Published in final edited form as:

Proc SPIE. 2012 February 23; 8313: 831357–. doi:10.1117/12.910945.

Dose Reduction Technique Using a Combination of a Region of Interest (ROI) Material X-Ray Attenuator and Spatially Different Temporal Filtering for Fluoroscopic Interventions

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Abstract

We demonstrate a novel approach for achieving patient dose savings during image-guided neurovascular interventions, involving a combination of a material x-ray region of interest (ROI) attenuator and a spatially different ROI temporal filtering technique. The part of the image under the attenuator is reduced in dose but noisy and less bright due to fewer x-ray quanta reaching the detector, as compared to the non-attenuating (or less attenuating) region. First the brightness is equalized throughout the image by post processing and then a temporal filter with higher weights is applied to the high attenuating region to reduce the noise, at the cost of increased lag; however, in the regions where less attenuation is present, a lower temporal weight is needed and is applied to preserve temporal resolution.

A simulation of the technique is first presented on an actual image sequence obtained from an endovascular image guided interventional (EIGI) procedure. Then the actual implementation of the technique with a physical ROI attenuator is presented. Quantitative analysis including noise analysis and integral dose calculations are presented to validate the proposed technique.

1. INTRODUCTION

X-ray endovascular image-guided interventions are carried out using the insertion and navigation of catheters through the vasculature under fluoroscopic image guidance [1]. Once the catheter is guided closer to the site of the pathology to be treated, the need for detailed image information outside this region is reduced and the dose can be reduced. This dose could be almost completely eliminated by collimating the x-ray beam into the region of the interest and completely cutting off the outside beam with the possible exception of a static reference image. However in this case, the interventionalist will not be able to see dynamically what is happening outside the region of interest as there is no current image in this region since there is no x-ray beam incident in this region.

In this paper we demonstrate a novel approach to achieve patient dose reduction, however not at the cost of losing the complete field of view outside the ROI. The technique involves a combination of using a material x-ray region of interest (ROI) attenuator and a spatially different ROI temporal filtering technique. The region of the image under the high attenuating material is noisy and less bright due to fewer x-ray quanta reaching the detector as compared to that in the non-attenuating (or less attenuating) region. First the brightness is equalized between the two regions and then a temporal filter with higher weights is applied

to the high-attenuating region to reduce the noise, at the cost of reduced temporal resolution; however in the regions where less attenuation is present, a lower temporal weight is applied to preserve temporal resolution.

2. METHODS

2.1 Spatially Different Temporal Filter

The equation for a basic temporal recursion filter is given below [2][3]:

$$y(t) = \frac{1}{k} \times x(t) + \left(1 - \frac{1}{k}\right) \times y(t-1)$$

where $x(t)$ is the current input signal at time or frame number t , $y(t-1)$ is the previous output, $y(t)$ is the present output of the filter and k is the filter weight (lag or memory) from 1 to ∞ . The output of the filter is the weighted sum of its current input and previous outputs.

Fluoroscopic systems have excellent temporal resolution, but are noisy due to lower dose per frame, hence inherent with x-ray quantum fluctuations. Spatial filters can be used to reduce noise but at the loss of some spatial resolution. Temporal filtering offers excellent noise reduction, preserving spatial resolution, but at the cost of some temporal resolution. However, since the operation on one pixel is independent of the other, different weights can be used in different spatial regions to achieve a compromise between temporal resolution and noise reduction. Higher filter weights offer a better noise reduction, however, at the cost of losing some temporal resolution, whereas a lower filter weight has a better temporal resolution but lesser noise reduction.

2.2 ROI FLUOROSCOPY

ROI fluoroscopy involves the use of an x-ray material attenuator with different attenuating regions. The basic idea of ROI fluoroscopy, as previously reported [4–6], is to modulate (using a beam modulating attenuation filter) the x-ray field incident to a patient to reduce the exposure and thus patient dose in the peripheral area surrounding the intervention. This results in a noisier and a less bright image in the ROI periphery due to fewer incident photons, whereas the image is brighter and relatively less noisy in the ROI due to higher exposure.

