World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:4, No:10, 2010

Adaptive Weighted Averaging Filter Using the Appropriate Number of Consecutive Frames

Mahmoud Saeidi, Ali Nazemipour

***Abstract*—**In this paper, we propose a novel adaptive spatiotemporal filter that utilizes image sequences in order to remove noise. The consecutive frames include: current, previous and next noisy frames. The filter proposed in this paper is based upon the weighted averaging pixels intensity and noise variance in image sequences. It utilizes the Appropriate Number of Consecutive Frames (ANCF) based on the noisy pixels intensity among the frames. The number of consecutive frames is adaptively calculated for each region in image and its value may change from one region to another region depending on the pixels intensity within the region. The weights are determined by a well-defined mathematical criterion, which is adaptive to the feature of spatiotemporal pixels of the consecutive frames. It is experimentally shown that the proposed filter can preserve image structures and edges under motion while suppressing noise, and thus can be effectively used in image sequences filtering. In addition, the AWA filter using ANCF is particularly well suited for filtering sequences that contain segments with abruptly changing scene content due to, for example, rapid zooming and changes in the view of the camera.

***Keywords*—**Appropriate Number of Consecutive Frames, Adaptive Weighted Averaging, Motion Estimation, Noise Variance, Motion Compensation

I. Introduction

IMAGE filtering is one of the most important operations used in image processing. The importance of image filtering is constantly growing because of ever increasing use of television and video systems in consumer, commercial, medical, and communication applications. Image filtering is not only used to improve image quality but is also used as a preprocessing before most image processing operations such as encoding, recognition, compression, tracking and etceteras. In other words, without filtering as a preprocessing, the other processing would have inappropriate or even false results.

Image filtering can be done in two different ways:

A. Using information of only one frame

B. Using information of consecutive frames containing the current, previous and next frames

Filtering using consecutive frames can attenuate noise and preserve the edges of images more effectively.

Mahmoud Saeidi is with the Education & Research Institute for ICT, Saveh Islamic Azad University, Iran. e-mail:msaeidi40@itrc.ac.ir

To reduce noise in consecutive frame filtering, several noise reduction methods have been proposed so far such as: using temporal averaging pixels after motion compensation in image sequences [1], adaptive weighted averaging pixels [2], [3] and probabilistic filter [4]. All of these methods utilize noise variance to eliminate noise. To implement those methods, we somehow need noise variance. If it is not known, in order to implement the above methods, noise variance should be accurately estimated from image sequences. In this case, the precision of noise variance estimation will directly affect the filtering algorithms. Any inaccuracy in noise variance estimation adversely affects performance of all of the mentioned methods.

On the other hands, methods of [1], [2], [3] and [4] assume a constant noise variance among consecutive frames. In our proposed algorithms, however, noise variance can vary from one frame to the other one. This independency is the direct result of using only intensity of pixels in filtering rather than noise variance. All of our algorithms are independent of noise variance in contrast to all previously reported methods.

II. Image sequences Filtering

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.

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 increase pixels correlation to compensate the motion among the consecutive frames. 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 [5], [6]. 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 at low SNR and also in the presence of occlusion and varying scene content.

Since motion trajectory estimation usually doesn't have enough accuracy at very low SNR, it could have undesirable effects on the filtering algorithms. Therefore, we don't use motion compensation at very low SNR to reduce the calculation burden on filtering algorithms.

III. OUR PROPOSED ADAPTIVE WEIGHTED AVERAGING FILTER USING ANCF

Our proposed filter is based on adaptive weighted averaging of spatiotemporal pixels among the consecutive frames after estimating trajectory and applying motion compensation. We will apply motion compensation to both medium and low *SNR* scenarios.

Suppose we want to filter the frame *k* of a given *N* consecutive frames:
k-l, k-(l-1), …, k, k+1, …, k+(l-1), k+l
Where *N=2l+1*.

Additionally, *(m,n;k)* coordinates each noisy pixel in frame *k*, *(m,n)* denotes the spatial coordinates and *k* denotes frame index.

