

Colour Image Noise Reduction Using Fuzzy Filtering

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Abstract

Image filtering is one of the most important image processing tasks. Recently, fuzzy techniques offer a suitable framework for the development of efficient methods. In this paper, a recursive fuzzy filtering technique is presented to reduce additive Gaussian noise from colour images using YIQ space. An adaptation scheme is developed to adapt the shape of membership functions of this filter according to remaining amount of noise after each iteration. After adaptation scheme, the fuzzy filter is based on two stages fuzzy reasoning. The first stage computes a fuzzy derivative for eight different directions. The second stage uses these fuzzy derivatives to perform fuzzy smoothing by weighting the contributions of neighboring pixel values.

The simulation results show the effectiveness of this filter in reducing the additive noise while preserving image edges very well. It also favorably compared with traditional mean filter.

الخلاصة

عملية تصفية الصور هي واحدة من العمليات المهمة في الصور. مؤخراً برزت العديد من التقنيات في هذا المجال والتي تعتمد في عملها على نظرية المنطق الغامض. يهدف العمل الحالي إلى تطوير مرشح بالاعتماد على هذه النظرية لتقليل الضوضاء الجمعية من الصور الملونة باستخدام فضاء YIQ. وهذه المرشح تم تطبيقه بصورة تكرارية، ومن أجل تحسين أداء هذا المرشح تم الاعتماد على طريقة لتكليف دوال المرشح تعتمد على كمية الضوضاء المتبقية بعد كل تكرار. يتكون هذا المرشح من مرحلتين أساسيتين: الأولى تتضمن حساب المشتقة الغامضة لثمانية اتجاهات مختلفة، أما الثانية فتستخدم هذه المشتقات لحساب نسبة مشاركة جميع عناصر الصورة الموجودة ضمن نفس النافذة في حساب القيمة النهائية للمرشح.

النتائج التي تم الحصول عليها تطهر كفاءة هذا المرشح في تقليل الضوضاء الجمعية مع المحافظة على الحافات مقارنة مع مرشح المعدل التقليدي.

1. Introduction

In recent years, several fuzzy techniques for noise reduction have been developed. These techniques are often complementary to existing techniques and can contribute to the development of better and robust methods^[1]. For instance in reference^[2] Russo and Ramponi proposed a dual-step fuzzy-rule-based filter to detect and remove large amount of impulse noise while preserving the image details. In^[3] application of fuzzy clustering for removal of mixed Gaussian and impulse noise was described. Vertan et. al.^[4] introduced a fuzzy approach to colour image filtering by the fuzzy modeling of the concept of colour credibility using CIELAB colour space. Al-Sultany^[5] developed a fuzzy technique which uses fuzzy logic (min/max) principles to remove salt and pepper noise from images. The hybrid filter design methodology containing a nonlinear filter and fuzzy weighted linear filter for efficiently remove large amounts of mixed Gaussian impulse noise while preserving the image details was presented in^[6].

In this work, a fuzzy filtering technique is developed for the enhancement of colour image corrupted by additive noise. The fuzzy filter takes care of image edges simultaneous with filtering by estimating a “fuzzy derivative”. The fuzzy rules are formulated according to local image characteristics and are applied on two stages of this filter. These rules make use of membership functions, small, positive, and negative. While the membership functions for positive and negative are fixed. The membership function for small is adapted after each iteration. This filter is called Iterative Fuzzy Averaging Filter, IFAF. The colour image here is processed by first converting it from RGB to YIQ domain. Then, the filter is applied by modifying only the luminance component of YIQ system.

2. Processing Colour Images

A colour image is usually represented in the RGB colour space, because most of the computer input and output devices use this colour system.

The early approaches to colour image processing is performed by processing each RGB components separately. A disadvantage of these methods is the loss of correlation between the colour channels resulting in colour shifts^[7].

