Effectiveness Of A Selected Mean Filter Algorithm To Reduce Noise In Fluoroscopy Images

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Abstract : This study aims to implement noise reduction algorithm with a selected mean filter (SMF) and to investigate its computation time in the denoising process on X-ray fluoroscopy images. The SMF was the mean filter (MF) technique, but in its application, selected pixels within threshold value were only used to calculate the average pixel value. The effectiveness of SMF was then compared to well-known filters, such as adaptive mean filter (AMF) and bilateral filter (BF). The notebook of Acer Nitro 5 Intel Core i5-8300H 2.3 GHz with 8GB RAM, Graphic Processor Unit (GPU) Nvidia Geforce GTX 1050 4GB, and the Windows 10 Home operating system with SSD M.2 NVMe 2280 256GB were utilized. The algorithm was implemented using Matlab R2019b. The fluoroscopy images of NEMA SCA & I Cardiovascular Fluoroscopic Benchmark Phantom with size of 512 x 512 pixels were filtered, exposure factors of 69.92 kV and 583 mA and a dose-area product (DAP) of 1,660 mGy-cm^2 with a field of view (FOV) of 25 cm. In addition, image quality of the filtered images was assessed, including noise level, signal-to-noise ratio (SNR), contrast-to-noise ratio (CNR), and spatial resolution. The results showed that by using the SMF, the higher improvement of image quality in terms of noise level, SNR, CNR, and spatial resolution compared to AMF and BF, was achieved. The time needed by SMF to process an image was about 0.36 seconds, while the AMF and BF are 10.6 and 1.4 seconds, respectively. The SMF was as fast as a traditional MF, which only need 0.33 seconds for an image.

Index Terms : Selected Mean Filter, Noise Reduction, Fluoroscopy, Cardiovascular, Image Quality, Radiation

1. INTRODUCTION

FLuoroscopy plays an important role in medical imaging, and has been widely used in the clinical examination of patients and in intervention procedures (angiography). Fluoroscopy employs ionizing radiation so that it poses a potential danger to patients [1], despite its benefits as a gold standard for diagnosis in many cases. Exposure to ionizing radiation must always be kept as low as reasonably achievable (ALARA), by providing the minimum amount of radiation required in order to provide useful diagnostic results [2].

Reducing radiation exposure is an essential challenge related to fluoroscopy X-ray imaging. However, when the radiation dose is minimized, the resulting high noise results in a reduced image quality that leads to a decreased accuracy of clinical diagnosis. Thus, some form of image denoising is required. A noise reduction algorithm is considered as an effective technique in reducing the dose received by patients [3], [4]. Previously, a study on non-linear filters showed that the bilateral filter (BF) could denoise images without causing a deterioration in the spatial resolution of the images [5]. It was observed that the BF produced images of similar quality to those from full-dose exposure, but with half the dose exposure. The average time required to apply the BF to 512 x 512 pixels image using a portable computer (Intel processor Core-2-due 2.6 GHz, RAM 4 GB, Cash Memory 3 MB) and a MATLAB (version 7.12 R2011) implementation was about 25 seconds [5]. Similar studies on the effectiveness of BF algorithm and other algorithms, such as adaptive mean filter (AMF), have also been carried out [6]–[10].

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Available denoising algorithms require a heavy computational burden and a long processing time, so that it is difficult to implement them in clinical X-ray fluoroscopy which typically results in 15-30 frames per second. This may be mitigated by using high-speed computer technology or a more efficient denoising algorithm. A selective mean filter (SMF) has been proposed as a fast filter which reduces noise while maintaining the spatial resolution of an image [11]. However, the algorithm has only been implemented in computed tomography (CT) images. The aim of this study is to implement SMF for X-ray fluoroscopy images, and to investigate the resulting computational time and image quality.

