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Dose reduction using non lineal diffusion and smoothing filters in computed radiography

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HIGHLIGHTS

- We have investigated the techniques to obtain the image quality to make a confident diagnosis.
- We have used diffusion and smoothing filter in order to reduce the exposure.
- Reducing CR doses, especially in pediatric applications.
- The new CR images allow medical researchers to analyze how low dose affects the patient diagnosis.

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ABSTRACT

The use of Computed Radiography (CR) into clinical practice has been followed by a high increase in the number of examinations performed and overdose cases in patients, especially children in pediatric applications. Computed radiographic images are corrupted by noise because either data acquisition or data transmission. The level of this inherent noise is related with the X-ray dose exposure: lower radiation exposure involves higher noise level. The main aim of this work is to reduce the noise present in a low radiation dose CR image in order to the get a CR image of the same quality as a higher radiation exposure image. In this work, we use a non lineal diffusion filtering method to reduce the noise level in a CR, this means that we are able to reduce the exposure, milliampere-second (mAs), and the dose absorbed by the patients. In order to get an optimal result, the diffusive filter is complemented with a smoothing filter with edge detection in order to preserve edges. Therefore, the proposed method consists in obtaining a good quality CR image for diagnostic purposes by selection of lower X-ray exposure jointly with a reduction of the noise. We conclude that a good solution to minimize the dose to patients, especially children in pediatric applications, in X-ray computed radiography consists in decreasing the mAs of the X-ray exposure and then processing the image with the proposed method.

1. Introduction

The use of Computed Radiography (CR) into clinical practice has increased the interest in finding ways to lower the exposure dose to patients. The increased use of CR produce overdose cases in patients, this problem is especially serious for children undergoing CR and, in this case, the exposure factors must be carefully adjusted for pediatric patients. In conventional radiographic technique, the quality of radiation needed to produce an adequate image is specific to the screen-film system and chemical processing conditions. Otherwise, the acquisition process in CR is independent from the display process, and allows producing acceptable images over a wide range of exposures. Unfortunately, this fact introduces the risk of systematic overexposure. According to the International Commission on Radiological Protection (ICRP), patient doses in CR, especially in case of children, should always be kept as ALARA criterion: "As Low As Reasonably Achievable", see ICRP (2007). Recently, several works have been devoted to the reduction of the exposure dose in radiography. For example, a novel CT reconstruction algorithm was proposed in Ref. Silva et al. (2010) to reduce the radiation dose at body, this method is based on the adaptive statistical iterative reconstruction method (Leipsic et al., 2010). A dose reduction method was presented in Ref. Singh

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et al.(2009) with pediatric CT protocols tailored to clinical indications, patient weight, and number of prior studies. In Ref. Juste et al. (2008), an analysis based on computer simulated noise reduction was presented.

However, there are only few papers analyzing exposure (mAs) reduction in patient X-ray imaging. Nevertheless, reducing X-ray exposure has the inevitable consequence of increasing statistical noise degradations in image quality (Wall et al., 2000). Ball scale-based filtering is a strategy for diffusion conductance to perform filtering. Radiation dose is one of the most significant factors determining CR image quality and thereby the diagnostic accuracy. Radiation dose should only be reduced if the diagnostic image quality is guaranteed. Therefore, it is necessary to relate the radiation dose in CR with image quality measurements. There are several parameters describing the image quality, in this work, we use an estimate of the noise level of the image evaluated in a uniform region. In this paper, we analyze the possibility of reducing CR doses, while maintaining diagnostic integrity. In particular, we study the feasibility of evaluating the diagnostic accuracy as a function of reducing dose, lowering the mAs, and applying a non-linear diffusive filter (NDF). In order not to blur the edges in the image, applies a method of edge detection and the filtered image is reconstructed.

The paper is organized as follows: Section 2 explains the algorithm and methodology used to remove the noise. The results of the experimental study are shown in Section 3 and finally, the conclusions are presented in Section 4.

