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A fuzzy logic approach for image restoration and content preserving

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***Abstract*—Image filtering, which removes or reduces noises from the contaminated images, is an important task in image processing. This paper presents a novel approach to the problem of noise reduction for gray-scale images.**

The proposed technique is able to remove the noise component, while adapting itself to the local noise intensity. In this way, the proposed algorithm can be considered as a modification of the median filter driven by fuzzy membership functions. Experimental results are compared to static median filter by numerical measures and visual inspection. As was expected, the new filter shows better performances.

***Keywords*— Image de-noising, fuzzy logic, variable median filter, noise cancellation.**

I. INTRODUCTION

In the process of imaging and transmission [1], it's hard to avoid the interference of different kinds of noise. So, image enhancement became an important step in many image processing applications.

Images can be contaminated [2] with different types of noise, for different reasons. For example, noise can occur because of the circumstances of recording, transmission, or storage, copying, scanning etc. Impulse noise and additive noise are most commonly found. It is a great challenge to develop algorithms that can remove noise from the image without disturbing its content.

In literature several (fuzzy and non-fuzzy) filters have been studied [3] [4] [5] [6] for impulse noise reduction. These techniques are often complementary to existing techniques and can contribute to the development of better and robust methods.

Traditionally, image enhancement techniques such median filtering has been employed in various applications in the past and is still being used but it still suffers from several drawbacks.

A fuzzy theory based image enhancement is used to create dynamic filter in order to avoid these problems and is a better method than the traditional methods such as static filter. The proposed filter provides an alternative approach in which the noise of gray-scale image is removed according to its intensity.

The organization of the paper is as follows. The proposed approach is described in Section 2 and we have compared the fuzzy smoothing simulation results with that of the non-fuzzy method in Section 3. At the end, conclusions and future prospects of the works are presented in Section 4.

II. IMAGE ENHANCEMENT

A. Impulse noise

The impulse noise (or salt and pepper noise) is caused by sharp, sudden disturbances in the image signal; its appearance is randomly scattered white or black (or both) pixels over the image. Fig. 1.1 shows an original image and the image which is corrupted with salt and pepper noise.

The mathematical formulation of the salt and pepper noise is defined as follows [10]:

$$P(z) = \begin{cases} P_a & for\ z = a \\ P_b & for\ z = b \\ 0 & otherwise \end{cases} \qquad (1)$$

Where, mean $\mu = aP_a + bP_b$, variance $\sigma^2 = (a-\mu)^2 P_a + (b-\mu)^2 P_b$, z random variable

$z = a + \sqrt{b \ln(1-w)}$ where w is uniformly distributed random variable in the interval (0,1).

(a) (b)

Figure. 1: (a) Original Image (b) Noisy image

Noise filtering can be viewed as replacing every pixel in the image with a new value depending on the fuzzy based rules. Ideally, the filtering algorithm should vary from pixel to pixel based on the local context [7].

B. Median filter

The median filter is the most popular nonlinear method for image filtering. In a sliding window, the value of a central pixel is replaced by the median of the gray levels in the neighbourhood of that pixel.

A median filter is more effective than convolution when the goal is to simultaneously reduce noise and preserve edges.

The output of the median filter sized N is given by:

$$\begin{cases} Y = R_{n+1,N}(X) & si\, N = 2n+1 \\ Y = \dfrac{R_{n,N}(X) + R_{n+1,N}(X)}{2} & si\, N = 2n \end{cases} \qquad (2)$$

Another more explicit notation is often used for the median filter:

$$Y = median(X) \qquad (3)$$

The original value of the pixel is included in the computation of the median. Median filters are quite popular because, for certain types of random noise they provide excellent noise reduction capabilities, with considerably less blurring than linear smoothing filters of similar size [8][9].

C. Adjustment of Filter size

In order to choose the appropriate adjustment of the filter size, we have analysed the filter performance in terms of PSNR and for different gray-scale images, which have been contaminated with different densities of salt and pepper noise.

We have observed that when the percentage of impulses is low the optimal performance is obtained for filter sized (3×3). However, as the number of impulses in the image increases, the size of median filter should also increase.

But, despite the fact that noise have the same intensity for the entire image, each area of the image requires to be filtered with a specific filter size.

The figure below (Figure.2) show different areas of the image with the corresponding filter size.

