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Anti-scatter grid artifact elimination for high-resolution x-ray imaging detectors without a prior scatter distribution profile

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Abstract

Using anti-scatter grids with high-resolution imaging detectors could result in grid-line artifacts, with increasing severity as detector resolution improves. Grid-line mask subtraction can result in residual artifacts that are due to residual scatter penetrating the grid and not subtracted. By subtracting this residual scatter, the grid artifacts can be minimized. In the previous works, an initial residual-scatter estimate was derived by placing lead markers on a test object; however, any change in the object geometry requires a new scatter estimate. Such a method is impractical to implement during a clinical procedure. In this work, we present a new method to derive the initial scatter estimate to eliminate grid-line artifacts during a procedure.

A standard stationary Smit-Roentgen x-ray grid (line density - 70 lines/cm, grid ratio - 13:1) was used with a high-resolution CMOS detector (Dexela Model 1207, pixel size - 75 μm) to image an anthropomorphic head phantom. The initial scatter estimate was derived from the image itself and the grid artifacts were eliminated using recursive correction estimation; this result was compared to that with the estimate derived from placing lead markers on the phantom.

In both cases, the contrast-to-noise ratio (CNR) was improved compared to the original image with grid artifacts. Percentage differences in CNR's for three regions between the images corrected with the two estimates were less than 5%. With the new method no a priori scatter distribution profiles are needed, eliminating the need to have libraries of pre-calculated scatter profiles and making the implementation more clinically practical.

INTRODUCTION

During endovascular image guided intervention (EIGI) procedures, the patient is the most significant source of scattered radiation. When these scattered x-rays are collected by the imaging detector, they do not provide any additional information about the anatomy of the patients, but they degrade the image quality by reducing the contrast and contrast-to-noise ratio (CNR) of the image. Use of a stationary grid is one of the most common methods to reduce the effects of scatter on the fluoroscopic image.

High resolution capabilities are essential for an efficient, accurate, and successful endovascular interventional procedure[1]. However, when stationary grids are used with these high resolution imaging detectors, since the lead septa dimension of the grid is a substantial fraction of the pixel size and there is residual scatter reaching the detector, the images contain grid line artifacts. The presence of this fixed-structure pattern noise

diminishes the advantage of using the grid with high resolution detectors, by masking the fine anatomic details present in the image.

Previously it was shown that by first subtracting the residual scatter from the image and then by logarithmic subtraction of the reference image of the grid, grid artifacts can be eliminated [2,3]. The residual scatter was recursively derived from an initial scatter estimate obtained by placing lead beads on the test object being imaged. Figure 1 shows an example case of an anthropomorphic phantom being imaged with the lead beads [1]. Implementing such a method in the clinical imaging suites can be impractical. Any changes in the object geometry (patient profile) requires re-acquisition of the initial residual scatter profile. In this work we propose a new method to obtain the initial residual scatter estimate, which is more easily implementable in the clinical imaging suites.

METHOD AND MATERIALS

The experimental setup for this work is shown in Figure 1. The Toshiba Infinix C-Arm system has both a standard flat panel detector (FPD) and an interchangeable high-resolution CMOS detector, which is shown in its deployed position in front of the FPD. For this study, a stationary Smit-Röntgen x-ray grid was used with the high resolution Dexela 1207 CMOS x-ray detector (pixel size 75 μm , sensitivity area 11.5cm $\times$ 6.5cm) (Fig. 2). An anthropomorphic head phantom SK150, The Phantom Laboratory, NY (Figure 2) was used to simulate patient x-ray attenuation and scatter along with anatomical features.

Grid artifact removal algorithm

After subtracting the residual scatter ($I_{\text{residual scatter}}$) from the acquired image (I_{input}), a grid reference image ($I_{\text{grid reference}}$), which is an image of the grid without scatter, is divided (logarithmically subtracted) resulting in a grid-artifact-free image. The equation is shown below

$$I_{\text{output}}(x, y) = \frac{I_{\text{input}}(x, y) - I_{\text{residual scatter}}(x, y)}{I_{\text{grid reference}}(x, y)} \times \text{Normalization factor}$$

The residual scatter image ($I_{\text{residual scatter}}(x, y)$) is recursively derived from the initial residual scatter estimate image I_{initial_s} . The recursive algorithm [2] is shown in the flowchart presented in Figure 3.

Initial residual scatter estimation method - Old Method

Previously an initial scatter estimate was derived by placing lead disks or markers (1 mm thick with 3 mm diameter), at regular intervals on the anthropomorphic phantom [1]. With the primary x-ray beam blocked, the signal registered by the detector under the lead marker position was the residual scattered radiation penetrating the grid. Figure 4 shows the x-ray image with lead markers and Figure 5 shows the residual scatter derived from this image.

