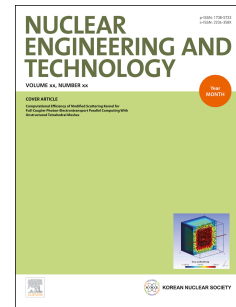


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Median modified Wiener filter for improving the image quality of gamma camera images

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Abstract

The filter technique was applied to noise images, as noise is the significant factor that cause poor image quality due to lower photon counting. The purpose of this study is to confirm that image quality can be improved using the median modified Wiener filter (MMWF) technique; this is achieved via a National Electrical Manufacturers Association International Electrotechnical Commission body phantom with four large spheres that are filled with the ^{99m}Tc radioisotope when evaluating the image quality. Conventional filters such as Wiener, Gaussian, and median filters were designed, and signal to noise ratio, coefficient of variation, and contrast to noise ratio were used as the evaluation parameters. The improvement in the image quality was in the following order, from the least to the highest improvement, in all cases: Wiener filter, Gaussian filter, median filter, and the MMWF technique. The results show that the image quality was improved from 20.6 - 65.5%, 7.4 - 40.3%, and 12.7 - 44.7% for the SNR, COV, and CNR values, respectively, when using the MMWF technique, compared with the use of conventional filters. In conclusion, our results demonstrated that the MMWF technique is useful for reducing the noise distribution in gamma camera images.

Keywords: Median modified Wiener filter, Gamma camera image, Nuclear medicine, Noise reduction technique, Evaluation of image quality

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1.Introduction

Gamma cameras play a crucial role in nuclear medicine image as a means for diagnosing several diseases. This is because the functional information of patients can be obtained without surgery by using gamma images [1-3]. The principle involved in obtaining gamma images is detection of gamma rays originating from the body of a patient that are subsequently incident on a detector, by using the ^{99m}Tc radioisotope [4]. In the nuclear medicine modality, gamma images are prone to noise owing to attenuation and scattering of the gamma rays before they are incident on the detector [5]. This leads to poor image quality, which is characterized by low signal distribution, low signal contrast, and high noise. Therefore, development of an appropriate denoising process to enhance the image quality of degraded images has been a crucial and long-standing issue in digital image processing. In nuclear medicine image, a common method used to obtain denoised gamma images is the application of a digital filter to the degraded gamma images before and after the image reconstruction process. The purpose of using a filter is to compensate for the loss of the signal while simultaneously reducing the noise distribution.

In general, filters are classified as spatial and spatial frequency domain filters. Specifically, spatial frequency domain filters that are used to reduce noise in degraded gamma images, such as wavelet denoising filters, have drawbacks when compared with spatial domain filters [6]. In spatial frequency domain filter-based methods, many parameters are required to obtain the denoised gamma image; and needed to setting value for more complex method. Therefore, many researchers use spatial domain filters to reduce the noise distribution owing to the ease of application of such filters, as this method primarily involves only setting a new matrix [7]. Many researchers have also improved the effectiveness of application of existing noise reduction filters to degraded images and developed novel noise reduction filters [8, 9]. Wiener, median, and Gaussian filters, which are processed using spatial domain filters, are typically used to reduce the noise distributions of degraded images [10-12]. These filters denoise the degraded image by setting the mask of a new $n \times m$ matrix in the image. These filters are useful for simultaneously focusing the signal intensity and preserving the edge signal in the image. *Tsakanikas et al.* reported that spatial domain filters are advantageous for noise reduction in that they increase the signal intensity and decrease distortion in the image [8]. In addition, a modified filter that involves merging the Wiener and median filters, is often used to enhance degraded images. This filter is known as the median-

modified Wiener filter (MMWF); in this technique, the average value of the mask matrix in the Wiener filter is replaced by the median value to reduce the noise distribution [9]. These filters are often applied to X-ray images to evaluate the noise distribution and achieve noise reduction. However, only a few studies have been conducted regarding the application of such filters to nuclear medicine images. Therefore, this study aimed to evaluate the effectiveness of using the MMWF technique to enhance the quality of gamma images using the National Electrical Manufacturers Association (NEMA) International Electrotechnical Commission (IEC) body phantom. The performance of the MMWF was compared those of Wiener, Gaussian, and median filters. Furthermore, the signal to noise ratios (SNRs), coefficients of variation (COVs), and contrast to noise ratios (CNRs) of the images obtained using the MMWF technique and conventional filters were analyzed.

