b) the physical skull phantom (*left*) used to experimentally acquire the dental CT data (*right*) in the simulation. The numerical chest phantom was originally produced by Kramer et al. at the University of Pernambuco [12]. The skull phantom dental CT data was reconstructed by using the filtered-backprojection (FBP) algorithm with all 669 available projections from the commercially-available dental cone-beam CT.

Conventional DTS images are typically reconstructed with fully sampled data by using the FBP algorithm. However, this often produces relatively poor image quality mainly due to limited angular DTS sampling. Furthermore, the projection data available for image reconstruction in the proposed DTS is only half of the fully sampled data, which results in under-sampling related artifacts in the FBP-reconstructed images. Thus, it was necessary to develop an advanced reconstruction algorithm for the proposed DTS. Due to the rapid advances in computer technology, iterative algorithms are often used in DTS reconstruction. Further, the advances in the compressed-sensing (CS) mathematical theory over the last decade has led to the development of 3D reconstruction algorithms from sparse-view and/or limited angle-view data, as in DTS [13,14].

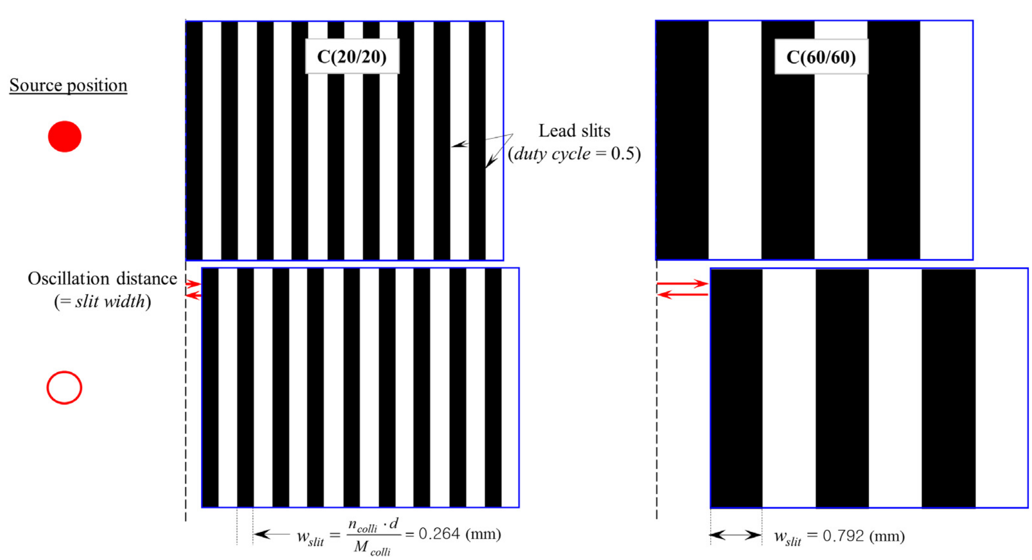

Fig. 2. The two sets of multislit collimators designed for the simulation: (a) C(20/20) and (b) C(60/60). Here C(20/20) denotes the collimator layout that blocks the X-ray beam over 20 detector pixels vertically with a 20-pixel interval. The duty cycle of the multislits is 0.5 for both collimator layouts.