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Design of a new filtering for the noise removing in images by fuzzy logic

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Abstract. Removing noise from the color images is a very active research scope in image processing. In this paper, a new fuzzy based image filtering algorithm is proposed for reducing and removing impulse noise in color images. For dealing with the Impulse noise, an algorithm is developed to search for a set of uncorrupted pixels in the neighborhood of the pixel of interest and to compute the median of this set. A modified fuzzy filter consisting of two sub filters with novel membership functions is proposed to cancel out the impulse noise. The first sub filter detects the noisy pixel by utilizing three fuzzy membership functions, defined for this purpose. The corrupted pixels are then corrected using the median of the noise free pixels. The second sub filter makes use of the relation between different color components of a pixel to remove the residual noise in the color image. Simulation results shows that the proposed fuzzy filter effectively removes the additive noise by preserving fine details in the image.

Keywords: Impulse noise, fuzzy filter, reducing noise, median filter, membership functions

1. Introduction

Digital image processing is based on a wide range of hardware, software and the theoretical principles. The first stage of image processing is imaging. After the digital images are obtained, the next step is preprocessing. The main task of preprocessing is improving image processing as well as other methods that increase the possibility of success. Noise removing or reduction in images is a section of preprocessing. The next step deals with the segmentation. In a broad definition, segmentation is a process in which the input image parts into its component. In general, segmentation is one of the most difficult tasks in digital image processing. The final step involves the detection and interpretation. Recognition process that is based on the data descriptors is assigned a label to an object.

Image restoration is a major research area in image processing. Images can become corrupted during any of the phase take acquisition, pre-processing, compression, transmission, storage and/or reproduction phases of the processing [1]. Noise reduction or removing is a preprocessing step in image enhancement. Analysis and improvement of image consists of the following operations: Get the value of video and apply statistical operations on them, image analysis to extract information about the general structure and the enhancement of image for a clearly image detail and removing noise in order to prepare for subsequent processing.

The image enhancement operations that are commonly known as preprocessing operations are performed before the main processing operation or operations image analysis. In this operation the improvements is made on the image data to extract precise and accurate information. This operation will be described in three parts: Set the intensity, Balancing histogram or contrast enhancement and noise removing.

The types of the noise are: additive and multiplicative. The major category in additive noise is Impulsive noise and Gaussian noise. Speckle noise is the multiplicative noise [2, 14–16].

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Digital images are usually more or less noisy. Noise removing should be considered prior to any processing. Several filters are designed to remove noise: Mean filter, Median filter and Fuzzy filter. For further reading, see the reference [17–21].

Generally the noise reduction process has two phases. The first phase is called noise detection, which is used to identify whether the pixels are corrupted by noise or not. The second phase is noise reduction. Before applying the filter, the identified pixel is discriminated by either the pixel is noise or image fine details like edge, texture, color, etc. Then the noise affected pixel is replaced by the filter value. Almost all noise reduction algorithms are executed in two steps; I) detect the corrupted pixels and II) correct the pixels by replacing the filter estimated values [2].

The application of fuzzy techniques in image processing is a promising research field. 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) [3].

Image filters exist in three domains: spatial, frequency and fuzzy domain. This study deals with fuzzy filters which offer several advantages over classical filters even as they preserve the image structure. Moreover, fuzzy filters are easy to realize by means of simple fuzzy rules that characterize a particular noise.

In this paper a new fuzzy filter was proposed for the removal Impulse noise in color images. Already several fuzzy filters for noise reduction have been developed, e.g., the well-known FIRE-filter from [7–9], the weighted fuzzy mean filter from [10] and [11], and the iterative fuzzy control based filter from [12]. Also, [13] represent a robust fuzzy median filter for impulse noise reduction of gray scale images.

Most fuzzy techniques in image noise reduction mainly deal with fattailed noise like impulse noise. These fuzzy filters are able to outperform rank-order filter schemes (such as the median filter). Nevertheless, most fuzzy techniques are not specifically designed for Gaussian noise or do not produce convincing results when applied to handle this type of noise [3, 4, 6]. The proposed new fuzzy filter produce better results unlike other similar filters and maintains image clarity. Also, this filter increases system reliability in noise removing or reduction in color images. This filter recognizes the noisy pixel, modifies the corrupted pixel value and removes impulse noise.