Other colour systems like YIQ and HLS represent the colour image according to the human visual perceptual attributes (luminance, hue, and saturation) are often useful, since many colour image processing tasks, such as enhancement and filtering, require that only the luminance component be processed. However, the hue is usually preserved in order to not disturb the natural colouring of the image^[7,8].

In this work, the YIQ system is used to process colour image. The principle advantage of this space in image processing is that the luminance component (Y) and colour information (I and Q) are decoupled. It will be a need to convert RGB to YIQ system for the purpose. The conversion from RGB to YIQ is given as follow^[9]:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \dots\dots\dots (1)$$

3. Filter Structure

The filtering process is divided into four steps as shown in **Fig.(1)**. The filter consists of edge detector, filtering, averaging, and adaptation scheme. The first step (edge detector) drives a fuzzy derivative value which is based on the following observation that a small fuzzy derivative is most likely caused by noise, while a large fuzzy derivative is most likely caused by an edge in the image. The second step (filtering) uses these fuzzy derivatives as input and applies two fuzzy rules in each direction around the processed pixel. These rules will determine the contribution of the neighboring pixel values. In the final step (averaging and rescaling), the results of these rules (16 in total) is defuzzified to obtain the correction term (Δ_s) which would be added to the pixel luminance value of location (x, y) in order to cancel the noise. Further description of the filter will be discussed in the next sections.

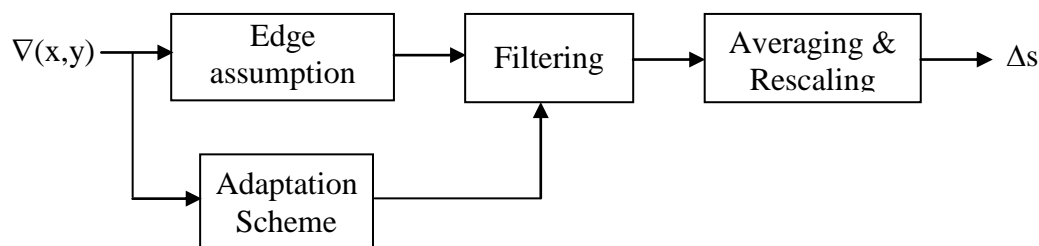


Figure (1) The structure of the IFAF filter

3-1 Fuzzy Derivative Estimation (Edge Assumption)

The first stage of this filter starts by looking for the edges and trying to provide a robust estimate by applying the fuzzy rules as follows:

Consider the 3×3 neighborhood of a pixel (x,y) within the luminance component as displayed in **Fig.(2.a)**.

A simple derivative at the central pixel position (x,y) in the direction D ($D \in \text{dir} = \{\text{NW}, \text{W}, \text{SW}, \text{S}, \text{SE}, \text{E}, \text{NE}, \text{N}\}$) is defined as the luminance difference between the pixel at (x,y) and its neighbor in the direction D. The derivative value is denoted by $\nabla_D(x,y)$. For example,

$$\begin{aligned} \nabla_N(x,y) &= I(x,y-1) - I(x,y) \\ \nabla_{NE}(x,y) &= I(x+1,y-1) - I(x,y) \dots\dots\dots (2) \\ \nabla_E(x,y) &= I(x+1,y) - I(x,y) \end{aligned}$$

Next, the principle of the fuzzy derivative is based on the following observation. Consider an edge passing through the neighbourhood of a pixel (x,y) in the $SE-NW$ direction. The derivative value $\nabla_{NE}(x,y)$ will be large, but also derivative values of neighboring pixels perpendicular to the edge's direction can be expected to be large. For example, in the NE -direction the following values are calculated $\nabla_{NE}(x,y)$, $\nabla_{NE}(x-1,y-1)$ and $\nabla_{NE}(x+1,y+1)$ [as shown in Fig.(2.b)].