2 RESEARCH METHODS

2.1 SMF algorithm

The SMF was recently introduced and is based on the simple mean filter technique. However, not all neighboring pixels are used to calculate the average pixel value, rather it is done selectively based on a threshold value (h). That is, if the differences of the values of neighboring pixels in a kernel and the central pixel are greater or smaller by a threshold value h, then the neighboring pixel is not included in the selective mean. The selection of pixels uses equation (1).

$$I(x,y) = \begin{cases} I(x,y), & if \ |\Delta I(x,y)| \le h \\ 0, & if \ |\Delta I(x,y)| > h \end{cases} \quad (1)$$

Noise reduction in the image is computed using the equation (2),

$$I_s(x,y) = \frac{\sum_1^N I(x,y)}{N(x,y)} \quad (2)$$

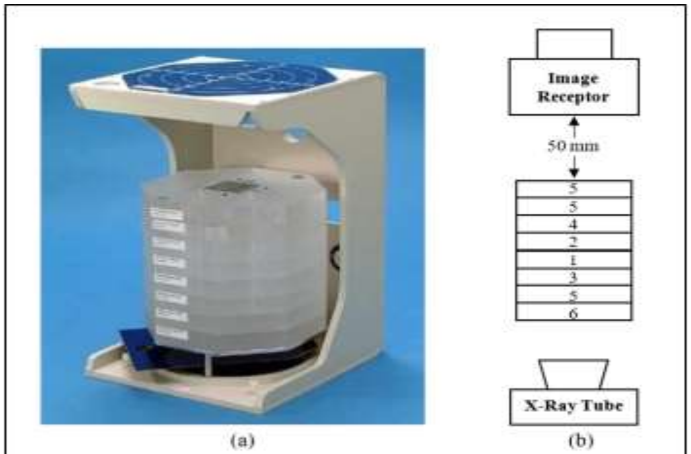

Fig. 1. (a) NEMA SCA&I Cardiovascular Fluoroscopic Benchmark Phantom. (b) Plate sequence number of the phantom.

There N is number of pixels which are their value more than h. Based on equations (1) and (2), at the edge area, the difference of all neighboring pixel values from the central pixel value may exceed the value of h. Conversely at homogeneous areas, it is possible that the difference of all neighboring pixel values from the central pixel value is smaller than the value of h. In this case, the pixel value of I_s (x,y) is the same as I (x,y). Technically, the threshold value h was taken based on the magnitude of the standard deviation (σ) of the image indicating the noise level in the image. The value σ can be obtained using the automatic noise calculation method [11].
As comparison to SMF, the AMF and bilateral filter were used. The AMF was to reduce noise of image and it was based on local deviation standard compared to global deviation standard of the image. The original image was filtered using equation (3) [11],

$$I_{AMF}(x,y) = I_{MF}(x,y) + \frac{\sigma_L^2 - \sigma_g^2}{\sigma_L^2}\left(I(x,y) - I_{MF}(x,y)\right) \quad (3)$$

where σ_g is the standard deviation of global area of image, and σ_L is the standard deviation of each kernel. While Bilateral Filter (BF) was a state-of-the art filter taking into account the geometric and pixel intensity spreads. It was computed using equation (4) [11],

$$I_{BF}(x,y) = \frac{1}{k}\sum_{i=-\frac{n-1}{2},\, j=-\frac{m-1}{2}}^{+\frac{n-1}{2},\, +\frac{m-1}{2}} e^{-\frac{\|x-i\|^2+\|y-j\|^2}{2\sigma_d^2}}\, e^{-\frac{(I(x,y)-I(x+i,y+j))^2}{2\sigma_r^2}}\, I(x,y) \quad (4)$$

where σ_d is defined as the geometric spread and σ_r is defined as the pixel intensity spread (as the standard deviation of the image) [11].

2.2 Fluoroscopy unit and phantom

The study was specifically conducted on fluoroscopy images of the NEMA SCA & I Cardiovascular Fluoroscopic Benchmark Phantom. The phantom was mounted with a distance to the image receptor of about 50 mm and a phantom thickness of 200 mm with a plate sequence number of 5, 5, 4, 2, 1, 3, 5, and 6 (Figure 1) [12]. Then phantom was exposed by the fluoroscopic system of Philips MRC200508 (Philips Medical Systems) installed at Tarakan Hospital, Jakarta, Indonesia, with a field of view (FOV) of 25 cm, exposure factors of 69.92 kV and 583 mA and a dose-area product (DAP) of 1,660 mGy-cm^2.

2.3 Computer unit

The denoising process of fluoroscopy images was performed using a netbook of Acer Nitro 5 Intel Core i5-8300H 2.3 GHz with 8GB RAM, Graphic Processor Unit (GPU) Nvidia Geforce GTX 1050 4GB and under the Windows 10 Home operating system with SSD M.2 NVMe 2280 256GB. The Nvidia GTX 1050 card has 640 CUDA cores operating at 1.3 GHz, with 4GB of GDDR5 RAM. The algorithm was implemented using Matlab R2019b. To assess the effectiveness of the SMF, the results of SMF filtering were compared with other filtering results, such as AMF and BF. The image processing speed of each filter was carried out 25 times. Each image of the phantom was 512x512 pixels with 15 frame per second in the Digital Imaging and Communications in Medicine (DICOM) format.

2.4 Image quality assessment

To assess the quality of the original image and the results of filtering from the SMF and other filters, the noise level, signal-to-noise ratio (SNR), contrast-to-noise ratio CNR and spatial resolution were measured. The values of the SNR and CNR were computed using equations (5) and (6), respectively.

$$SNR = \frac{I_a}{\sigma_a} \quad (5)$$

$$CNR = \frac{|I_a - I_b|}{\sigma_b} \quad (6)$$

where I_a and I_b are the intensities of the pixel values in areas a and b, and σ_a and σ_b are the standard deviations of the pixel values in areas a and b respectively [13], [14]. Four ROI circles were located within the metal object area and four other ROIs were outside of the object (Figure 2(a)), to obtain the SNR and CNR values. Spatial resolution was assessed using a line pair per millimeter (LP/mm) phantom (Figure 2(b)). Spatial resolution was determined as the largest LP/mm that can still be visually seen. This technique is the most convenient for spatial resolution, but is biased by the subjectivity of the observer [12]. A more objective assessment of spatial resolution is by using the modulation transfer function [15].

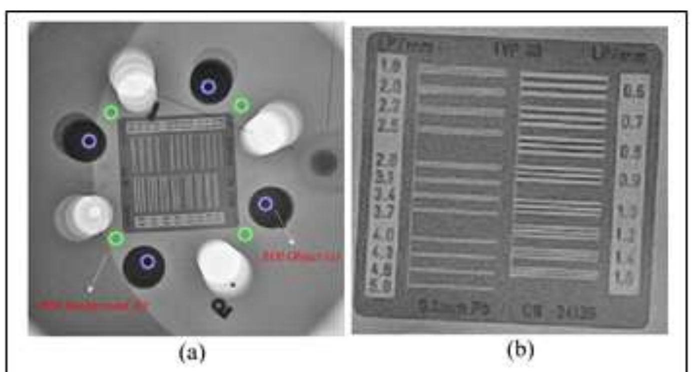

Fig. 2. *(a) Determination of ROI for measuring SNR and CNR, and (b) Line pairs object for assessment of the spatial resolution of the image within the NEMA SCA&I Cardiovascular Fluoroscopic Benchmark Phantom.*

3 RESULTS

The original image and filtered images using various filter are shown in in Figure 3, and the values of noise level, SNR and CNR values in Table 1. The noise values produced by the SMF are lower than the BF, but higher than those produced by the MF and AMF filters. The SNR's are inversely related. The CNR trend follows the SNR for all filters. The SMF and BF filtered images have very similar image spatial resolutions to the original image (2.0 LP/mm), whereas the spatial resolution of the MF and AMF filtered images is significantly worse (0.7 LP/mm).

