AN ITERATIVE METHOD FOR IMAGE ENHANCEMENT BASED ON FUZZY LOGIC

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ABSTRACT

This paper presents a new filtering approach based on fuzzy-logic which has high performance in mixed noise environments. This filter is mainly based on the idea that each pixel is not allowed to be uniformly fired by each of the fuzzy rules. We perform several test experiments in order to highlight the merit of the proposed method. The results are very promising and indicating the high performance of the proposed filter in image restoration in compared with those of the filters which have been recently cited in image processing literature.

I. INTRODUCTION

As an important task in image enhancement, noise filtering can be viewed as replacing the gray-level value of each 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. For example, if the local region is relatively smooth, then the new value of the pixel is worth being determined by averaging neighboring pixels values. On the other hand, if the local region contains edge or impulse noise pixels, a different type of filtering should be used. However, it is extremely hard, if not impossible, to set the conditions under which a certain filter should be selected, since the local conditions can be evaluated only vaguely in some portions of an image. Therefore, a filtering system needs to be capable of performing reasoning with vague and uncertain information; this is a clear justification of fuzzy logic common usage [1]-[3].

In this paper, we proposed a new filter, based on fuzzy logic control [4], which can efficiently restore images in the mixed noise environments (i.e. impulsive and Gaussian noise). The filter is mainly based on the idea that each pixel is not allowed to be uniformly fired by each of the fuzzy rules.

II. THE PROPOSED METHOD

This section presents the architecture of our proposed rule-based image processing system. In this system, we adopt the general structure of fuzzy if-then-else rule mechanism originally proposed by Russo in his papers [5]-[13]. In contrast to Russo's technique, our approach is mainly based on the idea of not letting each point in the area of concern being uniformly fired by each of the basic fuzzy rules. This idea is widely used in fuzzy control applications [4]. To furnish this goal, the following fuzzy rules and membership functions given in figure 1 are proposed for image filtering:

R1:	IF (**more** of x_i are **NB**)	THEN y is **NB**
R2:	IF (**more** of x_i are **NM**)	THEN y is **NM**
R3:	IF (**more** of x_i are **NS**)	THEN y is **NS**
R4:	IF (**more** of x_i are **PS**)	THEN y is **PS**
R5:	IF (**more** of x_i are **PM**)	THEN y is **PM**
R6:	IF (**more** of x_i are **PB**)	THEN y is **PB**
R0:	ELSE	y is **Z**

(1)

In the above, x_i's are the luminance differences between neighboring pixels, P_i (located in a window of size N×N), and the central pixel, P, : $x_i = P_i - P$. The output variable y is the quantity which is added to P to yield the resulting pixel luminance, P'. The term, **more,** represents a S-type fuzzy function and may be described by the following formula:

$$\mu_{\text{more}}(z) = \begin{cases} 0 & z \le a \\ .5\left\{1-\cos\left[\dfrac{\pi(z-a)}{b-a}\right]\right\} & a < z < b \\ 1 & z \ge b \end{cases} \qquad (2)$$

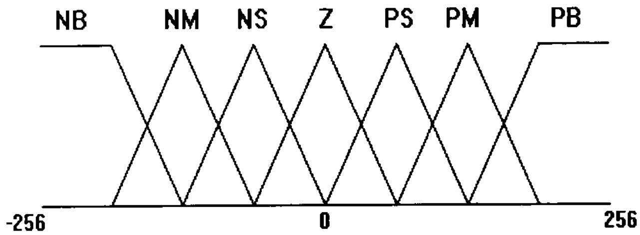

Figure 1. Membership functions

The Rule degree's activity calculation

The activity degree of R1 is computed by the following relationship (the other if-then rules degree of activities are computed similarly)

$$\lambda_1 = \min\{\mu_{\mathrm{NB}}(x_i) : \mu_{\mathrm{NB}}(x_i) > 0\} \times \mu_{\mathrm{more}}\left[\frac{\text{number of } x_i \text{ which } \mu_{\mathrm{NB}}(x_i) > 0}{\text{total number of } x_i}\right] \tag{3}$$

and for the ELSE rule, R0, we may apply the following formula to evaluate the degree of activation:

$$\lambda_0 = Max\{0, 1 - \sum_{i=1}^{6} \lambda_i\} \tag{4}$$

To infer the output numerically from the fuzzy rules given in (1), we employ the *correlation-product* inference mechanism [4] as:

$$y = \frac{\sum_{i=0}^{6} C_i w_i \lambda_i}{\sum_{i=0}^{6} w_i \lambda_i} \tag{5}$$

where C_i and w_i are respectively, the center point and width of the membership function used in the ith fuzzy rule in Eq(1).