For dealing with the Impulse noise, an algorithm is developed to search for a set of uncorrupted pixels in the neighborhood of the pixel of interest and to compute the median of this set. A new fuzzy filter consisting of two sub filters with several novel membership functions is proposed to cancel out the impulse noise. The first sub filter detects the noisy pixel along with the amount of noise in it by utilizing three fuzzy membership functions, defined for this purpose. The corrupted pixels are then corrected using the median of the noise free pixels. The second sub filter makes use of the relation between different color components of a pixel to remove the residual noise in the color image. The result of this method can be compared with those obtained by other filters.

Organization of the paper is as follows: Section 2 presents the problem statement. Section 3 illustrates the design of the proposed fuzzy filter by introducing the relevant concepts. The main results are detailed in Section 4. Finally, conclusions are drawn in Section 5.

2. Problem statement

2.1. Impulse noise for color images

A color image can be represented via several color models such as RGB, CMY, HSV and CIE. The most well known of these is the RGB model which is based on Cartesian coordinate system. Images presented in the RGB color model consists of three component images, one for each primary color (Red, Green and Blue) [4]. Consider a color image represented in the i−j plane, then the third coordinate $k = 1, 2, 3$ will represent the color component of the image pixel at (i, j). Let A be the image function then $A\ (i, j, 1)$ will represent the Red component of pixel at (i, j). Similarly, $A\ (i, j, 2)$ and $A\ (i, j, 3)$ represent the Green and Blue components respectively.

Images corrupted with impulse noise contain pixels affected by some probability. This implies that some of the pixels may not have a trace of any noise at all. Moreover, a pixel can have either all or one or two of its components corrupted with impulse noise. Mathematical modeling of impulse noise in color images is as follows:

$$A(i, j, k) = \begin{cases} O(i, j, k) & with \quad p_k \\ \eta(i, j, k) & with \quad (1 - p_k) \end{cases} \tag{1}$$

where, $k = 1, 2, 3$ represents red, green and blue components. The probabilities' P_k can have equal or unequal values. In Equation (1), A represents the final corrupted image, while O and η are the numbers of corrupted and uncorrupted pixels respectively [4, 5].

2.2. Algorithm for Median of noise

This paper uses an algorithm to determine the median of noise free pixels in the neighborhood of a pixel under interest that is presented in [4]. The median of the noise free pixels is utilized to modify the pixel corrupted with impulse noise. This median is computed separately for each color component in the following steps:

- Take a window of size w×w centered on the pixel of interest in the corrupted image.
- Arrange all the pixels of the window as a vector. Sort the vector in an increasing order and compute the median of the sorted vector.
- Calculate the difference between each window pixel and the median of the vector.
- Arrange all the window pixels having the differences less than or equal to a parameter δ_1 in a vector.
- Sort the new vector and obtain the median med of the sorted vector.

The above Algorithm uses a mask 3×3 for image scanning and median (med) is used to find the correction term for each pixel in the noisy image.

3. Proposed fuzzy filter

3.1. Structure of impulse filter

The proposed filter is designed for the reduction of impulse noise in color images. The designing of Filter is done by treating each color component separately. Interactions among these color components are used to determine the similarity of the central pixel against the neighboring pixels. The nature of impulse noise is random in the sense that it corrupts some pixels while leaving others untouched. So our objective is to identify the noisy pixels along with the amount of noise present. It may be noted that the impulse noise bears similarity with the high frequency content of images like edges and fine details because both reflect sudden changes in pixel values. The novel of three different membership functions, viz., Great, Dissimilar and Extreme are used to differentiate the noisy pixels from the high frequency contents. The proposed impulse filter consists of two sub filters as follows.

