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Anti-scatter grid artifact elimination for high resolution x-ray imaging CMOS detectors

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Abstract

Higher resolution in dynamic radiological imaging such as angiography is increasingly being demanded by clinicians; however, when standard anti-scatter grids are used with such new high resolution detectors, grid-line artifacts become more apparent resulting in increased structured noise that may overcome the contrast signal improvement benefits of the scatter-reducing grid. Although grid-lines may in theory be eliminated by dividing the image of a patient taken with the grid by a flat-field image taken with the grid obtained prior to the clinical image, unless the remaining additive scatter contribution is subtracted in real-time from the dynamic clinical image sequence before the division by the reference image, severe grid-line artifacts may remain.

To investigate grid-line elimination, a stationary Smit Röntgen X-ray grid (line density: 70 lines/cm, grid ratio 13:1) was used with both a 75 micron-pixel CMOS detector and a standard 194 micron-pixel flat panel detector (FPD) to image an artery block insert placed in a modified uniform frontal head phantom for a 20×20 cm FOV (approximately). Contrast and contrast-to-noise ratio (CNR) were measured with and without scatter subtraction prior to grid-line correction. The fixed pattern noise caused by the grid was substantially higher for the CMOS detector compared to the FPD and caused a severe reduction of CNR. However, when the scatter subtraction corrective method was used, the removal of the fixed pattern noise (grid artifacts) became evident resulting in images with improved CNR.

Keywords

high resolution detector; CMOS detectors; x-ray imaging; anti-scatter grid; grid artifacts; CNR; scatter

1. INTRODUCTION

During endovascular interventions, the interventionalist guides a catheter and an endovascular device to the pathological sites using x-ray image guidance. These endovascular procedures are done using devices (such as stents, balloons, coils, snare devices, etc.) which are delivered using catheters. The size of these devices are of the order of millimeters with structure details smaller than 100 microns and these devices may require sub-millimeter placement accuracy. Hence, high resolution imaging capabilities are essential for an efficient, accurate, and successful endovascular interventional procedure¹.

In digital radiographic imaging, the image quality is degraded a lot by the scatter produced when the primary beam passes through an object. Different techniques such as air-gap

technique², scanning beam³, collimation, moving⁴ and stationary grids may be used to control the amount of scatter. Due to its compact design and simplicity compared to scanning-beams or moving grids, the stationary grid has usually proved to be the most practical choice for fluoroscopy.

However, when these stationary anti-scatter grids are used with high resolution detectors, they leave very prominent grid-line shadows and moiré patterns⁵ on the images. Appearance of these artifacts makes it difficult to use anti-scatter grids with a high-resolution detector. These artifacts add structure noise which can result in a decrease in the contrast to noise ratio (CNR).

The purpose of this work is to investigate the effectiveness of a method to remove the anti-scatter grid-line artifacts when a grid is used with a high resolution CMOS detector.

2. METHOD AND MATERIALS

In order to perform this study we made a wooden grid holder (Fig 1.) so that the grid can be placed perfectly and rigidly beneath the high resolution CMOS detector⁶. In this study, we used a stationary Smit Röntgen X-ray detector grid with a high resolution Dexela 1207 CMOS X-ray detector (pixel size 75 μm and sensitivity area 11.5cm $\times$ 6.5cm) to image the simulated artery block phantom (Nuclear Associates, Stenosis/Aneurysm Artery Block 76-705) with the frontal head equivalent phantom^{7,8} used as the scattering source. The artery phantom contained three iodine-filled simulated arteries of widths and depths 1, 2 and 4 mm in one half of the block and the other half of the block had no features (Fig 2a). Each artery included stenoses and aneurysms that are one-fourth, one half and three fourth of the artery's width. The concentration of the iodine is 15 mg/ml. The artery block can be slid into the slot located in the middle of the frontal head phantom when the artery features are to be evaluated (Fig 2b, 2c).

Also, we are using a 20 $\times$ 20 cm beam size at the detector in this study (which is different than our previously reported study⁹ done at 15 $\times$ 15 cm beam size) as 20 $\times$ 20 cm looks forward to a future of larger high resolution detectors. A previously reported study involved a standard flat panel detector (FPD) with less resolution (194 μm pixels) and hence grid-line artifacts were less prominent⁹.

