Image Sequences Filtering Using a New Fuzzy Algorithm Based On Triangular Membership Function

Mahmoud Saeidi, Leila Chehreghani Anzabi, and Mahmoud Khaleghi
Iran Telecommunication Research Center
msaeidi40@itrc.ac.ir, leilachan@itrc.ac.ir, khaleghi@itrc.ac.ir

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 function: Symmetrical, Continuous Function. 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, is much more effective in suppressing noise and preserving edges than the previously reported algorithms such as [1-13]. Indeed, assigned weights to noisy pixels are very adaptive so that it well makes 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 filtering, adaptive fuzzy based image filtering, weighted triangular membership function, weighted median filter*

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 [1-3].
b) Noise filtering using the information of consecutive frames including the current frame which we are filtering it, previous and next frames [4-13]

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 [4], which could remove noise when images are corrupted by Salt and Pepper noise.
- Spatiotemporal Center Weighted Median, CWM Filter [5], which is well known for removing Salt and Pepper noise among filters based on Median.
- Unidirectional Multistage Filters, UMF, and Bi-directional Multistage Filters, BMF, which called Multistage Order Statistic Filters [6].
- Nonlinear Spatiotemporal Filter, NSF, which efficiently removes low-density Salt & Pepper noise [7].
- Adaptive Temporal Filter [8], Probabilistic Filter [9], and Adaptive weighted Averaging Filters [10-13]

Averaging-based algorithms [8-13] are efficient for removing Gaussian noise while median-based algorithms [4-7] remove Salt & Pepper noise efficiently. So in order to removing Salt & Pepper noise, we only focus on previous median-based filters.

NS, CWM and CM Filters are more efficient than UM and BM Filters under of low-density Salt & Pepper noise. On the other hand CWM and CM Filters remove medium-density Salt & Pepper noise better than NS, UM and BM 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 Symmetrical and Continuous Triangular Membership Function is discussed in section 4. Experimental results are shown in section 5 and conclusion appears in section 6.

2. 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 algorithm 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 $k-l, \ldots k-1, k, k+1, \ldots, k+l$. 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 [14], [15]. 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.

3. 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. As shown in Figure 1(a), in the first stage, this filter selects some pixels in each frame. By referring to Figure 1(a), the selected pixels could be selected either according to (a) or (b). 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. Figure 1(b) illustrates the second and third stages.

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 $S_{m,n;k}$.

4. Adaptive Fuzzy Weighted Filter based on Symmetrical and Continuous 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:

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

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

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

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

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

It is obvious from eq.4 that, 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:

$(1 - \frac{10}{c(m,n;k)}|g(i,j;l) - c(m,n;k)|)$ Otherwise the weight is zero.

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:

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

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.

5. Experimental Results

In this section, we evaluate the performance of our proposed filter. We also compare the results of the proposed algorithm with those of other methods such as CM Filter [4] and CWM Filter [5] under different noise densities. Since CM and CWM Filters are more efficient than UM and BM Filters [6] and NS Filter [7] under of medium and high-density Salt & Pepper noise, so we haven't included NS, UM and BM algorithms 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.

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

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. Figure 2(a) and 2(b) illustrate MSE and PPEP comparison of CM, CWM, and our proposed fuzzy filter using symmetrical and continuous weighted function after applying them on noisy frames of 331 to 339 of a moving patrol, with noise density of 50%. Figure 3(a) and 3(b) show these comparisons for noisy frames of 461 to 469 of moving cars. 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 based on symmetrical function 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 filter is more effective than so far reported filters.

Figure 4(a) and 4(b) illustrate the effect of number of frames in performance of our proposed fuzzy filter at 50% noise density. As shown in these figures, using 3 or 5 frames for filtering is more effective than using only one frame.

Figure 5 and Figure 6 show the original, noisy image and the results of applying different filtering algorithms including CM, CWM and the proposed algorithm to patrol and cars 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.

6. Conclusion

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

The 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.

