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Spatially Different, Real-Time Temporal Filtering and Dose Reduction for Dynamic Image Guidance during Neurovascular Interventions

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Abstract

Fluoroscopic systems have excellent temporal resolution, but are relatively noisy. In this paper we present a recursive temporal filter with different weights (lag) for different user selected regions of interest (ROI) to assist the neurointerventionalist during an image guided catheter procedure. The filter has been implemented on a Graphics Processor (GPU), enabling its usage for fast frame rates such as during fluoroscopy.

We first demonstrate the use of this GPU-implemented rapid temporal filtering technique during an endovascular image guided intervention with normal fluoroscopy. Next we demonstrate its use in combination with ROI fluoroscopy where the exposure is substantially reduced in the peripheral region outside the ROI, which is then software-matched in brightness and filtered using the differential temporal filter. This enables patient dose savings along with improved image quality.

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I. Introduction

x-ray image-guided interventions are carried out using the insertion and navigation of catheters through the vasculature. After drug treatment, the primary interventional therapy for vascular diseases is minimally invasive endovascular image-guided interventions (EIGIs). EIGIs generally involve the insertion of a catheter into the femoral artery, which is then threaded under fluoroscopic guidance through the vasculature to the site of the pathology to be treated [1]. Once the catheter is guided to a region closer to the aneurysm (which is treated as an ROI), unnecessary dose to the patient outside the ROI can be reduced by using an ROI x-ray beam filter. However due to the lower number of x-ray quanta, the image is noisy outside the ROI.

In this paper we present a novel approach towards patient dose reduction by combining the use of an ROI x-ray beam filter and Spatially Different, Real-Time Temporal Filtering, to achieve an overall acceptable image at lower dose to the patient.

First we present the use of spatially different temporal filtering on the image sequence obtained during an EIGI procedure, on a user selected ROI. Three images are presented in Figs. 1, 2 and 3 to illustrate the essence of an EIGI procedure.

Secondly we simulate ROI fluoroscopy conditions on the EIGI image sequence. Finally we use the spatially different temporal filtering on the simulated images to demonstrate the dose reduction technique.

II. THEORY

A. RECURSIVE FILTERING

The equation for a basic linear recursive filter is

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

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 α is the filter weight (lag or memory). The output of the filter is the weighted sum of its current input and previous outputs. The higher the weight, the greater are the lag and the degree of smoothing.

Fluoroscopic systems have excellent temporal resolution, but are relatively noisy due to a low dose rate and concomitant x-ray quantum fluctuations. Using the recursive temporal filtering scheme allows for noise reduction, however at the cost of temporal resolution. In this paper we present a technique to apply different filter weights in different regions of the image so that the temporal resolution in the ROI is not compromised while achieving better noise reduction in the periphery.

B. CUDA ARCHITECURE

It is the computing engine in the NVIDIA graphics processing unit (GPU) that allows high-speed image-processing and is accessible using various industry standard programming languages. An example of a simple CUDA (Compute Unified Device Architecture) processing flow [2] is shown in Fig. 4.

III. IMPLEMENTATION

With the current generation multicore-CPU operating at faster speeds it is possible to process 1Mega pixel images at fast frame rates. With the introduction of CUDA computing by NVIDIA (Santa Clara, CA), it has become possible to implement complex image processing algorithms on a graphics processor (GPU) which has a hardware platform for massive parallel computing, thus achieving reduction in processing time. For parallel algorithms, a GPU implementation is faster than a CPU implementation, thus easily achieving fast frame rates such as 30fps. The temporal filtering and other image processing were implemented on a dedicated graphics card GTX 285 from NVIDIA.

During the intervention, a total of 2700 images were acquired using a custom-built Micro-Angiography (MAF) x-ray detector [3] at the rate of 15fps and were stored in the computer hard disk memory. Each image is of size 1024×1024 pixels with 16 bits in each pixel. The stored images were played back at the rate of 20 fps and sent to the Graphics card for processing. A screen shot of the playback program along with the output from the GPU is presented in Fig. 5.

IV. APPLICATION TO EIGI UNDER NORMAL FLUOROSCOPY

EIGI techniques and theory have been reported before [1]. A circular region around the aneurysm (Fig. 1) of the patient is selected as the ROI. During the beginning of the intervention while the coil-wire is being guided towards the aneurysm, a lower lag is selected outside the ROI, to avoid any loss in temporal resolution (Fig. 6). Once the coil-wire is inside the ROI, the weight in the non-ROI or peripheral region is increased to reduce noise thus providing a smoother image to the neurointerventionalist for reference, while the lag in the ROI is decreased to allow unblurred imaging of fine wire and coil movements within the aneurysm itself (Fig. 7). If needed and if temporal resolution is not an issue, equally high weights can be used in both regions for a better overall image quality as shown in Fig. 8.

V. APPLICATION TO ROI FLUOROSCOPY

The basic idea of ROI fluoroscopy, as previously reported [4–7], is to modulate the x-ray field (using a beam modulating attenuation filter) 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. Previously, techniques have been reported to equalize the two regions for a better display [8–10]. Along with brightness and contrast restoration, the differential temporal filtering technique discussed above can be used to reduce the noise in the periphery and assist the interventional procedure by providing a better quality real-time image sequence.