In our proposed motion-compensated spatiotemporal filtering, the filter support $S_{m,n;k}$ is defined as the union of predetermined spatial neighborhoods (e.g., 3*3 or 5*5 square regions) centered about the pixel (sub-pixel) locations on the motion trajectory. In other words, the filter support $S_{m,n;k}$ coincides with the motion trajectory $T_{m,n;k}$.

The number of consecutive frames is adaptively calculated for each $S_{m,n;k}$ and its value may change from one $S_{m,n;k}$ to another $S_{m,n;k}$ depending on the pixels intensity within the $S_{m,n;k}$.

This proposed filter, first choices appropriate numbers of the consecutive frames and then assigns a weight to each noisy pixel within the $S_{m,n;k}$. Each weight value is a function of a variable threshold and the square difference between central pixel in current frame denoted by *g(m,n;k)*, and each of the pixels within the $S_{m,n;k}$ denoted by $g(i,j;l)\quad i,j;l \in S_{m,n;k}$.

The algorithm for calculation of the filter output within each $S_{m,n;k}$ in this method has the following steps:

Stage 1: Determine the mean square difference of *g(m,n;k)* and *g(i,j;l)* when N=3 & 5 frames.

$$TR_3(m,n;k) = \frac{\sum_{(i,j;l)\in S3_{m,n;k}} (g(i,j;l) - g(m,n;k))^2}{Number\ of\ the\ Pixels\ within\ the\ S3_{m,n;k}} \tag{1}$$

$$TR_5(m,n;k) = \frac{\sum_{(i,j;l)\in S5_{m,n;k}} (g(i,j;l) - g(m,n;k))^2}{Number\ of\ the\ Pixels\ within\ the\ S5_{m,n;k}} \tag{2}$$

Stage 2: Determine the appropriate number of frames (which case is better, N=3 or N=5).

$$\begin{aligned}
&if\ TR_3(m,n;k) \le TR_5(m,n;k)\, then \\
&\qquad S_{m,n;k} := S3_{m,n;k}; \\
&\qquad TR(m,n;k) := TR_3(m,n;k); \\
&Else \\
&\qquad S_{m,n;k} := S5_{m,n;k}; \\
&\qquad TR(m,n;k) := TR5(m,n;k) \\
&End
\end{aligned} \tag{3}$$

Stage 3: Determine the weights of noisy pixels with regard to the number of frames according to the following equation:

$$w(i,j;l) = \frac{\dfrac{1}{1+\max\{2\sigma^2, (g(i,j;l)-g(m,n;k))^2\}}}{\sum_{(i,j;l)\in S_{m,n;k}} \dfrac{1}{1+\max\{2\sigma^2, (g(i,j;l)-g(m,n;k))^2\}}} \tag{4}$$

where σ^2 is noise variance.

Stage 3: Estimate proposed filter output according to the following equation:

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

From (1) & (2), one can induce that the threshold values within the different support $S_{m,n;k}$ are variable. Moreover, with regard to (4), if the square of difference between *g(i,j;l)* and *g(m,n;k)* is less than the threshold value *TR(m,n;k)*, then *g(i,j;l)* joins filtering with the weight of $2\sigma^2$. However, if the square of difference *g(i,j;l)* and *g(m,n;k)* is more than the threshold value, then *g(i,j;l)* joins filtering with the weight of $\frac{1}{1+(g(i,j;l)-g(m,n;k))^2}$, which is lesser than $2\sigma^2$.

Consequently, if the difference is greater, then the corresponding pixel joins filtering with a lesser weight.

From (4), it can also be inferred that the pixel, whose estimated motion trajectory is inappropriate, resulted from noise, would have smaller contribution to the proposed filter due to smaller assigned weight.

Our proposed filter is based upon weighted averaging pixel values whose weights are adaptive with the pixels values of the region of support $S_{m,n;k}$. The process of adaptation is done by determining the threshold values, set by using pixel values within the $S_{m,n;k}$.