2. Materials and methods

2.1. Image acquisition

The NEMA IEC body phantom was filled with a ^{99m}Tc radioisotope solution to obtain the images. The ratio of the ^{99m}Tc sphere activity concentration to the background activity concentration was 8:1 (sphere:background = 8:1). The phantom consists of spheres of six different diameters (inner diameters: 10, 13, 17, 22, 28, and 37 mm). Four large spheres of the phantom (inner diameters: 17, 22, 28, and 37 mm) were filled with the ^{99m}Tc solution. The image acquisition time was set as 5 min using the gamma camera. Fig. 1 shows the images of the various regions of interest (ROIs) according to the sphere sizes, which are 17, 22, 28, and 37 mm, and the profile of the pixels along the center line for quantitative evaluation of the fluctuation of signal intensity.

2.2. Median and Wiener filters

In general, degraded images that are prone to noise, are restored using an appropriate technique, such as filtering. Mathematically, this can be expressed as follows [13]:

$$g(x, y) = f(x, y) * u(x, y) + n(x, y) \quad (1)$$

$$h(x, y) = R [g(x, y)] \quad (2)$$

where $f(x, y)$ is the acquired image, $u(x, y)$ is the degradation function, “*” denotes convolution, $n(x, y)$ represents noise, such as Gaussian noise, $g(x, y)$ is the output degraded image, and $h(x, y)$ is the final output image subsequent to the application of the technique R . To acquire denoised gamma images, the degraded images were input to a conventional noise reduction filter. Median and Wiener filters, which are noise reduction filters with nonlinear spatial domains, are often used to obtain denoised images. The procedure for improving image quality is as follows: First, a mask matrix of size $n \times m$ is set for the spatial noise reduction filter. Then, the mask matrix is used to recalculate the new pixel value compared to the mask pixel value for the degraded image corresponding to the mask pixel size. The median filter changes each pixel value to the median pixel value corresponding to the mask matrix at the center pixel value [14]. Therefore, this method is advantageous in that outliers can be removed without reducing the sharpness of the image. The Wiener filter involves both the variance and average pixel values in the $n \times m$ sized mask matrix and is represented as follows:

$$\mu = \frac{1}{NM} \sum_{n,m \in \eta} a(n, m) \quad (3)$$

$$\sigma^2 = \frac{1}{NM} \sum_{n,m \in \eta} a^2(n, m) - \mu^2 \quad (4)$$

where μ is the mean, σ^2 is the variance of Gaussian noise in the image, $n \times m$ is the size of the neighborhood area η in the mask, and $a(n, m)$ represents each pixel in the area η . The Wiener filter is expressed to the new pixels, which are represented as $b_w(n, m)$, using the estimated values.

$$b_w(n, m) = \mu + \frac{\sigma^2 - v^2}{\sigma^2} \cdot (a(n, m) - \mu) \quad (5)$$

where v^2 is the noise variance setting of the mask matrix for application of the Wiener filter.

2.3. MMWF technique

The MMWF technique, which is used to reduce the noise distribution in degraded images, was designed by Cannistraci *et al* [9]. The aim of this technique is to improve image quality by denoising the background region of a degraded image using the median filter. In addition, this technique primarily preserves the edge signal using the Wiener filter. The MMWF technique, which is based on the Wiener filter, replaces the pixel values of the mask matrix with the median values, thereby reducing the noise in the degraded image. The average value (μ) in the Wiener filter formula is replaced by the median value ($\tilde{\mu}$). Thus, the MMWF is represented as follows:

$$b_{mmwf}(n, m) = \tilde{\mu} + \frac{\sigma^2 - v^2}{\sigma^2} \cdot (a(n, m) - \tilde{\mu}) \quad (6)$$

The advantage of using the MMWF technique is that the image quality of degraded images can be enhanced as follows: Because of the drop-off-effect, the edge signal is better preserved when compared with the use of the median and Wiener filter techniques. In summary, the MMWF technique can perform substantially better than conventional filters with regard to the denoising effect; furthermore, it can simultaneously preserve the edge signal and remove the background noise signal [15].