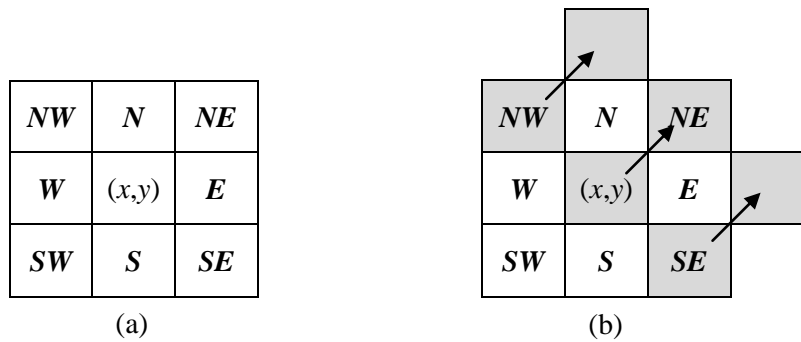


Figure (2) (a) Neighborhood of a pixel (x,y) , (b) Pixel values indicated in gray are used to compute the “fuzzy derivative” of the central pixel (x,y) for the NE -direction

Then, if two out of three derivative values are small, it is safe to assume that no edge is present in the considered direction. Based on this observation, the fuzzy rules will be formulated to calculate the fuzzy derivative values. These rules make use of fuzzy set small that indicates the degree to which the fuzzy derivative in a certain direction is small. The membership function $\mu_{sm}(t)$ for the fuzzy set small [as shown in Fig.(3)] is given by [10]:

$$\mu_{sm}(t) = \begin{cases} 1 - \frac{|t|}{q} & 0 \leq |t| \leq q \\ 0 & |t| > q \end{cases} \dots\dots\dots (3)$$

Where (q) is an adaptive parameter and the proper choice of its value depends on adaptation scheme that will be described in section (3.4).

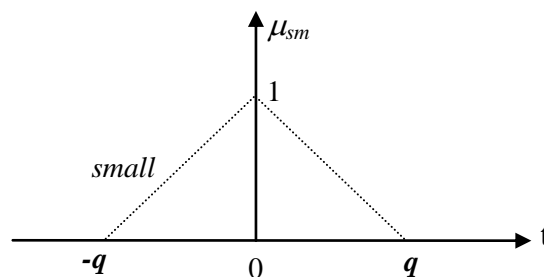


Figure (3) Membership function for the fuzzy set small

The fuzzy rule that used to compute the value of the fuzzy derivative $\nabla_{NE}^F(x,y)$ for the pixel (x,y) in the NE-direction is as follows [10]:

- If $(\nabla_{NE}(x,y)$ is small AND $\nabla_{NE}(x-1,y+1)$ is small) OR
- $(\nabla_{NE}(x,y)$ is small AND $\nabla_{NE}(x+1,y-1)$ is small) OR
- $(\nabla_{NE}(x-1,y+1)$ is small AND $\nabla_{NE}(x+1,y-1)$ is small)

Then:

$$\nabla_{NE}^F(\mathbf{x},\mathbf{y}) \text{ is small} \dots\dots\dots (4)$$

Eight such rules are applied, each computing the degree of membership of the fuzzy derivatives $\nabla_D^F(\mathbf{x},\mathbf{y})$, $D \in \text{dir}$, to the set small. These rules are implemented using the minimum to represent the AND-operator, and the maximum for the OR-operator. A defuzzification is not needed since the second stage directly uses the degree of membership of the fuzzy derivatives to the fuzzy set small.

3-2 Fuzzy Smoothing (Filtering)

To compute the correction term (Δs) for the processed pixel value within the luminance component, a pair of fuzzy rules for each direction will be used. The idea behind the rules is the following: if no edge is assumed to be present in a certain direction, the derivative value in that direction will be used to compute the correction term (Δs).