A computer simulation has been performed and presented here. The images from the sequence of an actual procedure shown in Figs. 1–3 were reduced in brightness and mixed with Poisson noise to simulate images obtained from ROI fluoroscopy (Fig. 9 and 10). These images were played back at 20 fps and were sent to the GPU for real-time processing. The images were first equalized to restore the image brightness (Fig. 11) and then the temporal filtering technique described above was applied to the restored images (Fig. 12). As it can be seen from Fig. 11, the image outside the ROI is noisy due to fewer quanta incident on the sensor. Hence applying temporal filtering to this part of the image can reduce the noise and make it appear smoother.

A larger temporal weight can be applied on the outside, as movement in the periphery would not be as crucial since it is used only for monitoring whether anything should go wrong during the intervention (Fig. 12). If needed a higher filter weight can also be applied inside the ROI, however at the cost of losing some temporal resolution.

VI. CONCLUSION & FUTURE WORK

In this paper we have demonstrated how a differential temporal recursive filter implemented on a GPU can help in providing improved image guidance during neurovascular interventions at realistically fast frame rates. We have also demonstrated its potential use in ROI fluoroscopy where patient dose can be substantially lowered in the periphery. Currently work is in progress toward use of these techniques in clinical applications to achieve dose savings as well as improved image quality due to reduced scatter from the periphery entering the ROI image.

Acknowledgments

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References

1. Rudin S, Bednarek DR, Hoffmann KR. Endovascular image guided interventions (EIGIs). Med Phys. Jan.2008 35:301–309. [PubMed: 18293585]
2. http://en.wikipedia.org/wiki/File:CUDA_processing_flow_(En).PNG.
3. Wang W, Ionita CN, Keleshis C, Kuhls-Gilcrist A, Jain A, Bednarek D, Rudin S. Progress in the Development of a new Angiography Suite including the High Resolution Micro- Angiographic Fluoroscope (MAF), a Control, Acquisition, Processing, and Image Display System (CAPIDS), and a New Detector Changer Integrated into a Commercial C-Arm Angiography Unit to Enable Clinical Use. Proc SPIE. Mar.2010 7622
4. Rudin S, Bednarek DR. Region of interest fluoroscopy. Med Physics. Sep-Oct;1992 19(5):1183–1189.
5. Rudin S, Guterman LR, Granger WE, Bednarek DR, Hopkins LN. Application of region-of-interest imaging techniques to neurointerventional radiology. Radiology. Jun.1996 199:870–873. [PubMed: 8638020]
6. Rudin S, Bednarek DR, Kezerashvili M, Granger WE, Serghany JE, Guterman LR, Hopkins LN, Szymanski B, Loftus RJ. Clinical application of region-of-interest techniques to radiologic imaging. Radiographics. Jul.1996 16:895–902. [PubMed: 8835978]
7. Kezerashvili M, Rudin S, Bednarek D. Automatic filter placement device for region of interest (ROI) fluoroscopy. Health Phys. Jan.1997 72:141–146. [PubMed: 8972840]
8. Fletcher LM, Rudin S, Bednarek DR. Method for image equalization of ROI fluoroscopic images using mask localization, selection and subtraction. Comput Med Imaging Graph. 1996; 20:89–103. [PubMed: 8891426]
9. Rudin S, Bednarek DR, Yang CY. Real-time equalization of region-of-interest fluoroscopic images using binary masks. Med Phys. Jul.1999 26:1359–1364. [PubMed: 10435538]
10. Robert N, Komljenovic PT, Rowlands JA. A filtering method for signal equalization in region-of-interest fluoroscopy. Med Phys. May.2002 29:736–747. [PubMed: 12033570]

