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Towards dose reduction for dual-energy CT: A non-local image improvement method and its application

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ABSTRACT

Dual-energy CT (DECT) has better material discrimination capability than single-energy CT. In this paper, we propose a low-dose DECT scanning strategy with double scans under different energy spectra. In the strategy a low-energy scan is performed with a complete number of views, and the high-energy scan is in much sparser views to reduce radiation dose. In such conditions, the high-energy reconstruction image suffers from severe streak artifacts due to under-sampling. To address this problem a novel non-local image restoration method is proposed. Because the low and high energy scans are performed on the same object, the reconstructed images should have identical object structures. Therefore the low-energy reconstruction that comes from the complete scan may serve as a reference image to help improving the image quality of the high-energy reconstruction. The method is implemented with the following steps. First, the structure information is obtained by a non-local pixel similarity measurement on the low-energy CT image, and second after a registration between the high and low reconstructions the high-energy image is restored by normalized weighted average using the calculated similarity relationship. Compared with previous methods, the new method achieves better image quality in both structure preservation and artifact reduction. Besides, the computation is much cheaper than iterative reconstruction methods, which makes the method of practical value. Numerical and pre-clinical experiments have been performed to illustrate the effectiveness of the proposed method. With the novel DECT scanning configuration and non-local image restoration method, the total dose is significantly reduced while maintaining a high reconstruction quality.

1. Introduction

The technique of dual-energy CT (DECT) was first introduced by Alvarez in 1976 [3], which provides more information about the scanned materials and has better performance in material discrimination compared with conventional CT system [1]. The basic idea of DECT is that materials absorb X-Ray emission at different strengths with respect to X-ray energies. Initial investigations of dual energy were in bone mineral analysis, quantification of hepatic iron and calcium in pulmonary nodules, and for the differentiation of various tissues [1]. In clinical application, DECT dose not only provides excellent morphologic detail but also material-specific and quantitative information that may be helpful for clinical diagnosis [2].

The initial DECT imaging depends on dual-exposure, with different X-ray energy spectrums. Later, a practical dual-energy system equipped with a double-layer detector was proposed. However the drawback of such detector is the poor spectral separation that results in large errors on the reconstructed images. In 2005, Siemens launched their first clinical DECTSOMATOM definition, which generates two spectra by installing two X-ray tubes in one CT gantry [4]. Besides the material discrimination, the temporal resolution was also improved. It provides images of exceptional quality to explore new clinical opportunities as reported [5]. The dual-source DECT composed of two X-ray tubes and two detectors arranged at an angular off-set on the rotating gantry (see Fig. 1) was recognized to have better image quality. When the two X-ray tubes operate at different tube voltages, two different X-ray spectra are simultaneously obtained; this gives rise to dual-energy tissue characterization. Due to the angular off-set of the tube–detector combinations, image registration is needed and dual-energy decomposition has to be performed in the image space. With the rapid development of DECT technique, a lot of research work has been focused on DECT image reconstruction methods [6–9]. Because CT images are dependent on the X-ray voltage, X-ray energy spectrum, the density of the material

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through which the beam passes, and so on, possible assumptions can be made based on them.

As reported, the dual-source DECT system demonstrates higher dose efficiency as compared to former single-energy CT system [10]. Thus, it does not need additional radiation dose to achieve similar image quality as that of conventional single-source CT. However, the dose of current DECT scan still remains at a high level and becomes a significant concern in clinical applications, especially for sensitive organs and populations. Recent studies indicate that dose from CT scans may have an attributable risk of cancer higher than previously assumed [11]. CT radiation dose reduction has been an area of active research in CT imaging. To further reduce the radiation dose in dual-source DECT, in this paper we propose a novel scanning configuration which performs the high-energy scan with much sparser views than those of the low-energy scan. The two tubes of DECT rotate simultaneously; however they work on different voltages and pulse frequencies in generating dual-energy X-ray. The low-energy X-ray tube scans the object with normal dose while the high-energy scans the object with lower dose because of the sparse projection. The novel dual-source DECT scanning configuration is shown in Fig. 2.