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

In short, with regard to our implementations, we recommend the proposed symmetrical fuzzy algorithm for removing medium to high-density Salt and Pepper noise.

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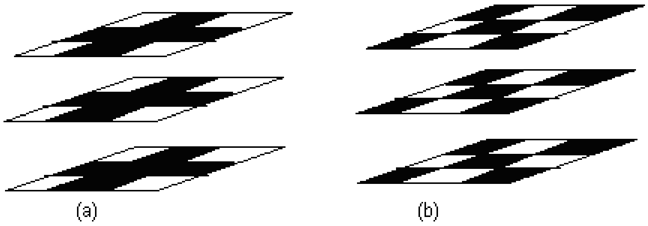

Figure 1(a). High lightened pixels as the selected pixels in Concatenated Median filter

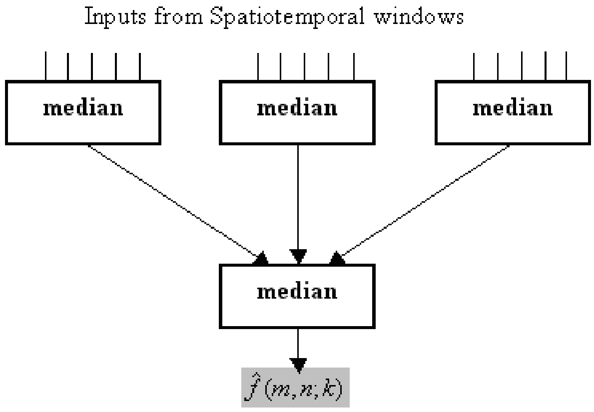

Figure 1(b). The second and third stages of Concatenated Median Filter using N=3 frames

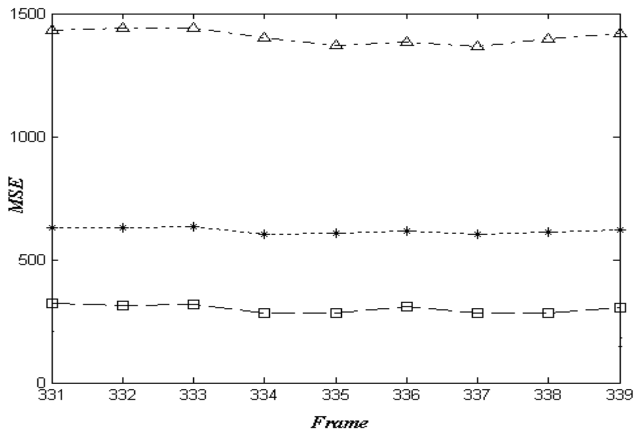

Figure 2(a). MSE Comparison of CM Filter (△), CWM Filter (*), our proposed fuzzy filter based on symmetrical weighted function (□), after applying to noisy frames 331 to 339 of moving patrol corrupted with Salt and Pepper noise under 50% density noise using N=3 frames

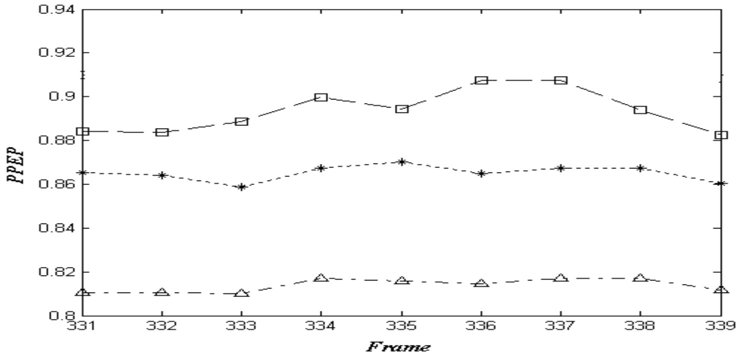

Figure 2(b). PPEP Comparison of CM Filter (△), CWM Filter (*), our proposed fuzzy filter based on symmetrical weighted function (□), after applying to noisy frames 331 to 339 of moving patrol corrupted with Salt and Pepper noise under 50% noise density using N=3 frames