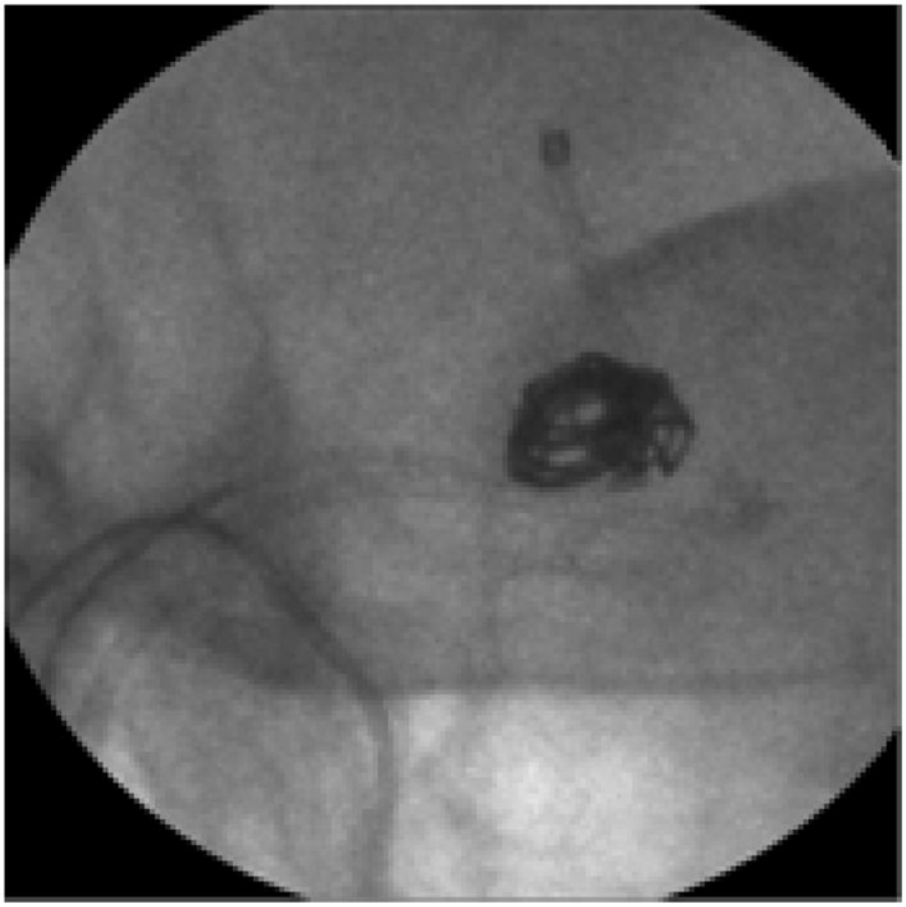

Figure 1.
Coil wire outside the aneurysm fed through smaller catheter. Larger catheter is in place, in case stent deployment would be needed to keep coil mass within the aneurysm.

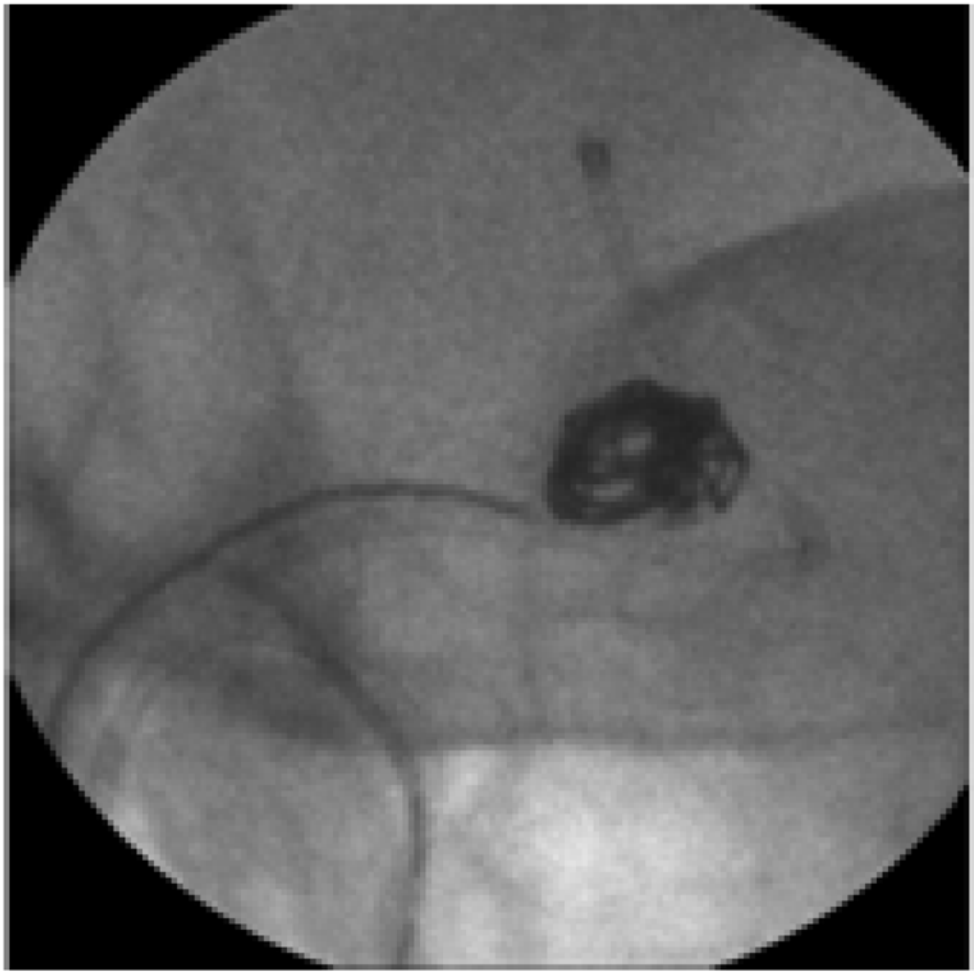

Figure 2.
Coil-wire entering the aneurysm.

