MULTI-RESOLUTION CONTRAST AMPLIFICATION IN DIGITAL RADIOGRAPHY WITH COMPENSATION FOR SCATTERED RADIATION

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ABSTRACT

In x-ray projection radiography, especially if area detectors are used, scattered radiation can strongly degrade the image contrast [1]. Although the amount of radiation scatter is partly reduced by the use of anti-scatter grids or air gaps [2], the contrast is mostly still substantially degraded in large areas of the images. In this paper, the radiation scatter in radiographs is modeled as the sum of a low-pass filtered version of the primary radiation distribution and a residual scatter component. We show in this paper how the Multiscale-Image-Contrast-Amplification (MUSICA) algorithm for contrast enhancement [4] can automatically remove the degrading effect of scattered radiation on image contrast, by selectively suppressing low resolution components, without significantly affecting the primary radiation distribution at any spatial resolution.

1. INTRODUCTION

Scattered radiation in radiographs can substantially reduce contrasts in the images, by adding a relatively large component with low spatial frequency content. E.g., in a chest radiograph scatter fractions can range from 0.4 in the lung area to over 0.9 in the mediastinum area and in the abdomen area [1]. Therefore reduction of the radiation scatter component in radiographs is mostly necessary. The use of anti-scatter grids or air gaps [2] reduces the radiation scatter only partially. Often (such as in [3]) the radiation scatter component in a radiograph is modeled as a low-pass filtered version of the primary radiation distribution, or of the image itself. Subtracting such low-pass filtered version from the original image compensates for scattered radiation and restores the contrasts in the primary radiation distribution. The MUSICA algorithm [4], based on Laplacian pyramid decomposition [5], is a multi-resolution technique in which contrast is transformed in a uniform way for all image scales. In this paper we apply the MUSICA algorithm for contrast enhancement with partial suppression of the lower-resolution components of the image. The multiresolution technique on its own gives excellent results in contrast enhancement. We suppress the lower-resolution components of the image such that scatter is subtracted. This results in an extra contrast enhancement without significantly affecting the primary radiation distribution at any spatial resolution.

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2. METHODS

2.1. MUSICA algorithm

The basic idea of MUSICA is to selectively amplify detail amplitude across the image plane, and across all resolution levels, since diagnostic details often occur at different scale levels within the same image. With the term 'detail' we indicate the local signal variation in the image. The algorithms consists of three steps.

1. First the original image is decomposed into a multiresolution pyramid which represents local detail at subsequent scales. The decomposition is based on the very efficient DoG (Difference of Gaussian) scheme as proposed by Burt [5], but other ones e.g. wavelet-based representations are suited as well.

2. Next the pyramid values at all resolution levels are modified according to a non-linear conversion function. Pyramid values with a low amplitude (either positive or negative) correspond to subtle details in the image, and are boosted due to the high slope of the conversion curve near the origin. High contrast details on the contrary are represented by a high amplitude pyramid value, and are reduced with respect to the subtle details, since the slope of the curve is decreasing further from the origin (fig.1).

3. By applying the inverse of the decomposition operator to the modified detail pyramid a result image is obtained which shows improved contrast throughout the image, independent of feature size or local brightness. A more extensive description is given in [4].

2.2. Scattered radiation in radiographs

The radiation scatter is spatially diffuse and its distribution $I_s(x,y)$ can be written, in a good approximation, as a low-pass filtered version of the primary distribution $I_p(x,y)$ [3] with large amplitude plus a residual component $\Delta I_s(x,y)$ with small amplitude.

$$I_s(x,y) = A \times G_\sigma(x,y) \otimes I_p(x,y) + \Delta I_s(x,y) \qquad (1)$$

$$I_s(x,y) \; = \; 'Low\,pass'\,term \; + \; 'Residual'\,term$$

where A is a constant and $G_\sigma(x,y)$ a normalized Gaussian convolution kernel (with standard deviation σ). Therefore the images are often compensated for scattered radiation by subtracting a low-pass filtered version of the image [3].

2.3. Compensation for scattered radiation

In the MUSICA algorithm details with small amplitude, which corresponds to a low contrast, are amplified compared to details with larger amplitudes. This means that the degrading effect of the scattered radiation component on the image contrast is partly reduced by the algorithm.

In its basic form MUSICA has no explicit preference for specific spatial frequencies. A straightforward modification of this basic concept gives the possibility to further attenuate the slowly varying image components [4].

