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Probabilistic atlas prior for CT image reconstruction

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ABSTRACT

Background and objectives: In computed tomography (CT), statistical iterative reconstruction (SIR) approaches can produce images of higher quality compared to the conventional analytical methods such as filtered backprojection (FBP) algorithm. Effective noise modeling and possibilities to incorporate priors in the image reconstruction problem are the main advantages that lead to continuous development of SIR methods. Oriented by low-dose CT requirements, several methods are recently developed to obtain a high-quality image reconstruction from down-sampled or noisy projection data. In this paper, a new prior information obtained from probabilistic atlas is proposed for low-dose CT image reconstruction.
Methods: The proposed approach consists of two main phases. In learning phase, a dataset of images obtained from different patients is used to construct a 3D atlas with Laplacian mixture model. The expectation maximization (EM) algorithm is used to estimate the mixture parameters. In reconstruction phase, prior information obtained from the probabilistic atlas is used to construct the cost function for image reconstruction.
Results: We investigate the low-dose imaging by considering the reduction of X-ray beam intensity and by acquiring the projection data through a small number of views or limited view angles. Experimental studies using simulated data and chest screening CT data demonstrate that the probabilistic atlas prior is a practically promising approach for the low-dose CT imaging.
Conclusions: The prior information obtained from probabilistic atlas constructed from earlier scans of different patients is useful in low-dose CT imaging.

1. Introduction

X-ray computed tomography (CT) has evolved into an essential imaging modality in clinical routines. It is hard to find a hospital that has no in-duty CT imaging equipments worldwide. Clinical diagnostic applications of CT are known as high-dose imaging techniques compared to the conventional plain-film radiography. The extensive use of CT scanning leads to a notable increase of the average patient dose and, consequently, increases possibilities to produce malignancy. The side effects of the radiation dose generated from CT scans become a concerning topic for further investigations. Although it is not yet strictly proven that regular CT scans may lead to malignancy, it is estimated that a rough of 2% of cancers may eventually be caused by the average radiation dose

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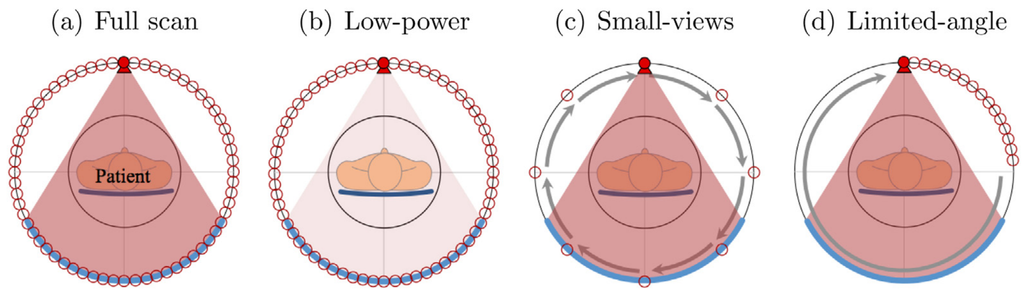

Fig. 1 – Different CT imaging configurations. Small red circles indicate possible X-ray tube positions during data acquisition. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

currently used in clinical CT [1]. Moreover, cancer lesion in radiosensitive organs such as lungs is correlated to relatively low dose of 100 mGy [2]. It is estimated that about 75% of the collective dose from radiology is resulted from high-dose procedures such as CT in which organ doses are large enough to confirm a significant evidence on cancer risk increase [3]. The optimization of hardware factors such as scanning geometry, tube current and pitch factor would probably lead to a dose reduction. However, it is always preferable to obtain standard imaging techniques that minimize the patient dose with acceptable image quality. The conventional image reconstruction methods based on analytical inversion formulae are still the fundamental choice in clinical equipment [4]. On the other hand, statistical iterative reconstruction (SIR) methods are known to provide a higher image quality thanks to noise modeling and possibilities to incorporate prior information, which has a potential to be useful for some low-dose imaging protocols [5–8].

In this work, we investigate the problem of image reconstruction from low-dose imaging protocols. By low-dose imaging, we consider reducing X-ray beam intensity, which is known to increase statistical noise in the reconstructed image (Fig. 1(b)). Moreover, we consider the problem of image reconstruction from a small number of projection views (Fig. 1(c)) and limited angle problem (Fig. 1(d)). Reducing the data sampling rate corresponds a reduction of patient dose, though it may meet some technical challenges when being implemented in clinical routines. In tomographic imaging, it is important to find the appropriate prior model to fit with the imaging application and data limitation. In this context, several prior models are presented to solve problems generated from limited tomographic data. Prior models can be classified into two categories based on the source of knowledge. First category is image-domain-based prior, where prior information is acquired from the reconstructed image domain such as Gibbs smoothing prior [9], total variation (TV) prior [10], Non-local means (NLM) [11] and Gaussian mixture priors [12]. Second category is auxiliary-domain-based, where prior information is calculated from auxiliary source such as reference image [13], dictionary-based [7] and intensity prior [14]. Anatomical information has been used in several tomographic imaging modalities such as emission tomography [15–21], transmission electron microscopy [22].

Using of prior information obtained from earlier CT scans to improve the quality of low-dose CT imaging is become an interesting research topic. Several approaches are developed to address this problem. For example, Ma et al. proposed a post-processing method based on nonlocal means filtering, named ndiNLM algorithm [23]. The ndiNLM algorithm is proved to be powerful approach for noise reduction. However, it does not consider the statistical properties of photons. Chen et al. proposed the PICCS algorithm, which incorporate prior information obtained from reference image into the image reconstruction problem within the framework of compressed sensing [13]. Another interesting approach is the PWLS-PINL algorithm [24], which consider a nonlocal regularization using prior image obtained earlier with normal-dose scan. Major limitation of prior image-based reconstruction is the requirement of an earlier scan of the same patient, which is not always available in several CT applications. A hybrid reconstruction method is proposed by Sadowwsky et al. for cone-beam C-arm CT to solve the problem of data truncation with the limited field-of-view of C-arm scanners [25].

The present study proposes a new framework for image generation in medical applications, which exploit a probabilistic atlas constructed by processing archived dataset to generate images with superior quality features in future scans. This framework might have a large potential to contribute to future trends in medical imaging such as modulating the patient dose, reducing data measurements, and improving image quality. Conceptually, the overlap between techniques of medical image creation (*i.e.* image reconstruction and imaging physics) and techniques of image processing (*i.e.* computational anatomy and computer-aided-diagnosis) is weak. The main stream between these two tracks is limited to forward medical images generated by imaging equipments into processing for diagnosis and analysis. In the context of image segmentation, the use of probabilistic atlas is a common approach to achieve accurate image segmentation in different imaging modalities. The atlas is essentially generated from a population of co-registered images corresponding to distinct patients and is then used to provide a complete spatial distribution of probability that a pixel belongs to each organ. This may provide a useful information that is used to decide an organ to which each pixel should be classified [26].

In this paper, we propose a new SIR method using prior information obtained from probabilistic atlas computed using auxiliary dataset. We used a set of reconstructed volumes obtained from previous scans of several patients to construct a probabilistic atlas using the Laplacian mixture model (LMM).