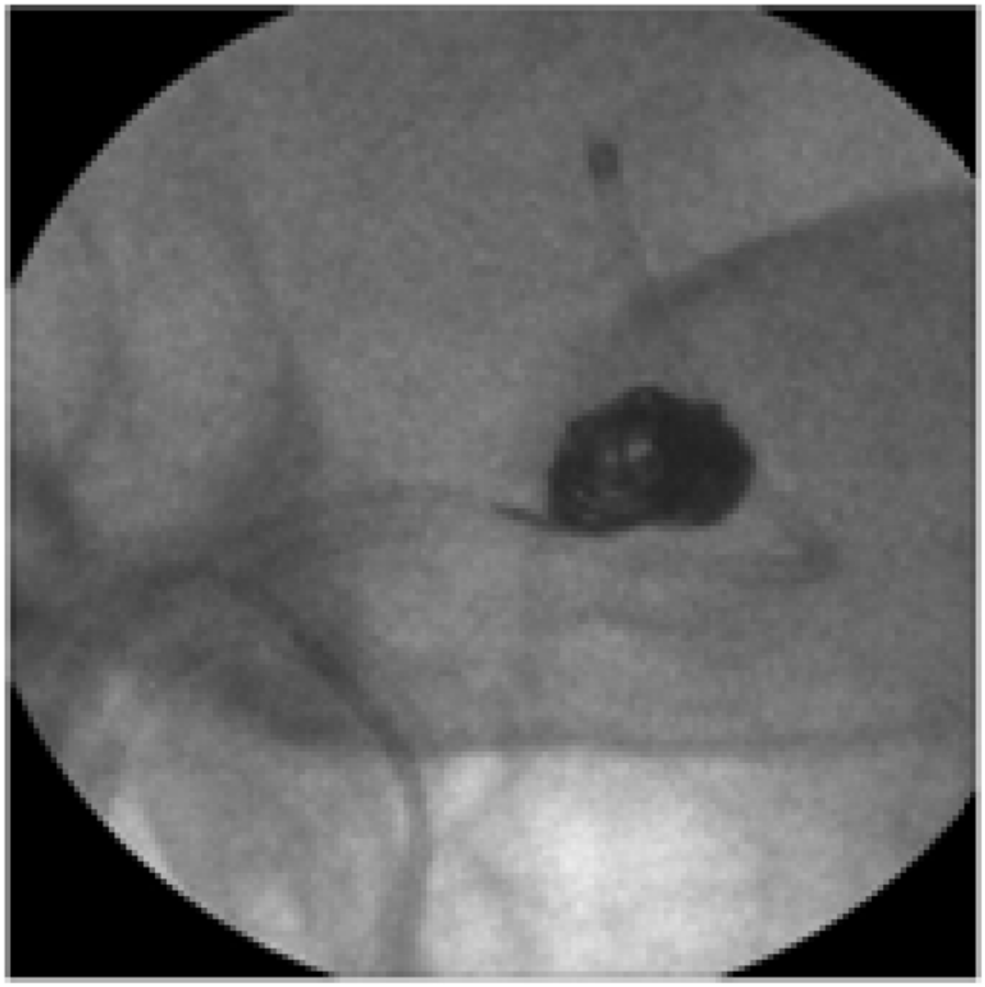

Figure 3.
Coil-wire successfully guided into the aneurysm.