2.3 DOSE REDUCTION WITH COMBINATION OF ROI FLUOROSCOPY AND SPATIALLY DIFFERENT TEMPORAL FILTERING

Significant dose reduction can be achieved by using the ROI fluoroscopy technique. However, due to the reduction in the number of x-ray quanta, the region of the image underneath the filter is noisier and is less bright. So the image is first brightness corrected and then the spatially different temporal filter is applied to the image. Higher temporal weight is chosen for the region under the filter material, which results in the loss of some temporal resolution, however the weight inside the ROI is less as it is less noisy due to zero added attenuation of the incident x-rays. This process results in an overall acceptable image which is visually comparable to the image obtained without an ROI filter.

For our demonstration, we used an ROI attenuator filter consisting of Kodak Lanex Regular gadolinium screen material with a hole in the middle. The image processing was done on a dedicated graphics card, Model GTX 285 (NVIDIA Corp., Santa Clara, CA).

3. IMPLEMENTATION

The Control, Acquisition, Processing, and Image Display System (CAPIDS) [7], originally developed for the custom built Micro-Angiographic Fluoroscope (MAF) detector [8][9], was modified to implement ROI fluoroscopy with the Toshiba Infinix Flat Panel system. First the image from the Toshiba Infinix system is acquired using CAPIDS. The acquired image is then sent to the GPU for processing. In the GPU, first the brightness in the two regions is equalized using standard mask subtraction with an image of the filter alone. Figure 1 shows a typical mask that was obtained as an integral of many frames before the imaging run. Following brightness equalization, the noise in the periphery of the subtracted image is more prominent as compared to the noise in the ROI. To reduce this noise a recursive temporal filter with higher weight is applied in the periphery as compared to in the ROI. The image is then sent back to the CPU for display to the user. Figure 2 shows the workflow involved.

4. RESULTS

To evaluate the technique, a simulation was first done on a sequence of images obtained from a clinical EIGI procedure performed on a patient. The images were captured using the MAF detector. A circular region around the aneurysm was chosen as the ROI. The image area outside the ROI was mixed with Poisson noise to simulate the lower dose of ROI fluoroscopy (Fig. 3). These images were used as the input for the image correction program. First the input images were corrected for brightness mismatch (Fig. 4) and then the temporal weight outside the ROI was increased (to $k = 5$) to reduce noise; whereas the weight inside the ROI was kept lower (to $k = 1.25$) to preserve temporal resolution (Fig. 5)[10].

An actual implementation of the technique was performed on a skull phantom. The ROI attenuator (a stack of 4 layers of Kodak Lanex Regular gadolinium screen material with a hole in the middle) was placed on the x-ray collimator of the Toshiba Infinix C-Arm machine (Toshiba Medical Systems, Tustin CA). The images were captured using a flat panel detector. As can be seen from Figs. 6 and 7, the region of the image outside the ROI is less bright and much noisier due to fewer x-ray quanta reaching the detector. After the image is equalized in brightness (Fig. 7), a spatially different temporal filter is applied with a higher weight ($k = 5$) outside the ROI to reduce noise at the cost of losing temporal resolution and a lower weight ($k=1.25$) is applied inside the ROI so that temporal resolution is preserved (Fig. 8).

5. PRELIMINARY QUANTITATIVE ANALYSIS

A quantitative analysis of signal to noise ratio in comparable regions inside and outside the ROI for the skull phantom study (refer to Fig. 7 to see the two rectangular regions) is presented in Table 1 for different temporal weights outside the ROI. The signal to noise ratio is measured after the images are brightness corrected and spatially different temporal filter is applied with different weights inside and outside the ROI.

The kerma area product (KAP) can be used as a measure to gauge the integral dose [4] assuming the patient intercepts the entire beam. The ratio of the KAP with (K) and without the material filter (K_0) is given below

$$\frac{K}{K_0} = \frac{K_f \cdot (A-a) + K_{nf} \cdot a}{K_0 \cdot A}$$

where K_f is the air kerma calculated in the attenuated region of the filter with area $(A - a)$ and K_{nf} is the air kerma calculated in the non-attenuated region of the filter with area a , K_0 is the kerma calculated without any material attenuator and A is the total field of view.

