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Dose reduction by moving a region of interest (ROI) beam attenuator to follow a moving object of interest

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Abstract

Region-of-interest (ROI) fluoroscopy takes advantage of the fact that most neurovascular interventional activity is performed in only a small portion of an x-ray imaging field of view (FOV). The ROI beam filter is an attenuating material that reduces patient dose in the area peripheral to the object of interest. This project explores a method of moving the beam-attenuator aperture with the object of interest such that it always remains in the ROI. In this study, the ROI attenuator, which reduces the dose by 80% in the peripheral region, is mounted on a linear stage placed near the x-ray tube. Fluoroscopy is performed using the Microangiographic Fluoroscope (MAF) which is a high-resolution, CCD-based x-ray detector. A stainless-steel stent is selected as the object of interest, and is moved across the FOV and localized using an object-detection algorithm available in the IMAQ Vision package of LabVIEW. The ROI is moved to follow the stent motion. The pixel intensities are equalized in both FOV regions and an adaptive temporal filter dependent on the motion of the object of interest is implemented inside the ROI. With a temporal filter weight of 5% for the current image in the peripheral region, the SNR measured is 47.8. The weights inside the ROI vary between 10% and 33% with a measured SNR of 57.9 and 35.3 when the object is stationary and moving, respectively. This method allows patient dose reduction as well as maintenance of superior image quality in the ROI while tracking the object.

Keywords

Dose reduction; Region-of-interest (ROI) fluoroscopy; object tracking; adaptive temporal filtering

1. INTRODUCTION

Neurovascular interventional procedures involve placement of small devices such as stents and coils with strut sizes and wire diameters as small as 80 microns. High quality fluoroscopic images provide great assistance to the interventionalists [1]. In most of the cases, the region where the actual intervention is carried out does not cover the full field of view of commercial detectors. The concept of region of interest (ROI) fluoroscopy was proposed by Rudin and Bednarek in the paper "Region of Interest Fluoroscopy" [2], where the number of x-ray photons is reduced in the region peripheral to the ROI by placing a material attenuator in the x-ray beam. Thus the patient dose is substantially reduced in the peripheral region, and the image quality is maintained inside the ROI.

Numerous approaches achieve ROI fluoroscopy using different kinds of pre-patient x-ray beam attenuators. Roberts et al use an attenuator with a Gaussian center profile and equalize the intensities using image filtering [3]. Labbe et al used an x-ray fovea similar to Rudin and Bednarek, differing in the method for intensity equalization [4]. Sassi and Alan used multiple rotating lead segments as ROI beam attenuator [5]. Rowlands and Roberts described a collimator which allows exposure at 30 frames/sec inside the ROI and exposure at lower frame rates in the peripheral region [6].

The interventional procedures are dynamic; hence the region where superior image quality is needed changes its location in the detector field of view (FOV) during the procedure due to patient motion, table motion or even change of treatment area. In this project we automatically move the material attenuator during the interventional procedure to maintain the ROI over the object of interest by tracking that object in the fluoroscopic images. The image quality in the low dose peripheral region is improved by equalizing the pixel intensities between both regions and using greater temporal filtering in the peripheral region where there is greater quantum mottle.

2. MATERIALS AND METHOD

2.1 Microangiographic Fluoroscope (MAF)

The MAF has 1024×1024 pixels of 35 microns effective size and is capable of real-time imaging at 30 fps. The scintillator is 300 micron CsI(Tl) and is coupled to a CCD camera through a 2.88:1 fiber optic taper and light image intensifier (LII). The large variable gain of the LII provides quantum limited operation with essentially negligible additive instrumentation noise [7]. The MAF is designed to be used in conjunction with larger FOV commercial detectors such as a flat panel detector or an x-ray image intensifier when higher resolution is needed. The MAF is used here for fluoroscopy since it is able to capture real-time fluoroscopic images. Nevertheless, this technique can be used with any x-ray detector where real time access to the fluoroscopic images is available.

2.2 Phantom and ROI Beam Attenuator

A stainless steel stent with 100 micron struts was chosen as the object of interest (Figure 1). An anthropomorphic head phantom was used to add anatomic noise. The SNR was calculated on images where the anthropomorphic head phantom was replaced by a uniform head equivalent phantom specified in AAPM Report 31.

An attenuator constructed of 4 layers of Lanex Regular gadolinium screens with a hole punched in the center was used as the ROI attenuator. The transmission through the attenuator was measured to be about 20%. X-ray technique parameters used were 86 kV, 50 mA and 10 ms. The attenuator was mounted on a linear stage which was controlled by a stepper motor controller. This assembly was placed near the x-ray tube of a Toshiba Infinix C-arm gantry as shown in the illustration in figure 2. The dotted arrows show the movement of linear stage and the stent. The stent was moved by another linear stage independently controlled to ensure repeatability of the movement. Fluoroscopy was carried out in the HD mode of the MAF [8].

2.3 ROI attenuator repositioning

Initially, the ROI attenuator position is manually adjusted so that the stent lies completely within the ROI. As fluoroscopy is carried out, the stent is moved in one direction. The object is tracked using a detection algorithm that is available as a part of the IMAQ Vision package for LabVIEW. It uses “image understanding” techniques such as geometric modeling of images, efficient non-uniform sampling of images and extraction of template information that is rotationally independent and scale independent. Details of the algorithm can be found in the IMAQ Vision Concepts Manual [9]. The object detection algorithm detects the position of the stent in every frame. The distance through which the stent moved between consecutive frames is calculated. The distance through which the ROI attenuator has to be moved so as to keep the stent inside the ROI is calculated and the ROI attenuator is repositioned using its linear stage. This ensures that the ROI attenuator always follows the object of interest.

2.4 Pixel intensity equalization and temporal image filtering

Figure 3 shows a raw image from the sequence before any processing. This image was divided in two regions, one inside the ROI and the other in the peripheral region. Different amount of temporal filtering was used for each of the regions. Pixel intensity equalization was carried out by generating a multiplying factor mask from a radiographic mask of the ROI attenuator without any anatomical noise. When the ROI was moved, the mask was registered over the ROI location in the fluoroscopic frame.

Inside the ROI, an adaptive temporal filter [10] was used based on the motion of the stent. The temporal filtering was increased when the stent was found to be stationary and the amount of temporal filtering was reduced when it was moving. As only 20% of photons reach in the peripheral region, the quantum noise is higher compared to the region inside the ROI. To reduce the quantum noise, a temporal filter weight for the current frame of 5% was used in the peripheral region. The temporal filter used is given as

$$I_{filt} = \alpha \cdot I_{curr} + (1 - \alpha) \cdot I_{prev} \quad (1)$$

Where α is the weight for current image, I_{filt} is the filtered image, I_{prev} is the previous filtered image, and I_{curr} is the current acquired image.

3. RESULTS

SNR was measured in images acquired where the anthropomorphic head phantom was replaced by a uniform head equivalent phantom. SNR was calculated as the ratio of mean value inside a selected region as shown in figures 4(a) and (b) and its standard deviation. The temporal filter weight for the current frame in the peripheral region was kept at 5% for the duration of the experiment. Thus the SNR is seen to be around 48 in the peripheral region. The temporal filter weight for the current frame inside the ROI was varied according to the motion of the stent. When the stent was stationary as seen in figure 4(a), the weight was 10% and when the stent was in motion, the weight was 33%. This is reflected in the SNR inside the ROI which reduces from 57.9 to 35.3 as the temporal filtering is reduced to avoid blurring of the stent due to motion.

Figure 5 shows adaptive temporally filtered and intensity equalized images. In both figure 5(a) and 5(b) the temporal filter weight for the current frame in the stationary peripheral region is 5%. The filter weight for the current frame inside the ROI is changed adaptively depending on the motion of the stent. When it is stationary, the weight is 10% and it is changed to 33% when the stent is moving.

4. INNOVATIONS

This project utilizes modern computing capabilities to extend the idea of ROI fluoroscopy to improve the image quality in the peripheral region. The ROI beam attenuator is now moved to provide superior image quality within the region where the intervention is being performed by tracking an endovascular device as it may be moved. A new concept of motion based adaptive temporal filtering has been used enabling the use of optimum temporal filtering to avoid motion blur. The concept of spatially different temporal filtering [11] has been adapted to involve a moving ROI.

5. CONCLUSIONS

In this paper, we have successfully demonstrated how the ROI beam attenuator can be moved to achieve improved image quality in the region of intervention when it moves

anywhere within the detector FOV. Using different temporal filters in the ROI and peripheral regions, high SNR in the peripheral region could be maintained even when the ROI was moving.

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Figure 1.
Stainless steel stent template image

Figure 2.
Experimental Setup

Figure 3.
Unprocessed raw image

Figure 4(a)

Figure 4(b)

Figure 4.

Figure 4(a). Image of a stationary stent showing regions used to calculate the SNR. SNR outside = 47.8, SNR inside = 57.9

Figure 4(b). Image of a moving stent showing regions used to calculate the SNR. SNR outside = 48.1, SNR inside = 35.3

Fig 5(a)

Fig 5(a)

Figure 5.

Fig 5(a). Adaptive temporally filtered and equalized images when the stent was stationary with a peripheral region temporal filter weight = 5% and with a temporal filter weight inside the ROI = 10%

Fig 5(b). Adaptive temporally filtered and equalized images when the stent was moving with the peripheral region temporal filter weight = 5% and with a temporal filter weight inside the ROI = 33%