IV. Comparison the Proposed AWA Filter Using the Appropriate Number of Consecutive Frames (ANCF) to the Previous AWA Filter

In this section, we will evaluate the performance of our proposed filter, AWA using ANCF, and compare it against that of AWA using only three or five frames [2], under different noise variance.

The criterions for comparing the performance of algorithms are Mean Square Error MSE, and Percentage of Preserved Edge Points PPEP. MSE represents noise suppression and image smoothness while PPEP denotes edge preservation and image structure. We determine PPEP using Sobel method, which finds edges by Sobel approximation derivative. It returns edges at those points where the gradient of image intensity is at maximum level.

These noise reduction algorithms are applied to image sequences containing moving objects with added Gaussian noise with various noise variances. In our consecutive frames, not only the objects are moving but also the camera is moving. We will compare noise suppression and structure and edge preservation for the mentioned algorithms. Although we have applied our proposed filter and the mentioned previous filter on noisy frames of various moving objects, we will present only the results of filtering on moving Patrol under various noise variances. The size of Patrol frame is 288*352.

Table (1) illustrates MSE and PPEP comparison of AWA without using ANCF and AWA using ANCF after applying to noisy frame 334 of moving Patrol added with Gaussian noise under varying SNR=0, 3 and 5dB.

The table shows that noise attenuation in AWA using ANCF is better than both AWA using N=1, 3 & 5 frames and also preserving edges in proposed filter is better than AWA using N=1 & 3 frames and is pretty close to AWA using N=5 frames.

TABLE I
MSE AND PPEP COMPARISON OF AWA FILTER WITHOUT USING ANCF, N=1,3,5, AND OUR AWA FILTER USING ANCF AFTER APPLYING TO NOISY FRAME 334 OF MOVING PATROL ADDED WITH GAUSSIAN NOISE UNDER VARYING SNR=0,3,5 DB

Noise	*Filter*	*N*	*MSE*	*PPEP*
SNR=0dB	*AWA*	*1*	*715.6709*	*81637*
		3	*438.5846*	*85811*
		5	*432.0611*	*87395*
	AWA using ANCF	***3,5***	***417.1674***	***87200***
SNR =3dB	*AWA*	*1*	*408.7278*	*85564*
		3	*266.5731*	*91436*
		5	*257.8535*	*91955*
	AWA using ANCF	***3,5***	***251.6302***	***91620***
SNR=5dB	*AWA*	*1*	*283.9812*	*87753*
		3	*191.7388*	*92948*
		5	*190.3267*	*93801*
	AWA using ANCF	***3,5***	***185.5531***	***93732***

Fig. 1(a), 1(b) and Fig. 2(a), 2(b) illustrate the comparison of the results of two algorithms after applying them to noisy frames 332 to 338 of moving patrol at SNR=0dB and SNR=3dB respectively. As shown in these curves, the noise suppression in our proposed AWA using ANCF is more effective than the pervious AWA and the edge preservation in our proposed filter is better than the previous AWA using N=1 & 3 frames and very close to AWA using N=5 frames.

Fig. 3(a) and 3(b) illustrate original and noisy frame 334 of moving patrol added with Gaussian noise at SNR=0dB condition. Fig. 3(c), (d) and 3(e) show this frame after applying AWA without using ANCF and our AWA using ANCF. It is clearly that our proposed filter attenuates noise better than the previous AWA using N=3 and N=5 frames and that is because of using adaptive number of frames based upon a suitable criterion.

V. Conclusion

We have proposed a new spatiotemporal adaptive filter, the adaptive weighted averaging filter using Appropriate Number of Consecutive Frames (ANCF), for motion-compensated filtering of noisy image sequences. Then, we evaluated performance of our proposed method under different SNR conditions. We also compared our proposed filter, AWA filter using ANCF against conventional AWA filter.