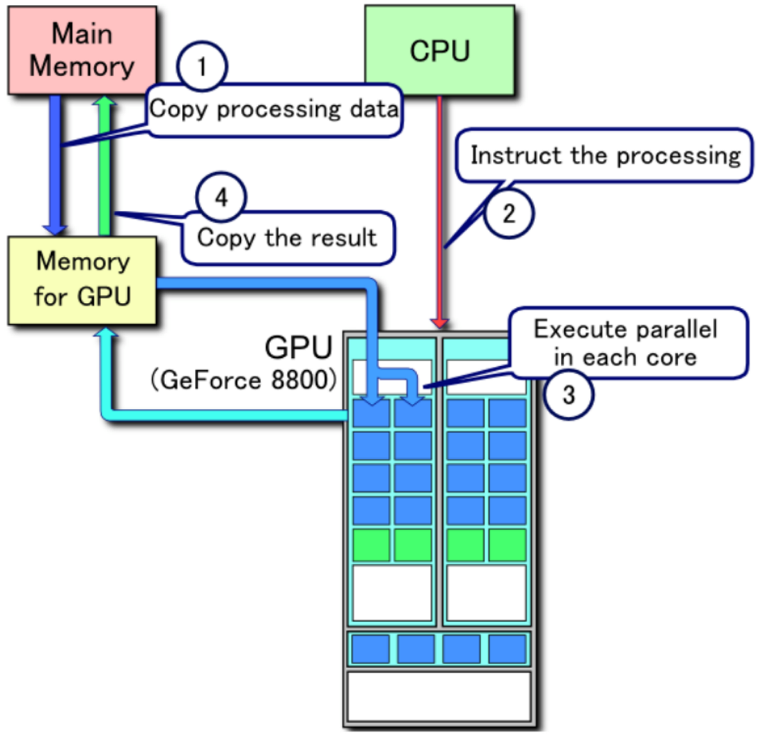

Figure 4.
Example of a CUDA processing flow

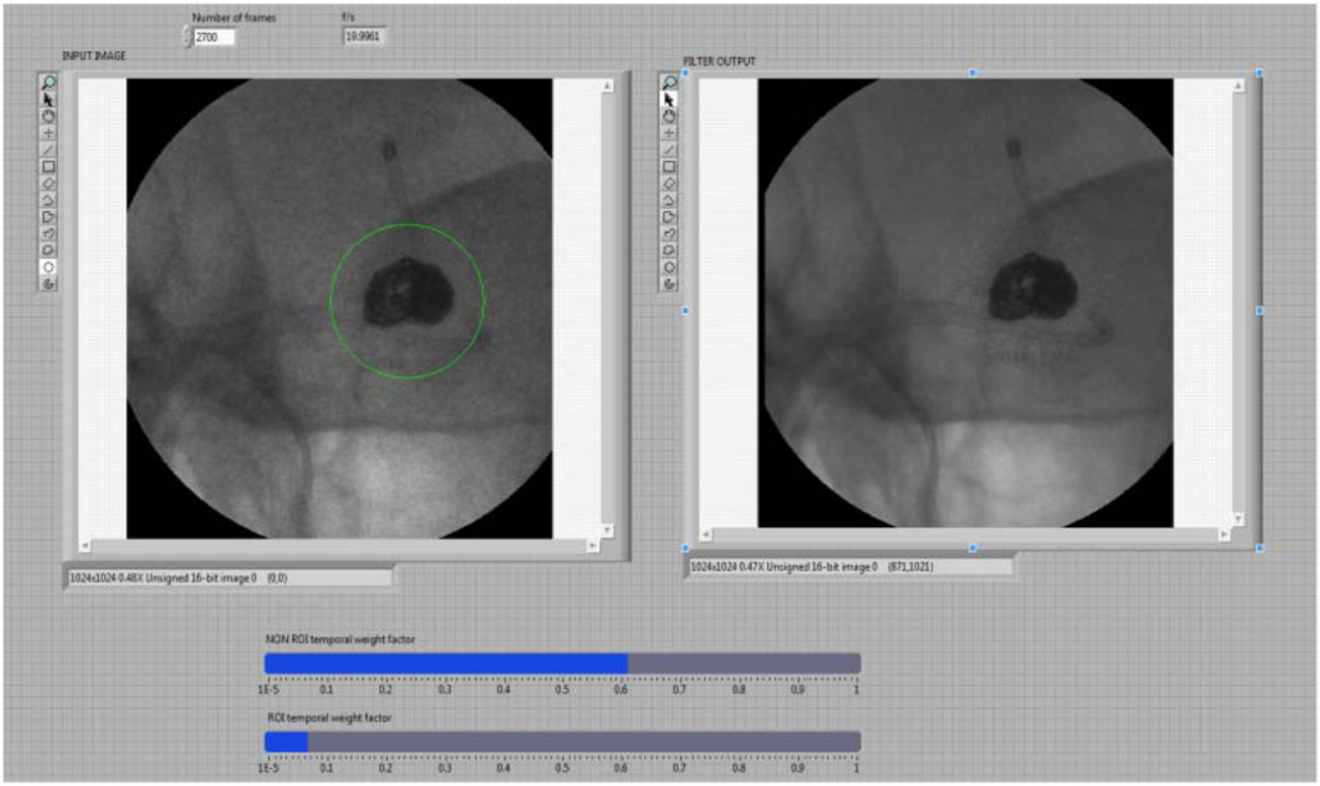

Figure 5.

Front Panel of the playback program with the processed temporally-filtered output indicating lower noise. The marked circle indicates the unfiltered ROI.

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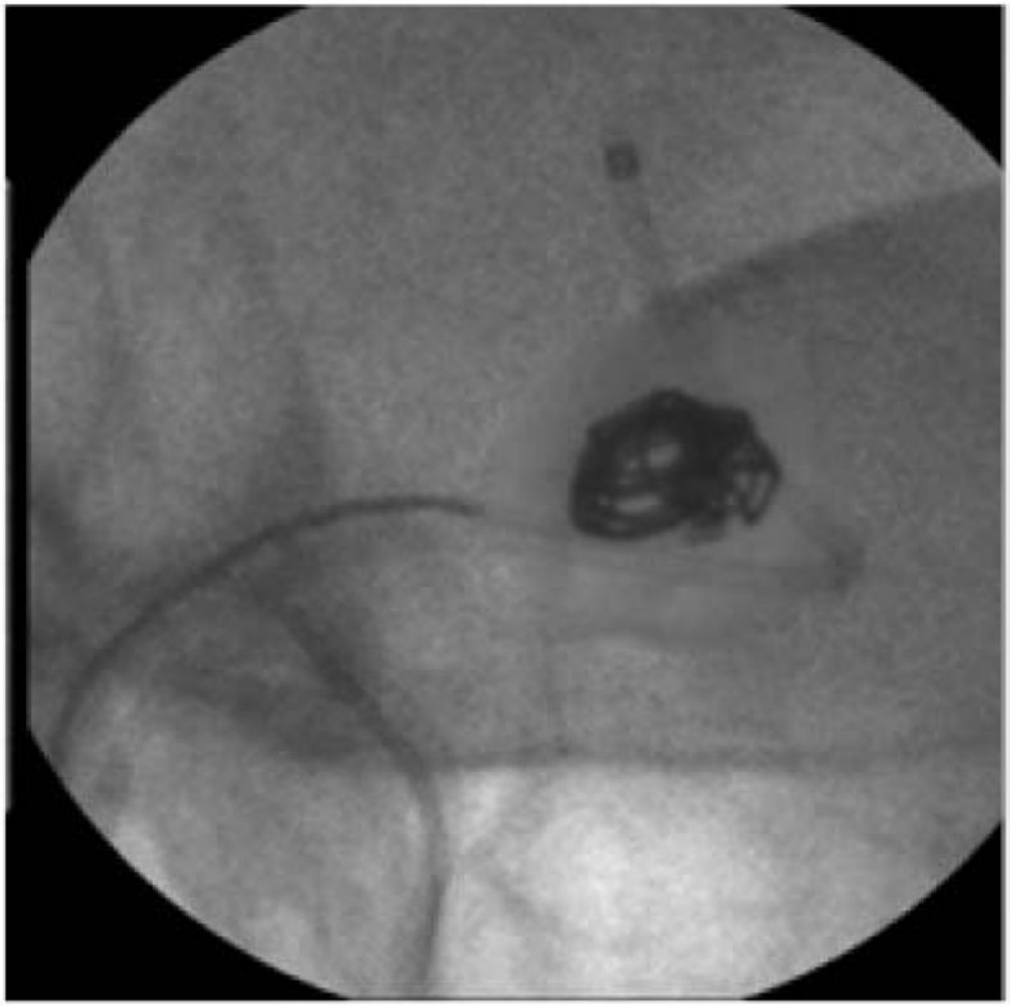

Figure 6.
Filter Weight in ROI is 0.70, while it is 0.25 on the outside.