For the discussion of the influence of scattered radiation on the MUSICA processing, we treat the two terms of the right hand side of expression (1) separately:

2.3.1. 'Low pass' term

Since the term $A \times G_\sigma(x,y) \otimes I_p(x,y)$ in expression (1) is proportional to the primary radiation at lower levels of resolution, the details corresponding to the scattered radiation are also linearly proportional to the details of the primary distribution at the lower levels of resolution (fig. 2). Therefore, further reduction of the scattered radiation component can be achieved by suppressing the low-resolution components of the entire image with factors which are dependent on the scatter fractions in the image. For the study presented in the paper, basically two parameters of the MUSICA processing are adjusted. The first parameter is the *'MUSI-contrast'*, which gives a measure for the contrast enhancement. Referring to fig. 1, larger MUSI-contrast indicates that the conversion curve behaves more non-linear. The second parameter is the *'latitude reduction'*, which indicates how strong the lower levels of resolution are additionally suppressed. Again referring to fig. 1, *'latitude reduction'* could be considered as a downward reduction of the conversion curve for lower scales of the Laplacian pyramide. For a specific value of *'latitude reduction'*, the suppression factor of the different resolution levels decreases from the lowest resolution level to the highest resolution level according a geometric progression.

2.3.1.A. Basic method

For the removal (or suppression) of the scattered radiation component non-zero values of the *'latitude reduction'*

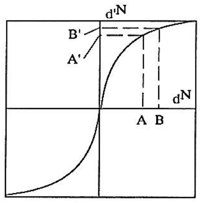


Fig. 1.

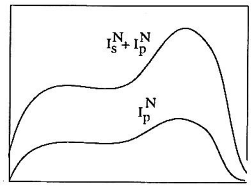


Fig. 2

Figure 1: At all levels of resolution, e.g. level N, of the Laplacian pyramid the detail values d^N are modified to values d'^N according to a non-linear conversion function. $(\frac{B'-A'}{B-A})$ decreases when A and B increase. Fig. 2. The figure shows an example of two plotted profiles of a radiograph (as a function of one pixel coordinate x). At lower levels of resolution, e.g. level N, the total signal $(I_s^N + I_p^N)$ is proportional (in a good approximation) to the primary signal I_p^N.

are used. Chest radiographs made in similar circumstances (kV, filtering,average thickness of patient, anti-scatter grid, detector, FFD, ...) also have similar scatter fractions (within a certain range) in specific regions of the images [1]. Applying the MUSICA processing to these images, with the same value of the *'latitude reduction'* parameter, gives similar results. Therefore optimal values for the *'latitude reduction'* are determined for a specific type of radiograph as function of the acquisition parameters. The determination of the parameter is based on qualitative comparison of two sets of radiographs. The first set includes a number of the same type of radiographs (e.g. chest radiographs) made with the same acquisition parameters. These radiographs contain a considerable amount of radiation scatter. The second set includes the same radiographs but from which scatter has been removed with a reference method [8]. Both sets of radiographs are processed with MUSICA, with the same value of *'MUSI-contrast'*, with *'latitude reduction'* = 0 for the scatter-free images, and with a non-zero value of *'latitude reduction'* for the images with scatter. The value of *'latitude reduction'* was adjusted until the results for the scatter-free images looked similar to the results for the other images. In critical regions, where the scatter fractions are very large, e.g. in the area of the mediastinum, the contrast increases only slightly when unsufficient suppression of the lower resolution levels is applied. Therefore it is recommended to adjust the *'latitude reduction'* to regions with large scatter fractions (which mostly correspond to regions with low intensities of the detected radiation). On the other hand the contrast in other regions may not be over-enhanced. From our experience it became clear that a compromise gave the best results.

