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Impulse response in various scanning geometries for digital tomosynthesis

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1. Introduction

Digital tomosynthesis (DTS) is a three-dimensional imaging technique to reconstruct a set of planes in the object. Opposed to the computed tomography (CT), however, DTS uses projection images obtained from limited angular scanning [1], hence there exist some artifacts such as blurs that are originated from depletion of data in the Fourier domain. The main advantages of DTS technique are shorter reconstruction time and less patient dose.

There are various geometries for angular scanning available in DTS, and which is mainly dependent upon specific imaging task and applications, such as mammography, dental imaging, industrial laminography etc. In principle, DTS shares the same concept in imaging reconstruction with the conventional CT, and thus incorporates a back-projection operation. This back-projection operation determines the transfer function, which is mainly resulted from the scanning geometry, if we regard the image reconstruction as an inverse problem. Therefore, the investigation of impulse response with respect to various imaging geometries is valuable to identify artifacts associated with the scanning geometry and thus optimize the system performance.

We investigate and compare the system-transfer functions (impulse-response functions) for various image acquisition schemes to acquire projection data by numerical simulation. This study may suggest fundamental limitations of a certain scanning geometry and provide the best geometry with least blur artifacts.

2. Methods and Results

2.1 Scanning geometries for DTS

Fig. 1 schematically demonstrates possible scanning geometries for DTS. Fig. 1-(a) shows the linear motion that consists of stationary imaging detector and x-ray tube moving horizontally onto detector plane. A linear scan requires relatively short data acquisition time, but it is difficult to reconstruct clear images because little information in the three-dimensional Fourier space is acquired.

In the partial iso-centric scanning geometry as shown in Fig. 1-(b), the x-ray tube moves around pivot point with arc trajectory. This scanning geometry has several advantages especially for mammography. There are no moving parts near the breast or abdomen. Existing mammography machines can be easily extended to allow DTS function. Fig. 1-(c) shows the circular geometry. The x-ray tube and imaging detector rotates around object upper and lower, respectively [3].

There are several parameters to determine the imaging geometry such as number of views and total scan angles. Hence the blur characteristics which describe the impulse response function of DTS system, are mainly dependent on imaging geometry and parameters.

2.2 Numerical simulation

Impulse response analysis is an important method for comparison of performances of imaging systems. In the space domain, impulse responses represent simple and intuitive artifact corresponding to the width of response function. In the frequency domain, the Fourier transformation of impulse response corresponds to modulation transfer function (MTF), which can describe the spatial resolution [1].

To investigate the effect of variation in scanning geometry and total scan angles on impulse responses, we have carried out numerical simulation. In this study, we used ball phantom as input impulse signal and investigated blur in the reconstructed planes. Phantom dimensions are $512\times 512\times 512$ voxels, each voxel is 0.0156 mm in length and thus 1mm of ball radius.

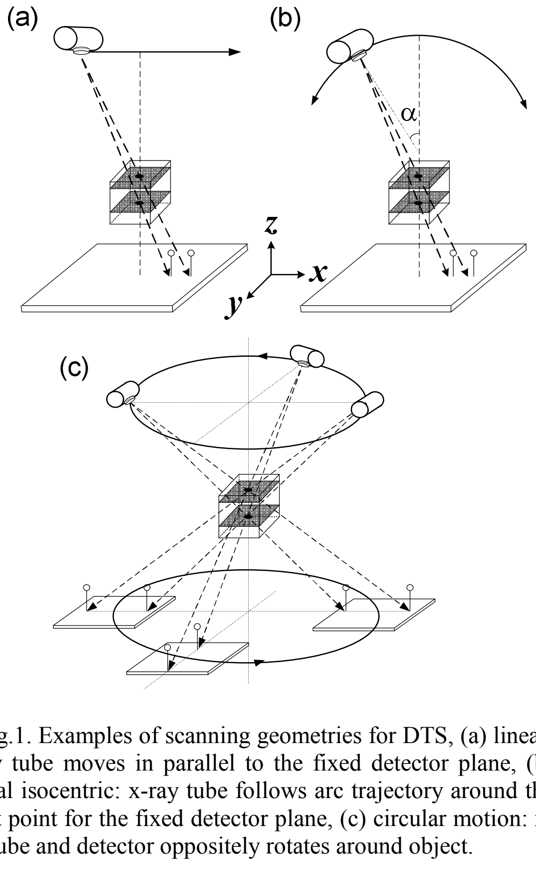

Fig.1. Examples of scanning geometries for DTS, (a) linear: x-ray tube moves in parallel to the fixed detector plane, (b) partial isocentric: x-ray tube follows arc trajectory around the pivot point for the fixed detector plane, (c) circular motion: x-ray tube and detector oppositely rotates around object.

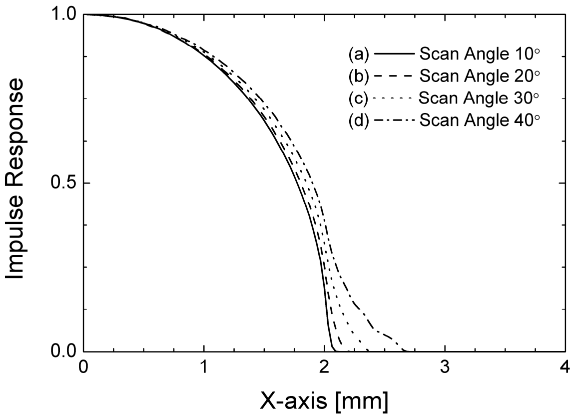

Fig.2. Example of impulse response for partial isocentric scanning geometry. (a)-(d) are impulse responses in the in-plane at 10°,20°,30° and 40° scanning angles, respectively.

Location of impulse signal is defined at the reconstructed plane (250 mm above the detector plane). The source-to-detector distance was set to 500 mm. The scan angles are ± 10°, 20°, 30° and 40° with a fixed 11 views. Reconstruction method is simple shift-and-add method.

Fig. 2 shows the results of numerical simulations. Fig. 2-(a)-(d) show the impulse response functions at in-plane for 10°,20°,30° and 40° scan angles, respectively. The x-axis represents the direction of x-ray tube motion. From the results, the width of response function increases with wider scan angle.

For quantitative comparison, we measured full width at half-maximum (FWHM) values of response functions. Table I shows the FWHM values of impulse responses at the in-plane along tube motion direction (x-axis). The calculated FWHM values represented amount blur artifacts [4].

3. Conclusions

It is inevitable that blur artifacts occur from scanning motion during the acquisition of projection images. Therefore, characterization of blur effects with impulse response analysis may derive an advancement of de-blurring technique.

In this study, we only measured FWHM of response function, however, it is feasible to calculate two-dimensional MTF and figure out blurring function in various scanning geometries. Impulse responses analysis of the other scanning geometry will be performed.

Table I . FWHM in the in-plane impulses at 10°,20°,30°, and 40° scanning angles, respectively.

Scan Angle (°)	FWHM (mm)
10	3.5000
20	3.5626
30	3.6250
40	3.7500

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