2.4. Evaluation of image qualities

To evaluate the phantom images obtained using the various noise reduction filters, the COV, SNR, and CNR were calculated as follows:

$$SNR = \frac{S_A}{\sigma_A} \quad (7)$$

$$COV = \frac{\sigma_A}{S_A} \quad (8)$$

$$CNR = \frac{|S_A - S_B|}{\sqrt{\sigma_A^2 + \sigma_B^2}} \quad (9)$$

where S_A and σ_A are the mean counts and standard deviations for ROIs corresponding to the various hot sphere sizes, respectively; in addition, S_B and σ_B are the mean counts and standard deviations for the background noise, for ROIs corresponding to the various hot sphere sizes, respectively. The experiment was performed ten times under equivalent conditions.

3.Results and discussion

In this study, we compared the effectiveness of the MMWF technique with regard to gamma image noise reduction with that of conventional noise reduction filters (i.e., Wiener, Gaussian, and median filters) using the NEMA IEC body phantom with the ^{99m}Tc radioisotope. The SNRs, COVs, and CNRs of the images obtained subsequent to the application of the noise reduction filters were analyzed for the various ROIs in the four large spheres.

Figure 2 shows the phantom images obtained subsequent to the application of the MMWF technique and conventional noise reduction filters. Based on the magnified portion of the 17-mm sphere shown in Fig. 2, we confirmed that the MMWF technique can clearly separate the hot and background regions in the image.

The SNR, COV, and CNR results obtained using the conventional noise filters and MMWF technique are shown in Fig. 3. First, the average SNR values are improved by approximately 65.5%, 58.7%, 46.7%, and 20.6% when the MMWF technique is used, compared with the SNR values of the acquired image and the images obtained using the Wiener, Gaussian, and median filters, respectively. Second, the COV values are decreased by approximately 40.3%, 35.8%, 23.7%, and 7.4% when the MMWF technique is used, compared with the COV values of the acquired image and the images obtained using the Wiener, Gaussian, and median filters, respectively. From the SNR and COV results, it is clear that the signal intensity is the highest and noise is the lowest in the ROIs of the images obtained using the MMWF technique when compared with those of the images obtained using the other techniques evaluated in this study. Finally, the average CNR values are increased by approximately 44.7%, 36.5%, 26.7%, and 12.7% when the MMWF technique is used, compared with the CNR values of the acquired image and the images obtained using the Wiener, Gaussian, and median filters. Based on the CNR result, it can be concluded that when the MMWF technique is applied to a gamma image, it is possible to distinguish the hot sphere portions from the background portion more clearly when compared with the use of other noise reduction filters. Consequently, when the images obtained using the MMWF technique and conventional filters were compared, the images to which the median filter was applied showed the least difference. This result confirmed that application of the median filter, which uses the median value, can lead to improved image quality when compared with that of the Wiener and Gaussian filters, which use the mean and variance values of the image pixels. In addition, by comparing the images obtained using the MMWF technique

with the acquired images, it was found that the average SNR and CNR values were improved by approximately 65.6 and 44.4%, respectively, and the average COV value was decreased by approximately 38.6% for the images obtained using the MMWF technique. In summary, the image quality is confirmed to be in the following order of superiority: median filter, Gaussian filter, Wiener filter, and acquired images. In addition, it is observed that the image quality can be improved to various degrees by applying the three noise reduction filters. Comparing the images obtained using the noise reduction filters with the acquired images, it can be seen that the image quality of the images obtained using the noise reduction filters is improved by 1.9 to 2.2 times in terms of SNR, 1.6 to 1.8 times in terms of CNR, and decreased by 1.7 to 1.9 times in terms of COV. In addition, there is no significant correlation between the results obtained for the SNR, CNR, and COV for the spheres of various sizes and the sizes of the spheres.

Based on the resultant profiles, it can be confirmed that the fluctuations of the signal intensities of the images obtained using the various techniques are in the following descending order: MMWF technique, median filter, Gaussian filter, and Wiener filter. When comparing the fluctuation degree for the reference signal intensity of 0.35 for all images obtained using the various techniques, the MMWF technique exhibits the smallest fluctuation degree, whereas the acquired image exhibits the largest. Based on the profile figure, it can be seen that, although there is no substantial signal loss at the edge portion of each image, the noise distribution is reduced to a significant extent compared with that of the acquired image. In particular, the image obtained using the MMWF technique shows the least fluctuation among the various images evaluated in this study.