The primary task of this sub filter is to recognize the noisy pixel along with the amount of noise present, and modify the corrupted pixel value with the median (med) of the noise-free pixels present in the neighborhood. The three above mentioned novel membership functions are framed subsequently to identify the noisy pixels. The difference between the central pixel and the median of the noise-free pixels in the neighborhood of a window is denoted as [4, 5]:

$$D_m(i,\ j,\ k) = |A(i,\ j,\ 1) - med(i,\ j,\ 1)| \qquad (2)$$

The difference equations for the other two color components are obtained by replacing 1 in Equation (2) by 2 and 3 respectively.

We now suggest a new membership function, to represent a fuzzy set "Great" that indicates how large the difference is. A pixel with higher noise will have a larger difference with the median value. This is defined by the membership function as:

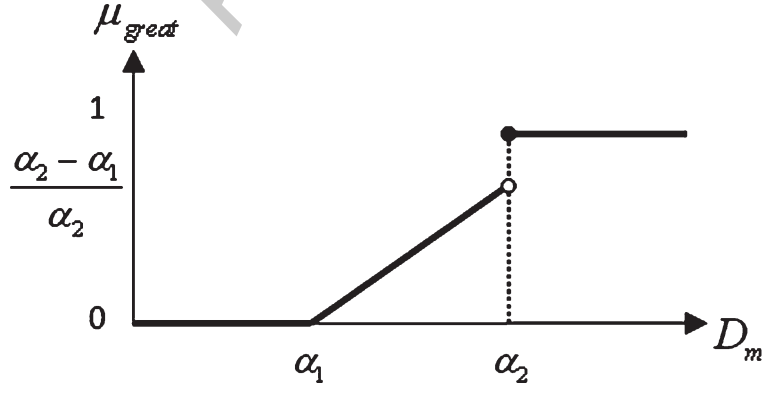


Fig. 1. Membership Function for fuzzy set "Great".

$$\mu_{great}(D_m(i,\ j,\ 1)) = \begin{cases} 1 \ D_m(i,\ j,\ 1) \geq \alpha_2 \\ \frac{D_m(i,j,1)-\alpha_1}{\alpha_2}\ \alpha_1 \leq \ \ D_m(i,\ j,\ 1) < \alpha_2 \\ 0 \ D_m(i,\ j,\ 1) < \alpha_1 \end{cases} \quad (3)$$

The parameters α_1 and α_2 in Equation (3) are obtained from experimentation. The membership function that represented by Equation (3) is depicted in Fig. 1.

3.1.1. Similarity criterion

The degree of similarity of a pixel with respect to its neighborhood pixels means whether it is noisy or not. To decide whether a pixel is similar to a neighborhood pixel, a similarity criterion is devised. For example, for the red component, the differences between red and green component and that between red and blue components are computed as follows [4, 5]:

$$\begin{aligned} d_{rg}(i,\ j) &= |A(i,\ j,\ 1) - A(i,\ j,\ 2)| \\ d_{rb}(i,\ j) &= |A(i,\ j,\ 1) - A(i,\ j,\ 3)| \end{aligned} \quad (4)$$

Similarly the differences between red and green components and that between red and blue components of the neighboring pixels at $(i+\sigma,\ j+\rho)$ are calculated as [4, 5]:

$$\begin{aligned} d_{rg}(i+\sigma,\ j+\rho) &= |A(i+\sigma,\ j+\rho,\ 1) - A(i+\sigma,\ j+\rho,\ 2)| \\ d_{rb}(i+\sigma,\ j+\rho) &= |A(i+\sigma,\ j+\rho,\ 1) - A(i+\sigma,\ j+\rho,\ 3)| \end{aligned} \quad (5)$$

The second differences of the above pair-wise differences in (5) are computed from the following equation:

$$\begin{aligned} \Delta_{rg}(i+\sigma,\ j+\rho) &= \left|d_{rg}(i+\sigma,\ j+\rho) - d_{rg}(i,\ j)\right| \\ \Delta_{rb}(i+\sigma,\ j+\rho) &= |d_{rb}(i+\sigma,\ j+\rho) - d_{rb}(i,\ j)| \end{aligned} \quad (6)$$