The images were taken in four different experimental setups, explained below:

- 1. Table with grid** (Fig. 3): We started first by "table with grid" image acquisition. We kept the frontal head phantom (with the uniform section of the artery block inserted) on the x-ray tube (in order to keep filtration of the x-ray beam consistent). The grid is placed in the front of the CMOS detector and patient table is in the beam.
- 2. Object with grid** (Fig. 4): Second set of images taken were "object with grid". In this case, we carefully (without moving the other adjustments and especially not touching the grid) removed the frontal head from the top of the x-ray tube, placed it on the table (close to CMOS detector) with vascular section of the artery inserted.

3. **Object without grid** (Fig. 5): Then we took “Object without grid” images. In this case, we carefully removed the grid from the front of the CMOS detector keeping rest of the set-up exactly same as “Object with grid”.
4. **Table without grid** (Fig. 6): Finally, “Table without grid” images were taken. In this arrangement, we carefully removed the frontal head phantom from the table and placed it again on the x-ray tube with the uniform section of the artery block inserted. This arrangement is exactly similar to “table with grid”, except that the grid is not used.

One of the main challenges while carrying out this experiment was to avoid unnecessary disturbances in the experimental set-up. If the grid moves even very slightly, this technique of getting rid of grid-line artifacts will not work properly. Keeping this condition in mind, we carried out the image acquisition carefully in the order mentioned above as this particular order gives us the freedom of making only the required changes to the set-up keeping the rest of the set-up untouched.

Table 1 shows the relevant specification of the grid used

The images of the artery block on the table were taken with two sets of tube parameters (88 kVp, 200 mA, 16 ms and 98 kVp, 200 mA, 16 ms) in angiography mode without the grid (‘object w/o grid’, set-up 3) and with the grid (‘object with grid’, set-up 2). For the two other set-up (1 and 4), the whole phantom is kept far from the detector and close to the source and scatter free images of the table without the grid (‘table w/o grid’, set-up 4) and with the grid (‘table with grid’, set-up 1) and the flat-fields of the detector were taken. In order to keep the filtration of the x-ray beam the same, the scatter free images (set-ups 1 and 4) are taken with the featureless part of the artery block in the phantom slot. All the images were flat-field and offset corrected and the table was always in the beam requiring care to eliminate not only the gridlines but also blotches in the images caused by table structure⁹.

Image corrections

As we can see in Fig 7, “Object without grid”, the contrast appears much reduced. Fig 8, “Object with grid” images have grid artifacts as we can see quite prominent grid lines. These artifacts can be partially removed by dividing the ‘Object with grid’ image by the average of 75 frames of the ‘table with grid’ (Fig 9.). However, as we know from our experimental set-up, ‘Object with grid’ images contain some residual scatter not removed by the grid whereas ‘Table with grid’ images are scatter-less because of the large air gap and hence we are not able to get rid of grid-line artifacts completely by dividing the images. The additive scatter in the “Object with grid” image must first be removed.

Scatter is actually not uniform throughout the field but it is a very low spatial frequency distribution so it can be represented by a constant number as a good approximation for this low contrast phantom. Hence, an estimate of the scatter component was obtained by taking the difference in the mean values of a selected region in the average frame of the ‘object with grid’ images minus the ‘table with grid’ images. This difference is then subtracted from the ‘object with grid’ images and the resultant images are then divided by the “Table with grid”. The grid-line artifacts were removed quite effectively using this method (Fig 10).

Contrast, Noise and CNR Calculation

An area was selected in the 4 mm thick artery to serve as signal and the same size area is selected in the background in the central part of the image. The average pixel intensity value of background ($I_{background}$), the signal (I_{signal}) and the standard deviation of the pixel intensity value of the background ($\sigma_{background}$) were measured and the following equations were used to calculate the contrast, the noise and the CNR. Contrast was calculated from an image obtained by averaging 75 frames and Noise was obtained from single frame images.

$$Contrast (\%) = \frac{I_{background} - I_{signal}}{I_{background}} \times 100, \quad Noise (\%) = \frac{\sigma_{background}}{I_{background}} \times 100, \quad CNR = \frac{Contrast}{Noise}$$

3. RESULT AND DISCUSSION

Fig 7 shows the 'object without grid' image. Grid lines were quite prominent in 'object with grid' images (Fig 8). However, we got rid of grid lines partially by doing 'Table and Grid correction' (dividing the 'Object with grid' image by the average of 75 frames of the 'table with grid') (Fig 9). The grid lines after 'Table and Grid correction' could not be removed completely because the images of the table alone used for the correction were scatter free while the image of the object with the table-included scatter. Almost all of the grid-line artifacts were removed by doing 'Table, Grid and Scatter correction' (a suitable estimated scatter being subtracted from the 'object with grid' images before doing 'Table and Grid Correction') (Fig 10). Fig. 7, 8, 9 and 10 are images averaged over 75 frames and zoomed over the same region.

