Speckle Noise Reduction from Medical Images Using Gaussian Fuzzy Membership Function

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***Abstract*—The primary concept of this paper is a fuzzy membership function-based filter with the expertise to reduce speckle noise that is often utilized in clinical diagnosis such as ultrasonography. In medical science, image sharpening is a highly effective approach for recognizing human inner organs and body tissues. Speckle noise is multiplicative in nature and it highly affects the image and reduces some useful information. The target of image noise reduction is to extract the genuine image from a noisy speckled image. In this paper, a Gaussian fuzzy-based system has been developed that is fast and provides good accuracy depending upon the membership function. Also, experimental results demonstrate that the proposed algorithm ensures better filtering quality and image restoration ability in comparison with others.**

***Index Terms*—Ultrasound imaging, speckle noise, Gaussian membership function, fuzzy logic, image restoration.**

I. Introduction

An informative medical image is mainly infected due to the harmony of dispersed echo signals. Image restoration is a remarkable milestone in the area of image processing, which reconstructs the images and objects to eliminate noise and blurriness and makes them reasonable for human insight [1]. Image may be distorted due to impulse noise, uniform noise, Gaussian noise, exponential noise, photon noise, speckle noise, etc [2]-[4]. In the medical field, ultrasound (US) imaging is a kind of standard for diagnosing inflammation, swelling of the body's internal organs, guiding biopsies, recognizing heart conditions, and determining the extent of damage after a heart attack [2]. Even though speckle is a small dot spot area on an image, it is caused by the action of environmental variables on the imaging sensor during image acquisition [3]-[6]. Randomly distributed speckle noise decays the quality of the image that causes complications for future operations. Over the last few years, many researchers have introduced several filtering techniques to remove the speckle noise.

In recent years, different types of standard techniques have been used to reduce speckle noise, such as mean filter, median filter, Wiener filter, fuzzy logical filter, triangular fuzzy filter, and so on. Generally, these types of non-linear filters have better performance in terms of noise attenuation and detail preservation. The lack of a generalized signal-to-noise relationship makes it difficult to develop an effective speckle removal technique in US imaging [7]. In fact, they have several barriers as well. A fuzzy function is a set of components each of which is linked with a membership function value that determines the degree of belonging of a specific value to a set [8]. Fuzzy logic functions that deal with estimated data instead of exact data can be considered as a useful strategy for achieving a clearer output depending on unsatisfactory inputs such as noisy images [5].

The above-mentioned filtering techniques are specifically not designed for US image denoising and may not provide sufficient image restoration accuracy [3]. The triangular membership functions are not utilized in applications permitting continuously differentiable curves [9]. Chowdhury *et al.* [4] developed a fuzzy logic-based filter for image denoising. Similar algorithms are proposed in [10]-[11] for speckle noise reduction, but these algorithms suffer from computational complexities due to the extraction of distribution parameters, internal or external factors that commonly exist in the medical images.

In this paper, an improved speckle noise reduction technique is developed using the Gaussian fuzzy membership function. In comparison to alternative filters, the presented filter improves the output quality in terms of accuracy.

II. Proposed Methodology

The presented method gives an efficient filter for image denoising utilizing fuzzy logic for a gray-scale image with values ranging from 0 to 255 for a total of $2^8 = 256$. A 3×3 square window or mask, as depicted in Fig. 1, is considered in such a way that the noisy pixel is at the center of the window. For removing high-density speckle noise, the Gaussian membership function is considered as shown in Fig. 2.

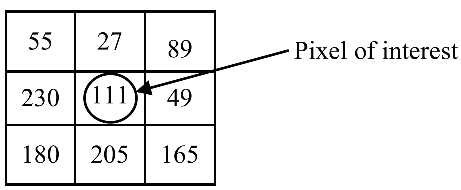

Fig. 1: A central pixel to be filtered using a 3×3 window.

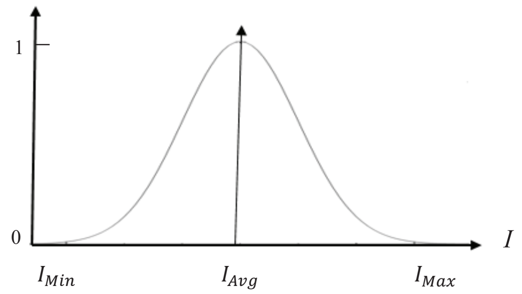

Fig. 2: Representation of Gaussian membership function at different pixel intensities.