4. Conclusion

In this paper, we proposed that the MMWF technique, which is used to denoise degraded images, can play a crucial role in improving the quality of gamma images used in nuclear medicine. To confirm this, first, we performed an experiment using the NEMA IEC body phantom; four large spheres and the background of the phantom were filled with a radioisotope. Second, we evaluated the image quality of the acquired images and those of the images obtained using Wiener, Gaussian, and median filters and the MMWF technique. Based on the results, it was concluded that the noise reduction filters can improve the quality of gamma images. In addition, the MMWF was particularly suitable for reducing the noise distribution of the degraded images used in this study.

187

188 **Acknowledgments**

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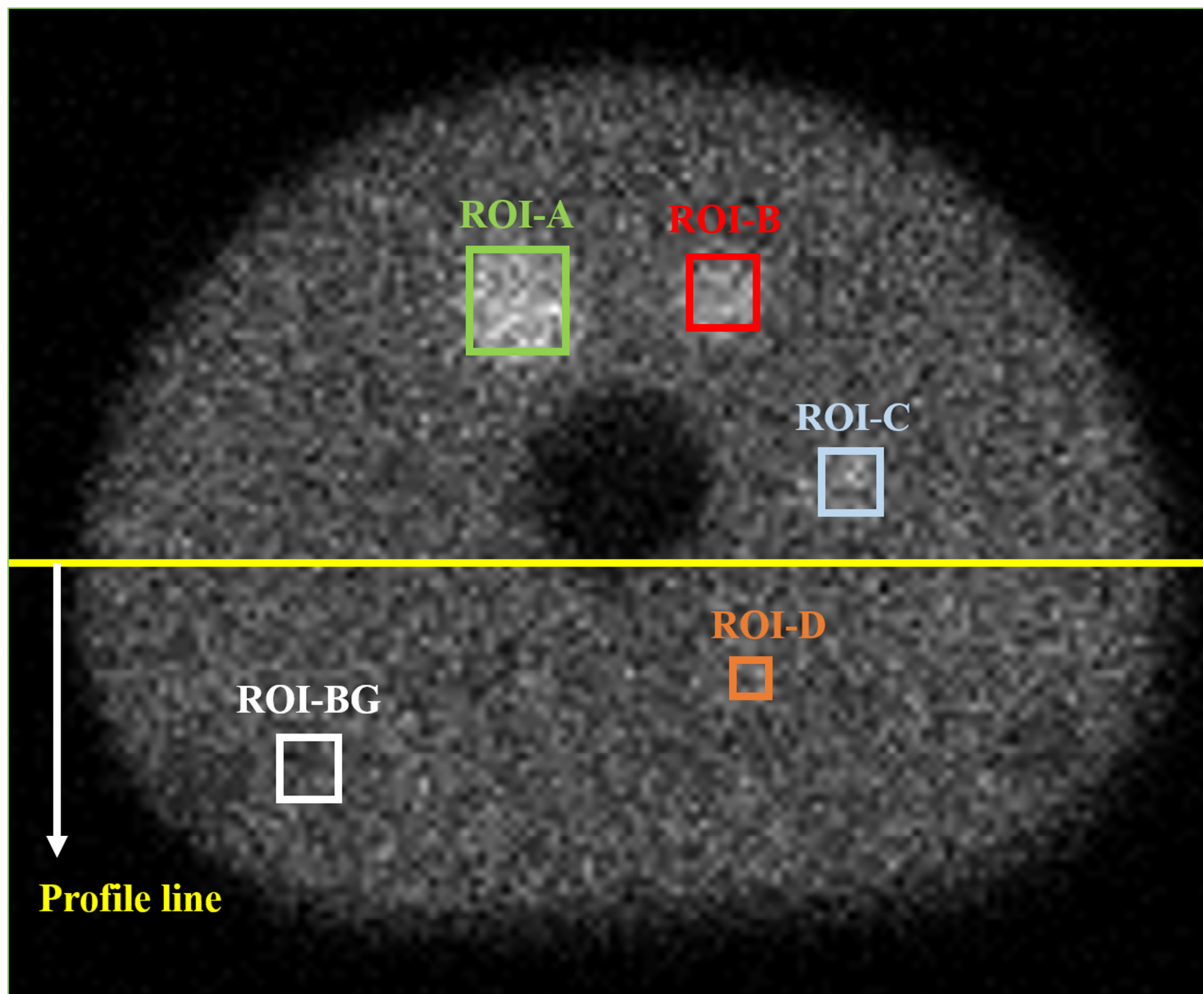