We also need the differences between the neighboring pixels and the central pixel of the same color component in the window given by:

$$\Delta_r(i+\sigma, j+\rho) = |A(i+\sigma, j+\rho, 1) - A(i, j, 1)| \quad (7)$$

A second membership function is devised to measure the degree of similarity of the central pixel to the neighboring pixels. This membership function describes the fuzzy set called Dissimilar over the discrete universe of discourse $N = \{0,\ 1,\ 2,\ 3,\ 4,\ 5,\ 6,\ 7,\ 8\}$. Let, N be the number of similar pixels (excluding the central pixel) in the window of size w×w. The number N is decided based on the differences calculated in Equations (6) and (7) and the similarity criterion. Considering a 3×3 window, the membership function is now defined as:

$$\mu_{dissimilar}(O,\ D_m) = \begin{cases} 0.2\ O \geq 4\ \ and\ \ D_m < \delta_2 \\ 0.4\ O = 3\ \ and\ \ D_m < \delta_2 \\ \quad 1 \quad otherwise \end{cases} \quad (8)$$

Note that D_m in Equation (8) is defined in Equation (2) and the parameter δ_2 is the same as used in the similarity criterion. Therefore if a pixel has more than half pixels similar in the window and its value is close to the median, then it can be considered as a noise-free pixel. The membership function for Dissimilar is shown in Fig. 2.

The third membership function is characterized as follows. If we arrange pixels of the window in a vector V and sort them in an increasing order, we will obtain two extreme pixel values in the window, $V_{\min}$ and $V_{\max}$. The closer the value of a pixel is to these extremes,

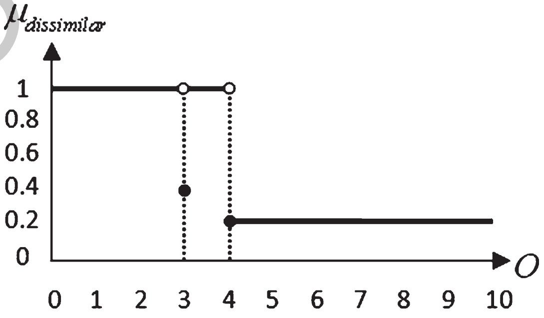


Fig. 2. Membership function for fuzzy set "Dissimilar".

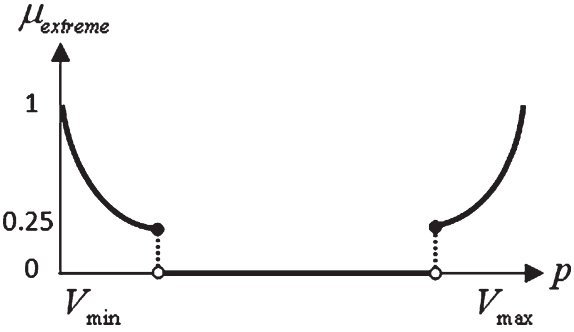


Fig. 3. Membership function for fuzzy set "Extreme".

the higher is the possibility of the pixel being noisy. This concept is used in obtaining Fuzzy set "Extreme". The membership function for the fuzzy set "Extreme" applicable to each color component is given as:

$$\mu_{extreme}(p) = \begin{cases} \frac{0.01}{(p-V_{\min}+0.1)^2} & p \geq V_{\min} \ \& \ p \leq V_{\min}+0.1 \\ \frac{0.01}{(p-V_{\max}-0.1)^2} & p \geq V_{\max}-0.1 \ \& \ p \leq V_{\max} \\ 0 & otherwise \end{cases} \quad (9)$$

where, p represents the pixel value of each color component.

The membership function for the fuzzy set Extreme is shown below.

The degree of noise present in a pixel is ascertained from the following fuzzy rule [4]:

Lemma 3.1.1. *IF $D_m(i,\ j,\ 1)$ is Great and $A(i,\ j,\ 1)$ is Dissimilar neighborhood and the central pixel is Extreme THEN this pixel is noisy.*

In this rule, noise designated by $N_d\ (i,\ j,\ 1)$ is a fuzzy variable. This rule is the Mamdani fuzzy model. Note that we are not using any membership function for the fuzzy set formed by the variables.

