A Novel Fuzzy Technique for Image Noise Reduction

Hamed Vahdat Nejad, Hameed Reza Pourreza, and Hasan Ebrahimi

Abstract—A new fuzzy filter is presented for noise reduction of images corrupted with additive noise. The filter consists of two stages. In the first stage, all the pixels of image are processed for determining noisy pixels. For this, a fuzzy rule based system associates a degree to each pixel. The degree of a pixel is a real number in the range [0,1], which denotes a probability that the pixel is not considered as a noisy pixel. In the second stage, another fuzzy rule based system is employed. It uses the output of the previous fuzzy system to perform fuzzy smoothing by weighting the contributions of neighboring pixel values. Experimental results are obtained to show the feasibility of the proposed filter. These results are also compared to other filters by numerical measure and visual inspection.

Keywords—Additive noise, Fuzzy logic, Image processing, Noise reduction.

I. INTRODUCTION

THE objective of image restoration is to reconstruct the image from degraded one resulted from system errors and noises and so on. There are two ways to achieve such an objective [4]. One is to model the corrupted image degraded by motion, system distortion, and additive noises, whose statistic models are known. And the inverse process may be applied to restore the degraded images. Another is called image enhancement, that is, constructing digital filters to remove noises to restore the corrupted images resulted from noises.

Noise filtering can be viewed as replacing the gray-level value of every pixel in the image with a new value depending on the local context. Ideally, the filtering algorithm should vary from pixel to pixel based on the local context. We use a fuzzy technique to achieve this goal. Fuzzy techniques have already been applied in several domains of image processing (e.g., filtering, interpolation, and morphology), and have numerous practical applications (e.g., in industrial and medical image processing). Already several fuzzy filters for noise reduction have been developed, e.g., the well-known FIRE-filter from [5]–[6], the weighted fuzzy mean filter from [7] and [8], and the iterative fuzzy control based filter from [9]. Most fuzzy techniques in image noise reduction mainly deal with fat-tailed noise like impulse noise. These fuzzy filters are able to outperform rank-order filter schemes (such as the median filter).

Authors are with Ferdowsi University of Mashad, Computer Department, Iran (e-mail: Hamed.vh@gmail.com, hpourreza@ferdowsi.um.ac.ir).

The fuzzy weighted mean filter [1] is an extension of the adaptive weighted mean filter. The idea behind the FWM filter is that the weights should take values in [0,1], instead of only the crisp values 0 , 1, and that the weights should not depend on a threshold value, but should be determined by means of fuzzy rules. The idea behind this filter is good, but it does not use enough parameters. In our approach we extend WFM filter by considering other important parameters to the fuzzy rule based system.

The rest of the paper is organized as follows: section 2 describes the proposed fuzzy approach for additive noise reduction. Section 3 presents some experiments, and section 4 concludes.

II. PROPOSED FUZZY SYSTEM

The adaptive weighted mean filter replaces the gray value of a pixel (i,j) by a weighted average of the gray values in a neighborhood of that pixel. The choice of the weights is based on the gray value differences $|f(x,y) - f(x-k,y-l)|$: if this difference exceeds a certain threshold, one defines $w_{ij}(k,l)=0$; in the other case $w_{ij}(k,l)=1$. In our approach the weights take values in the range [0,1], and they do not depend on a threshold value, but they are determined by means of fuzzy rules. The proposed approach has two stages; each of them uses a fuzzy rule based system. In the first stage, we try to determine whether a pixel is a noisy pixel or not. For this purpose, we use a fuzzy rule based system to determine a degree for each pixel of the image. The degree is a real number in the range [0,1]. If the degree of a pixel is equals to 1, we'll assume that the pixel is not corrupted, and if it is less than 1, we'll assume the pixel is noisy. The nearer the degree of a pixel to zero, the more it is considered as a noisy pixel. After finishing this stage, we'll have a degree matrix as the same size as the corrupted image. We use this matrix in the next stage which performs fuzzy smoothing by weighting the contributions of neighborhood pixel values. In the rest of this section, we describe these two stages with more detail.

