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A model-based radiography restoration method based on simple scatter-degradation scheme for improving image visibility

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ABSTRACT

In conventional planar radiography, image visibility is often limited mainly due to the superimposition of the object structure under investigation and the artifacts caused by scattered x-rays and noise. Several methods, including computed tomography (CT) as a multiplanar imaging modality, air-gap and grid techniques for the reduction of scatters, phase-contrast imaging as another image-contrast modality, *etc.*, have extensively been investigated in attempt to overcome these difficulties. However, those methods typically require higher x-ray doses or special equipment. In this work, as another approach, we propose a new model-based radiography restoration method based on simple scatter-degradation scheme where the intensity of scattered x-rays and the transmission function of a given object are estimated from a single x-ray image to restore the original degraded image. We implemented the proposed algorithm and performed an experiment to demonstrate its viability. Our results indicate that the degradation of image characteristics by scattered x-rays and noise was effectively recovered by using the proposed method, which improves the image visibility in radiography considerably.

1. Introduction

Since Roentgen discovered x-rays in 1895, conventional planar radiography has been a standard diagnostic tool in medicine, industry, material science, *etc*. However, its image visibility is often limited mainly due to the superimposition of the object structure under investigation and the artifacts caused by scattered x-rays and noise. Several methods, including computed tomography (CT) as a multiplanar imaging modality to remedy the shortcoming of the planar radiography [1], air-gap and grid techniques for the reduction of scatters [2,3], phase-contrast imaging (PCI) as another image-contrast modality [4–6], *etc.*, have extensively been investigated in attempt to overcome these difficulties. However, those methods typically require higher x-ray doses or special equipment. Especially, PCI technique is a very promising approach to the image visibility problem in conventional radiography that utilizes the phase shift (or slight refraction) introduced by the examined object to the transmitted x-rays. It offers the potential to enhance the image contrast of the object considerably because the variation in phase of x-rays is much larger than that in intensity due to absorption. However, PCI usually puts higher demands on the equipment (*e.g.*, good optics, detectors, and sources for x-rays), which has limited the widespread use of the technique into many related applications.

In this work, as another approach, we propose a new model-based radiography restoration method based on simple scatter-degradation scheme where the intensity of scattered x-rays and the transmission function of a given object are estimated from a single x-ray image to restore the original degraded image. In fact, significant model-based restoration algorithms, particularly Laplacian filters, variants of wavelet transformations, and multi-resolution algorithms, exist for x-ray image processing [7–9]. However, most of the algorithms typically have their own weaknesses in the aspect of computational complexity, processing speed, and/or image quality. On the contrary, the proposed method does not put higher demand on equipment or x-ray doses to patients and can provide better image quality, significantly faster processing, and less complexity than others. We implemented the proposed restoration algorithm and performed an experiment to demonstrate its viability. In the following sections, we briefly describe the proposed method and present the experimental results.

2. Material and methods

Fig. 1 shows the schematic illustration of the proposed radiography restoration model in which the intensity observed at a detector pixel at (x,y), $I(x,y)$, is described by Eq. (1) in a way similar to that used in the

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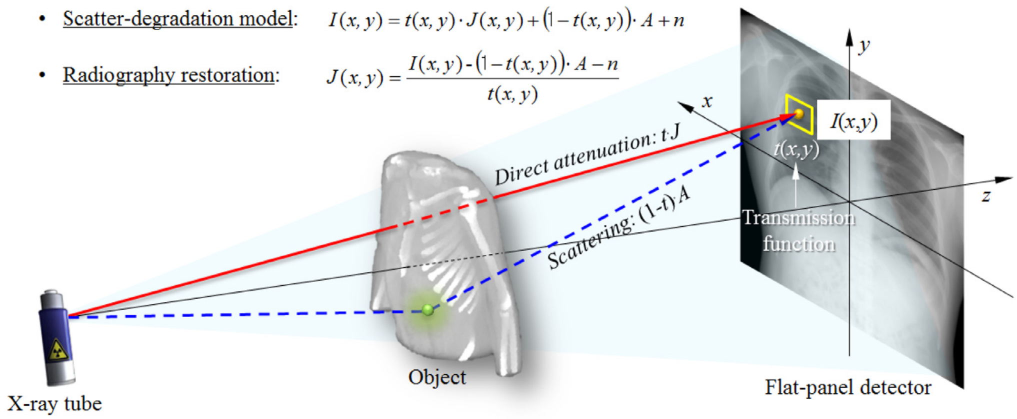

Fig. 1. Schematic illustration of the proposed radiography restoration model. Here $I(x,y)$ and $t(x,y)$ are the intensity observed at a detector pixel at (x,y) and its transmission function, respectively, $J(x,y)$ is the intrinsic intensity of the object without scattering degradation, A is the intensity of scattered x-rays, and n is the system noise.