Fig. 1. Various regions of interest (ROIs) for quantitative analysis in terms of the signal to noise ratio and coefficient of variation: ROI-A, ROI-B, ROI-C, and ROI-D, corresponding to each sphere; and contrast to noise ratio calculation: ROI-A, ROI-B, ROI-C, ROI-D, and ROI-BG corresponding to each sphere and to the background, represented as BG (Here, the inner diameters of ROI-A, ROI-B, ROI-C, and ROI-D are 37 mm, 28 mm, 22 mm, and 17 mm, respectively). The profile line was set to the center pixel position from the left to the right of each image.

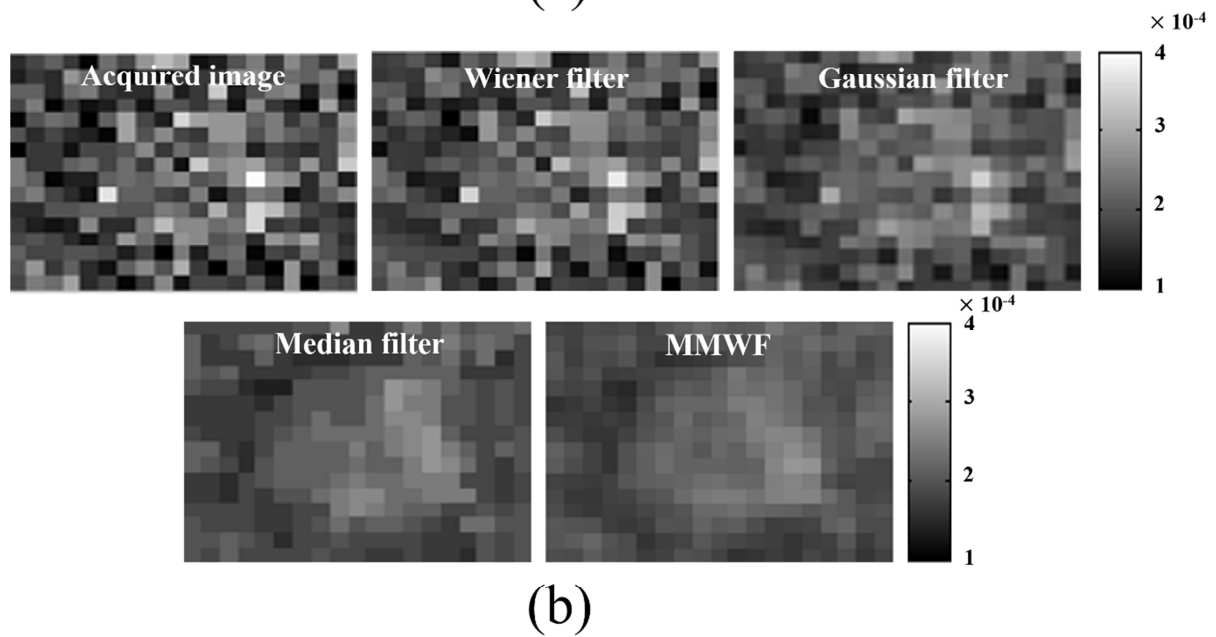
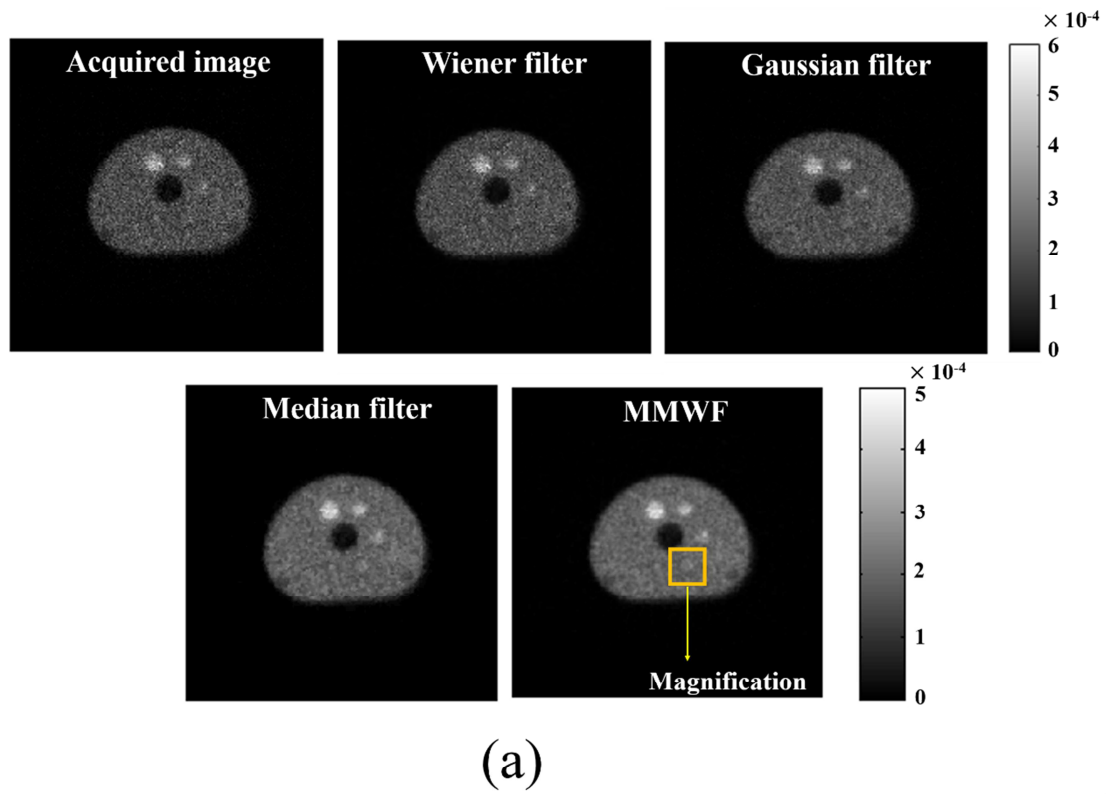
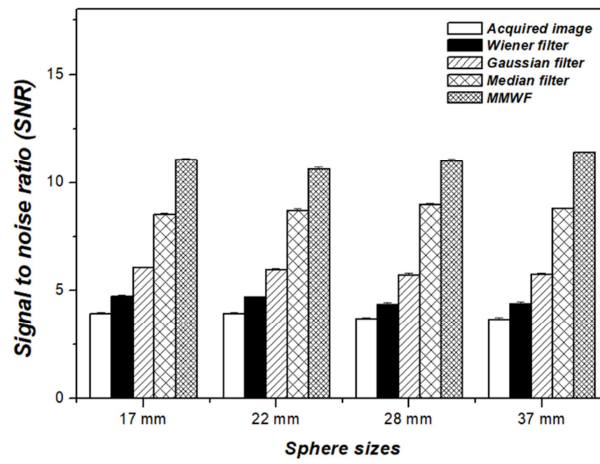
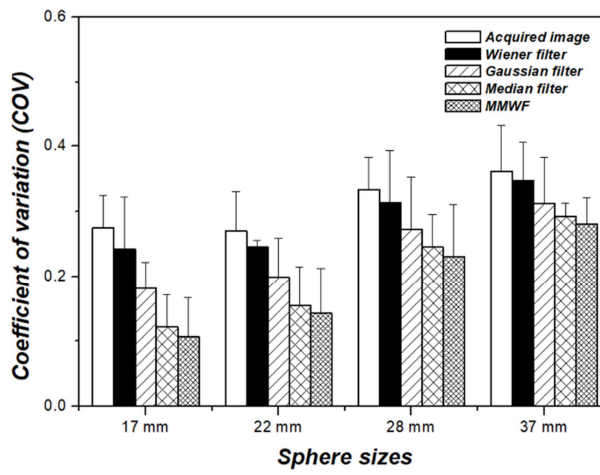


