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Image enhancement for computed tomography using directional interpolation for sparsely-sampled sinogram

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ABSTRACT

This paper presents an image enhancement for computed tomography (CT) using a directional sparsely-sampled sinogram interpolation. In CT scanning, radiation exposure to human tissues needs to be minimized. Naturally reducing radiation dose has been discussed in various approaches. Among them, a sparsely-sampled sinogram is an effective approach to minimize radiation dose itself in CT scanning. However, less radiation in CT scanning provide a poor image quality since reconstructed images suffer from the streak artifact due to lack of X-ray views. To reduce the streak artifact, an efficient sinogram interpolation method needs to be studied. In this paper, to enhance image quality, we propose a novel sinogram interpolation based on directional information. To do this, a directional interpolation from deinterlacing is introduced and applied to sinogram interpolation efficiently. To evaluate the proposed method, experiments with a simulated phantom and clinical CT images are carried out. The results indicate that the proposed sinogram interpolation method outperforms the existing interpolation methods in terms of image quality.

1. Introduction

The X-ray computed tomography (CT) is a radiological imaging technique to produce cross-sectional images of a three-dimensional (3D) object [1]. This technique has been successfully applied to various areas such as medical imaging due to its usefulness. In order to produce sectional images in medical imaging, an assembly of an X-ray source and detectors rotates around the body of a patient. While rotating, an array of detectors then measures the attenuation owing to the absorption of X-ray energy by tissues. The data acquisition of X-ray computed tomography results in two-dimensional (2D) data, which is called as sinogram. As depicted in Fig. 1, a sinogram image is an array of rotational projections. It is composed of line projections by a parallel or fan beam X-ray for every rotational angle. CT images for diagnosis are then obtained from the sinogram by reconstruction methods such as back-projection, filtered back-projection, and so on. The conventional back-projection algorithm can simply reconstruct cross-sectional images as an inverse process of the rotational projection. However, the back-projection leads to a blurring artifact in the reconstructed images [2]. To exactly reconstruct cross-sectional images from the rotational projection data, the Radon transform and its inverse transform provide mathematical basis. The reconstruction algorithm based on the Radon transform is called the filtered back-projection (FBP) [3,4]. As computing power increase, more complicated methods have been developed, such as algebraic reconstruction techniques

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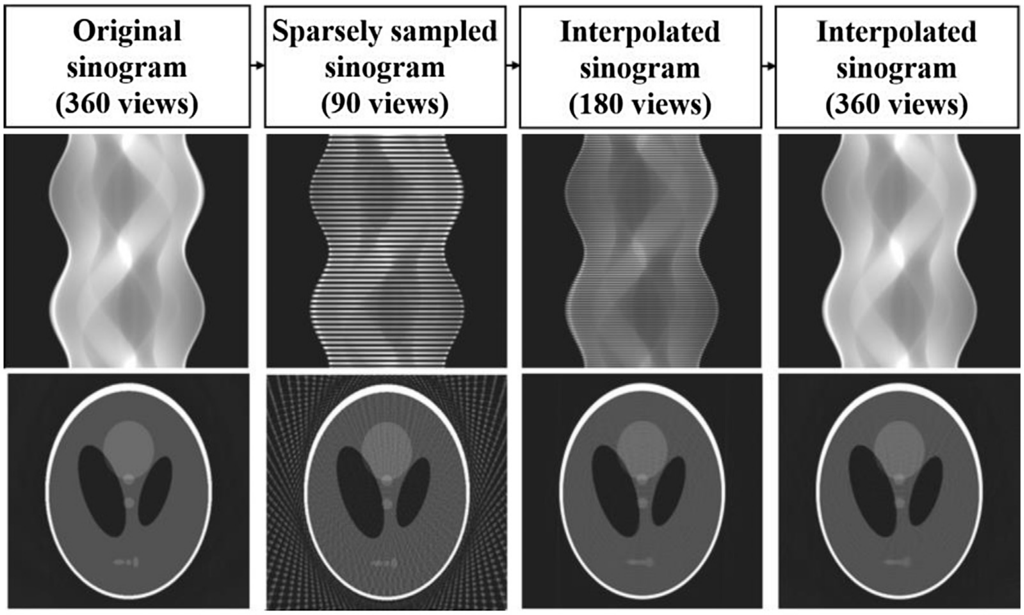

Fig. 1. Illustration of sinogram interpolation. The upper images are sinograms and lower images are their reconstructed images by a filtered back-projection method.

(ART), adaptive statistical iterative reconstruction (ASIR), iterative reconstruction in image space (IRIS), and adaptive iterative dose reduction (AIDR) [5–8].

As the CT technique is enhanced, it is more frequently used for patient diagnosis. Also, a concern for medical radiation exposure has been raised [9]. Thus, methods are required to minimize radiation dose while maintaining image quality. There are largely two approaches for the reducing radiation dose in CT scans: one is reducing dose per view while keeping the number of views the same, the other is reducing the number of views while keeping dose per view the same. The former is a simple method for reducing radiation dose. However, it has low-contrast and excessive noises so that reconstructed images are severely degraded. On the other hand, the latter is a method to reduce radiation exposure by decreasing the number of views; that is, it just increases sampling intervals to decrease the number of views. However, insufficient views cause the streak artifacts. To remedy this problem, a method for generating additional views is required, which is of interest in this paper, as illustrated in Fig.1.

Sinogram interpolation is defined as estimating intermediate projection data for uniformly spaced projection data, shown in Fig. 1. Thus, sinogram interpolation mainly focuses on interpolating the half location between two line data, called as 2-times interpolation. Normally, a 2-times interpolation method to extract a sample at the half location between two samples is much simpler than a general interpolation method to extract a sample at arbitrary location. Also, directional information can be easily applied to the 2-times interpolation with less complexity. A recursive use of a 2-times interpolation provides 4-times interpolation, 8-times interpolation, and so on.

A sparsely sampled sinogram is also considered as a sinogram of missing or corrupted data which are usually caused by detector faults or mechanical damages. Those physical problems create various noise patterns in reconstructed images, such as line patterns, ring patterns, diamond patterns, and so on. To remedy the problem, restoration methods to recover the missing or corrupted data in a sinogram are also studied [10–15]. These methods also are effective to remove diamond in the high-resolution positron emission tomography (PET) [12–15].

To estimate the immediate views in a sparsely-sampled sinogram, the linear interpolation and intermediate view projection (IVR), scene-based interpolation methods have been discussed in the literature [16–24]. Moreover, some sinogram recovery methods are addressed using a sinusoidal Hough transform, a structure tensor in cone beam data, and total variation [25–27]. Although the methods can be employed to generate intermediate views, they are computationally expensive because they are mainly focused on gap-filling or artifact-removing. Consequently, another design is required to efficiently interpolate uniformly missing lines in a sinogram.

As a sinogram interpolation to uniformly generate immediate views, systematic interpolation methods are useful to improve image quality in various image systems such as 3D imaging, deinterlacing, and so on [28–32]. A deinterlacing method is a technique to convert an interlaced video sequence in a line-by-line fashion. This line-based technique is very similar to a sinogram interpolation technique.

In this paper, we introduce an image enhancement method for CT images via directional sinogram interpolation. The proposed method is based on the DOI method for an efficient interpolation method of a sparsely-sampled sinogram. The DOI method is well-known for its ability to accurately detect low angles over a long-range. Thus, we propose a novel