For example, let us consider the direction (NE). Using the values λ_{NE}^+ and $\nabla_{NE}(x,y)$, the following two rules are fired [10]:

$$\lambda_{NE}^+ : \text{If } \nabla_{NE}^F(\mathbf{x},\mathbf{y}) \text{ is small And } \nabla_{NE}(\mathbf{x},\mathbf{y}) \text{ is positive} \\ \text{Then } c \text{ is positive} \dots\dots\dots (5)$$

$$\lambda_{NE}^- : \text{If } \nabla_{NE}^F(\mathbf{x},\mathbf{y}) \text{ is small And } \nabla_{NE}(\mathbf{x},\mathbf{y}) \text{ is negative} \\ \text{Then } c \text{ is negative} \dots\dots\dots (6)$$

where, c is the output of the rules (λ_{NE}^+) and (λ_{NE}^-). While, the positive and negative are fuzzy sets and two linear functions are used to described these sets as shown in Fig.(4.a) and (b) respectively.

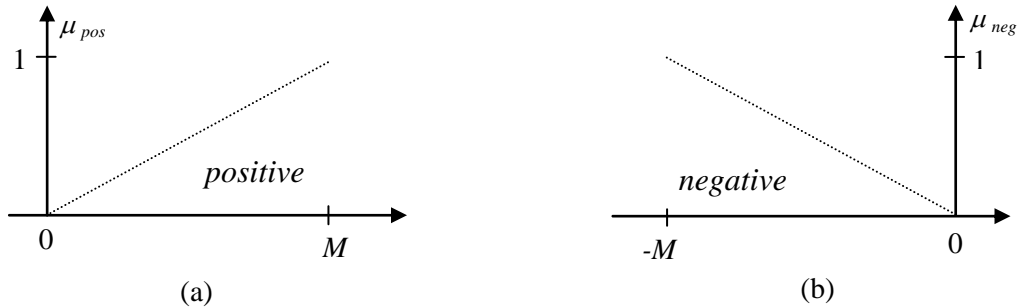


Figure (4) Membership functions (a) positive, and (b) negative

3-3 Averaging and Rescaling

The final step in the computation of this filter is the defuzzification which used to obtain a correction term (Δ_s), which can be added to the pixel value of location (x,y) within the luminance component values. Therefore, the outputs of the rules (λ_D^+) and (λ_D^-), $D \in \text{dir}$ (so for all directions) are aggregated by computing and rescaling the mean truthness as follows [10]:

$$\Delta_s = \frac{M}{8} \sum_{D \in \text{dir}} (\lambda_D^+ - \lambda_D^-) \dots\dots\dots (7)$$

where: $\text{dir} = \{\text{NW, W, SW, S, SE, E, NE, N}\}$ and M represents the maximum value of intensity levels. So, each direction contributes to the correction term (Δ_s).

3-4 The Adaptation Scheme

Instead of making use of larger windows to obtain better results for heavier noise, the filter is suggested to apply iteratively by adapting the shape of membership function small [see Fig.(3)] according to remaining amount of noise after each iteration. The adaptation scheme starts by dividing the image into small $r \times r$ nonoverlapping blocks. The value of (r) that will be used in the experiments was (8). For each block (B), compute the standard deviation using the following equation:

$$\sigma_i = \sqrt{\frac{1}{r \times r} \sum_{(x',y') \in B_i} (I(x',y') - m_i)^2} \dots\dots\dots (8)$$

where: m_i is the mean value of block (B_i), $I(x',y')$ is the pixel data inside the block (B_i)

Then, find σ_{\min} which represents the minimum (σ) in all blocks. Finally, the value of adaptive parameter (q) can be computed using the following equation [11]:

$$q = \alpha \sigma_{\min} \dots\dots\dots (9)$$

where, α represents the amplification factor. One could prefer lighter or heavier filtering by choosing α correspondingly. So (α) could be determined according to noise level. Care must also be taken to retain fine textures in images. This scheme can be applied before each iteration to obtain the adaptive parameter (q), which determines the shape of the membership function small.

Algorithm of Adaptation Scheme

1. Divide the image (luminance component) into $r \times r$ nonoverlapping blocks and compute the standard deviation (σ_i) in each block.
2. Find the minimum σ in all blocks (σ_{\min}).
3. Select the value of amplification factor (α) according to noise level, then compute the value of q using eq.(9).