Our experiments show that from viewpoint of attenuating noise, our proposed filter, AWA using ANCF, is much more better than the previous AWA using N=3 and N=5 frames. In addition, from viewpoint of preserving edges, the proposed filter is better than AWA using N=3 frames and is pretty close to AWA using N=5 frames.

In short, our proposed filter, AWA using ANCF, attenuates noise better than the previous AWA using N=3 and N=5 frames and that is because of using adaptive number of frames based upon a suitable criterion by the proposed filter.

In addition, our implementations showed that using multi-frame filtering is more effective than using one frame. However, beyond a certain number of frames, the effectiveness of filtering may get reduced in practice due to inaccurate motion estimation.

ACKNOWLEDGEMENT

Authors would like to thank Education & Research Institute for ICT and Saveh Islamic Azad University for the supports throughout this research.

REFERENCES

[1] 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.

[2] M.K. Ozkan, M.I.Sezan, and A.M. Tekalp, "Adaptive motion–compensated filtering of noisy image sequences", *IEEE Trans, circuits and systems for video Technology,* Vol. CSVT-3, PP.277-294, Aug.1993.

[3] M.I.Sezan, M.K.Ozkan, and S.V.Fogel, "Temporally adaptive filtering of noisy image sequences using a robust motion estimation algorithm", *in IEEE proc. Int. Conf. Acoustic. Speech, and signal proc.,* Vol.4, (Toronto, Canada), PP.2429-2432, May 14-17, 1991.

[4] A.M. Alattar "A probabilistic filter for eliminating temporal noise in time-varying image sequences" circuits and systems, *ISCAS'92, proceedings, 1992 IEEE International symposium on*, volum: 3, 1992 page(s): 1491-1494 Vol.3.

[5] F.Dufaux, F.Moscheni " Motion Estimation Techniques for Digital TV: A Review and New Contribution " *Proceedings of the IEEE*, Vol.83, No.6, June 1995.

[6] 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.

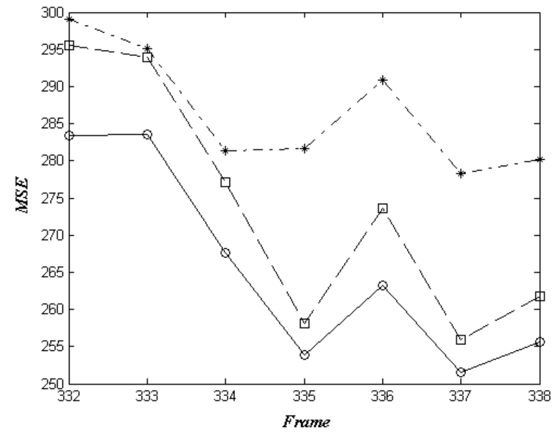

Fig. 1(a). MSE Comparison of AWA filter without using ANCF, N=3 (*), AWA filter without using ANCF, N=5 (□), and our AWA filter using ANCF (○) after applying to noisy frames 332 to 338 of moving Patrol added with Gaussian noise under SNR=0dB

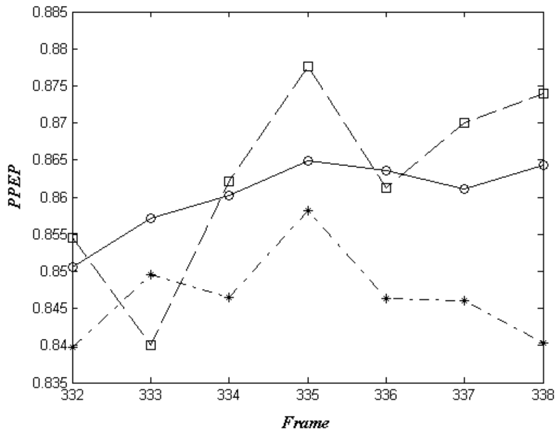

Fig. 1(b). PPEP Comparison of AWA filter without using ANCF, N=3 (*), AWA filter without using ANCF, N=5 (□), and our AWA filter using ANCF (○) after applying to noisy frames 332 to 338 of moving Patrol added with Gaussian noise under SNR=0dB