A. Mathematical models

The following equation can be used to represent an original image that has been influenced by speckle noise:

$$I'(x, y) = I(x, y).n(x, y) + q(x, y), \tag{1}$$

where $I'(x, y)$ represents the noisy image, $I(x, y)$ is the true image, $q(x, y)$ is the additive noise in the image, and $n(x, y)$ is the multiplicative noise.

In fuzzy logic-based image processing, different membership functions can be used and the shape of these functions are important criteria that need to be thought about [1]. A Gaussian fuzzy membership function, which is depicted by non-linear boundaries, can be defined as

$$\Delta(x) = \frac{1}{\sqrt{2\pi\sigma^2}} \exp \frac{(a-b)^2}{2\sigma^2}, \tag{2}$$

where a is any pixel within the square window, b is the average value, and σ represents the width. The presented membership function in (2) is focused on the intensity difference between nearby pixels in a window and the central pixel.

B. Proposed fuzzy algorithm

The complete method is shown as a flow chart in Fig. 3. The step-wise algorithm is given below.

Proposed Fuzzy Algorithm

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1. Read the noisy input image.
2. Consider a 3×3 neighborhood window for a pixel of interest.
   - Calculate the average intensity value I_{avg} within the specified window.
   - Calculate the minimum I_{min} and maximum I_{max} intensity values within the specified window.
   - Use the Gaussian-shaped membership function to assign a fuzzy membership value to each pixel value of the window as below:

$$Y = \begin{cases} 0 & \text{if } I(x,y) = I_{max} \text{ or } I_{min} \\ 1 & \text{if } I(x,y) = I_{avg} \\ \frac{1}{\sqrt{2\pi\sigma^2}} \exp \frac{-(I_{max}-I_{avg})}{2\sigma^2} & \text{if } I_{min} < I(x,y) < I_{avg} \\ \frac{1}{\sqrt{2\pi\sigma^2}} \exp \frac{-(I-I_{avg})}{2\sigma^2} & \text{if } I_{avg} < I(x,y) < I_{max} \end{cases}$$

3. Update the center of the window with the pixel value that has the greatest membership value, Y.
4. Repeat Steps 2 and 3 for every pixel in the input image.

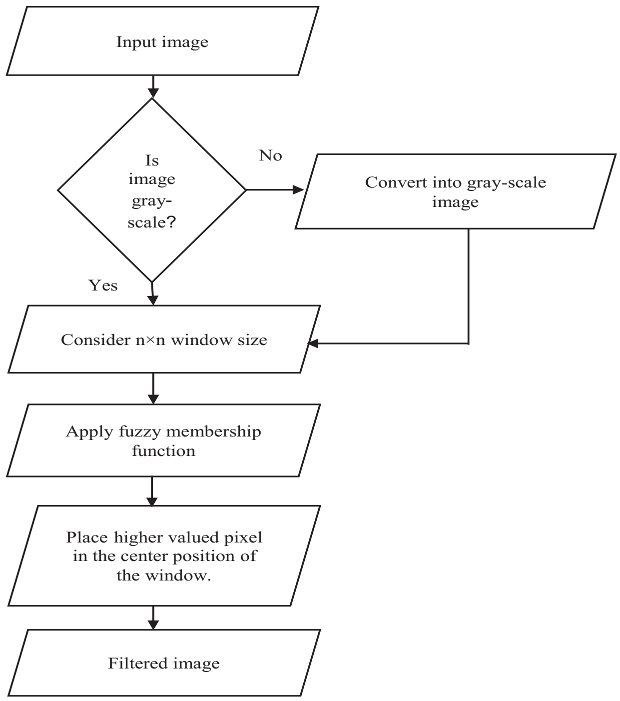

Fig. 3: Flow chart for the fuzzy-based image restoration algorithm.

III. Experimental Result and Discussion

Using MATLAB, we assessed the effectiveness of the proposed technique on two gray-scale images. A comparison is made based on similarity metrics, such as mean square error (MSE), peak signal-to-noise ratio (PSNR), normalized absolute error (NAE).