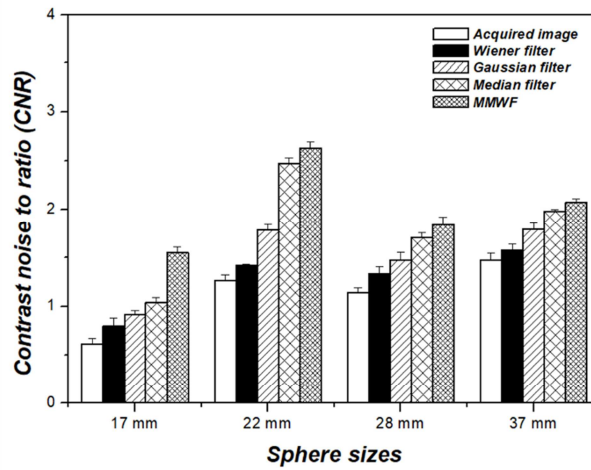
Fig. 2. Resultant (a) acquired and filtered images and (b) magnified resultant images for 17-mm sphere with color bar.



(a)



(b)



(c)

250

251 Fig. 3. Results for (a) signal to noise ratio, (b) coefficient of variation, and (c) contrast to noise ratio of the

252 images obtained using each noise reduction filter according to sphere sizes.

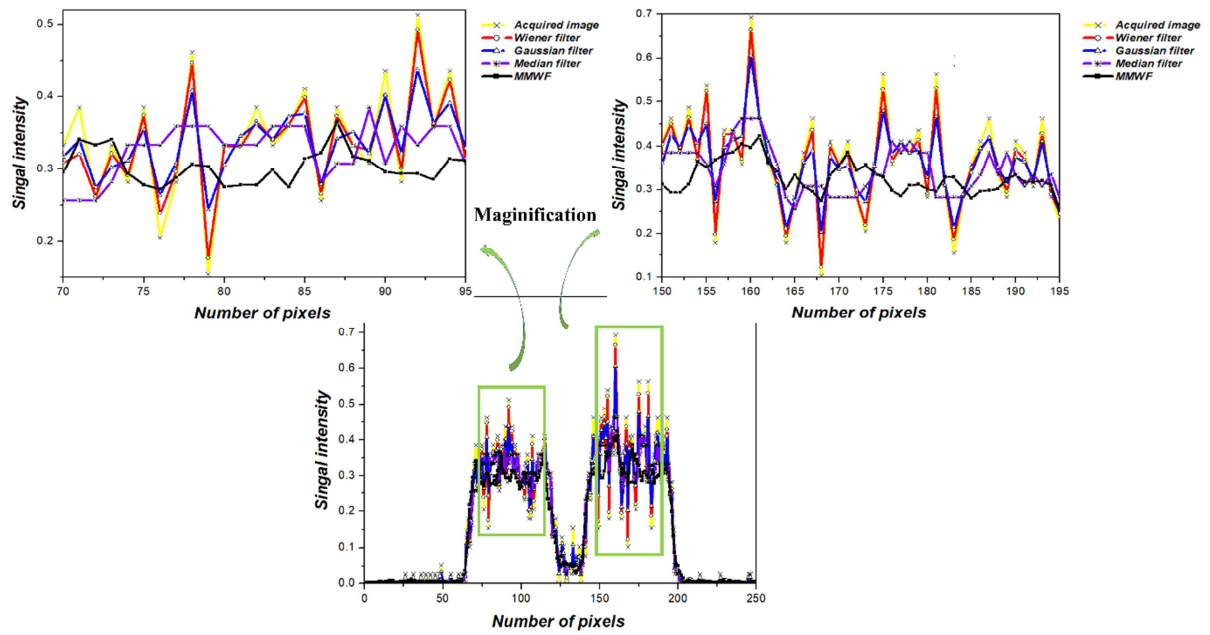


Fig. 4. Resultant plots of the signal intensity according to number of pixels drawn the line profile at the horizontal center line. The magnified images indicate the fluctuation of signal intensity when the number of pixels is 70 to 95 (left side figure) and 150 to 195 (right side figure).

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: