ELSEVIER MASSON

CrossMark

Disponible en ligne sur
ScienceDirect
www.sciencedirect.com

Elsevier Masson France
EM|consulte
www.em-consulte.com

IRBM 38 (2017) 42–55

IRBM

Original Article

A Landmark Detection Approach Applied to Robust Estimation of the Exposure Index in Digital Radiography

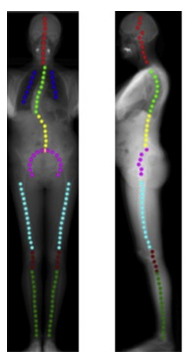
P. Irrera [b,*], I. Bloch [a], M. Delplanque [b]

[a] LTCI, CNRS, Télécom ParisTech, Université Paris-Saclay, Paris, France
[b] EOS Imaging, Paris, France

Received 19 September 2016; received in revised form 12 December 2016; accepted 13 December 2016

Available online 16 January 2017

Graphical abstract



	Exposure index value
Head	33.0
Thoracic spine	38.3
Lungs	104.5
Lumbar spine	25.4
Pelvis	28.8
Femurs	41.5
Knees	67.5
Tibiae	77.6

Abstract

Purpose: The exposure index is an important measure used in digital radiography to control the dose at the detector. This value should be computed in regions of interest that are adapted to each patient's anatomy and pose.
Material and methods: We propose to define automatically these regions based on anatomical landmarks in the main structures of interest (head, thoracic spine, lungs, lumbar spine, pelvis, femurs, knees, tibiae). This task is achieved by combining the global information on the size and the positions of the anatomical structures on the one hand, with local analysis on the other hand.
Results: Experimental results, on a varied database of 82 full-body acquisitions, demonstrate the interest of the proposed approach, with less errors than existing approaches, in particular on frontal view acquisitions. The method is also robust to variations in patient's conditions and to the potential presence of metallic objects.
Conclusion: The approach proposed in this paper allows consistently estimating exposure index values associated with different X-ray acquisitions. This suggests that the application of the proposed method to clinical practice is promising.

Keywords: Automatic anatomical landmark detection; Digital radiography; Exposure index

1. Introduction

Digital radiography has many advantages over screen-film detectors. For example, digital systems are able to generate

* Corresponding author.
E-mail address: irrera.paolo@gmail.com (P. Irrera).

http://dx.doi.org/10.1016/j.irbm.2016.12.001
1959-0318/

well contrasted images at wider dose ranges than analogical ones [11]. Indeed, in screen-film imaging, the quality totally depends on acquisition conditions because the image is not post-processed. Overexposed images tend to look too dark and underexposed ones are too bright. On the other hand, digital systems allow obtaining images that are well balanced in terms of contrast by using post-processing methods. However, the relationship between image quality and X-ray dose is lost. This was the reason of the *exposure creep* in digital X-ray radiography. Basically, since the noise level is the only image quality measurement that changes according to the amount of dose, the users may tend to prefer overexposed images that have better signal to noise ratio (SNR) than correctly exposed one. Nevertheless, this choice is clearly in conflict with the ALARA principle that strongly suggests clinicians to optimize the amount of X-ray exposure *As Low As Reasonably Achievable* according to the purpose of the exam.

The Exposure Index (EI) is a standardized image quality measure that has been proposed thanks to a joint initiative of the International Electrotechnical Commission [5] and of the American Association of Physicists in Medicine [11] in order to specifically address this issue. The EI quantifies the amount of dose at the detector, and, hence it must not be mistaken with patient radiation dose. Nevertheless, since it is proportional to the squared SNR [10], it can be used to define the lower limit of radiation exposure depending on the intended use of the exam and the maximum acceptable amount of noise for clinicians.

The standard IEC 62494-1 [5] is extremely clear on the procedure to follow in order to estimate EI values from image gray levels and we refer to it for any information about, for example, X-ray beam characterization. Nevertheless, the manufacturers are free to choose a method to define the region of interest (ROI) where the EI is computed. It is worth noting that this aspect is not only important as the EI value depends on the selected ROI, but also not trivial to address.

It is then important to define the ROI used to compute the EI in such a way that the comparison between acquisition protocols on different patients is consistent. Furthermore, the variations of patients' poses or the presence of multiple anatomical structures in the field of view make it very challenging to get significant EI measurements. This is even more important for clinical exams requiring a full-body analysis of the musculoskeletal apparatus [6]. As a typical example, we consider in our experiments images acquired with EOS system, which is dedicated to this type of analysis. Table 1 provides an example of EI measurements computed from an EOS frontal view acquisition of the full body. The values given in this example show how heterogeneous is the information. For example, the EI value behind the lung region is four times higher compared with the measurement behind the lumbar spine, which is a region at higher density than the chest. As a consequence, a unique EI value computed at the center of the image gives a poor description of the image quality of an exam. It is therefore necessary to detect the anatomical regions of interest that appear in the image.

Irrera et al., [8] have recently proposed a landmark-based approach that allows addressing the aforementioned issues. However, the evaluation of the method was conducted from manually annotated landmarks. In this work we propose an unsupervised approach that automatically detects these landmarks. Multiple aspects make anatomical structures detection challenging on planar 2D radiographic images: the image quality significantly changes from an exam to another, there are rotational issues due to the projection of the 3D volume on a 2D plane and the intensity values inside the same structure are not homogeneous given tissue superposition. The proposed method should then be able to address all these challenges while being efficient in terms of computational time because the EI has to be immediately displayed on the processed image. The validation is another significant contribution of this work as we consider eight anatomical regions, two acquisition views, patients of different ages and morphotypes, and acquisition protocols at several X-ray exposition levels.

Table 1
Exposure index measurements in anatomical regions of a full-body frontal view exam acquired with the EOS system.

	Exposure index value
Head	33.0
Thoracic spine	38.3
Lungs	104.5
Lumbar spine	25.4
Pelvis	28.8
Femurs	41.5
Knees	67.5
Tibiae	77.6

The paper is organized as follows. Section 2 starts by introducing the EI algorithm and by presenting the method for computing EI values with a landmark-based approach [8]. We then present the proposed landmark detection approach and describe our clinical database. Section 3 evaluates the proposed method and discusses the obtained results. Section 4 concludes the paper, and summarizes the achieved objectives and perspectives.

2. Materials and methods

2.1. Exposure index

The exposure index is a standardized measure that represents the amount of dose at the detector in a region that is of interest for the undergoing clinical exam (ROI). The amount of dose measured in Gy is estimated from intensity image values by means of a calibration function that depends on the system [5].

The input to the exposure index algorithm is the acquired image corrected in offset, gain and dead pixel. It is worth noting that any further operation on the image that changes intensity values or noise distribution, for example contrast enhancement, must be avoided as the exposure index describes the image quality at the acquisition. The input image is denoted by $\mathbf{u}$. A ROI $\Psi \subset \Omega$, where Ω is the whole pixel space, indicates the region of the image that is considered meaningful for the undergoing exam. The ROI selection methods presented in the standard IEC 62494-1 [5] and by Shepard et al. [11] are based