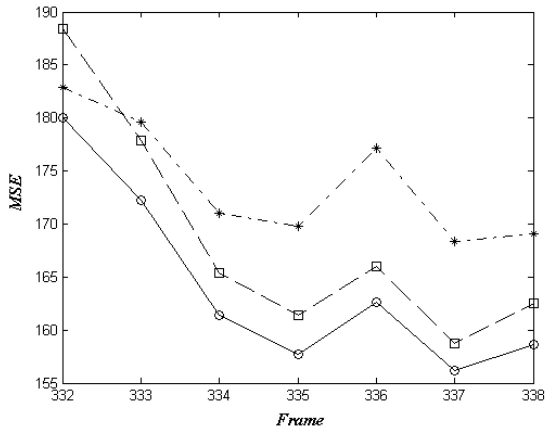

Fig. 2(a). MSE Comparison of AWA filter without using ANCF, N=3 (*), AWA filter without using ANCF, N=5 (□), and our AWA filter using ANCF (○) after applying to noisy frames 332 to 338 of moving Patrol added with Gaussian noise under SNR=3dB

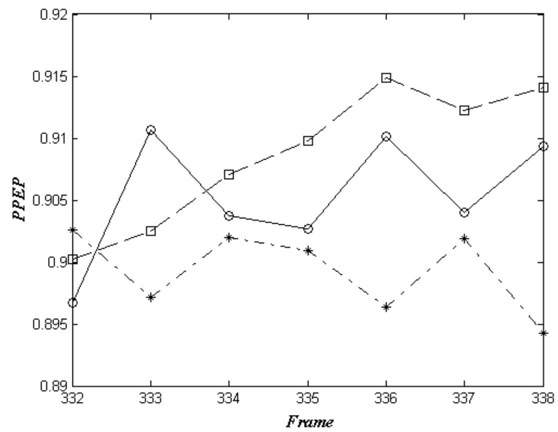

Fig. 2(b). PPEP Comparison of AWA filter without using ANCF, N=3 (*), AWA filter without using ANCF, N=5 (□), and our AWA filter using ANCF (○) after applying to noisy frames 332 to 338 of moving Patrol added with Gaussian noise under SNR=3dB

Fig. 3(a). Original frame 334 of moving Patrol

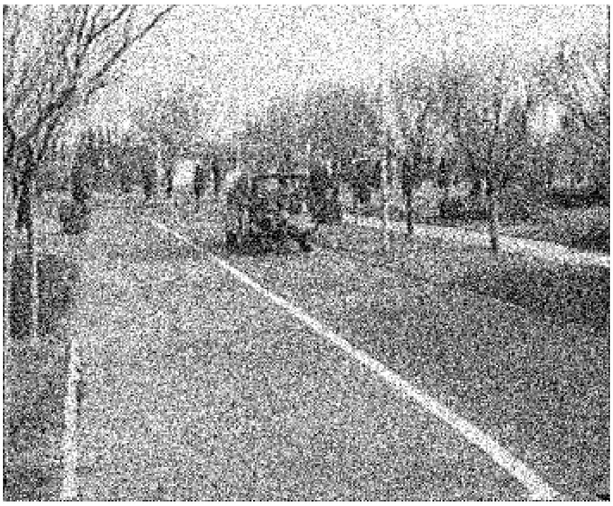

Fig. 3(b). Noisy frame 334 of moving Patrol added with Gaussian noise under SNR=0dB

Fig. 3(c). Filtered frame 334 of moving Patrol after applying AWA filter without using ANCF, N=3 frames under SNR=0dB

Fig. 3(d). Filtered frame 334 of moving Patrol after applying AWA filter without using ANCF, N=5 frames under SNR=0dB

Fig. 3(e). Filtered frame 334 of moving Patrol after applying AWA filter using ANCF, under SNR=0dB