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A novel Region of Interest (ROI) imaging technique for biplane imaging in interventional suites: high-resolution small field-of-view imaging in the frontal plane and dose-reduced, large field-of-view standard-resolution imaging in the lateral plane

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Abstract

Endovascular-Image-Guided-Interventional (EIGI) treatment of neuro-vascular conditions such as aneurysms, stenosed arteries, and vessel thrombosis make use of treatment devices such as stents, coils, and balloons which have very small feature sizes, 10's of microns to a few 100's of microns, and hence demand a high resolution imaging system. The current state-of-the-art flat panel detector (FPD) has about a 200-um pixel size with the Nyquist of 2.5 lp/mm. For higher-resolution imaging a charge-coupled device (CCD) based Micro-Angio -Fluoroscope (MAF-CCD) with a pixel size of 35um (Nyquist of 11 lp/mm) was developed and previously reported. Although the detector addresses the high resolution needs, the Field-Of-View (FOV) is limited to 3.5 cm $\times$ 3.5 cm, which is much smaller than current FPDs. During the use of the MAF-CCD for delicate parts of the intervention, it may be desirable to have real-time monitoring outside the MAF FOV with a low dose, and lower, but acceptable, quality image.

To address this need, a novel imaging technique for biplane imaging systems has been developed, using an MAF-CCD in the frontal plane and a dose-reduced standard large FOV imager in the lateral plane. The dose reduction is achieved by using a combination of ROI fluoroscopy and spatially different temporal filtering, a technique that has been previously presented.

In order to evaluate this technique, a simulation using images acquired during an actual EIGI treatment on a patient, followed by an actual implementation on phantoms is presented.

Introduction

Neuro-Endovascular Image Guided Interventions (EIGI's) [1] are modern day, minimally invasive treatments of neurovascular conditions such as aneurysms or stenosed arteries. The treatment involves the inserting of a catheter into the femoral artery, and guiding the catheter under x-ray imaging to the treatment area. Then treatment devices such as stents, coils, and balloons are deployed. These treatment devices have very small feature sizes of the order of

tens to a few hundreds of microns. Current state-of-the-art flat-panel detectors (FPDs), with a pixel size of $200\mu\text{m} \times 200\mu\text{m}$, do not have sufficient resolution to adequately image these devices.

In order to provide high resolution imaging of these treatment devices during an intervention, a high resolution Micro Angiographic Fluoroscope (MAF) based on a charge couple device (MAF-CCD) was developed [2]. The construction of the MAF is shown in figure 1 [2]. The main image capture device is the CCD sensor. The x-ray photons incident on the phosphor are converted to light photons, which are then amplified by the Light Image Intensifier (LII). The output of the LII is then collected by the Fiber Optic Taper (FOT) which is coupled to the active image area of the CCD sensor via the fiber optic plate. The CCD sensor has a pixel size of $12\mu\text{m} \times 12\mu\text{m}$, with an active matrix of 1024×1024 pixels. This gives a field of view (FOV) of approximately $1\text{ cm} \times 1\text{ cm}$ for the CCD sensor. While the resolution of CCD is higher than the FPD, the FOV is extremely small and is impractical for any intervention. To expand the FOV, a FOT with a magnification ratio of 2.9 was used. This gives a total FOV of $3.5\text{ cm} \times 3.5\text{ cm}$ with an effective pixel size of about $35\mu\text{m}$ resulting in a Nyquist frequency of 11 lp/mm.

The MAF-CCD is mounted on a mechanical changer in the frontal plane of a Toshiba Infinix C-arm. During the critical stages of the intervention such as a stent deployment, when high resolution imaging is needed, the MAF-CCD is brought into the FOV in front of the FPD, making the MAF-CCD the primary imaging detector. During this stage while the resolution of the images is much higher than the images from the FPD, the FOV is restricted.