2. Methodology

2.1. Non-linear diffusive filter (NDF)

As mentioned in the introduction, a class of image restoration methods is based on the use of non-linear diffusion equations (Catté et al., 1992; Rudin et al., 1992), which usually appear associated to a total variation problem and may be obtained from the minimization of the appropriate functional. The choice of a particular functional depends on the specific goal of interest. For example, several diffusive filters, suitable for medical imaging (Catté et al., 1992), have been obtained from the minimization of the appropriate functional. Let us consider the following functional (Rudin et al., 1992),

$$J(u,\beta,\mu,\varepsilon)=\int_{\Omega}\left(\sqrt{\beta^2+||\vec{\nabla}u||^2}+\frac{\mu}{2}(u-I_0)^2+\frac{\varepsilon}{2}(\vec{\nabla}u)^2\right)d\vec{x}, \tag{1}$$

where I_0 is the observed image (with noise), u is the filtered image, μ and ε are constants and Ω is a convex region of R2 constituting the support space of the surface $u(x,y)$, representing the image. The first term in the functional for $\beta=1$ represents the area of the surface which accounts for the image, (Catté et al., 1992), the second term gives account of the distance between the observed image and the desired solution u, and the third term controls the regularity of the solution. We will consider the constrained minimization problem.

$$\min_u J(u,\beta,\mu,\varepsilon)\ subject\ to\ \frac{\int_{\Omega}(u-I_0)^2\,d\vec{x}}{\int_{\Omega}d\vec{x}}=\sigma^2 \tag{2}$$

that is, we search for the image u that minimizes the functional $J(u,\beta,\mu,\varepsilon)$ and the constrain means that the quadratic error between the original and the reconstructed image must be equal to σ^2, which represents the variance of the noise in the observed image. The standard deviation (SD) σ of the noise in the image I_0 is a priori unknown, but it is important to estimate its value to minimize the Eq. (2). In our work, we use a robust estimate of the noise standard deviation proposed by Donoho, (Weickert et al., 1998). We estimate σ by taking the median absolute deviation of the empirical wavelet coefficient of the finest scale and dividing by 0.6745 (Donoho, 1995). For all the studied images, the wavelet was a Daubechy of order 25. This process is the key stone of the NDF.

The (diffusion) equation obtained from the minimization problem has to be discretized spatially and temporally. For time discretization, we use a semi-implicit scheme and for solving the

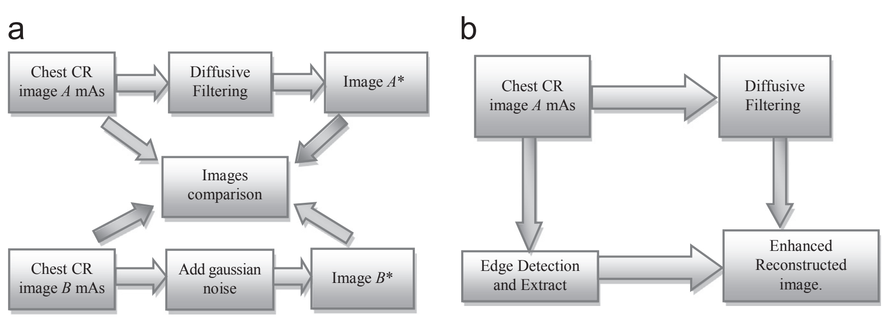

Fig. 1. (a) Process to dose reduce and (b) process of filtering and detection of edges.

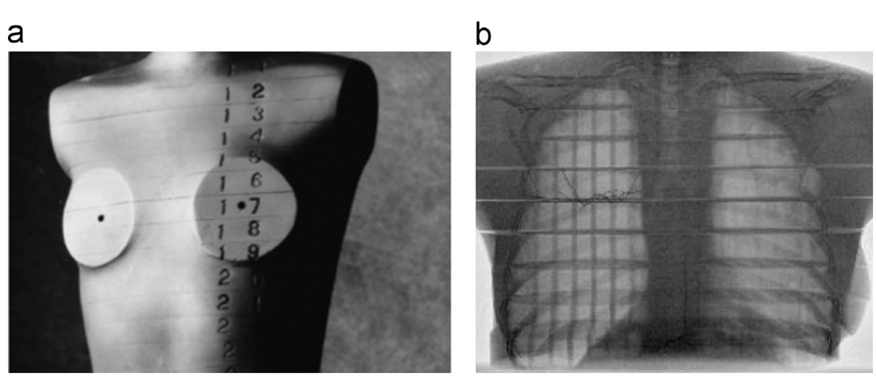

Fig. 2. (a) Chest RANDO phantom and (b) chest CR of RANDO phantom with 80 V.