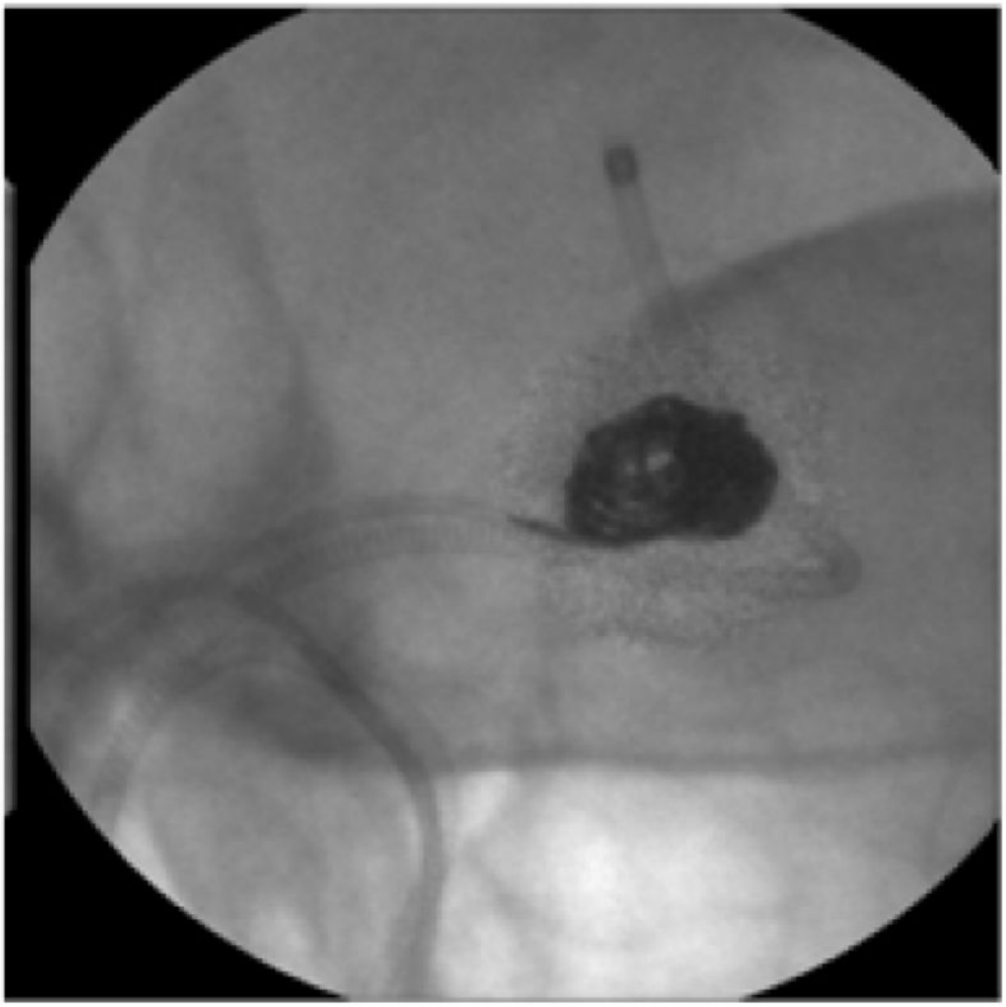

Figure 7.
Filter Weight in ROI is 0.25, while it is 0.7 on the outside.