TABLE 1
NOISE LEVEL, SNR AND CNR AS FUNDAMENTAL IMAGE QUALITY INDICATOR FOR FLUOROSCOPY IMAGES.

Filter type	Image quality			
	Noise	SNR	CNR	Spatial resolution
Original	3.75 ± 0.57	23.33	14.90	2.0 LP/mm
MF	1.67 ± 0.82	52.51	24.73	0.7 LP/mm
AMF	1.67 ± 0.82	52.51	24.73	0.7 LP/mm
BF	3.60 ± 0.60	24.32	15.61	2.0 LP/mm
SMF	2.85 ± 0.75	30.76	19.63	2.0 LP/mm

Figure 4 shows the computational times needed for various filters. As expected, the MF requires shortest time to denoise the image. It is interesting that the SMF is significantly shorter than the BF. It requires a comparable time to the traditional MF. The standard AMF required more than 10 seconds to denoise the fluoroscopy images.

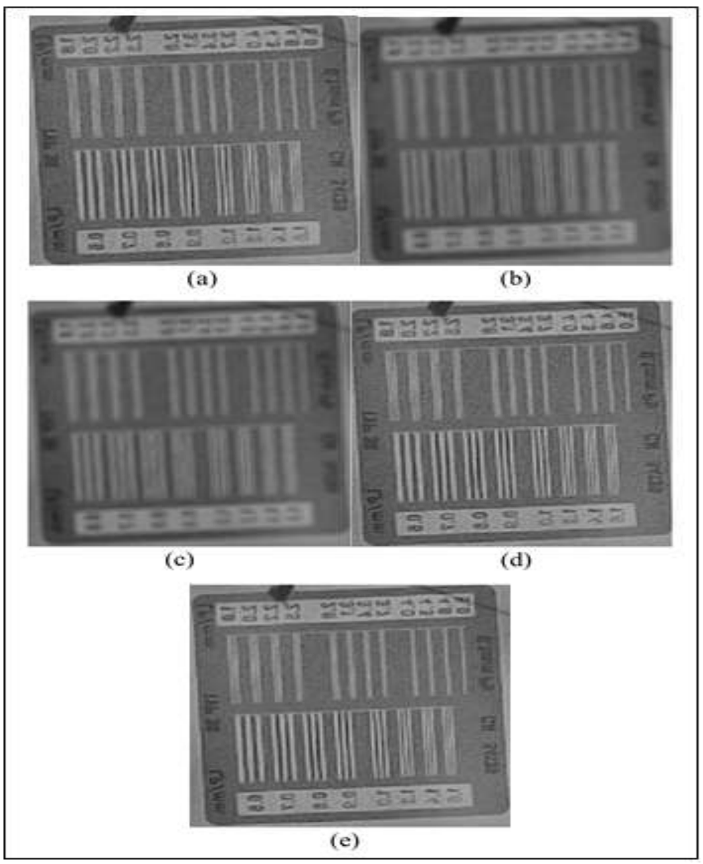

Fig. 3*. Images of fluoroscopy NEMA SCA&I Cardiovascular Fluoroscopic Benchmark Phantom; (a) Original image; (b) Image after MF filtering; (c) Image after AMF filtering; (d) Image after BF filtering; (e) Image after SMF filtering.*