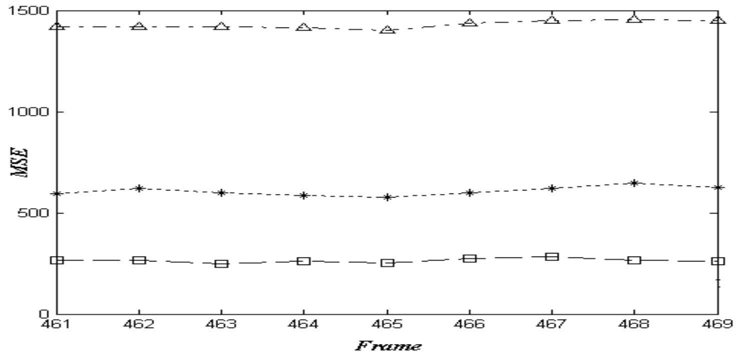

Figure 3(a). MSE Comparison of CM Filter (△), CWM Filter (*), our proposed fuzzy filter based on symmetrical weighted function (□), after applying to noisy frames 461 to 469 of moving cars corrupted with Salt and Pepper noise under 50% density noise using N=3 frames

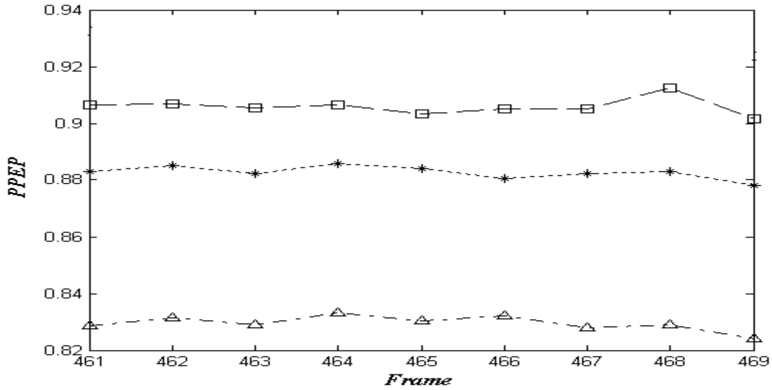

Figure 3(b). PPEP Comparison of CM Filter (△), CWM Filter (*), our proposed fuzzy filter based on symmetrical weighted function (□), after applying to noisy frames 461 to 469 of moving cars corrupted with Salt and Pepper noise under 50% noise density using N=3 frames

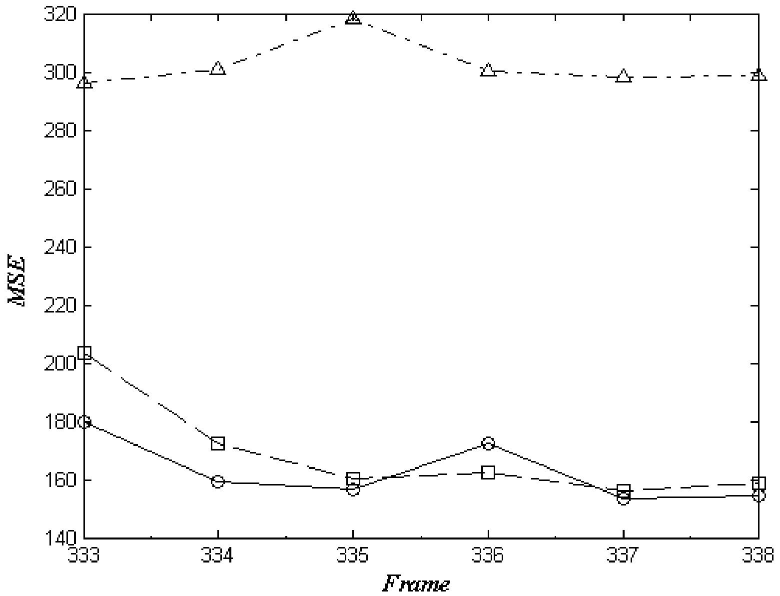

Figure 4(a). MSE Comparison of fuzzy filter after applying to noisy frames 333 to 337 of moving patrol corrupted with Salt and Pepper noise under 50% noise density using N=1 (△), N=3 (○), and N=5 (□)