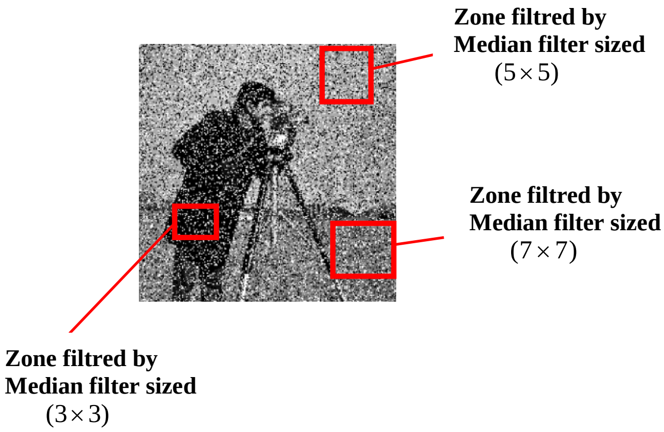


Figure.2 Principle of dynamic filtering

D. Proposed approach:

The proposed algorithm is to avoid the problem that occurs by the variation of noise intensities in the same image. The proposed algorithm is started by the following steps:

- Input to the system original image.
- Adding salt and pepper noise to the original image.
- A 2-D window "$W_{8\times8}$" of size 8 X 8 is selected. Assume that current pixel under processing is H (i,j).
- Construct the histogram for each image window, and compute the number of pixels having intensities 0 and 255 (black and white).
- Produce fuzzy logic rules.

In order to differentiate between local variations due to noise and due to image structure, we have to set a constant such as:

a) $If\ (H(i,j)=255) > n\times(H(i,j)=0)$
$then\ N = 2\times sum(H(i,j)=255)$

b) $$\begin{aligned}&If\ \ (H(i,j)=0) > n\times(H(i,j)=255)\\ &then\ N = 2\times sum(H(i,j)=255)\end{aligned}$$

• Corrupted image will be passed to fuzzy logic.

• Fuzzy output will differentiate between noise intensities and assigns each intensity, the right size filter.

• Compare the results with static filter with the best size.

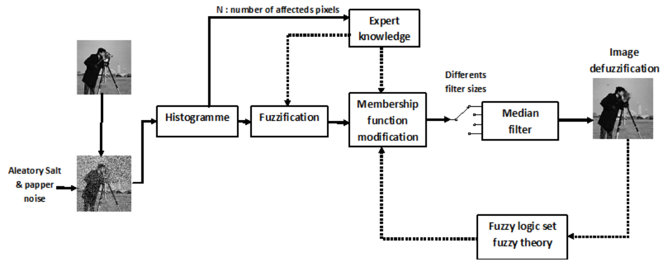


Figure.3 Fuzzy Image Processing

III. EXPERIMENTS AND RESULTS

The proposed fuzzy filter is applied on different gray-scale images to test its performance by visual inspection, at first.

The results from standard median filter and the proposed fuzzy median filter respectively.

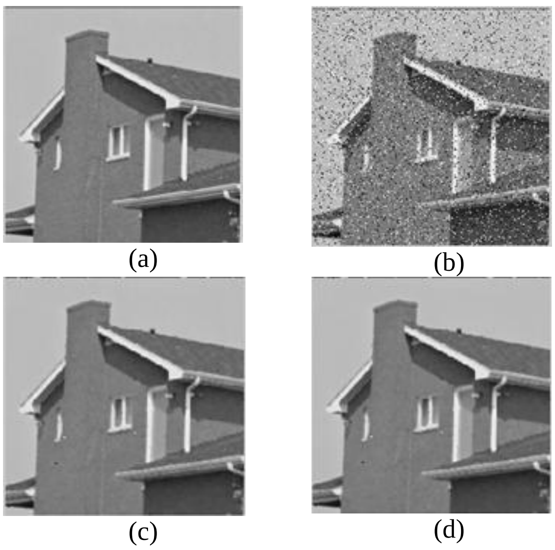


Figure. 4: (a) Original Image, (b) Noisy image (noise rate: 0.1), (c) Filtered image using static median of size 3×3, (d) Filtered image using proposed fuzzy median filter