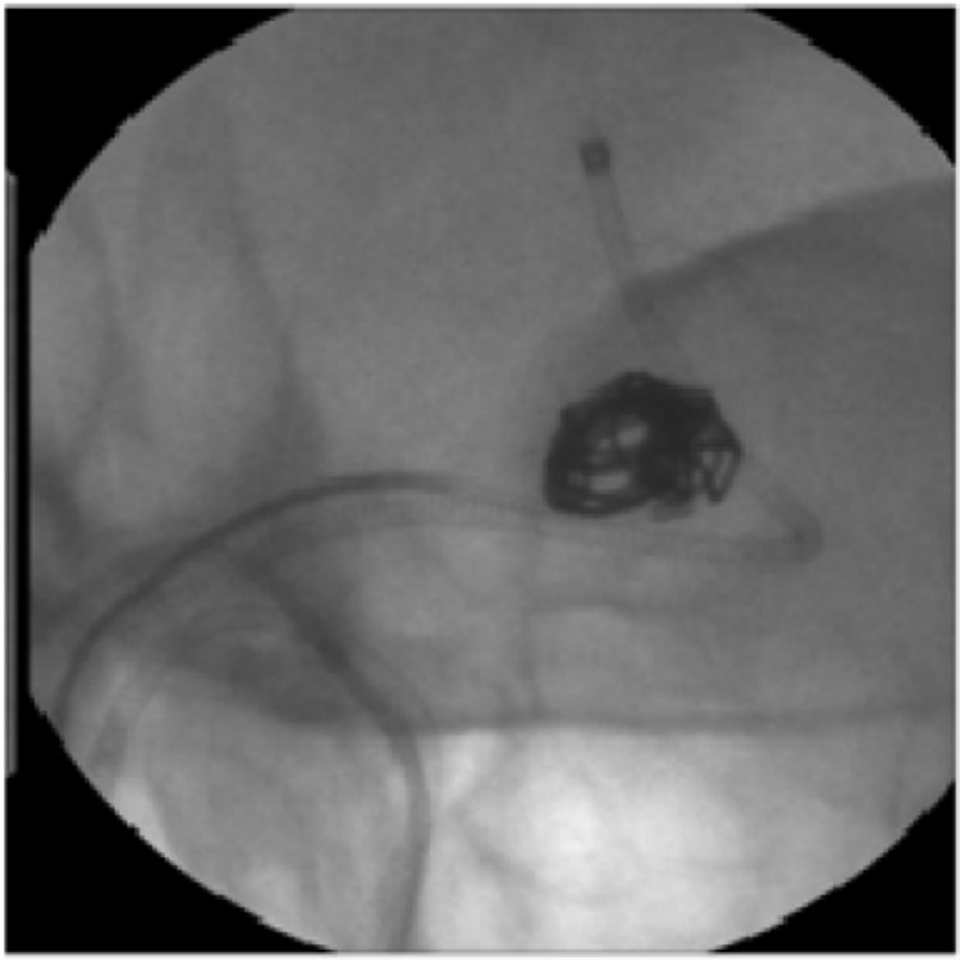

Figure 8.
Processed images with equal filter weight of 0.7.

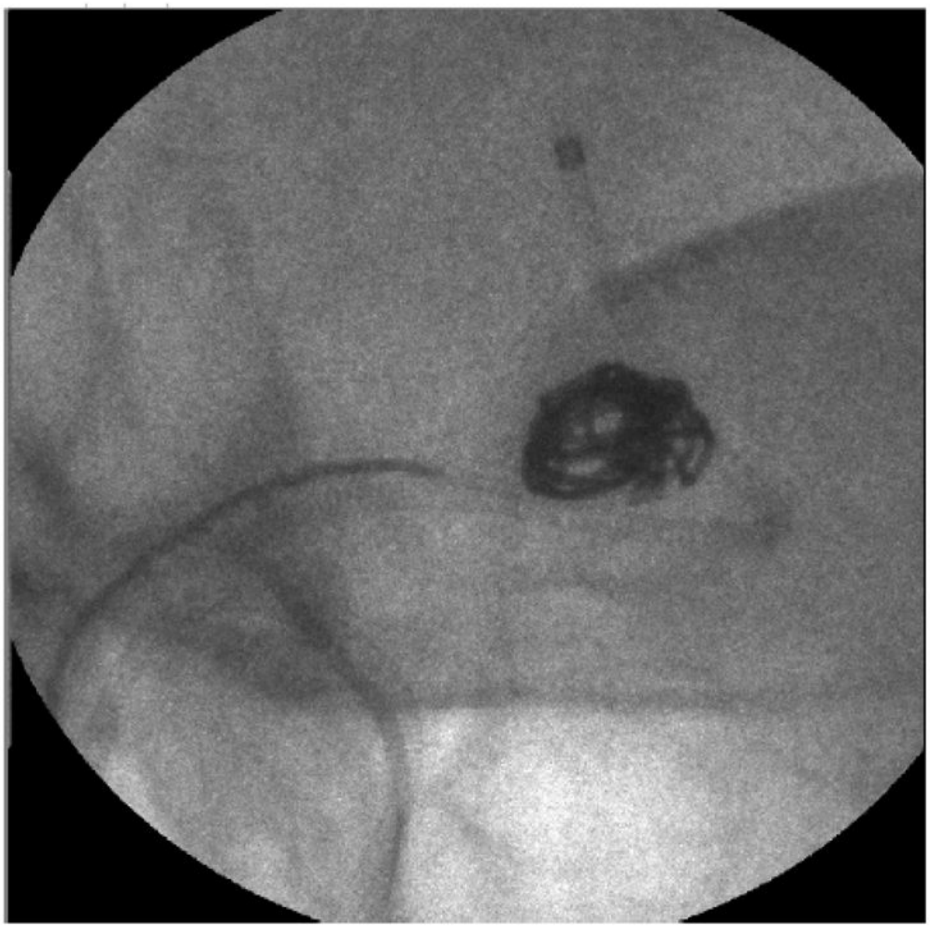

Figure 9.
Image reduced in overall pixel values (dose) by a factor of 10 with Poisson noise added; however the display is brightness adjusted for reader convenience.