A. Fuzzy Noise Estimation

In this part we want to determine whether a pixel is corrupted or not. For this, the following criteria are considered:

1. if a pixel is severely noisy, there aren't any similar gray level value in its neighborhood pixels, so the minimum gray value difference of that pixel and its 8-neighborhood pixels is large. Reversely, if minimum gray level difference of a pixel and its neighborhood pixels is small, one assumes that the

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:2, No:9, 2008

pixel is not categorized as a noisy pixel. Hence we use minimum gray level differences as the first parameter of our fuzzy rule based system:

$$dif = \min |f(x, y) - f(x', y')|$$

,where (x', y') is an 8-neighborhood pixel of (x,y).

2. if a pixel has many similar pixels in its neighborhood, one assumes that it is uncorrupted, so we can use number of similar pixels to an assumed pixel in its 8-neighborhood as an important parameter to realize whether the pixel is corrupted or not. For this, we determine the number of pixels in the 8-neighborhood of a given pixel that their gray level differences with central pixel is less than a predefined threshold. We exploit this number as the second parameter of our fuzzy rule based system:

Number Of Similar = {Number of (x', y') | $(x', y') \in N_8(x, y)$ & $|f(x, y) - f(x', y')| < Threshold$ }

In this paper we set threshold statically equal to 5, but it may determined dynamically for each image to gain better results. The output of the fuzzy system is a degree associated to each pixel that is a real number between 0 and 1. It denotes the degree which a pixel is considered as an uncorrupted pixel. Fuzzy membership functions are illustrated in Fig 1. The rules of the fuzzy system are as follows:

1. If (dif is low) and (num is none) then (deg is moderate)
2. If (dif is low) and (num is few) then (deg is big)
3. If (dif is low) and (num is many) then (deg is very big)
4. If (dif is med) and (num is none) then (deg is small)
5. If (dif is med) and (num is few) then (deg is moderate)
6. If (dif is med) and (num is many) then (deg is big)
7. If (dif is high) and (num is none) then (deg is small)
8. If (dif is high) and (num is few) then (deg is moderate)
9. If (dif is high) and (num is many) then (deg is moderate)

We use Mamdani inference engine, max fuzzifier, and centroid defuzzifier.

B. Fuzzy Smoothing

In this stage, the fuzzy weighted averaging is accomplished. The weights of pixels in each neighborhood are obtained using a fuzzy smoothing technique. For this, we consider the following criterion: if the difference $|f(x, y) - f(x - k, y - l)|$ is large, a small weight $w_{ij}(k,l)$ must be applied to the pixel to reduce its contribution in averaging process. Hence we use $|f(x, y) - f(x - k, y - l)|$ as first parameter in fuzzy smoothing process:

$$diff = |f(x, y) - f(x - k, y - l)|$$

The second parameter is the output of previous fuzzy rule based system, which denotes the degree that a pixel is not considered as a noisy pixel .The output of fuzzy smoothing is the weight of pixel in the averaging process. Fuzzy

membership functions are illustrated in Fig 2. Fuzzy rules are as follow:

1. If (diff is small) and (deg is low) then (weight is medium)
2. If (diff is small) and (deg is medium) then (weight is medium)
3. If (diff is small) and (deg is large) then (weight is large)
4. If (diff is medium) and (deg is low) then (weight is low)
5. If (diff is medium) and (deg is medium) then (weight is medium)
6. If (diff is medium) and (deg is large) then (weight is large)
7. If (diff is large) and (deg is low) then (weight is low)
8. If (diff is large) and (deg is medium) then (weight is low)
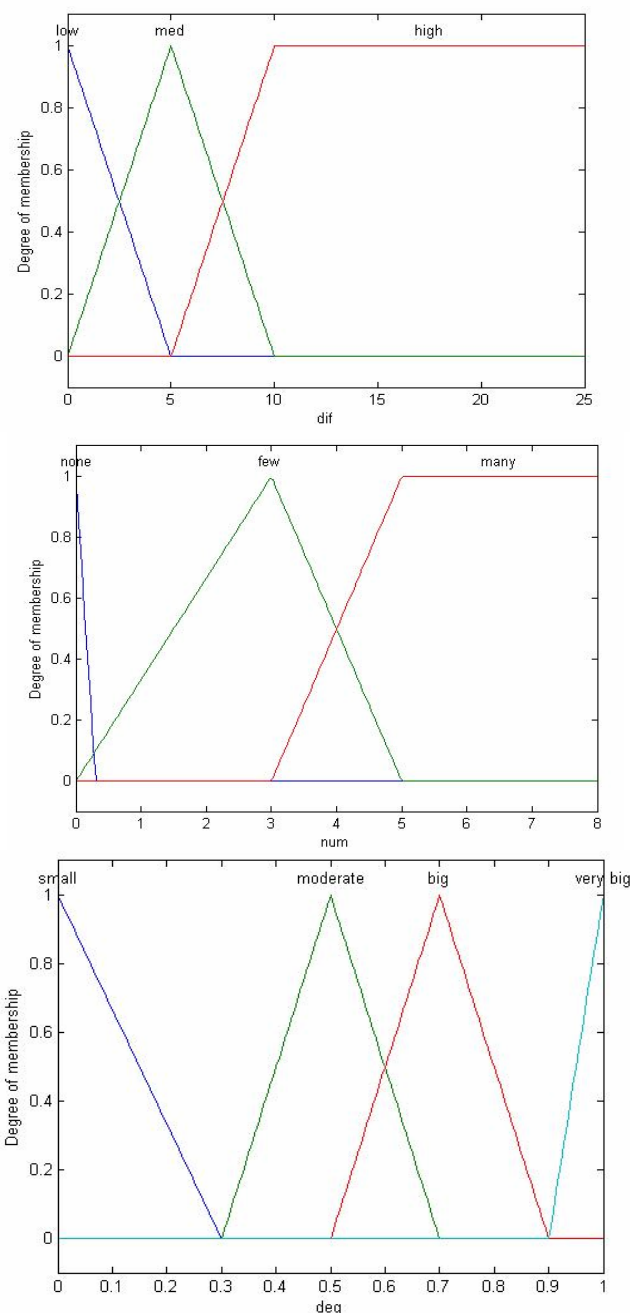*9. If (diff is large) and (deg is large) then (weight is medium)*

Fig. 1 Membership functions for fuzzy noise estimation

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:2, No:9, 2008

We use a 3×3 mask for filtering process. In each location of mask, the weights of pixels are determined using the second fuzzy rule based system, and the weighted averaging is accomplished to determine the new value of central pixel. Then mask is moved and the procedure is repeated in the new location.
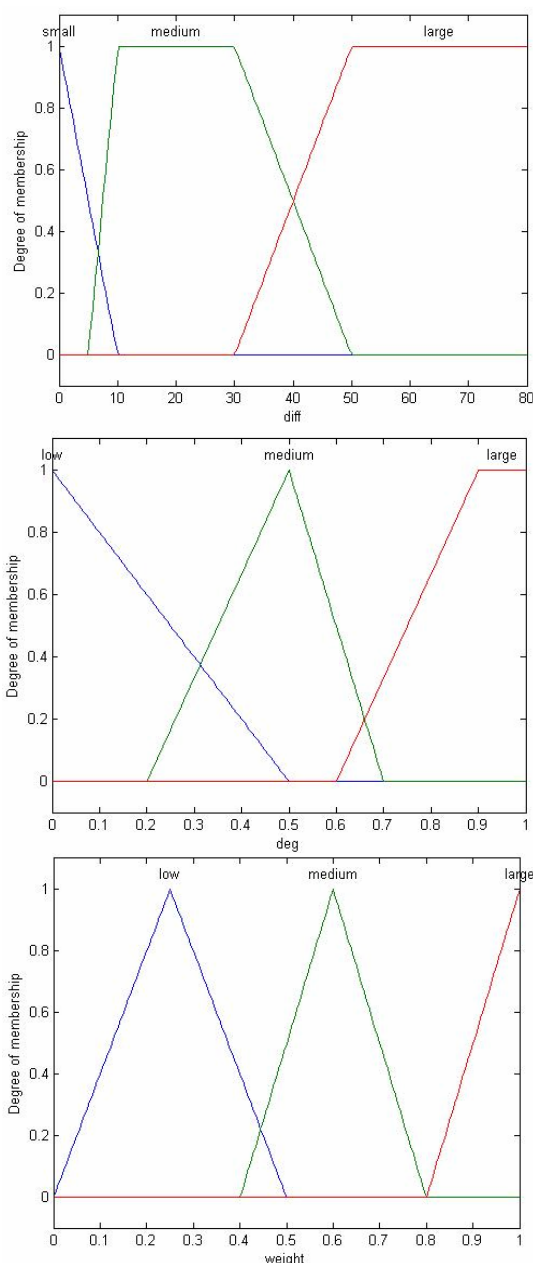

