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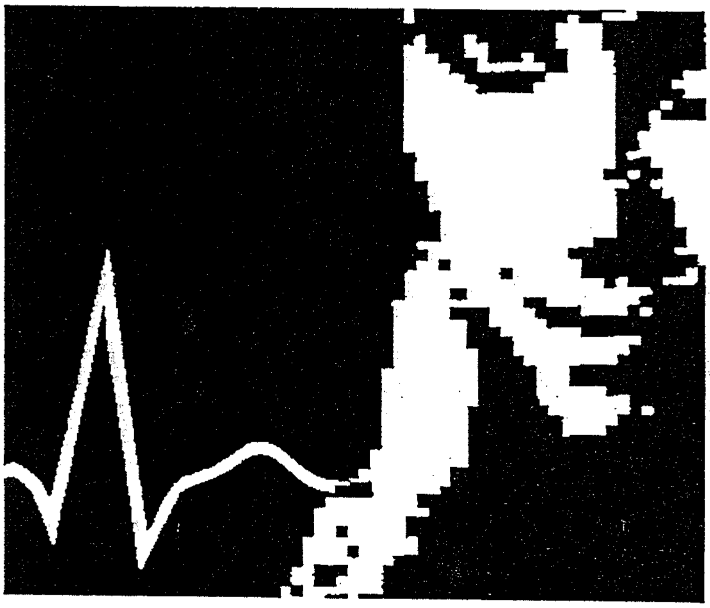

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Contrast enhancement in digital radiographs with multiresolution techniques in the presence of scattered radiation.

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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. 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 without significantly affecting the primary radiation distribution at any spatial resolution.

1. Methods.

The MUSICA algorithm, based on a Laplacian pyramid decomposition [5], transforms contrast in a uniform way for all image scales. The basic idea 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.

° 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 in [5], but other ones e.g. wavelet-based representations are suited as well.

° Next the pyramid values at all resolution levels are modified according to a non-linear conversion function (fig. 1). 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.

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

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

The radiation scatter is spatially diffuse and its two-dimensional 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.

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

where A is a constant and $G_\sigma(x,y)$ a normalized Gaussian convolution kernel.

Since the first component 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). Then, if we compare the image where scattered radiation is present with the scatter-free image (fig. 1 & 2), a detail at a specific location at a lower level of resolution in the first image (detail value B) will be less enhanced with respect to the detail at the same location and at the same level of resolution in the scatter-free image (detail value A). This is due to the decreasing slope of the conversion curve. This means that the influence of the scattered radiation component in the contrast-enhanced image is reduced by the algorithm. 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. The determination of these factors can be performed in different ways. One manner is used in section 2, and can be summarized as follows. From a large set of radiographs scattered radiation is subtracted, utilizing a reference method [7], before the MUSICA processing. These scatter-free images are then processed with MUSICA, without suppression of the lower resolution levels. Then the original images (with scatter) are processed with MUSICA, this time utilizing suppression of the lower resolution levels. The amount of suppression of the different lower levels of resolution is then optimized by comparing results with the results of the images of the first procedure (obtained by first subtracting scattered radiation and then applying MUSICA without suppression of lower resolution levels).

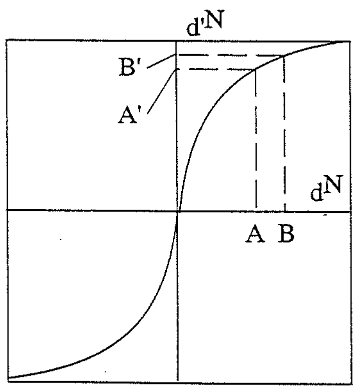

Fig. 1.

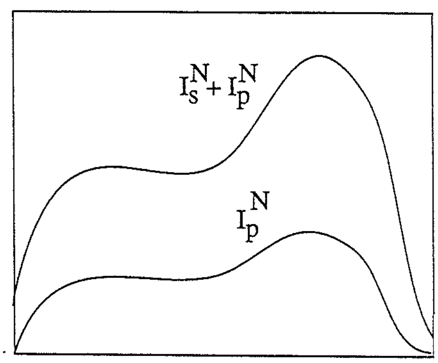

Fig. 2

Fig. 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.
Fig. 2. The figure shows an example of two plotted profiles of a radiograph (as a function of one pixel coordinate). At lower levels of resolution, e.g. level N, the total signal ($I^N{}_s+I^N{}_p$) is proportional to the primary signal $I^N{}_p$.

The residual scatter component ΔI_S 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. Consequently they do not lead to enhancement artifacts.

2. Results.

We evaluate our statements with digital chest radiographs, made with a Computed Radiography system [6] (AGFA ADC70-system with AGFA PS5000 workstation). The images are processed with experimental offline image processing software, which includes the MUSICA-algorithm for multiscale image contrast amplification. The MUSICA-version which we used is essentially the same as the commercial version on the PS5000 workstation for offline processing. For the study of the influence of scatter on image contrast an unprocessed chest radiograph with scatter was compared with the same radiograph, from which scatter was subtracted after acquisition, using a reference method [7]. Further the images were processed with the MUSICA algorithm. Two parameters were varied for the processing. The first parameter is the 'MUSI-contrast', giving a measure for the contrast enhancement. The second parameter is the 'latitude reduction', which indicates how much the lower levels of resolution are suppressed. In a first step the settings of the MUSICA-processing were the same for the image with scatter and for the scatter-free image. No suppression of the lower levels of resolution was applied ('latitude reduction' = 0). These results were 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 was processed again, but with suppression of the lower levels of resolution. The 'latitude reduction' was changed until the result looked similar to the MUSICA-processed version of the scatter-free image.

3. Acknowledgements.

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