World Academy of Science, Engineering and Technology
International Journal of Computer and Information Engineering
Vol:2, No:7, 2008

Noise Reduction in Image Sequences using an Effective Fuzzy Algorithm

Mahmoud Saeidi, Khadijeh Saeidi, Mahmoud Khaleghi

Abstract**—**In this paper, we propose a novel spatiotemporal fuzzy based algorithm for noise filtering of image sequences. Our proposed algorithm uses adaptive weights based on a triangular membership functions. In this algorithm median filter is used to suppress noise. Experimental results show when the images are corrupted by high-density Salt and Pepper noise, our fuzzy based algorithm for noise filtering of image sequences, are much more effective in suppressing noise and preserving edges than the previously reported algorithms such as [1-7]. Indeed, assigned weights to noisy pixels are very adaptive so that they well make use of correlation of pixels. On the other hand, the motion estimation methods are erroneous and in high-density noise they may degrade the filter performance. Therefore, our proposed fuzzy algorithm doesn't need any estimation of motion trajectory. The proposed algorithm admissibly removes noise without having any knowledge of Salt and Pepper noise density.

Keywords**—**Image Sequences, Noise Reduction, fuzzy algorithm, triangular membership function

1. Introduction

ONE of the most important stages in image processing applications is the noise filtering. The importance of image sequence processing is constantly growing with the ever increasing use of digital television and video systems in consumer, commercial, medical, and communicational applications. Image filtering is not only used to improve image quality but also is used as a preprocessing stage in many applications including image encoding, pattern recognition, image compression and target tracking, to name a few. This preprocessing stage is essential in most of the image-processing algorithm and improper noise filtering may result in inappropriate or even false outcome. Different methods have been proposed for the purpose of noise filtering. However these methods can be categorized in two categories as follows:

A. Noise filtering using the information of only one frame [1-2].

B. Noise filtering using the information of consecutive frames including the current frame which we are filtering it, previous and next frames [3-7]

The use of consecutive frames for the purpose of noise filtering has the advantage of preserving image details such as edges and is a proper choice for noise removal of image sequences especially in the presence of high-density noise. Different averaging-based and median-based algorithms have been proposed for noise filtering of image sequences such as:

- Spatiotemporal Concatenated Median, CM Filter [3], which could remove noise when images are corrupted by Salt and Pepper noise.
- Spatiotemporal Center Weighted Median, CWM Filter [4], which is well known for removing Salt and Pepper noise among filters based on Median.
- Nonlinear Spatiotemporal Filter, NSF, which efficiently removes low-density Salt & Pepper noise [5].
- Adaptive weighted Averaging Filters [6-7]

Averaging-based algorithms [6-7] are efficient for removing Gaussian noise while median-based algorithms [3-5] remove Salt & Pepper noise efficiently. So in order to removing Salt & Pepper noise, we only focus on previous median-based filters.

Although CM and CWM filters attenuate low and medium-density Salt & Pepper noise but they couldn't reduce high-density Salt & Pepper noise permissible.

This paper is organized as follows. In the next section we review image sequences filtering. Concatenated Median, CM Filter, and Center Weighted Median, CWM Filter, is discussed in section 3. The proposed Adaptive Fuzzy Weighted Filter based on a Triangular Membership Function is discussed in section 4. Experimental results are shown in section 5 and conclusion appears in section 6.

II. Image Filtering Using Consecutive Frames

Since correlation of corresponding pixels among consecutive image frames is much more than that of a single frame, using consecutive frames can reduce image noise and preserve image structure and edge far better than using just one frame. There are two types of image sequences filtering:

A. **Temporal Filtering:** this type of filtering removes noise using only temporal information of image sequences

B. **Spatiotemporal Filtering:** in this type of filtering, noise is removed by using both spatial and temporal information of image sequences. This method utilizes more information than temporal filtering. Consequently noise attenuation, and structure and edge preservation in this type of filtering is accomplished more effectively than the temporal filtering. Our proposed filtering method is a spatiotemporal one.

Suppose we want to filter the frame *k* of a given image sequences with *N=2l+1* consecutive frames including frames *k-l,…. k-1, k, k+1, …, k+l.* Consider a noisy pixel with spatial coordinates of *(m,n)* in frame *k*. The intensity value of this pixel is specified by *g(m,n;k)*.