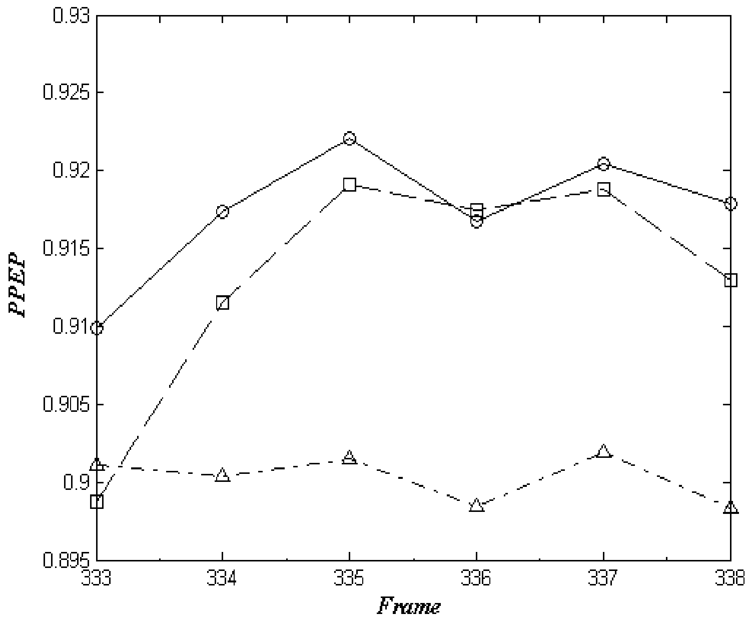

Figure 4(b). PPEP Comparison of fuzzy filter after applying to noisy frames 333 to 337 of moving patrol corrupted with Salt and Pepper noise under 50% noise density using N=1 (△), N=3 (○), and N=5 (□)

Figure 5(a). Original frame 335 of moving patrol

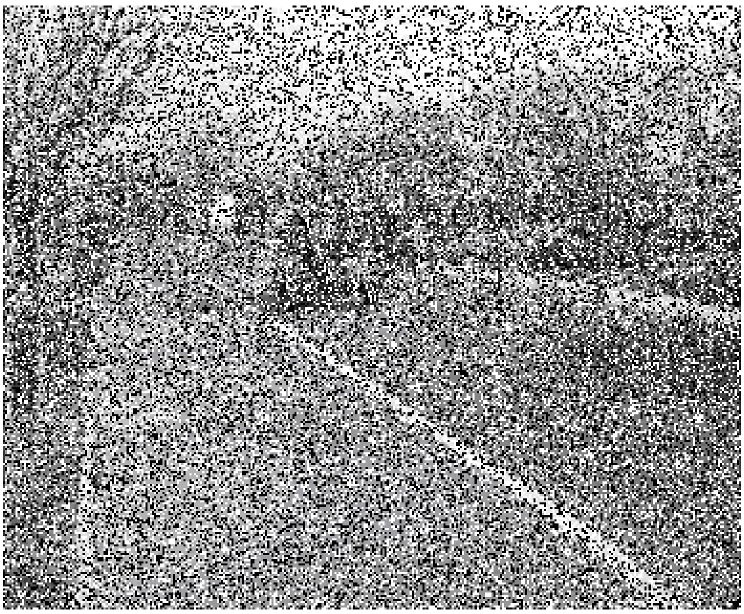

Figure 5(b). Noisy frame 335 of moving Patrol corrupted with Salt and Pepper noise fewer than 50% noise density

Figure 5(c). Filtered frame 335 of moving Patrol after applying CM filter using N=3 frames under 50% noise density