Considering a true gray-scale image $f(x, y)$ of size M×N and a noisy image $f'(x, y)$, the MSE can be determined by

$$MSE = \frac{1}{MN} \sum_{x=1}^{M} \sum_{y=1}^{N} (f(x, y) - f'(x, y))^2. \tag{3}$$

PSNR is a regularly used tool for assessing image reconstruction quality, which can be calculated as

$$PSNR = 10 \log_{10} \frac{L^2}{\text{MSE}} dB, \tag{4}$$

where L is the maximum pixel value of the image.

NAE metric determines how much the modified image differs from the original image, basically in numbers. If the value is closed to 0, it suggests that the image is highly comparable to the original. While results close to 1 mean that the image is of very poor quality. The metric is represented by

$$NAE = \frac{\sum_{x=1}^{M} \sum_{y=1}^{N} (|f(x,y) - f'(x,y)|)}{\sum_{x=1}^{M} \sum_{y=1}^{N} f(x,y)}. \quad (5)$$

A. Experiment–I

In order to evaluate the performance of the proposed filter, at first, two synthetically distorted noisy images are considered. Here, we choose a 512×512 pixels gray-scale 'Lena' image [12] and corrupt it with 10% speckle noise in MATLAB. The proposed filter and several existing filters such as Wiener filter, median filter, and triangular fuzzy filter [3] are applied on the noisy Lena image. Fig. 4(a) and 4(b) show the original Lena image and the corrupted image, respectively. The outputs of different filtering techniques are shown in Fig. 4(c)–4(f). A careful comparison shows that the proposed Gaussian fuzzy filter provides better output than the others.

Fig. 4: Results on gray-scale Lena image using different filters: (a) True image, (b) image corrupted by 10% speckle noise, (c) Wiener filter, (d) median filter, (e) triangular fuzzy filter, and (f) proposed fuzzy filter.

Table 1. Quality metrics for the results in experiment–I.

Methods	MSE	PSNR	NAE
Wiener	21.58	34.79	0.0208
Median	30.98	33.21	0.0269
Fuzzy tri.	24.92	34.17	0.0295
Proposed	12.18	37.27	0.0181

Table 1 shows the quantitative comparison of the results of the experiment–I. The lower the MSE and NAE values of the output images, the better the accuracy. In contrast, the higher the PSNR values, the better the quality of the output images. Table 1 exhibits that the proposed filter provides lower MSE and NAE values as well as higher PSNR value compared to the other methods.

B. Experiment–II

Another test image, 'Kingfisher' gray-scale image, is used to evaluate the performance of the proposed and the compared filters similar to the experiment–I. Fig. 5(a) shows the ground-truth Kingfisher image and Fig. 5(b) shows its noisy version. Fig. 5(c)–5(f) are the restored images using the Wiener filter, median filter, fuzzy triangular filter, and the proposed filter, respectively. Table 2 shows the quality measures of the restored images. Both qualitative and quantitative comparisons show that the proposed method outperforms the other existing methods.

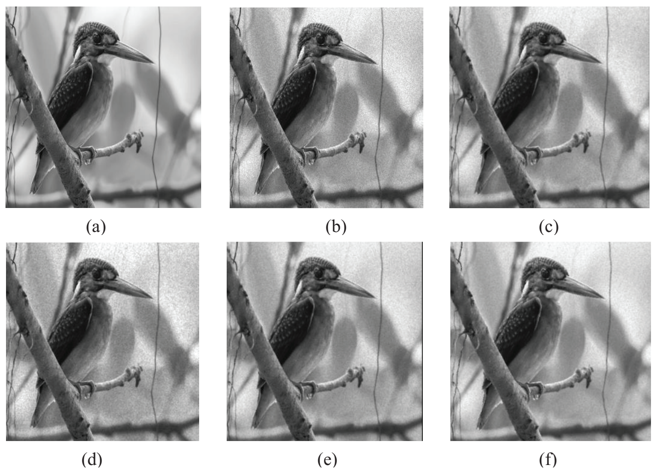

Fig. 5: Results on gray-scale Kingfisher image using different filters: (a) True image, (b) image corrupted by 20% speckle noise, (c) Wiener filter, (d) median filter, (e) triangular fuzzy filter, and (f) proposed fuzzy filter.

Table 2. Quality metrics for the results in experiment-II.