3.1.2. Correction term for impulse noise

Let the membership functions Great, Dissimilar and Extreme be denoted by μ_{gr}, μ_{dr} and μ_{er} respectively for the red component. Then the degree of noise in the red component of a pixel is evaluated as [4, 5]:

$$N_d(i,\ j,\ 1) = \min(\mu_{gr}(D_m(i,\ j,\ 1)), \mu_{dr}(O,\ D_m(i,\ j,\ 1)),\ \mu_{er}(A(i,\ j,\ 1))\} \quad (10)$$

Equation (10) is obtained using the fuzzy rule in Lemma 3.1. Antecedents in the fuzzy rule are combined using the fuzzy operator AND which is implemented as "minimum" operation. The correction term for the red component is computed as:

$$\Delta A(i,\ j,\ 1) = N_d(i,\ j,\ 1) \times (med(i,\ j,\ 1) - A(i,\ j,\ 1)) \quad (11)$$

As $N_d\ (i,\ j,\ 1)$ in Equation (10) gives the degree of noise present in the Red component of the pixel at the location $(i,\ j)$; it will be zero for noise free pixel and will have some value between 0 and 1 for the noisy pixel. The correction term will become zero if the pixel is noise free and its value is equal to the difference between the median (med) of noise free pixels in the neighborhood and the value of the pixel itself in the case of extremely corrupted pixels. Now the modified pixels arising out of the first sub filter (i.e. the output) are obtained as:

$$A_{F1}(i,\ j,\ k) = A(i,\ j,\ k) + \Delta A(i,\ j,\ k) \quad (12)$$

The extremely corrupted color components are replaced with the median (med) of the noise free color components of the neighborhood while the noise free components are left untouched. Pixels having noise in between are treated according to the amount of noise present in it. It can be observed that the above modified pixels are immediately put to use to correct the subsequent pixels.

The output from the first sub filter serves as the input to the second sub filter. This filter invokes the interactions among the color components to remove the impulse noise.

Differences between the color pairs are given as [4]:

$$\begin{aligned} d_{rg}(i,\ j) &= |A_{F1}(i,\ j,\ 1) - A_{F1}(i,\ j,\ 2)| \\ d_{rb}(i,\ j) &= |A_{F1}(i,\ j,\ 1) - A_{F1}(i,\ j,\ 3)| \quad (13) \\ d_{gb}(i,\ j) &= |A_{F1}(i,\ j,\ 2) - A_{F1}(i,\ j,\ 3)| \end{aligned}$$

A fuzzy rule is framed to express the degree of noise present in the color component of a pixel as part of this sub filter. For example for the Red component have [4]:

Lemma 3.1.2. *IF $d_{rg}(i,\ j)$ is Great and $d_{rb}(i,\ j)$ is Great THEN the red component of the pixel is noisy.*

This rule does not hold always. Suppose there is a red color region then the above differences will be large even without any noise but in that case the median of the region is again red. Hence this situation doesn't affect the performance of our filter. Similar fuzzy rules are coined for other color components. We fuzzify adaptive differences (13) to evolve the membership function (3) with two parameters α_1 and α_2. Note that β_1 and β_2 will replace the original α_1 and α_2 in the function Great so as to have different shapes. Correction terms for this filter are computed in similar lines as in the first sub filter. The degree of noise present in a pixel is [4]:

$$n_d(i,\ j,\ 1) = \min\{\mu_{grg}(i,\ j),\ \mu_{grb}(i,\ j)\} \quad (14)$$

where, μ_{grg} and μ_{grb} are the membership functions of Great sets of color pairs, red-green and red-blue respectively.

The correction term is given by:

$$\Delta A_{F1}(i,\ j,\ 1) = n_d(i,\ j,\ 1) \times (med(i,\ j,\ 1) - A_{F1}(i,\ j,\ 1)) \quad (15)$$

Median (med) values are calculated again as in the first sub filter whose output is A_{F1}. The final output of the impulse filter is a set of modified pixels given by:

$$A_{F2}(i,\ j,\ k) = A_{F1}(i,\ j,\ k) + \Delta A_{F1}(i,\ j,\ k) \quad (16)$$

The modified pixels from the second sub filter are immediately employed to correct the subsequent pixels [4, 5].