Fig. 2 Membership functions for fuzzy smoothing

III. EXPERIMENTS

The proposed filter is applied to gray scale test images (8-bit, L=255), after adding Gaussian noise of different levels. Such a procedure allows us to compare and evaluate the filtered image against original one. Fig. 3 shows two representative test images: "Cameraman" and "Lena".

A. Experiment 1

The image in Fig. 4(a) is the image in Fig. 3(a), which is corrupted by Gaussian noise with µ=0, $\sigma^2 = 100$. The images in Fig. 4(b),(c),(d), and (e) are the results of applying mean, Adaptive Wiener (with mask 3×3), Adaptive Wiener (with mask 5×5), and the proposed fuzzy filter to the corrupted image, respectively.

We also compared our fuzzy filter with several other filter techniques: the mean filter, the adaptive Wiener filter, fuzzy median (FM) [10], the adaptive weighted fuzzy mean (AWFM1 and AWFM2) [7], [8], the iterative fuzzy filter (IFC), modified iterative fuzzy filter (MIFC), extended iterative fuzzy filter (EIFC) [9], and fuzzy derivative estimation filter (FDE)[2]. Table I summarizes the results we obtained.

B. Experiment 2

In this section, we compare the proposed filter with the filters proposed in [11], [12], [13]. For this, we corrupted the image in fig 3(b) by Gaussian noise with µ=0, $\sigma^2 = 400$. Then we applied some previous filters and the proposed one to the corrupted image. Table II summarizes the result of proposed filter, and those of the median, FWM (proposed in [12]), EPS (proposed in [13]) with two different window sizes of 5×5 and 7×7, ENHANCE (proposed in [11]) with two window sizes of 3×3 and 5×5 , and FPF [3].

IV. CONCLUSION AND FUTURE WORK

This paper proposed a new fuzzy filter for additive Gaussian noise reduction. The main feature of the proposed filter is that it tries to determine corrupted pixels to reduce their contribution in smoothing process. Hence it performs fuzzy smoothing by the previous knowledge of the pixels. We performed some experiments in order to demonstrate the effectiveness of the proposed filtering approach. The fuzzy filter is able to compete with state-of-the-art filter techniques for noise reduction. A numerical measure, such as MSE, and visual observation show convincing results.

In fuzzy noise estimation stage, we used a fixed threshold for number of similar pixels in a neighborhood. One can investigate on determining the threshold value dynamically to gain better results. The histogram of the image or part of the image can be used in this process.