The exposure values were measured using an ion chamber (PTW, Freiburg, Germany) and the kerma calculated in the region of the ROI and in the region under the ROI filter, with no additional attenuating material present in the beam. With the measured values, the ratio calculated is

$$\frac{K}{K_0} = 0.14$$

Physically, the attenuator is a stack of Kodak Lanex Regular gadolinium screen material with a hole in the middle. The purpose of the attenuator is to reduce the number of x-ray quanta and thus the dose to the patient in the region outside the ROI. But the patient acts as additional attenuation which further reduces the number of x-ray quanta reaching the detector outside the ROI. If the attenuation is too high, there is a possibility that the information in the pixels falling under the attenuator might be further compromised due to the instrumentation noise of the detector.

Figs. 9 and 10 show the ROI fluoroscopy images obtained with a stack of 4 filter layers with an attenuation factor of 6. Figs. 11 and 12 show the ROI fluoroscopy images obtained with a stack of 8 filter layers with an attenuation factor of about 14. The brightness equalized image Fig 11 shows that the region outside the detector is extremely noisy; the exposure reaching the detector was measured to be around $0.33\mu\text{R/frame}$, which is well below the instrumentation noise level of the FPD detector estimated to be about $2\text{--}3\mu\text{R/frame}$ [11][12]. With a high weight temporal filter applied outside the ROI the noise is reduced so that major structures in the patient should still be visualized and able to be monitored during an interventional procedure. Nevertheless, because the lag is increased, the moving guidewire tip might not be visible in all part of the image outside the ROI.

Thus the amount of dose reduction possible may be limited by the tradeoff between the effect of noise and image lag on image quality.

6. CONCLUSIONS

From the calculated KAP ratio, it can be concluded that significant reduction in integral dose ($\sim 7\times$) can be achieved by using a material ROI attenuator. However, the image obtained is not uniform in brightness and is noisy in the region underneath the high attenuating region. The brightness in the two regions can be equalized in software and a spatially different temporal filtering technique can be applied to the corrected image to achieve significant noise reduction. Thus combining the two techniques of spatially different temporal filtering and ROI fluoroscopy, significant dose reductions can be achieved during fluoroscopically guided interventions without significant sacrifice of useful image quality.

Acknowledgments

The authors gratefully acknowledge the clinical sequences performed and supervised by Drs. E. Levy, S. Siddiqui, and L. N. Hopkins and the assistance received from their colleagues at the University at Buffalo, Toshiba Stroke Research Center, Buffalo, NY. This work was supported in part by NIH Grants R01-EB008425, R01-EB002873 and an equipment grant from Toshiba Medical Systems Corporation.

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A - non attenuating region (ROI)

B - attenuating region

Figure 1.

An example of image mask used for subtraction to equalize brightness throughout the image.

A - non attenuating region (ROI)

B - attenuating region

Figure 2.
ROI fluoroscopy - work flow

Figure 3.
Image from patient procedure reduced in brightness and mixed with noise outside the ROI

Figure 4.
Image in Fig. 3 with brightness corrected

Figure 5.
Image in Fig 3 with brightness corrected and higher temporal weight outside the ROI ($k = 5$)

Figure 6.
Input image of a skull phantom with ROI attenuator in the beam

Figure 7.
Image in Fig. 6 with brightness corrected. Colored boxes show sampled regions for quantitative evaluation.

Figure 8.
Image in Fig. 6 with brightness corrected and higher temporal weight outside the ROI ($k = 5$)

Figure 9.
An image with brightness equalized in both regions and a temporal filter weight of 1.0 applied in the periphery. ROI attenuator stack - 4 layers, attenuation factor – 6 x

Figure 10.

An image with brightness equalized in both regions and a temporal filter weight of 0.4 in the periphery and 0.8 in the ROI. ROI attenuator stack - 4 layers, attenuation factor - 6x

Figure 11.

An image with brightness equalized in both regions, and a temporal filter weight of 1.0 applied in the periphery. ROI attenuator stack - 8 layers, attenuation factor – 14 x

Figure 12.

An image with brightness equalized in both regions, and temporal filter weight of 5 in the periphery and 1.25 in the ROI. ROI attenuator stack -8 layers, attenuation factor – 14 x

Table 1

Signal to Noise Analysis in similar regions inside and outside the ROI with different temporal weights applied to the region outside the ROI

Temporal Weight outside the ROI (k)	SNR(signal to noise) - Outside ROI	SNR(signal to noise)- Inside ROI temporal weight: (k = 1)
1	2.77	5.27
1.25	3.17	5.27
1.66	3.71	5.27
2.5	4.26	5.27
5	5	5.27