3.2. Algorithm for impulse filter

The steps of the algorithm for Impulse filter by consider one color component are as follows [4, 5]:

Step 1: Compute the median of noise free pixels (med) as per algorithm in 2.1.

Step 2: Compute $D_m(i,\ j,\ 1) = |A(i,\ j,\ 1) - med\ (i,\ j,\ 1)|$ and Determine μ_{great} in the fuzzy set Great using (3).

Step 3: Calculate no. of pixels similar to central pixels ‘O’ using “Similarity Criteria”.

Step 4: Determine the degree of similarity of $A(i,\ j, 1)$ in the fuzzy set Dissimilar using (8).

Step 5: Determine the membership value of pixel in the fuzzy set Extreme using (9).

Step 6: Calculate the correction term using (11) and add it to original value to obtain denoised value. Repeat the steps for other color components. Apply the process for the whole image pixel by pixel.

Step 7: For the image obtain in above, Compute the differences: d_{rg}, d_{rb} and d_{gb} as per (13) and fuzzify them using membership function Great with parameter β_1 and β_2.

Step 8: Use (14) to calculate correction term for red component and for other similar equations are used.

Step 9: Final output of impulse filter is obtained using (16).

4. Main results

A color image consisting of an M × N × 3 array of pixels at locations $(i,\ j)$ was seen as three gray scale images corresponding to RGB components. The data class of the component images determines their range of values. If an image is of class double, the range of values is [0, 1]. Similarly, the range of values is [0,255] or [0, 65535] for RGB images of class uint8 or uint16, respectively [4]. The color images as follows with the impulse noise are considered as test images. The original images are shown in Fig. 4.

The impulse noise is added to above original images. Percentage of the added impulse noise to images or noise density is %20. The noisy images are shown in Fig. 5.

4.1. Results of the impulse noise fuzzy filter

In this paper, the window size of 3 × 3 is experimented. The primary process of simulation is done by median filter. A comparison between median filter and proposed fuzzy filter for different noisy densities (up to 20% and 30%) are drawn in Figs. 6 and 7. The best results for higher percentages of the impulse noise, as

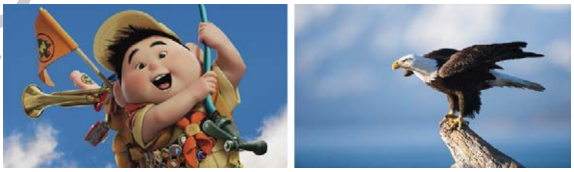
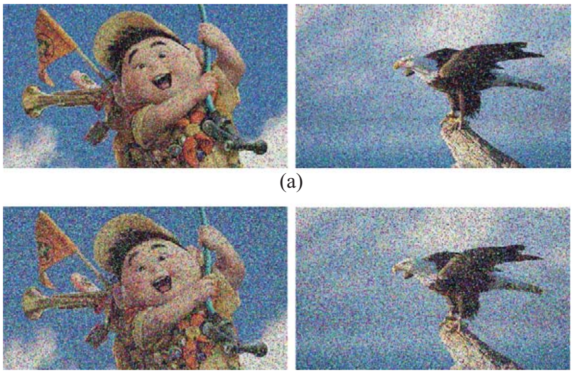


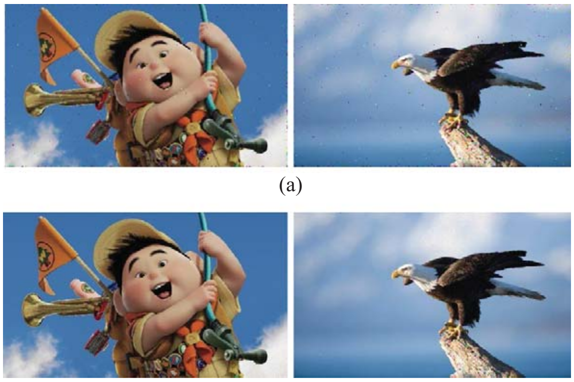
Fig. 4. Original images for simulation.