Figure 5(d). Filtered frame 335 of moving Patrol after applying CWM filter using N=3 frames under 50% noise density

Figure 5(e). Filtered frame 335 of moving Patrol after applying our proposed fuzzy filter based on symmetrical weighted function using N=3 frames under 50% noise density

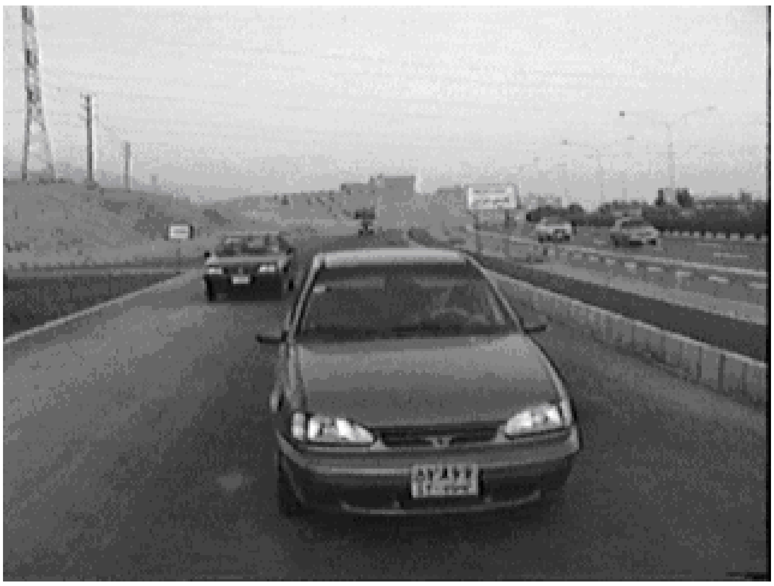

Figure 6(a). Original frame 465 of moving cars

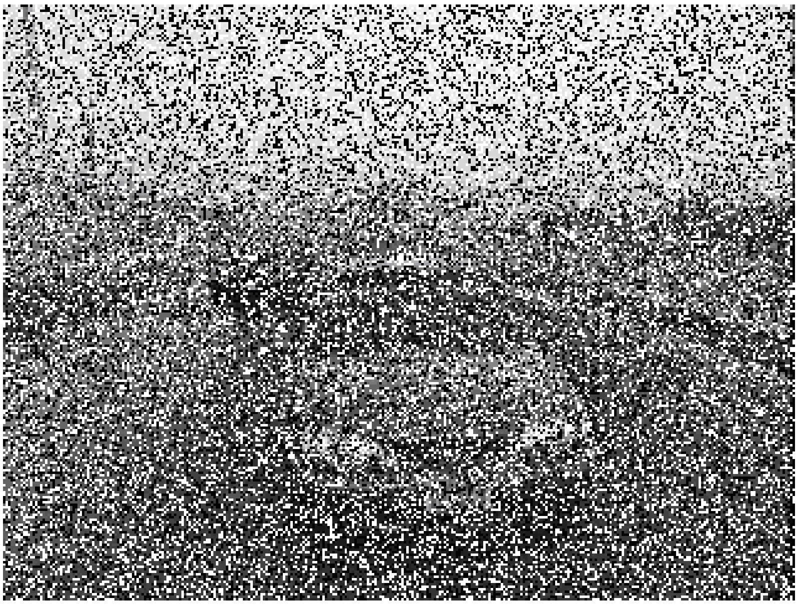

Figure 6(b). Noisy frame 465 of moving cars corrupted with Salt and Pepper noise under 50% noise density

Figure 6(c). Filtered frame 465 of moving cars after applying CM filter using N=3 frames under 50% noise density

Figure 6(d). Filtered frame 465 of moving cars after applying CWM filter using N=3 frames under 50% noise density

Figure 6(e). Filtered frame 465 of moving cars after applying our proposed fuzzy filter based on symmetrical weight function using N=3 frames under 50% noise density

Authors

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