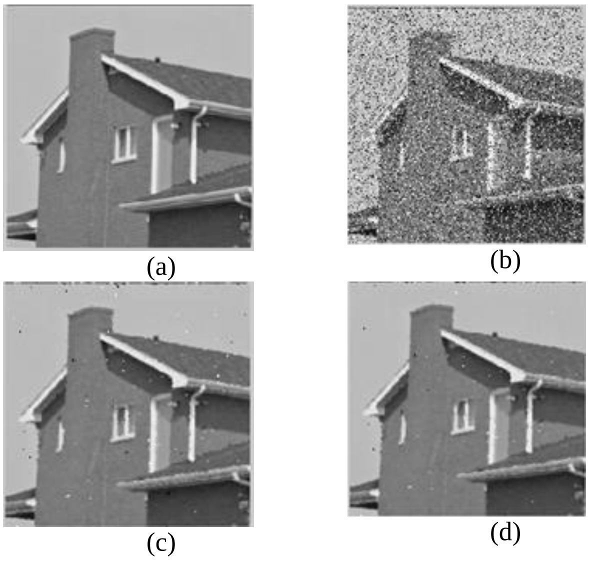


Figure.5: (a) Original Image, (b) Noisy image (noise rate: 0.2), (c) Filtered image using static median of size 3×3, (d) Filtered image using proposed fuzzy median filter

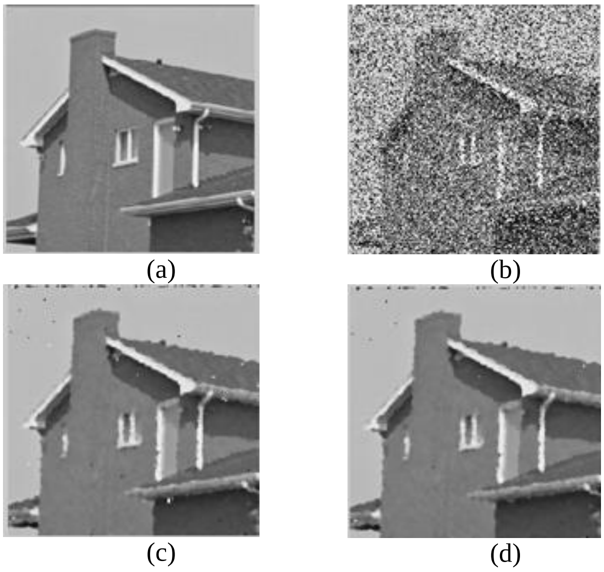
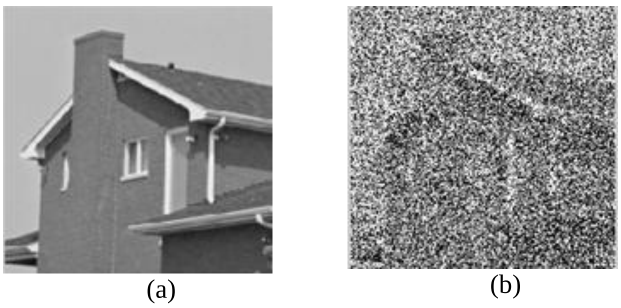


Figure.6: (a) Original Image, (b) Noisy image (noise rate: 0.4), (c) Filtered image using static median of size 5×5, (d) Filtered image using proposed fuzzy median filter



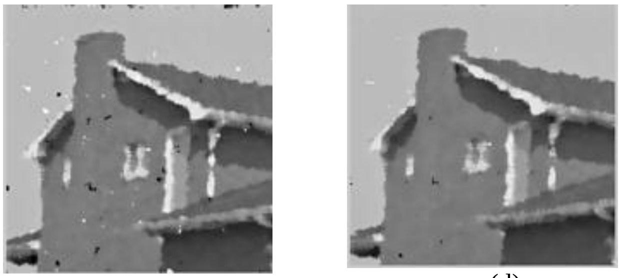

(c) (d)

Figure.7: (a) Original Image, (b) Noisy image (noise rate: 0.6), (c) Filtered image using static median of size 9×9, (d) Filtered image using proposed fuzzy median filter

In order to demonstrate the performance of the proposed method, we compared the experimental results of the proposed dynamic filter with those of static filter. Above, we present a few of the experimental results for gray-scale images contaminated with homogeneous impulse noise, which allows us to conclude that dynamic filter performs well in noise reduction and generates better results than the static filter.

The superior performance of the proposed approach is due to several reasons; Dynamic filter takes care of the fuzziness in the images by using fuzzy set theory, the necessary parameters are determined automatically based on the nature of the images, and the proposed approach uses noises intensities to decide enhancement/de-enhancement, since, in the same image, noise has different effects in different image regions, this amount to the difference in brightness, color and texture of an area to another, and therefore, it can prevent over-enhancement effectively.