REFERENCES

[1] K. Arakawa, Fuzzy rule-based image processing with optimization, Fuzzy techniques in image processing, Springer-Verlag, 2000.
[2] D. Van De Ville, M. Nachtegael, D. Van der Weken, E. Kerre, W. Philips, and I. Lemahieu, Noise Reduction by Fuzzy Image Filtering, IEEE transactions on fuzzy systems, vol. 11, No. 4, August 2003.
[3] F.Farbiz, M. Menhaj, S. Motamedi, Fixed Point Filter Design for Image Enhancement using Fuzzy Logic, In Proc. IEEE, 1998.
[4] P. Liu and H. Li, Fuzzy techniques in image restoration research- A survey, International Journal of Computational Cognition, Volume 2, pp 131–149, June 2004.
[5] F. Russo and G. Ramponi, A fuzzy operator for the enhancement of blurred and noisy images, IEEE Trans. Image Processing, vol. 4, pp.1169–1174, August 1995.

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:2, No:9, 2008

[6] F. Russo, "Fire operators for image processing," Fuzzy Sets Syst., vol. 103, no. 2, pp. 265–275, 1999.
[7] C.-S. Lee, Y.-H. Kuo, and P.-T. Yu, Weighted fuzzy mean filters for image processing, Fuzzy Sets Syst., no. 89, pp. 157–180, 1997.
[8] C. Lee and Y. Kuo, Fuzzy Techniques in Image Processing. New York: Springer-Verlag, 2000, vol. 52, Studies in Fuzziness and Soft Computing, ch. Adaptive fuzzy filter and its application to image enhancement, pp. 172–193.
[9] F. Farbiz and M. B. Menhaj, Fuzzy Techniques in Image Processing. New York: Springer-Verlag, 2000, vol. 52, Studies in Fuzziness and Soft Computing, ch. A fuzzy logic control based approach for image filtering, pp. 194–221.
[10] K. Arakawa, Median filter based on fuzzy rules and its application to image restoration, Fuzzy Sets Syst., pp. 3–13, 1996.
[11] Y.Choi and R. Krishnapuram, A robust approach to image enhancement based on fuzzy logic, IEEE Trans. Image Processing, vol. 6, no. 6, June 1997, p.808-825.
[12] A. Taguchi, A design method of fuzzy weighted median filters, In Proc. Third IEEE Int. Conf Image Processing, vol. 1,.1996 p.423-426.
[13] M. Muneyasu, Y. Wada, T. Hinamoto, Edge-preserving smoothing by adaptive nonlinear filters based on fuzzy control laws, In Proc. Third IEEE Int. Conf Image Processing,Vol.1,1996. pp. 785-788.

Fig. 3 Original test images (a)"Cameraman" (b)"Lena"

TABLE I
RESULT OF THE NEW FUZZY FILTER FOR THE TEST IMAGE "CAMERAMAN"

| | MSE | | |
| | Cameraman | | |
	$\sigma=5$	$\sigma=10$	$\sigma=20$
Noise image	24.9	97.0	371
Mean filter(3×3)	170	178	213
Adaptive wiener filter (3×3)	42.4	56.2	112
Adaptive wiener filter (5×5)	66.8	79.6	126
FM	16.8	56.4	151
AWFM1	189	215	342
AWFM2	123	132	175
IFC	49.2	80.6	173
MIFC	49.2	80.6	170
EIFC	49.2	80.6	171
FDE	18.6	51.2	124
Proposed filter	14.7	30.6	62.7