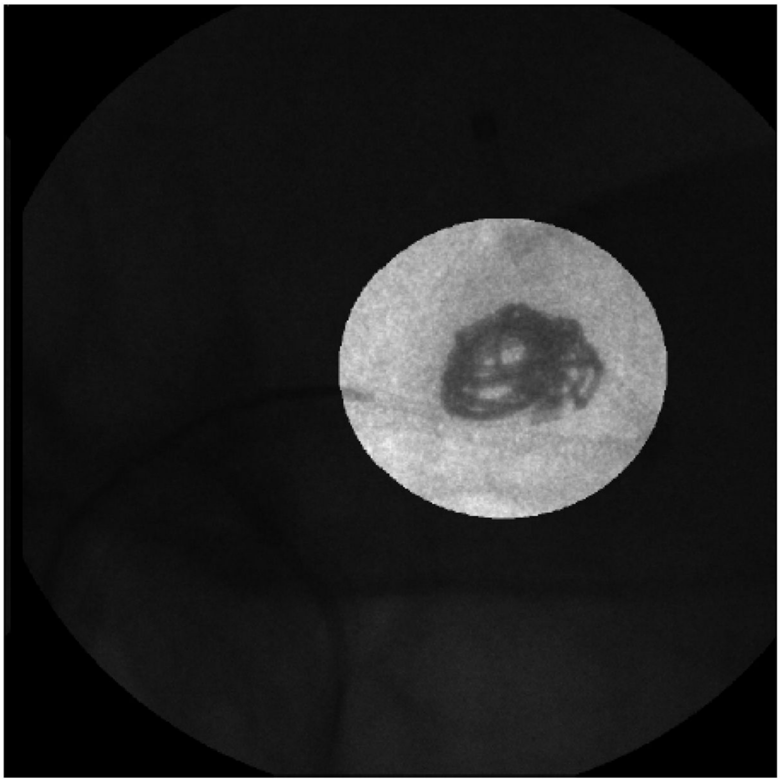

Figure 10.
Unprocessed Image obtained from ROI fluoroscopy. Peripheral region has pixel values (dose) reduced by a factor of 10.

Figure 11.
Display brightness enhanced outside the ROI.

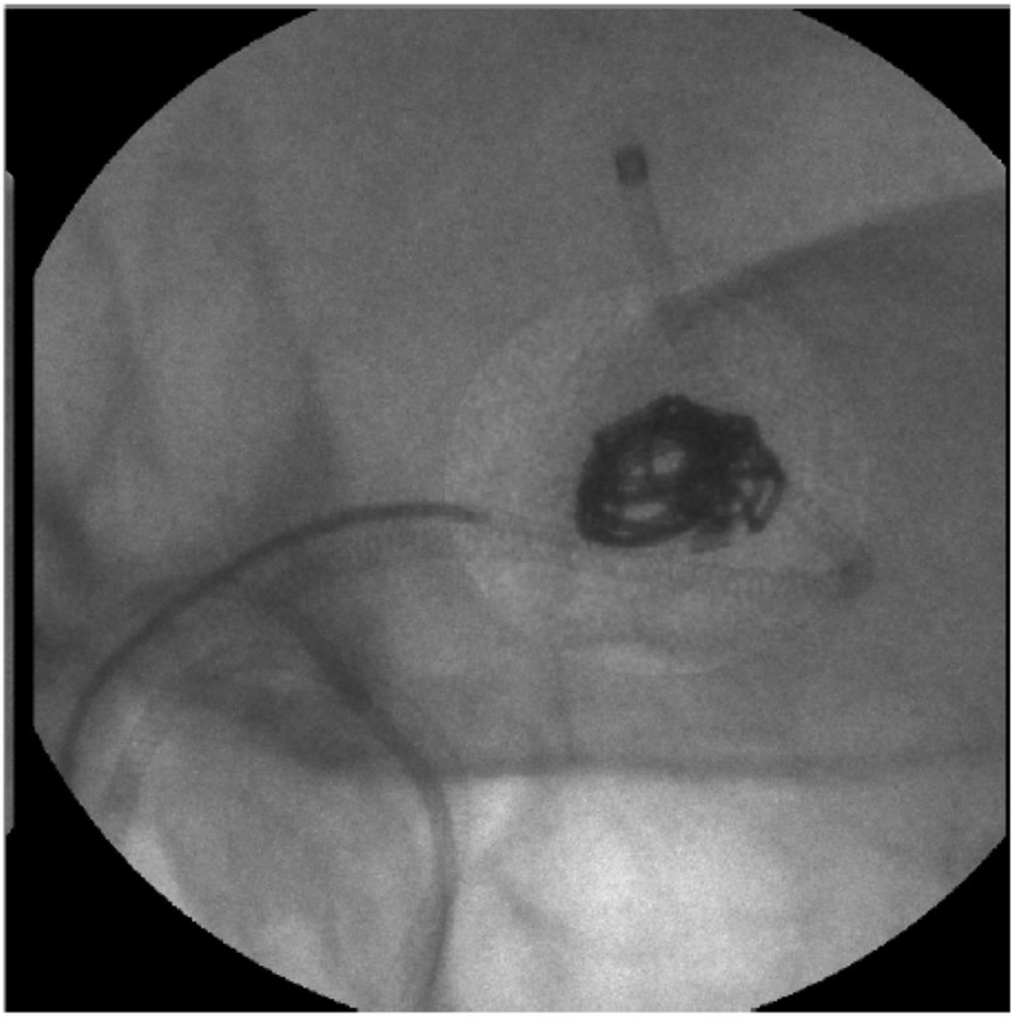

Figure 12.
Temporal Filter with a higher weight (0.75) applied only outside the ROI to reduce the noise due to 10X dose reduction.