However, such a visual comparison is not sufficient to evaluate accurately all filters. To compare quantitatively these filtering techniques, we use The Peak signal to noise ratio (PSNR) and the Mean Structure SIMilarity index (MSSIM).

The metrics for comparison are defined as follows:

$$MSE = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} \left([f(x,y) - r(x,y)]^2 \right) \quad (4)$$

$$PSNR = 10.\log_{10}\left(\frac{d^2}{MSE}\right) \quad (5)$$

Where MSE is the mean square error, d is the maximal coded intensity, N is the total number of pixels in the image, f and r are the original and filtered image.

$$SSIM(r,x) = \frac{(2\mu_r \mu_x + C1)(2\sigma_{xy} + C2)}{(\mu_r{}^2 + \mu_x{}^2 + C1)(\sigma_r{}^2 + \sigma_x{}^2 + C2)} \quad (6)$$

$$MSSIM = \frac{1}{G} \sum_{p=1}^{G} SSIM(r_p, x_p) \quad (7)$$

The Structure SIMilarity index between the original image and restored image is given by SSIM [11] where μ_r and μ_x are mean intensities of original and restored images, σ_r and σ_x are standard deviations of original and restored images, r_p and x_p are the image contents of p^{th} local window and G is the number of local windows in the image.

The obtained values of PSNR after de-noising different images with static and proposed filters are respectively reported in the next table.

Table 1.PSNR and MSSIM variation

Noise intensity	0.1	0.2	0.4	0.6
Fuzzy filter PSNR(dB)	31.76	28.70	25.67	23.64
Static filter PSNR (dB)	31.75	28.31	25.52	22.94
Fuzzy filter MSSIM	0.872	0.836	0.808	0.742
Static filter MSSIM	0.872	0.824	0.783	0.721

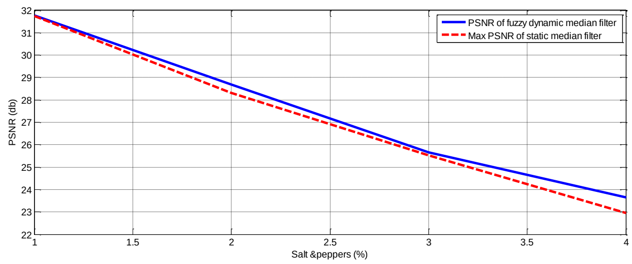


Figure.8: PSNR variation's curve

To increase performance of our proposed method, we apply it on different images contaminated with random noise, i.e., we apply to each window of the image a noise with different intensities, than we test the efficiency of the dynamic filter on it. The results from standard median filter and the proposed fuzzy median filter respectively.

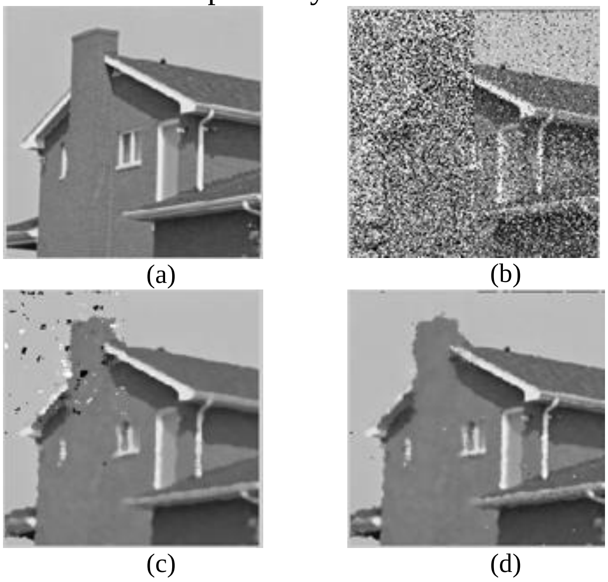


Figure.9: (a) Original Image, (b) Image contaminated with randomly, (c) Filtered image using static median of size 19×19, (d) Filtered image using proposed fuzzy median filter