(a)

(b)

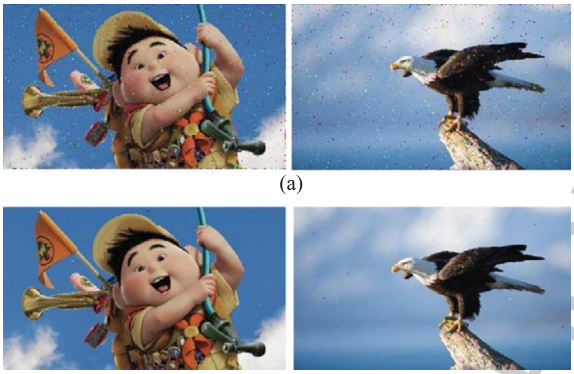
Fig. 5. Impulse noise in images: (a). Noisy density is 20%, (b). Noisy density is 30%.



(a)

(b)

Fig. 6. The comparison of between median filter and designed fuzzy filter (noisy density is 20%): (a). The results of Median Filter, (b). The results of fuzzy filter.



(a)

(b)

Fig. 7. The comparison of between median filter and designed fuzzy filter (noisy density is 30%): (a). The results of Median Filter, (b). The results of fuzzy filter.

the window size of 3 × 3 produces better results up to 30% impulse noise, this filter is meant to deal with low and middle percentages of the impulse noise. This level of noise is usually found in many practical applications.

The performance of this filter is illustrated through a set of color images with the impulse noise of densities up to 30%. The optimal values for the parameters of α_1, α_2, β_1, β_2, δ_1, δ_2 discussed in Section 3 are experimentally determined to be 0.078, 0.15, 0.5, 0.6, 0.0001 and 0.0001 respectively. The under tables demonstrate the result of experiments.

They are obtained using a window size of 3 × 3 for the lower and the middle percentage of the impulse noise. It can also be observed visually that the proposed filters are quite effective in noise reduction.

Table 1
The Comparison of between Methods: (a) ND = 20, (b) ND = 30

Methods	Noisy Density (ND)	Percentage of improvement
(a)		
Median Filter	%20	%60
Fuzzy Filter (Proposed)	%20	%90
(b)		
Median Filter	%30	%40
Fuzzy Filter (Proposed)	%30	%70

5. Conclusion

This paper proposed a new fuzzy filter for additive noise reduction consisting of only impulse noise. Most fuzzy techniques in image noise reduction mainly deal with fattailed noise like impulse noise. These fuzzy filters are able to outperform rank-order filter schemes such as the median filter. Nevertheless, most fuzzy techniques are not specifically designed for Gaussian noise or do not produce convincing results when applied to handle this type of noise. The proposed new fuzzy filter produce better results unlike other similar filters and maintains image clarity. Also, this filter increases system reliability in noise removing or reduction in color images. This filter recognizes the noisy pixel, modifies the corrupted pixel value and removes impulse noise.

Its main feature is that this filter with the new proposed of membership functions in equations (3), (8) and (9), removes the impulse noise of densities up to 30% (Table 1) and tries to determine corrupted pixels to reduce their contribution in smoothing process. The shape of the applied membership functions is modified and adapted according to the remaining amount of noise after each iteration, such that the performance of designed fuzzy filter is excellent toward median filter. Simulation results shows that the proposed fuzzy filter effectively removes the additive noise by preserving details in the color images. Experimental results show the feasibility of the new filter.

The future work for noise removing can be done by designing of the various filters using the fuzzy neural network, robust system and etc. The meaningful comparison between different filters can also be done.

References

[1] D. Van D. Ville, M. Nachtegael, D. Van der Weken, E. Kerre, W. Philips and I. Lemahieu, Noise reduction by fuzzy image filtering, *IEEE Transaction on Fuzzy System* **11**(4) (2003).