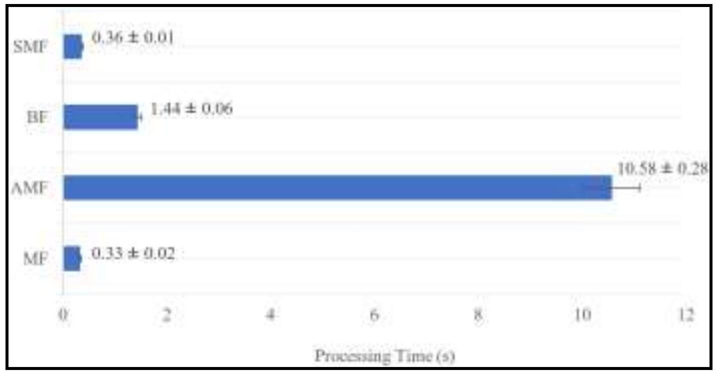

Fig. 4*. Processing time for various filters of SMF, BF, AMF and MF.*

4 DISCUSSION

The patient dose is a crucial issue in X-ray fluoroscopy examinations. Low numbers of X-ray photons can be achieved, for example, by decreasing tube current, but the resulting images tend to be heavily dominated by noise [3]. One way to remedy this problem is implementing a denoising algorithm. However, there are two main problems in the denoising process: it reduces the s spatial resolution of the image and it needs a long computation time. The current study tries to overcome these two main problems by using the SMF technique. A previous study reported that the SMF was able to maintain the spatial resolution of the image although it needed a faster processing time than other denoising algorithms for CT images [11]. We used a Graphic Processor Unit (GPU) Nvidia Geforce GTX 1050 4GB to speed up the computation time, hoping that the SMF could be implemented in a clinical environment, effectively reducing the noise in fluoroscopy images and resulting in a reduced radiation dose to both patients and staff. SMF is simpler than AMF and BF when viewed as a computation process, because SMF uses a mean filter-based approach. However, in its application, neighborhood pixels within a threshold value (h) are selectively included in the calculation. The current study shows that SMF is able to reduce noise while increasing SNR and CNR by around 14% compared to the original image, while BF is only able to increase SNR and CNR of around 4% compared to the original image, and MF and AMF are able to reduce noise while increasing SNR and CNR by around 55% compared to the original image. In SMF and BF, the spatial resolution of the image remains similar to the original image (2.0 LP/mm), while in MF and AMF, the spatial resolution of images decreases (to 0.7 LP/mm). The computational time, using our Acer Nitro 5 notebook, was 75% faster for the SMF than for the BF. The computation time for the AMF is much longer because the standard deviation must be calculated for each kernel. Al-Hinnawi et al [5] reported that the AMF filter took 25 s for a single 512x512 pixel CT image of (using a portable HP Intel Core-2-due 2.6 GHz processor, 4GB RAM, 3MB Cash Memory with MATLAB version 7.12 R2011a). Another previous study [11] reported that the computing time of the SMF method is 1.64 ± 0.05 s and the BF method is 3.6 ± 0.1 s for a single CT image (using a Lenovo Ideapad 330S with Intel Core i5). In the clinical practice of fluoroscopy, however, the SMF speed results would need to be increased, since fluoroscopy produces 15-30 images or frames per second (FPS). One strategy to shorten computation time would be to increase the hardware specifications for the image processing, such as increasing GPU and using higher RAM.

Furthermore, SMF needs to be compared with other recent filters such as the non-local mean filter (NLM) [3], [16], hybrid genetic algorithm [1] and non-linear diffusion and smoothing filters [5]. According to Lee [3], NLM was able to maintain high levels of I mage resolution and reduce noise by around 32%. It took about 0.43 s for 500 x 500 pixel fluoroscopy images using an Intel i5-4670k 3.4 GHz computer (CPU), 8-GB RAM, with C++ software implemented in MS Visual Studio 2015 for MS Windows 10.

5 CONCLUSIONS

Post-acquisition noise reduction is one way to optimize doses in fluoroscopy, by reducing radiation doses while maintaining image quality. Our results show that the SMF reduces noise and provides better image quality than other filters, such as MF, AMF and BF. Although the computation time for denoising using SMF is shorter than for the other filters, it still too long to be implemented in real-time for fluoroscopy imaging even at a frame rate of 15 FPS. Accordingly, its implementation is still challenging and will need to await improvements.

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