Fig. 11 is the actual (un-zoomed) image of 'Object without grid', averaged over 75 frames.

Fig. 12 is the actual (un-zoomed) image of 'Object with grid' after Table, Grid and Scatter corrections, averaged over 75 frames.

Figures 13, 14, 15 and 16 are single frame images, zoomed and showing the same region of the image. We can also observe here that there is a fixed noise pattern (grid-line artifacts) in the images when the stationary anti-scatter grid is used with the high resolution CMOS detector (Fig 14). This fixed noise pattern can be removed partially when table and grid corrections are carried out (Fig 15). However, subtracting the residual scatter approximated from a comparison of scatter and no-scatter images can remove these grid line artifacts to a greater extent (Fig 16).

Table 2 shows that the contrast improves when the grid is introduced but the CNR degrades. By using a grid for the high resolution detector, we are reducing the scatter (as evident by the increase in contrast) but at the same time we are also getting fixed pattern noise (grid-line artifact) in the images, thus increasing the noise further (and hence reducing the CNR).

Table 3 shows that for each kVp value, both contrast and CNR, improve after applying the table and grid correction. This behavior was expected because by doing the table correction blotches from the table are virtually eliminated and by doing the grid correction, fixed pattern noise is reduced - thus resulting in better contrast, as well as CNR.

To remove the grid-line artifacts more effectively, we first get rid of the residual additive scatter (by subtracting a suitable amount of scatter from the images) before applying table and grid correction. Table 2 shows that both contrast and CNR improve even more after table, grid and scatter correction.

In this study, we used a 75 μm pixel size detector and a grid with 27.5 μm septa and observed quite prominent grid-line artifacts in the images. However, if we want to use a 50 μm pixel size detector, then it would be advantageous to have a grid with thinner septa although further work will have to determine the effect of reduced septa thickness on scatter clean-up.

4. CONCLUSIONS

We observed that the use of a grid with a high resolution CMOS detector improves the contrast but the overall CNR is reduced because grid-line artifacts become more prominent as detector resolution is improved. However, by subtracting an estimate of the scatter in the images before dividing them by the detector's flat field, we can get rid of these artifacts. Here, we have demonstrated a method to enable these grid-line artifacts to be removed and images to be obtained with improved contrast and CNR.

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Fig 1.
Experimental set-up

Fig 2.

Picture of head phantom used: a) artery block insert, b) top view of head phantom with vascular section of artery inserted, c) top view of head phantom with uniform section of artery block inserted.

Fig 3.
'Table with grid' setup.

Fig 4.
'Object with grid' setup.

Fig 5.
'Object without grid' setup.

Fig 6.
Table without grid' setup.

Fig. 7.
Object without grid

Fig. 8.
Object with grid

Fig. 9.
Object with grid - After Table and Grid Correction

Fig. 10.
Object with grid - After Table, Grid and Scatter correction

Fig. 11.
Object without grid

Fig. 12.
Object with grid: After Table, Grid and Scatter Correction

Fig 13.
Object without grid

Fig 14.
Object with grid

Fig 15.
Object with grid - After table and Grid Correction

Fig 16.
Object with grid - After Table, Grid and Scatter correction

Table 1

Grid specifications

Type number	989601061091
Line rate	70 line/cm
Grid ratio	13 : 1
Septa	Lead, 27.5 μ
Interspace material	Fiber

Table 2

Contrast and CNR comparison between 'Object without grid' and 'Object with grid' image.

Images taken	Contrast (%)		CNR		Effect of grid on	
	w/o grid	with grid	w/o grid	With grid	Contrast	CNR
98kVp, 200mA, 16ms	1.52	2.51	0.73	0.62	increases	decreases
88kVp, 200mA, 16ms	1.72	2.85	0.69	0.61	increases	decreases

Table 3

Contrast and CNR comparison of 'Object with grid' image after 'table and grid correction' and 'table, grid and scatter correction'.

	Object with Grid		After table+grid correction		After table+grid+scatter correction	
	Contrast (%)	CNR	Contrast (%)	CNR	Contrast (%)	CNR
98kVp, 200mA, 16ms	2.51	0.62	2.71	0.87	3.60	0.91
88kVp, 200mA, 16ms	2.85	0.61	3.07	0.80	3.99	0.82