5. Results and Discussion

This section presents the simulation results illustrating the performance of the fuzzy filter. The test image employed here is the true colour image “parrot” with 512×512 pixels. For the addition of noise, the source image was corrupted by additive Gaussian noise with standard deviation $\sigma_n = 10, 20, \text{ and } 30$. The noise model was computer simulated.

The fuzzy filter, IFAF, had been tuned by assigning different values for the amplification factor (α), namely $\alpha=4, 5, \text{ and } 6$. Also, it was recursively implemented four times which was sufficient to effectively smooth out noise without degraded the important image structures. The performance of the IFAF is compared with the traditional mean filter. All filters considered operate using 3×3 processing window. The performance of different filters was evaluated by computing the Normalized Mean Square Error (NMSE) between the original image and filtered image as follow:

$$\text{NMSE} = \frac{\sum_{x=1}^{N1} \sum_{y=1}^{N2} \|\mathbf{R}(x,y) - \mathbf{R}'(x,y)\|^2}{\sum_{x=1}^{N1} \sum_{y=1}^{N2} \|\mathbf{R}(x,y)\|^2} \dots\dots\dots (10)$$

where, $\mathbf{R}(x,y)$ is the vector pixel value in the original image, $\mathbf{R}'(x,y)$ is the vector pixel value in the filtered image, and $N1 \times N2$ is the size of image.

Table (1) shows the results of NMSE for both IFAF and mean filter for different noise levels. As it can be seen, the minimum (NMSE) was obtained by the fuzzy filtering approach for all cases. It can also be noticed that the amplification factor (α) affects the amount of smoothing obtained by IFAF. Where for low noise levels; somewhat a low amplification factor ($\alpha=5$) give the best results (NMSE=0.001145). While, for higher noise levels ($\sigma_n=20, 30$) higher value of α ($\alpha=6$) is sufficient to effectively smooth out the noise. Thus, the value of amplification factor could be determined according to noise levels.

Table (1) NMSE for the filtering of parrot image corrupted by Gaussian noise with different levels ($\sigma_n = 10, 20, \text{ and } 30$) using YIQ space

Filters	NMSE		
	$\sigma_n = 10$	$\sigma_n = 20$	$\sigma_n = 30$
Noisy Image	0.006093	0.011642	0.013241
Mean Filter	0.001754	0.002655	0.002899
IFAF($\alpha=4$)	0.001287	0.002281	0.002312
IFAF($\alpha=5$)	0.001145	0.001841	0.001900
IFAF($\alpha=6$)	0.001169	0.001726	0.001887

In order to have subjective measure, one of the cases was reproduced. **Figure (5)** shows the results of smoothing parrot image corrupted by Gaussian noise with ($\sigma_n = 20$). As it can be noticed that the visual quality of the corrupted images is highly improved after applying the smoothing filters. While, the edges are best preserved by IFAF. This mean that the iterative application of IFAF does not blurring the edges.



(a)



(b)



(c)



(d)



Figure 5 (a) Original image, (b) image corrupted by Gaussian noise with ($\sigma_n = 20$), (c) result after mean filter, (d) result after IFAF ($\alpha=4$), (e) result after IFAF ($\alpha=5$), (f) result after IFAF ($\alpha=6$)

6. Conclusions and Future Works

A recursive fuzzy filtering technique can be used to smooth colour image by modifying the luminance component of YIQ system without colour shift.

The iterative application of IFAF was efficiently smooth out the noise, while in the same time; preserve the edges well. This came from the fact that the filtering process of IFAF depends on estimating the fuzzy derivative value which was used to distinguish between the local variations due to noise and due to image structures. Also, the amount of smoothing that was obtained by the fuzzy filter can be controlled by minimized or maximized by the amplification factor used in this filter.

Furthermore, the structure of this filter is simple, and can be easily to implement on hardware.

7. References

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