[2] P. Murugeswari and D. Manimegalai, Noise Reduction in Color image using Interval Type-2 Fuzzy Filter (IT2FF), *International Journal of Engineering Science and Technology (IJEST)* **3**(2) (2011).

[3] T.R. Mahesh, S. Prabhanjan and M. Vinayababu, Noise reduction by using fuzzy image filtering, *Journal of Theoretical and Applied Information Technology*, Islamabad Pakistan, **15**(2) (2010).

[4] O.P. Verma, M. Hanmandlu, A.S. Parihar and V.K. Madasu, Fuzzy filters for noise reduction in color images, *ICGST-GVIP Journal* **9**(5) (2009).

[5] S. Schulte, M. Nachtegael, V. Witte, D.V. Weken and E. Kerre, A Fuzzy Impulse Noise Detection and Reduction Method, Fuzziness and Uncertainty Modeling Research Unit.

[6] D.V. Ville and W. Philips, Noise reduction by fuzzy image filtering, *IEEE Transaction on Fuzzy System* **11**(4) (2003).

[7] F. Russo and G. Ramponi, A fuzzy operator for the enhancement of blurred and noisy images, *IEEE Trans Image Processing* **4** (1995), 1169–1174.

[8] F. Russo, A fuzzy filter for images corrupted by impulse noise, *IEEE Signal Processing Letters* **3** (1996), 168–170.

[9] F. Russo, Fire operators for image processing, *Fuzzy Sets Syst* **103**(2) (1999), 265–275.

[10] C.-S. Lee, Y.-H. Kuo and P.-T. Yu, Weighted fuzzy mean filters for image processing, *Fuzzy Sets Syst* **89** (1997), 157–180.

[11] C.S. Lee and Y.H. Kuo, Fuzzy Techniques in Image Processing, Studies in Fuzziness and Soft Computing, ch. Adaptive fuzzy filter and its application to image enhancement, New York: Springer-Verlag, 2000, vol. 52, pp. 172–193.

[12] F. Farbiz and M.B. Menhaj, Fuzzy Techniques in Image Processing, Studies in Fuzziness and Soft Computing, ch. A fuzzy logic control based approach for image filtering, New York: Springer-Verlag, 2000, vol. 52, pp. 194–221.

[13] J.H. Pujar, Robust Fuzzy median filter for impulse noise reduction of gray scale images, *World Academy of Science, Engineering and Technology* **64** (2010).

[14] A. Hussain, M. Arfan and A.M. Mirza, Detail preserving fuzzy filter for impulse noise removal, *International Journal of Innovative Computing, Information and Control* **5**(10(B)) (2009).

[15] A. Hussain, M. Arfan and A.M. Mirza, Random-valued impulse noise removal using fuzzy logic, *International Journal of Innovative Computing, Information and Control* **6**(10) (2010).

[16] A. Hussain, M. Arfan and A.M. Mirza, Directional weighted median based fuzzy filter for random valued impulse noise removal, *ICIC Express Letters Part B: Applications* **1**(1) (2010).

[17] M.S. Muhammad, H. Mutahira and T. Choi, Using a low pass filter to recover three-dimensional shape from focus in the presence of noise, *International Journal of Innovative Computing, Information and Control* **8**(3) (2012).

[18] T. Lin, A novel decision- based median- type filter using SVM for image denoising, *International Journal of Innovative Computing, Information and Control* **8**(5) (2012).

[19] S. Xiaojie, S. Peng, W. Ligang and S. Yong-Duan, A novel approach to filter design for T-S fuzzy discrete-time systems with time-varying delay, *IEEE Transactions on Fuzzy Systems* **20**(6) (2012), 1114–1129.

[20] S. Xiaojie, W. Ligang and S. Peng, Senor networks with random link failures: Distributed filtering for T-S fuzzy systems, *IEEE Transactions on Industrial Informatics* (2012).

[21] S. Xiaojie, S. Peng, W. Ligang and N.S. Kiong, Induced $\ell 2$ filtering of fuzzy stochastic systems with time-varying delays, *IEEE Transactions on Systems, Man and Cybernetics? Part B: Cybernetics* (2012).