It is reported that reducing the number of projection views leads to a challenging task for image reconstruction and optimization [12]. When the projection views are sparsely sampled, the analytic reconstruction algorithms which require densely sampled projection

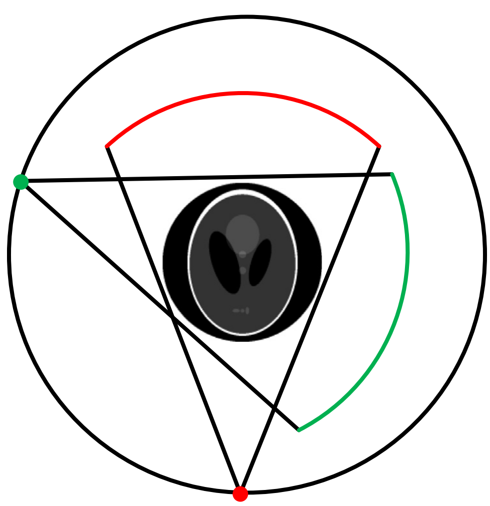

Fig. 1. The dual-source DECT scanning geometry with two X-ray tubes.

views will result in prominent streak artifacts. In the proposed scanning configuration, the low-energy reconstruction retains a high image quality while the high-energy reconstruction will suffer from severe under-sampling artifacts. However, in DECT the low-energy and high-energy attenuation map should have the same structure and edge information (or after an image registration process) as they represent the same object. Based on this prior knowledge, we propose a non-local image restoration scheme for this kind of scanning configuration, which effectively reduces the artifacts and preserves the structures and edges. Experiments with clinical datasets are provided in this paper. The proposed scheme is a post-processing method for image artifact suppression and noise reduction, which is implemented after CT reconstruction. This method establishes a relationship between the low-energy and high-energy reconstructions with their structure similarity information. Specifically, the high-quality low-energy reconstruction serves as a reference image in this non-local processing method. Compared with the previous iterative reconstruction methods, it achieves better results while maintaining a very low computation cost.

This paper is organized as follows. Section 2 introduces some well-known sparse-view reconstruction methods, especially the compressed sensing based methods. After that, the proposed method is established which is named as structure similarity constrained optimization method. In the following section (Section 3) numerical and pre-clinical experiments are presented as well as a comparison study with compressed sensing based method. In the last section, discussions are given and the whole paper is concluded.

2. Background and methodology

2.1. Previous methods for sparse-view image reconstruction

Reducing the number of projection views in CT scan is one of the common means to reduce radiation dose. However a few-view scan usually leads to prominent streak artifacts which degrades the image quality significantly. To suppress such artifacts, different methods have been proposed. The most attractive and popular methods are based on compressed sensing theory, which reconstructs image by solving a constrained minimization problem on images' total variation (TV). In 2006 Sidky introduced TV minimization method to few-view CT reconstruction, demonstrating that accurate image reconstruction from highly sparse-sampled projection views may be achievable [13]. Accordingly an adaptive steepest descent projection onto convex sets (ASD-POCS) algorithm was proposed which makes the TV minimization method

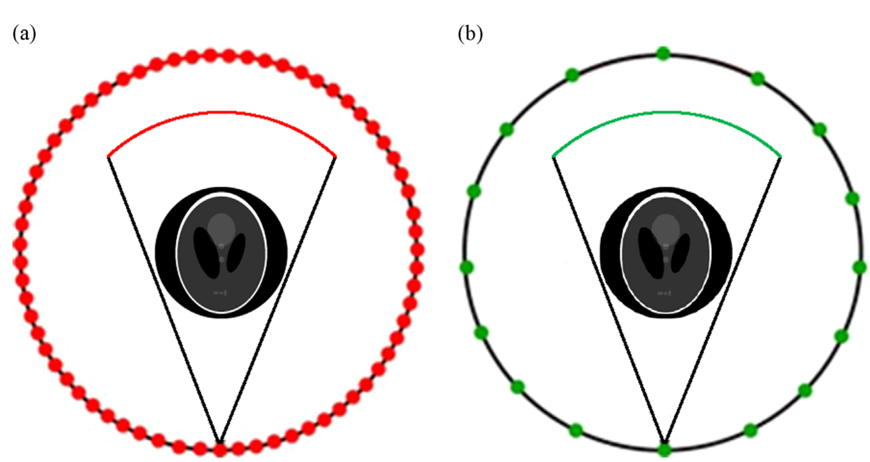

Fig. 2. The proposed low-dose DECT scanning configuration; (a,b) represent the low and high energy X-ray scanning respectively. The low-energy X-ray tube rotates around the object and generates X-ray with full angular sampling while the high-energy X-ray tube scans the object with a few-view sampling.