World Academy of Science, Engineering and Technology
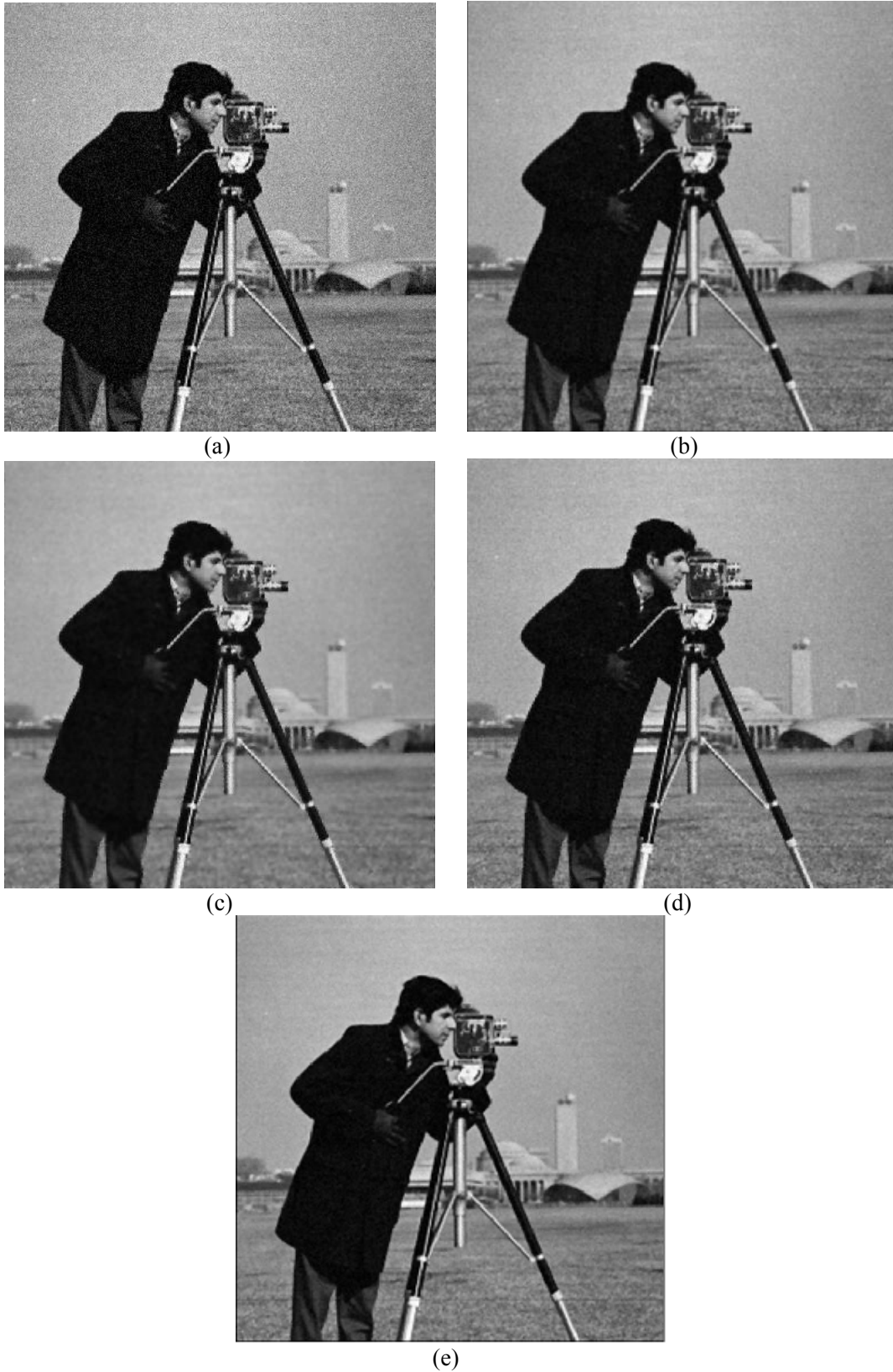International Journal of Electrical and Computer Engineering
Vol:2, No:9, 2008

Fig. 4 (a) "Cameraman" with additive Gaussian noise (σ=10) (b) After mean filtering (c) After adaptive Wiener filtering (3×3) (d) After adaptive Wiener filtering (5×5) (e) After proposed fuzzy filter

World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:2, No:9, 2008

TABLE II
RESULTS OF THE NEW FUZZY FILTER FOR THE TEST IMAGE "LENA"

	MSE
	Lena
Median 3×3	111.1
Median 5×5	127.1
FWM	113.4
EPS 5×5	87.61
EPS 7×7	98.67
ENHANCE 3×3	96.12
ENHANCE 5×5	102.4
FPF	86.45
Proposed filter	65.1636