To increase the FOV of the intervention, the FPD in the lateral C-arm is used. Since the interventional area is much smaller than the total FOV of the lateral FPD, the dose to parts of the patient outside the treatment area can be reduced without heavily compromising the overall image quality by using a combination of Region of Interest (ROI) fluoroscopy and spatially different temporal filtering [3][4][5][6]. ROI fluoroscopy uses a beam modulating attenuator with differential attenuation regions to achieve dose reduction. Parts of the patient outside the ROI treatment area are under the attenuator material, and receive less dose (refer to figure 2), thus achieving dose reduction. This results in an image with differential brightness between the ROI and peripheral regions; the image is less bright and more noisy in the dose reduced regions due to fewer quanta reaching the detector as shown in figure 3 [5].

The image is restored in brightness and reduced in noise in the dose reduced regions before it is displayed to the interventionalist. Figure 4 shows the software correction process involved in restoring the image quality in the brightness reduced regions [4]. The brightness is restored by subtracting a pre-acquired mask of the attenuator from the input raw images. The increased noise due to the reduced or attenuated quanta in the image outside the ROI is in turn reduced by using a spatially different, temporal filtering, with more filtering in the dose reduced regions and less in the ROI. The temporal filtering equation used is given below

$$y(t) = (1 - \alpha) \times x(t) + \alpha \times y(t - 1)$$

where $x(t)$ is the present input signal at time t (current image), $y(t-1)$ is the previous filtered output, $y(t)$ is the present filter output, α is the filter weight. The output of the filter is the weighted sum of its current input and previous outputs.

Methods and Materials

The novel Region of Interest (ROI) imaging technique for biplane imaging in interventional suites, using a high-resolution small FOV imaging in the frontal plane and dose-reduced, large FOV standard resolution imaging in the lateral plane, is presented here. In order to validate this combined imaging technique, first a simulation was performed using clinical images and is presented below. The MAF-CCD was successfully used during an EIGI on a human patient and the lateral FPD was used under regular dose for peripheral monitoring. The images from this are used for simulating the patient dose reduction. This is followed by two phantom studies using the ROI biplane imaging technique in real time.

Simulation

Figure 5 shows an angiogram of a patient diagnosed with an intracranial aneurysm. In order to treat the condition, three flow diverter stents (Pipeline Embolization Device, ev3 Endovascular, Inc, USA) were deployed over the aneurysm neck. The MAF was used to guide the deployment. The MAF was mounted on the AP plane of the Toshiba Biplane system. Figures 6a-c show three images from the entire deployment of the final stent. While the MAF offers high resolution imaging, the field of view is very limited. To image the deployment outside the MAF field of view, standard FPD imaging on the lateral plane of the C-arm system was used. Figures 7a-c show three images from the lateral FPD plane sequence of the deployment.

To simulate the images that would be obtained by using a ROI attenuator, a circular region around the deployment was chosen as the ROI in the FPD images. The peripheral regions were reduced in brightness and mixed with noise (standard deviation of 30 digital numbers corresponding to a dose reduction of approximately 5 times). Figure 8 shows the algorithm used to generate the ROI images. The simulated images were then processed according to the algorithm shown in figure 8. Figures 9a-c show the result of different stages of processing.

Three images from the simulated image sequence (similar to but not the same as the images presented in figures 7a-c) are presented in figures 10a-c. The image quality is comparable to images obtained under reduced dose. The features in the periphery are still clearly visible.

Phantom studies

To demonstrate the real time effectiveness of using the novel technique of combining high resolution small field of view imaging in one plane with dose reduced imaging in the other plane, two phantom studies were conducted. In both the studies the MAF was mounted on a

mechanical changer on the frontal plane of the C-arm, while a ROI attenuator (stack of Kodak Lanex screens [5]) was mounted on the collimator assembly on the lateral plane. An integral dose reduction of 86% per frame was measured. Figure 11 shows the biplane setup.