2.3.1.B. Further extensions

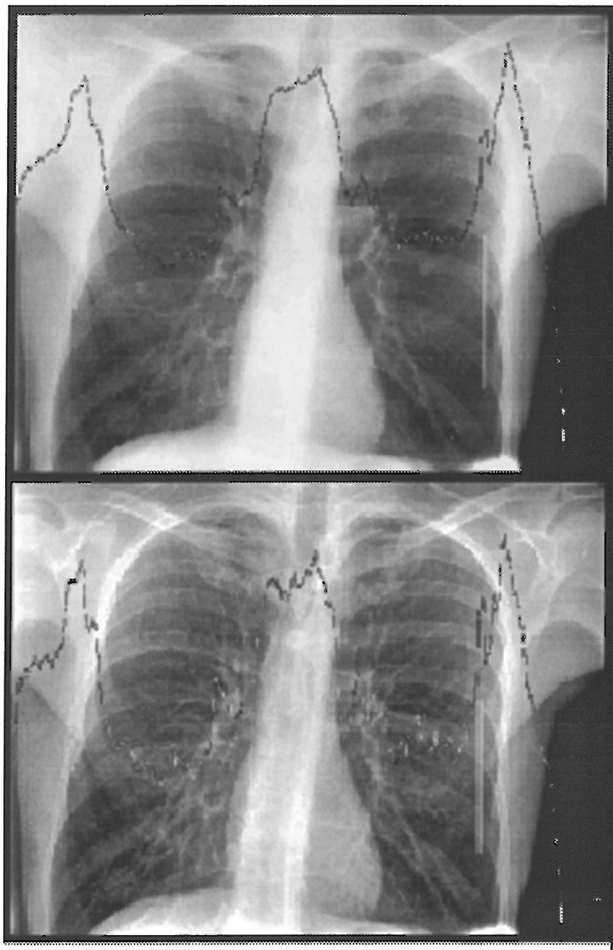
A further extension of the method gives the possibility to adjust the suppression of all levels of resolution separately. A multiresolution analysis of the scattered radiation can be made. In this case the method is not explicitely based on the scatter model of expression (1). The Laplacian pyra-