Since all w_i's are equal and $C_0 = 0$, Eq(5) can be simplified to:

$$y = \sum_{i=1}^{6} C_i \lambda_i \tag{6}$$

III. EXPERIMENTAL RESULTS

Experiment 1: In order to demonstrate the performance of the filter in a Gaussian noise environment, we consider the Lena image as a case study. This image is first contaminated by Gaussian noise with $\mu=0$, $\sigma^2=400$. Then, it is applied to the proposed filter. The result of filtering process is depicted in figure 2, labeled (b). We can easily observe from this figure that as the number of iterations increases, we will have better image restoration in the sense of MSE. To show the performance of the filter in the mixed noise case, we take the image considered in this experiment, added by [%2.5, %2.5] impulsive noise. The result is also shown in figure 3; in this case the plot is labeled by (a). From these two results, cases of Gaussian noise and mixed noise, we may conclude that the proposed filter has good ability in image restoration as the number of iteration increases.

Experiment 2: In this experiment we aim to show how the noise variance affects performance of the proposed filter. Here again we use the Lena image corrupted by zero mean Gaussian noise with different variances (σ^2 =0, 100, 200, 300, 400). Figure 3, which shows the MSE of the restored images as a function of the variance of Gaussian noise, compares the performance of the proposed filter with that of the FWM (proposed in [14]) & EPS (proposed in [15]) with two window size 5×5 and 7×7 filters. These results are encouraging and indicating the satisfactory performance of our proposed method.

Experiment 3: This experiment aims to show how the proposed filter would behave as the variance of Gaussian noise changes in a mixed noisy environment. The image in experiment 2 is mixed by [%2.5, %2.5] impulsive noise and used as an input to our proposed filter. The results in image restoration shown in figure 4 demonstrate that the proposed filter in mixed noise has the best performance among the filters listed in table 1.

Experiment 4: To show the performance of the proposed method in a mixed noise environment, we consider the image given in figure 5(b) which is actually the image given in figure 5(a) corrupted by Gaussian noise with $\mu=0$, $\sigma^2=400$ and [%2.5, %2.5] impulsive noise. The result of our method and those of the other filters listed in table 1, are depicted in figures 5(c)-(h). The MSE of these filters are reported in table 1, column 3.

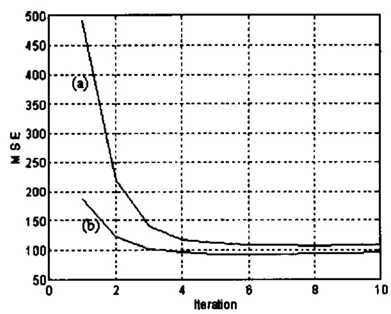

Figure 2. Performance of the proposed filter on 256×256 Lena image contaminated by Gaussian noise with $\mu=0$, σ^2 =400 and a) [%2.5, %2.5] impulsive noise; b) without impulsive noise

Table 1

	Image 1	Image 2	Image 3
median 3×3	127.9	115.7	111.1
median 5×5	134	122.5	127.1
FWM	130.3	108.3	113.4
EPS 5×5	136.9	119.5	87.61
EPS 7×7	129.7	109.3	98.67
proposed filter 3×3 (after 1 iteration)	491.6	450.8	187.8
proposed filter 3×3 (after 6 iterations)	109.8	101.4	93.61

Image 1: the Lena image contaminated by [%2.5, %2.5] impulsive noise and Gaussian noise with $\mu=0$, $\sigma^2=400$.
Image 2: figure 5(b).
Image 3: the Lena image contaminated by Gaussian noise with $\mu=0$, $\sigma^2=400$.

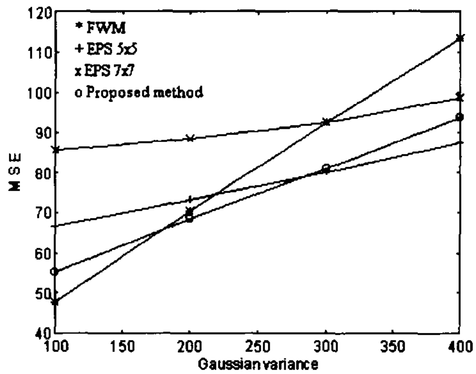

Figure 3. MSE as a function of variance of Gaussian noise computed for the Lena image.