Methods	MSE	PSNR	NAE
Wiener	24.85	34.18	0.0198
Median	36.62	32.50	0.0262
Fuzzy tri.	29.21	33.45	0.0305
Proposed	14.50	36.52	0.0196

C. Performance analysis on real US imaging dataset

The presented results of the experiment–I and II depict that among the four methods considered in this paper, the proposed method performs better. Therefore, the proposed method is applied to real US images and the output image quality is evaluated using blind image quality metrics. The dataset [13] contains several breast US images and three images of them are considered in this experiment. Fig. 6 presents the clinical US images and their filtered versions using the proposed and the compared techniques. Table 3 shows the numerical assessment of the approaches based on the non-reference image quality metrics - blind/referenceless image spatial quality evaluator (BRISQE) and naturalness image quality evaluator (NIQE). For both metrics, the lower the scores the better the images. As seen from Table 3, the proposed method gives lower scores than the other methods for all three images, confirming its effectiveness in speckle noise reduction.

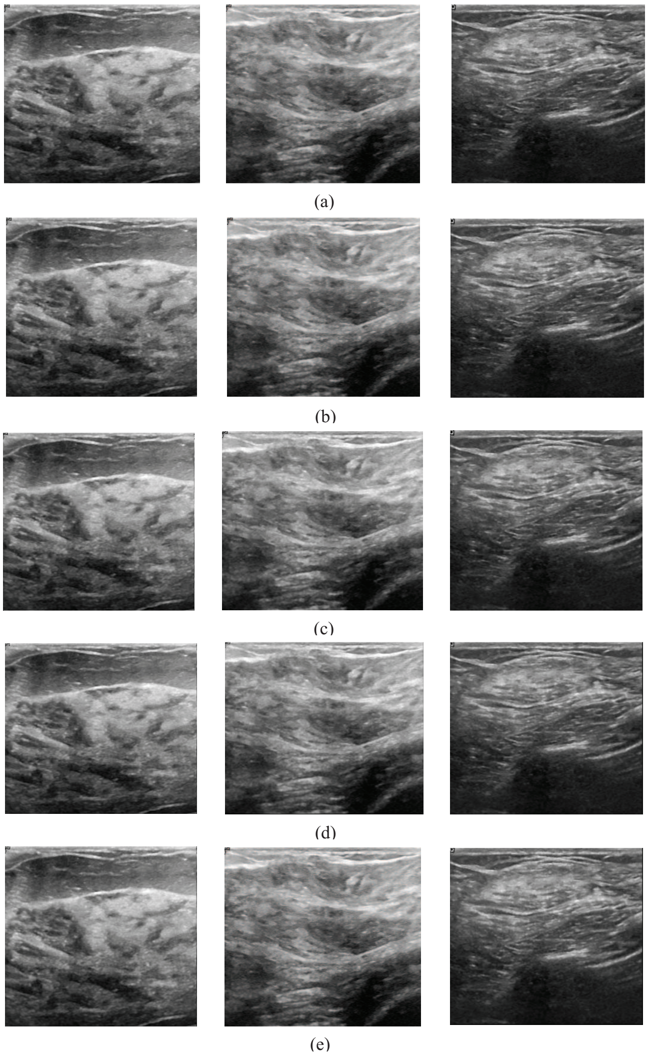

Fig. 6: Experimental results on real dataset: (a) Real US images, (b) Wiener filter, (c) median filter, (d) triangular fuzzy filter, and (e) proposed fuzzy filter.

Table 3. Quality metrics for the results on real images.

Methods	Data_1		Data_2		Data_3	
	BRISQUE	NIQE	BRISQUE	NIQE	BRISQUE	NIQE
Wiener	42.12	6.88	43.62	6.41	42.09	6.74
Median	43.58	10.22	43.44	8.77	43.45	8.88
Fuzzy-tri.	41.91	6.45	44.42	6.37	42.35	6.54
Proposed	**41.88**	**5.70**	**42.13**	**5.68**	**41.96**	**5.73**

IV. Conclusion

This paper presents an improved method for speckle noise reduction based on the Gaussian fuzzy logic technique. This fuzzy rule-based methodology is tested on several synthetic and real clinical images having different percentages of speckle noise. Both visual and numerical comparisons confirm that the proposed approach is capable to reduce the speckle noise to a greater extent and can preserve the sharper details of the US images. This technique could, therefore, be a useful tool for radiologists in their clinical diagnosis.

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