Using this method any changes in the object geometry, requires re-acquisition of the initial scatter estimate by placing lead markers on the new geometry. Implementation of such methods in a clinical environment are impractical.

Initial residual scatter estimation method - New Method

The scatter exiting the patient is typically related to the primary distribution exiting the patient. Convolution of the scatter spread function with the primary intensity distribution should provide a good first estimate of the scatter distribution. In this work we estimate the primary distribution by the image and estimate the scatter spread function with a Gaussian blur function. The equation for the 2D Gaussian blur kernel is shown below

$$G(x, y) = \frac{1}{2\pi\sigma^2} e^{-\frac{x^2 + y^2}{2\sigma^2}}$$

where σ is the standard deviation of the distribution.

Figure 6 shows an acquired image with grid artifacts. Convolving this image with the Gaussian filter with a σ of 20 results in the image shown in Figure 7. This is used as the initial residual scatter estimate for grid artifact removal.

Validation

The grid artifact removal algorithm was performed on the image shown in Figure 6 using the initial residual scatter estimate derived from the new method shown in Figure 7 as well as the old method using lead markers shown in Figure 5. Typically, the better the grid-line removal, the higher is the contrast to noise ratio (CNR) due to the reduced structure noise of the lines. The CNR between three regions and the background region defined in Figure 8 was used as a measure to compare the two methods. CNR is defined as

$$CNR = \frac{Mean_{background} - Mean_{ROI}}{Noise_{background}}$$

RESULTS

Figure 8 shows the result after applying the grid artifact removal algorithm using the initial scatter estimate shown in Figure 7 derived from the input image (Figure 6) using the new method.

To visually appreciate the results better Figure 9 shows a zoomed in portion of the input image with grid, Figure 10 shows the grid artifacts removed from Figure 9 using the initial scatter estimate derived from the new method and Figure 11 shows the grid artifacts removed from Figure 9 using the initial scatter estimate derived from the old method.

The CNR values for the three regions shown in Figure 8 for the uncorrected image and corrected images using the new method and old method, along with the CNR percentage differences between the old and the new method in the three regions is shown in Table 1.

DISCUSSION

The use of anti-scatter grids with high resolution detectors can result in an image with a structured grid pattern due to residual scatter coming through the grid. To eliminate this pattern, first the residual scatter needs to be removed from the grid image before the grid mask is subtracted. Since scatter is a low frequency component, by Gaussian blurring of the input image, an initial estimate of the residual scatter can be derived. Using this, the final scatter estimate that needs to be eliminated from the image can be recursively calculated and the grid artifacts can be removed.

Figure 8 shows that with the new method the grid artifacts are eliminated. The results in Table 1 show the contrast to noise is improved compared to the uncorrected image. The percentage difference in CNR between the old method and the new method was under 5% for the three region of interests shown. This is further supported when comparing the images shown in Figures 10 and 11.

With the new method, no prior scatter distribution profiles are needed, eliminating the need to have libraries of pre-calculated scatter profiles and making the implementation more clinically practical. As the patient geometry changes, new scatter estimates can be derived from the acquired image and artifacts can be corrected on the fly.

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Figure 1.
Experimental set-up

Figure 2.
SK150 Anthropomorphic phantom

Figure 3.

Flowchart showing the iteration process for deriving final correction factor map. Using this map the grid artifacts is eliminated in the entire image.

Figure 4.
Lead markers placed on the phantom to acquire initial residual scatter estimate

Figure 5.
Initial scatter estimate obtained using the old method, by placing lead markers on the test object

Figure 6.
Image of an anthropomorphic phantom with grid line artifacts

Figure 7.
Initial scatter estimate obtained using the new method, after blurring Figure 2 using a Gaussian blur with a $\sigma = 20$

Figure 8.
Image after grid artifact correction using the new method. Regions marked in the image are used for CNR calculation and comparisons.

Figure 9.
Uncorrected input (Figure 6) image zoomed in.

Figure 10.
grid artifacts removed from Figure 9 using new method.

Figure 11.
grid artifacts removed from Figure 9 using old method.

Table 1

CNR comparison table. Regions R1 R2 and R3 are shown in Figure 8.

	CNR		
	R1	R2	R3
Uncorrected	2.17	10.38	2.63
Corrected-Old Method	4.49	21.49	7.81
Corrected-New Method	4.33	20.63	7.72
% difference between old and new method	3.73	4.01	1.15