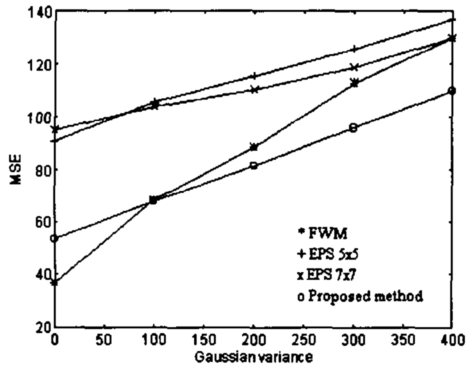

Figure 4. MSE of restored images of different filters for the Lena image corrupted by mixed noise (Gaussian and [%2.5, %2.5] impulsive noise)

IV. CONCLUSION

In this paper we presented a new filtering method based on fuzzy logic control to image enhancement. We performed several different experiments in order to demonstrate the effectiveness of the proposed filtering approach. The results of the proposed filter were compared with those of filters listed in table 1. From this table and figures 2-5 it can be concluded that the proposed filter possesses high capability of image restoration in noisy environment.

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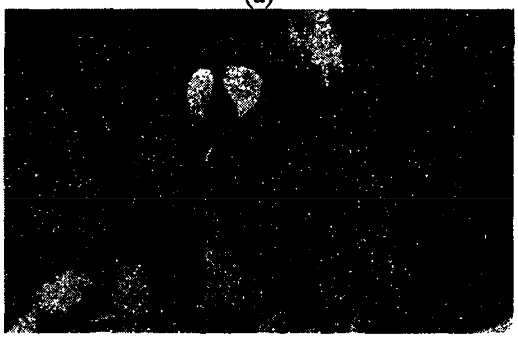
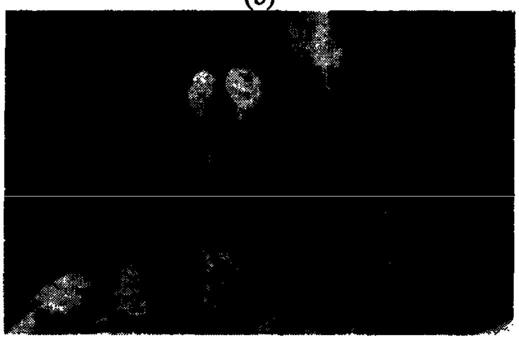
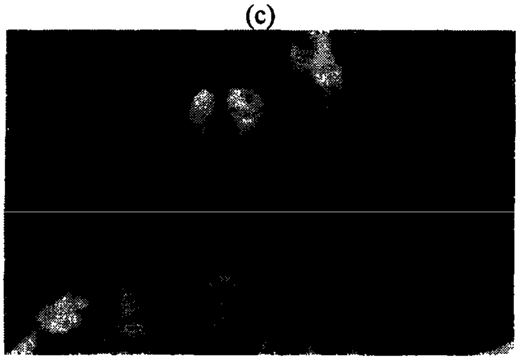
(a)



(b)



(c)



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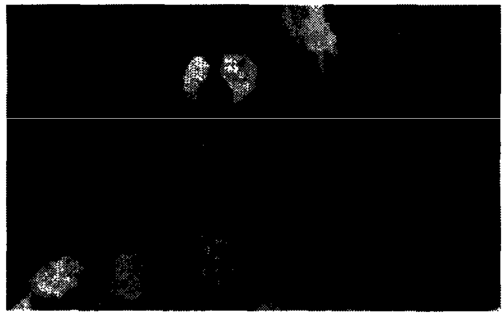
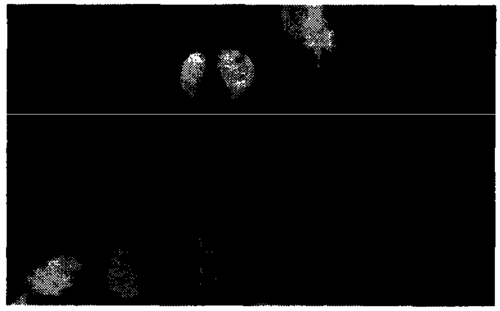
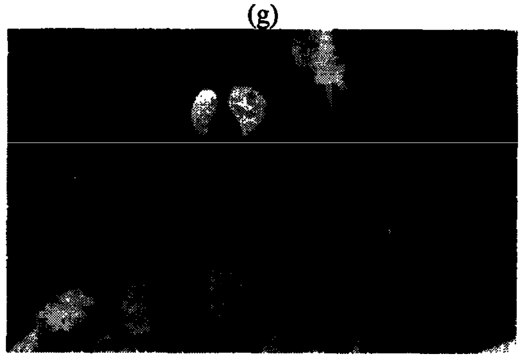


(e)



(f)

(g)



(h)

Figure 5. a) a 320×200 test image; b) the image corrupted by Gaussian noise with $\mu=0$, $\sigma^2=400$ and [%2.5, %2.5] impulsive noise; c) restored by median 3×3; d) restored by median 5×5; e) restored by EPS 5×5; f) restored by EPS 7×7; g) restored by FWM; h) restored by the proposed filter after six iterations.