To calculate the output of spatiotemporal filter for this point, a window area (typically *3*3*N* or *5*5*N*) is considered around the pixel *(m,n;k)*. This area is called filter support $S_{m,n;k}$ and is used for calculation of the filter output for pixel *(m,n)* in frame *k*. The proposed algorithm then assigns weights to all of pixels within the $S_{m,n;k}$ and based on the weight values, the output of the filter is calculated.

Although from noise reduction point of view, consecutive frame filtering performs better than single frame filtering, in case of moving objects (pixels), the correlation of pixels among the frames will be loosened which will lead to performance degradation of filtering. In this case, it is necessary to compensate the motion among the consecutive frames to increase pixels correlation.

The filtering algorithm using motion compensation consists of three stages:

1. Motion trajectory estimation among the current frame, previous and next frames. The motion trajectory $T_{m,n;k}$ is defined by the set of pixel (sub-pixel) locations, in the *N* neighboring frames that correspond to pixel *(m,n)* of the k^{th} frame
2. Motion compensation using motion trajectory estimation in stage 1
3. Applying the algorithms of filtering on the motion compensated frames

There are a number of algorithms for motion compensation [8]. One of the simplest and most effective ways to estimate motion is to utilize block-matching algorithm. In this algorithm, for each block in frame *i*, the closest matching block in frame *j* is found. The matching blocks are used to form the estimation. A widely used criterion in determining the closest match between two blocks is the Mean Absolute Difference, MAD.

Basically, the success of motion-compensated filtering strongly depends on the accuracy of the motion trajectory estimation, especially under high-density Salt & Pepper noise and also in the presence of occlusion and varying scene content.

Since motion trajectory estimation usually doesn't have enough accuracy under high-density Salt & Pepper noise, it could have undesirable effects on the filtering algorithms. Therefore, we don't use motion compensation under high-density noise to reduce the calculation burden on filtering algorithms.

III. Concatenated Median and Center-Weighted Median Filters

In this section we go over CM and CWM filters which are well-known filters in removing Salt and Pepper noise.

3.1. Concatenated Median Filter

This method of filtering consists of three stages. In the first stage, this filter selects the pixels located in the middle row and middle column of window area in each frame. In the second stage, CM filter applies median filter on the selected pixels in each of frames. Finally in third stage, it applies median function again on the resulted value of second stage.

3.2. Center-Weighted Median, CWM Filter

CWM is one of the well-known order statistic filters in removing Salt and Pepper noise.

Let $\{X(.,.,.)\}$ and $\{Y(.,.,.)\}$ be the input and output of the filter respectively. A CWM filter with window size of *3*3*N=2L+1* or *5*5*N=2L+1* and central weight *2D+1* is denoted by CWM (2L+1,2D+1), and is defined according to the following equation:

$$Y(m,n;k) = median\{X(i,j,l), 2D\,copy\,of\, X(m,n;k) \mid (i,j;l) \in S_{m,n;k}\} \quad (1)$$

It could be proven that the above equation is equal to the following equation:

$$Y(m,n;k) = median\ \{X(L+1-D), X(L+1+D), X(m,n;k)\} \quad (2)$$

Where *X(r)* is the *r*th largest sample (order statistic) among *2L+1* samples within the $S_{m,n;k}$, and *X(m,n;k)* is the central value of $S_{m,n;k}$.

IV. Adaptive Fuzzy Weighted Filter based on a Triangular Membership Function

The previous weighted median filters [4], [5], [6] could suppress low and medium-density noise very well but their performance decreases when the images are corrupted with high-density Salt and Pepper noise and they are not suitable for removing this type of noise. However our proposed filter not only suppresses low and medium-density noise very well but also its performance is very good for high density Salt and Pepper noise.

Fuzzy methods may use membership functions, which can be defined using two following forms:

A. The only one membership function may be defined using the intensity information of total pixels in image and then apply it for filtering of the all image pixels.

B. One adaptive membership function may be defined for each pixel in the image using the region of support $S_{m,n;k}$ and weights are assigned based on it.

Our proposed spatiotemporal filtering methods are designed based on membership function of type B where the filter support $S_{m,n;k}$ specifies a window area (*3*3*N or 5*5*N*) centered on pixel of coordinate *(m,n)* in the frame of *k.*

In first proposed filter, the algorithm for calculating weights and the filter output for the pixel *(m,n;k)* has the following steps:

Stage 1. Sort the intensity values of noisy pixels in the support $S_{m,n;k}$ and calculate median of intensity values as follow:

$$Med\_g(m,n;k) = Median\{g(i,j;l)\ i,j;l \in S_{m,n;k}\} \tag{3}$$

$$Min\_g(m,n;k) = Minimum\{g(i,j;l)\ i,j;l \in S_{m,n;k}\}$$

$$Max\_g(m,n;k) = Maximum\{g(i,j;l)\ i,j;l \in S_{m,n;k}\}$$

Med_g(m,n;k) is called central point of proposed filter.

Stage 2. Determine the weights of noisy pixels within the $S_{m,n;k}$ using a symmetrical triangular membership function, i.e.

$$w(i,j;l) = \max(0, 1 - \frac{10}{Med\_g(m,n;k)} |g(i,j;l) - Med\_g(m,n;k)|) \tag{4}$$

from eq.4, if the absolute difference between the intensity value of a noisy pixel and the center of the filter is less than one-tenth of the center of filter, the weight or the membership value of the pixel is calculated using the following equation:

$$(1 - \frac{10}{c(m,n;k)} |g(i,j;l) - Med\_g(m,n;k)|)$$

Otherwise the weight is zero.

This Triangular Membership Function is exhibited in Fig. 1.

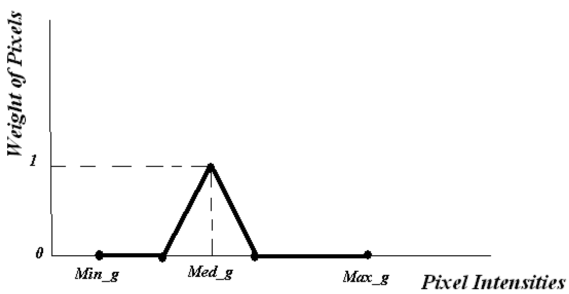

Fig. 1 The Triangular Membership Function

Stage 3. Finally, If $\hat{f}(m,n;k)$ denotes the intensity value of filtered pixel of the location *(m,n;k)*, it is determined using the following equation:

$$\hat{f}(m,n;k) = \frac{\sum_{(i,j;k)\in S_{m,n;k}} w(i,j;l)\, g(i,j;l)}{\sum_{(i,j;k)\in S_{m,n;k}} w(i,j;l)} \tag{5}$$

Where *g(i,j;l)* are the intensity values of noisy pixels within the support $S_{m,n;k}$, and *w(i,j;l)* are the corresponding weights.

V. Experimental Results

In this section, we evaluate the performance of our two proposed filters. We also compare the results of two proposed algorithms with each other and with those of other methods such as CM Filter [3] and CWM Filter [4] under different noise densities. Since CM and CWM Filters are more efficient than NS Filter [5] under of high-density Salt & Pepper noise, so we haven't included NS algorithm in our comparison.

The criterions for comparing the performance of algorithms are MSE (Mean Square Error), and PPEP (Percentage of Preserved Edge Points)

MSE represents noise suppression and is specified by the following equation.

$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} (\hat{f}(i,j;k) - f(i,j;k))^2 \tag{6}$$

Where f and $\hat{f}$ are original and estimated images.

PPEP shows the preservation of image edges and image fine structure and is determined using Canny edge detection algorithm, which finds edge pixels by looking for local maxima of the gradient of image. The gradient is calculated using the derivatives of Gaussian function Canny algorithm uses two thresholds, to detect strong and weak edges, and includes the weak edges in the output only if they are connected to strong edges.

These noise reduction algorithms are applied to image sequences containing moving objects, corrupted by Salt and Pepper noise with different densities. In the video images which are used for the test of different algorithms, not only the objects in the image but also the camera are moving.

We will compare noise suppression, image structure and edge preserving for all the mentioned algorithms.

Our implementations show that in presence of high-density noise, our proposed filter is much more efficient than CM and CWM Filters. Fig. 2(a) and 2(b) illustrate MSE and PPEP comparison of CM, CWM, and our proposed fuzzy filter after applying them on noisy frames of 331 to 339 of a moving patrol, with noise density of 50%. Fig. As seen in these figures, our proposed fuzzy filter suppresses noise much better than the other algorithms, the smallest MSE. It also preserves image edges and structures far better than the others, the largest PPEP. In addition, the proposed filter performs better than CM and CWM filter in suppressing noise and preserving image edges and structures. In short words, in presence of high-density Salt and Pepper noise, our proposed fuzzy filters are more effective than so far reported filters.

Fig. 3(a), (b), (c), (d), (e) exhibit the original, noisy image and the results of applying different filtering algorithms including CM, CWM and our proposed algorithm to patrol image sequences respectively. In these figures, image sequences are corrupted by Salt and Pepper noise with density of under 50% and we have used 3 frames for filtering including current, previous and next frames. As the figures show, the results obtained using our proposed algorithm is better than other methods.

VI. Conclusion

We have proposed two novel spatiotemporal adaptive filters based on fuzzy algorithms. We defined fuzzy sets, which make use of Triangular Membership Function to assign weights to pixels.

The first proposed algorithm employs a symmetrical and continuous membership function, in which the pixel with median intensity value, within the $S_{m,n;k}$, is considered as the center of the proposed weight function. In this filter, the pixel with median intensity value always has the maximum weight. In the second proposed filter, the weights are defined based on asymmetrical and discontinuous triangular membership function. The discontinuity of weight function causes the pixel with median intensity value within the $S_{m,n;k}$ to have either maximum or minimum value depending on the intensity of pixels in $S_{m,n;k}$.

Our implementations showed that both of our proposed fuzzy filters, especially the asymmetrical one, are very powerful in removing low, medium and particularly high-density noise using image sequences. In addition, our experiments showed that the proposed fuzzy algorithms are more effective than CM, CWM filters in Noise removing and preserving image structures and edges. From figures, it appears that asymmetrical one is always the best choice.

In addition, our implementations showed that if the function in the later proposed filter is defined based on continuous function then it will lose its power under high-density Salt and Pepper noise. So it’s quite necessary for the proposed weighted function to be discontinuous.

In short, with regard to our implementations, we recommend the proposed symmetrical fuzzy algorithm for removing low to medium-density Salt and Pepper noise. On the other hand, in the presence of medium to high-density Salt and Pepper noise, we recommend the proposed asymmetrical fuzzy algorithm

Acknowledgements

Authors would like to thank Iran Telecommunication Research Center, for the supports throughout this research.

References

[1] C. Jing, Y. Jinsheng and D. Runtao, "Fuzzy Weighted Average Filter" *IEEE 5th International Conf. on signal processing, Sch. of electron.inf.eng*., Tianjin Univ., China, 21-25 Aug. 2000.

[2] C.S. Lee, Y.H. Kuo and P.T.YU, "Weighted Fuzzy Mean Filters for Heavy-Tailed Noise Removal" *Proc. IEEE. On image processing.* PP. 601-606 (1995).

[3] M.B.Alp and Y.Neuvo, "3-dimensional median filters for image sequence processing", *in IEEE Proc. Int. Conf. Acoust., Speech, and Signal Proc*., vol. 4, (Toronto, Canada), PP. 2917-2920, May 14-17 1991.

[4] Ho, S.-J.; Lee, Y.H., " Nonlinear spatiotemporal noise suppression techniques with application in image sequence processing ", Circuits and Systems, *1991 IEEE International Symposium,* volume : 1, 1991 page(s) : 662-665 vol.1.

[5] M. Saeidi, S.A. Motamedi, A. Behrad, “A NEW NONLINEAR FILTER USING CONSECUTIVE FRAMES”, *IASTED Int. Conf. Circuits, Signals, and Systems, November 20, 2006.*

[6] J. Boyce, “Noise reduction of image sequences using adaptive motion compensated frame averaging*”, in IEEE Int. Conf. Acoustics, speech, signal processing*. San Francisco, CA, Mar. 1992, PP.461-464.