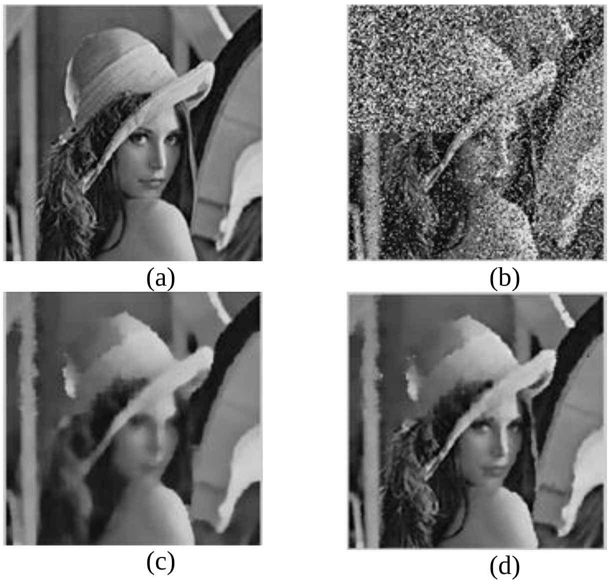


Figure.10: (a) Original Image, (b) Image contaminated with randomly noise, (c) Filtered image using static median of size 11×11, (d) Filtered image using proposed fuzzy median filter

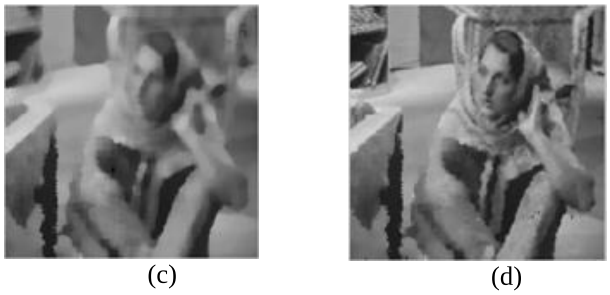


Figure.11: (a) Original Image, (b) Image contaminated with randomly noise, (c) Filtered image using static median of size 21×21, (d) Filtered image using proposed fuzzy median filter

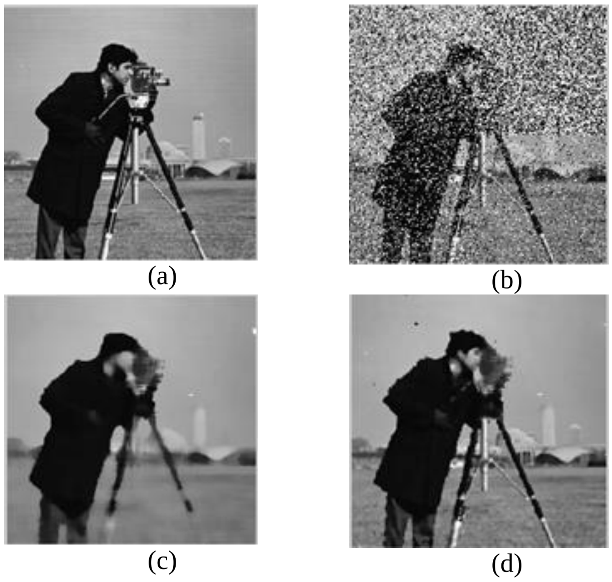


Figure.12: (a) Original Image, (b) Image contaminated with randomly noise, (c) Filtered image using static median of size 11×11, (d) Filtered image using proposed fuzzy median filter

The obtained values of PSNR after de-noising different images with static and proposed filters are respectively reported in the next table.

Table 2.PSNR and MSSIM variation

Fuzzy filter PSNR(dB)	24.15	28.47	20.10	19.84
Static filter PSNR (dB)	21.76	23.02	16.31	17.42
Fuzzy filter MSSIM	0.816	0.793	0.662	0.797
Static filter MSSIM	0.727	0.682	0.592	0.662

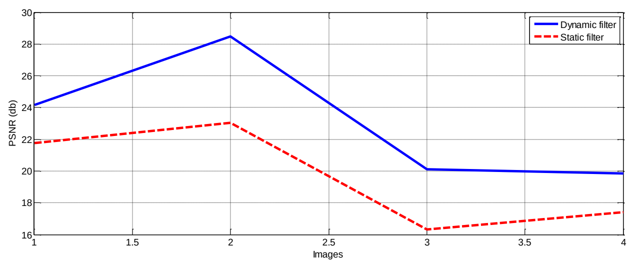


Figure.13: Comparison of PSNR variation

IV. CONCLUSION

In this paper, a robust filtering method based on fuzzy logic is proposed. The main feature of the proposed filter is that it tries to determine the best filter for each noise intensity, given that the noise spectrum is not uniform so it's spread randomly over the image.

The filter is able to perform a very strong noise cancellation compared with static median filter. The effectiveness of this efficient fuzzy image enhancement technique can be tested with binary and gray scale images

In future, modified algorithm using fuzzy logic and fuzzy sets may produce better results.

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