In the first study, an aneurysm model was placed inside a human skull in the Circle of Willis region. In order to simulate the brain, the skull was filled with brain imaging material previously described [7, 8]. A flow loop was connected to the aneurysm. A coronary stent (CYPHER, Balloon Expandable Stent System, Cordis Corporation, Bridgewater, NJ) was deployed near the aneurysm under x-ray guidance from the MAF. At the same time, the lateral plane was used for peripheral monitoring with ROI fluoroscopy and spatially different temporal filtering. Figure 12 shows the deployed stent image acquired using the small field-of-view MAF camera in the frontal plane and figure 13 shows a zoomed in view of the frontal view of the stent taken by the FPD looking at a similar FOV as of MAF. Figure 14 shows the corresponding large field-of-view, dose-reduced FPD image from the lateral plane. Comparing figures 12 and 14, the stent structure is visible in the MAF image due to its high resolution, whereas it is barely visible in figure 14 using the FPD.

A second phantom with complicated vessel features was used to further evaluate this technique. A Digital Subtraction Angiography (DSA) run was performed with the MAF in the frontal plane and FPD (under ROI fluoroscopy) in the lateral plane. Figure 15 shows the DSA run on the second vascular phantom using the MAF in the frontal plane and figure 16 shows the corresponding large field-of-view, dose-reduced FPD image from the lateral plane. Although the MAF offers high resolution, the field of view is small. With the lateral plane imaging, the complete vascular flow can be visualized.

Conclusion

The MAF demonstrates superior image resolution as compared to a state-of-the-art FPD. However, the field-of-view is significantly smaller compared to the FPD. In order to expand the FOV during the intervention, a standard large FOV but low resolution image with the FPD in the lateral arm can be used. However, since the treatment area is much smaller than the complete FOV of the FPD, unnecessary dose to the patient in the peripheral regions can be reduced by using the dose reduction technique achieved by a combination of ROI fluoroscopy with spatially different temporal filtering used for noise reduction.

From the simulation studies on the EIGI image sequence of a human patient, it can be seen that the novel ROI imaging technique enhances the image quality during the intervention. While the MAF-CCD provides superior imaging of the treatment devices as compared to the lateral FPD, the lateral FPD provides a larger FOV. Even with the dose reduced in the periphery, the image quality can still be restored to acceptable levels. The phantom studies show the real time implementation of novel ROI imaging technique in a clinical suite.

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Figure 1. Schematic of the MAF-CCD detector. The input x-ray photons incident on the CsI phosphor, get converted to light photons. The light photons are amplified by the LII which is coupled to the CCD sensor via a FOT.

Figure 2. Concept of ROI fluoroscopy. The attenuator has differential attenuation regions. For this study a stack of Kodak Lanex screens with a hole in the middle was used as the attenuator.

Figure 3.
Image of a head phantom acquired, with the ROI attenuator in the beam.

Figure 4.

Processing steps for ROI fluoroscopy images acquired with the attenuator in the beam.

Figure 5.
Angiogram of a patient taken with the FPD showing an intracranial aneurysm.

Figure 6.
EIGI image acquired using MAF-CCD detector on frontal plane of C-arm.

Figure 7. EIGI image acquired using FPD on lateral plane of C-arm

Figure 8.

A functional block diagram showing the different steps involved in generation of ROI fluoroscopy images for simulation.

Figure 9.

Different steps involved in the simulation of dose reduction concept on EIGI sequence acquired using the FPD in the lateral C-Arm. The processing demonstrating the steps for ROI fluoroscopy are shown as the interventional sequence is proceeding.

Figure 10. Simulated patient dose reduced EIGI

Figure 11. Bi-plane imaging setup. MAF mounted on the automatic changer on the frontal plane, ROI attenuator mounted on the collimator of the lateral C-arm

Fig 12.
Image of the deployed stent obtained using the frontal MAF.

Fig 13.
Image of the deployed stent obtained using the frontal FPD for a projection similar to that of the MAF as shown in Fig 12.

Fig 14.
Image obtained using FPD in lateral plane. The ring artifact is due to the mask subtraction process used to correct for the brightness mismatch resulting from the ROI attenuator.

Fig 15.
DSA Image of an aneurysm model, obtained using the MAF in frontal plane.

Fig 16. Lateral c-arm image of the entire vessel phantom obtained using the FPD with a ROI attenuator. The green circle (diameter approximately the MAF FOV) indicates the region of the phantom imaged by MAF in the frontal plane