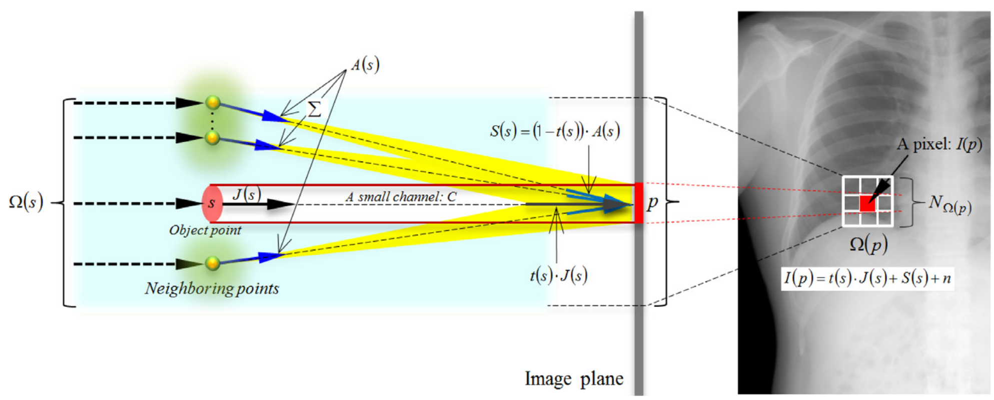

Fig. 2. Schematic illustration of a scatter-degradation scheme used for the proposed radiography restoration. Here the neighboring points around s are viewed as the local background sources of scattered x-rays (*i.e.*, $A(s)$), which produces a scattering component $S(s)$ along C.

Koschmieder model [10]:

$$I(x,y)=t(x,y)\cdot J(x,y)+(1-t(x,y))\cdot A+n, \tag{1}$$

where $t(x,y)$ is the transmission function that describes the relative portion of x-rays transmitting an object, $J(x,y)$ is the intrinsic intensity of the object without scattering degradation, A is the intensity of scattered x-rays, and n is the system noise. Based on Eq. (1), once $t(x,y)$ and A are properly estimated, $J(x,y)$ can be restored with a denoising process (*e.g.*, we used the non-local means (NLM) denoising algorithm [11] in this work) by using

$$J(x,y)=\frac{I(x,y)-(1-t(x,y))\cdot A-n}{t(x,y)}. \tag{2}$$

However, the proposed restoration method has the minimal requirement for a single x-ray image, that is $J(x,y)$ is restored from $I(x, y)$ based on Eq. (2) with two unknowns of $t(x,y)$ and A, which necessitates a solution of an ill-posed inverse problem. Meng et al. recently proposed an efficient image dehazing method based on Eq. (2) with a boundary constraint and contextual regularization in computer vision, which requires only a few general assumptions [12]. Here dehazing is an image restoration technique extensively studied in computer vision to recover hazy (or *foggy*) images that are often caused by suspended atmospheric particles such as haze, fog, smoke, and mist [13]. However, image dehazing techniques are not well suitable for radiography restoration because the effect of environmental illumination as well as airlight in the optical model of atmospheric scattering is not relevant to radiographic scattering phenomenon, although both are described by Eq. (1). Different from the environmental illumination in atmosphere, the intensity of scattered x-rays A varies spatially because its value is associated to the intensities of the object structure. Note that A in the optical model of atmospheric scattering is described as a global value of the scattering intensity and can be effectively estimated by using the dark-channel prior (DCP) [14–16]. Thus, a more suitable scatter-degradation scheme is necessitated for the proposed radiography restoration.

Fig. 2 shows the schematic illustration of a scatter-degradation scheme used for the proposed radiography restoration. Here C denotes a small channel in the background tissue corresponding to a beam from the object point s to a point p on the detector plane (*i.e.*, each pixel corresponds to a small channel), and $\Omega(s)$ and $\Omega(p)$ denote the two-dimensional (2D) neighborhoods centered at points s and p, respectively. The channel is a virtual volume having a cross-sectional area equal to the pixel dimension laid through the background tissue, independent of underlying anatomy and x-ray imaging parameters. As indicated in Fig. 2, the neighboring points around s are viewed as the local background sources of scattered x-rays (*i.e.*, $A(s)$), which would emit radiation and produce a scattering component $S(s)$ along the channel C:

$$S(s)=(1-t(s))\cdot A(s). \tag{3}$$

This scheme is based on the biological-optical model (BOM) recently proposed by Yang et al. for finger-vein image restoration [17]. From Eq. (3), the transmission function $t(s)$ can be obtained by

$$t(s)=1-\frac{S(s)}{A(s)}. \tag{4}$$

Thus, given the estimations of $S(s)$ and $A(s)$, $J(s)$ can be restored as follows:

$$J(s)=\frac{I(p)-S(s)-n}{t(s)}. \tag{5}$$