[7] M. Saeidi, S.A. Motamedi, A. Behrad, B. Saeidi, R. Saeidi, “Image Sequences Filtering using Adaptive Weighted Averaging Filter without Estimating Noise Variance”, *IASTED Int. Conf. Visualization, Imaging, and Image Processing, September 9, 2005.*

[8] Alireza Behrad, Ali Shahrokni, Seyed Ahmad Motamedi, Kurosh Madani,"A Robust Vision-based Moving Target Detection and Tracking System", *Proceeding of Image and Vision Computing conference (IVCNZ2001),* University of Otego, Dunedin, New Zealand 26th -28th November 2001.

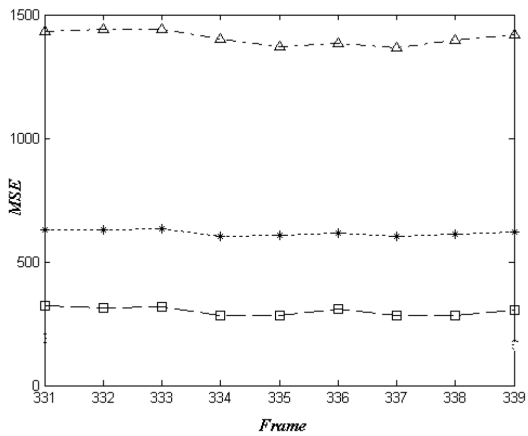

Fig. 2(a). MSE Comparison of CM Filter (△), CWM Filter (*), our proposed fuzzy filter after applying to noisy frames 331 to 339 of moving patrol corrupted with Salt and Pepper noise under 50% density noise using N=3 frames

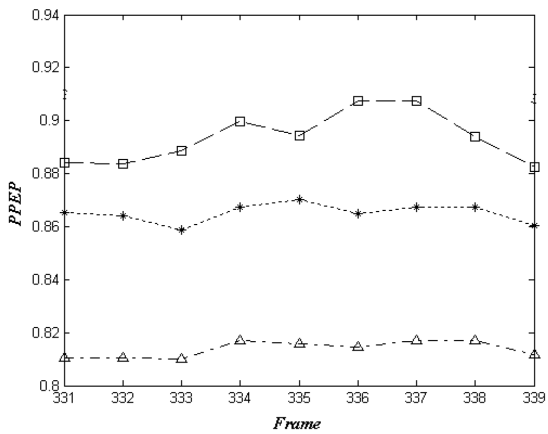

Fig. 2(b). PPEP Comparison of CM Filter (△), CWM Filter (*), our proposed fuzzy filter after applying to noisy frames 331 to 339 of moving patrol corrupted with Salt and Pepper noise under 50% density noise using N=3 frames

Fig. 3(a). Original frame 335 of moving patrol

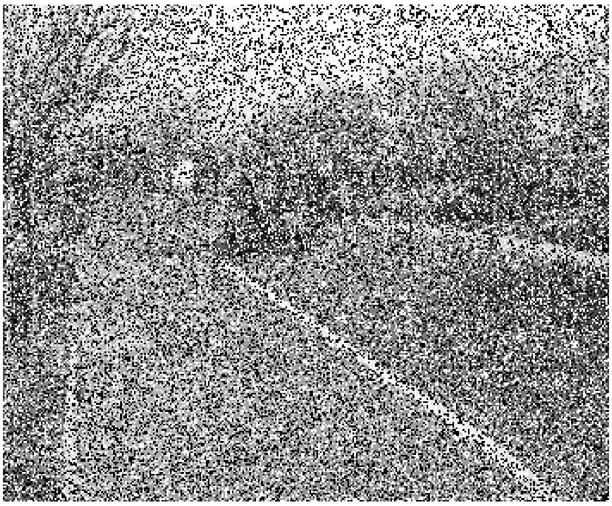

Fig. 3(b). Noisy frame 335 of moving Patrol corrupted with Salt and Pepper noise under 50% noise density

Fig. 3(c). Filtered frame 335 of moving Patrol after applying CM filter using N=3 frames under 50% noise density

Fig. 3(e). Filtered frame 335 of moving Patrol after applying our proposed fuzzy filter using N=3 frames under 50% noise density

Fig. 3(d). Filtered frame 335 of moving Patrol after applying CWM filter using N=3 frames under 50% noise density