3 4

A A

B B

C



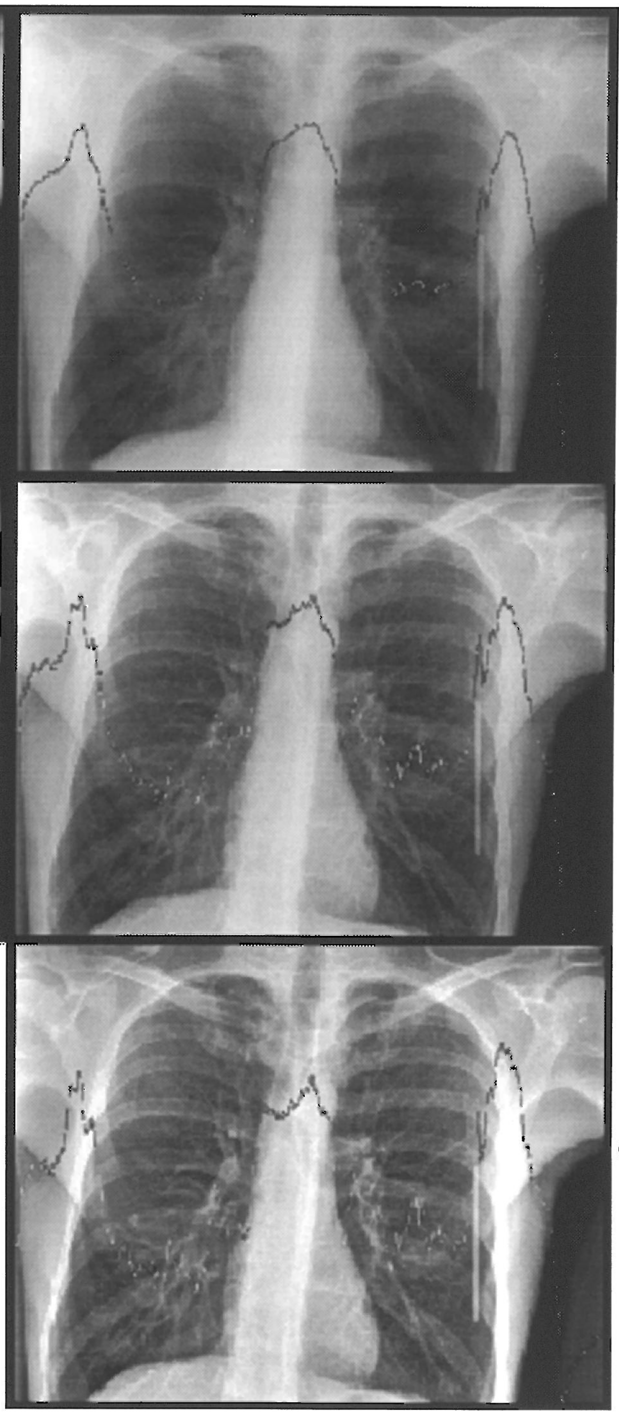


Fig. 3.A. Chest radiograph from which x-ray scatter has been removed with a reference method.
Fig. 3.B. MUSICA processed version of radiograph of fig. 3.A. No suppression of the lower levels of resolution is applied ('latitude reduction' = 0).
Fig. 4.A. The same chest radiograph in which x-ray scatter is not removed.
Fig. 4.B. MUSICA processed version of radiograph of fig. 4.A. The processing parameters ('MUSI - contrast' & 'latitude reduction') are the same as for fig. 3.B.
Fig. 4.C. MUSICA processed version of radiograph of fig. 4.A. The same value of 'MUSI - contrast' is used as for fig. 3.B. The 'latitude reduction' was adjusted until the result looked similar to fig. 3.B.

mids of the same two sets of radiographs of section 2.3.1.A are compared. The transformation of the pyramids of the first set to the pyramids of the second set should be determined. This is out of the scope of the paper, although it is subject of our present research.

Even better results are obtained when region-based processing is applied, suppressing levels of low resolutions more in regions with larger scatter fractions. This approach is also subject of further study.

2.3.2. Residual term

For every model for the radiation scatter, between the real scatter component and the component predicted by the model will mostly be a difference (in this paper defined as *residual scatter component*). The residual scatter component $\Delta I_s(x, y)$ in expression (1) consists of details with small amplitudes at middle and at larger scales. This component is non-linearly dependent on but strongly related to the primary radiation and therefore its details are always superimposed on details of the primary radiation distribution. No isolated details from the residual component will appear. Consequently they do not lead to considerable enhancement artifacts.

3. RESULTS

We evaluate our statements with digital chest radiographs. The chest images in this study were acquired using a conventional x-ray tube (Philips), a focussed grid (8:1 grid ratio, 70 lines/cm), no air gap, a focus-to-detector distance (FFD) of 150 cm, and a computed radiography system [6] (ADC70 system of AGFA with AGFA PS5000 workstation). The computed radiography system delivers the images in square root representation (proportional to the square root of the detected radiation intensity), with grey values between 0 and 4095. For our study we squared the grey values. The images are processed with experimental off-line image processing software, which includes the MUSICA algorithm for multi-scale image contrast amplification. The MUSICA version which we used is essentially the same as the commercial version on the PS5000 workstation for off-line processing.

Results for chest radiographs are shown in figures 3 and 4. The profiles of the horizontal image line in the middle of the images are plotted on top of each image.

For the study of the influence of scatter on image contrast an unprocessed chest radiograph with scatter (fig. 4.A) is compared with the same radiograph, from which scatter is removed after acquisition (fig. 3.A). For the subtraction of scattered radiation from fig. 4.A, resulting in fig. 3.A, a second image was made of the object, with an array of lead beams stops positioned between the x-ray source and the object. The observed signals under a beam stop are a measure for the scattered radiation component at that location. By interpolation techniques the radiation scatter in the entire image was calculated. This method with beam stop measurements is described in [8] and we used it as a reference method for comparison. Further the images are processed with the MUSICA algorithm. In a first step the settings of the MUSICA processing are the same for the image with scatter (fig. 4.B) and for the scatter-free image (fig. 3.B). No suppression of the lower levels of resolution was applied (*'latitude reduction'* = 0). These results are compared with the originals and with each other for the evaluation of the influence of the MUSICA processing on the scatter component. In a second step the image with scatter is processed again, but with suppression of the lower levels of resolution (fig. 4.C). The *'latitude reduction'* was adjusted until the result (image plus plotted profile) looked similar to the MUSICA-processed version of the scatter-free image.

4. CONCLUSION

We gave an analysis of automatic compensation for scattered radiation within the MUSICA algorithm for contrast enhancement. In its basic form the method consists of using an appropriate value of *'latitude reduction'* for the MUSICA processing. At this stage validation of the method is exclusively based on qualitative comparison or results. For this study the method was validated for chest radiographs, but is appicable to most radiographs.

With new multiscale contrast enhancement techniques, such as those using wavelets [7], compensation for scattered radiation can be achieved in essentially the same way, by suppressing the larger scale components with scatter-fraction dependent factors.

It should be mentioned that the use of anti-scatter grids or air gaps is still recommended since they have a positive influence on the Signal-to-Noise-Ratio (SNR) [2].

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