A Band Stop Filter for Pre-Processing Image Sequences

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Abstract

In this paper, we have proposed a band stop filter (BSF) for pre-processing of image sequences before encoding. By pixel-wise temporal filtering of the image sequences using the BSF, the bandwidth and noise of the signal are reduced, while preserving the image quality in view of human visual perception. As a result, when compared to the original image sequences, the pre-filtered image sequence requires lower bit-rates for encoding, while there is not much degradation in quality. Also, it has been shown that the proposed BSF causes less smearing and blurring than the conventional recursive low pass filter for bandwidth and noise reduction.

I. Introduction

Noise arises in many different paths of communication system and electric circuits involved. For example, there are photon, thermal, or film grain noise from image sources and various noise from electronic circuits which process these signals. Noise degrades the coding gain as well as the quality of the images [1, 2]. The effect of noise on coding performance can be illustrated by the example that the uniformly distributed noise with the values of -1, 0, 1 is added to the original image of 256 gray levels. The PSNR of the noisy image is 45.8dB, which is barely perceptible. However, it has an entropy of 1.58 bit/sample, which will affect the coding performance as much. Hence noise reduction filtering is required for better coding performance. Also, when the bandwidth of the channel is much narrower than that of the encoded video signal data, it is required to further compress the signal, which results in degradation of images. In this case, by low-pass or band-stop filtering of the image signal, the bandwidth can be reduced. If the filter is devised to remove the components of the signal which is less important with respect to human visual perception, we can obtain less degraded images while further reducing the bits required for encoding, compared to the image without pre-filtering. That is, by intentionally increasing the correlation of the signals through filtering, the coding performance can be increased.

In order to improve the image quality and also the coding efficiency, there have been much research on filtering of image and video signals in spatial and temporal domains. In case of spatial domain filtering for still images, LPF (low pass filter) or median filter can be considered [3, 4]. In case of video signals, it is well known that it is more efficient to use the temporal domain filter such as 3-D median, Kalman filter and motion adaptive filters [5-9]. However, these techniques are too complicated to be easily implemented in real-time. There have also been very simple methods to perform pixel-wise temporal domain FIR or first order recursive filtering [1, 2, 10-13]. However, FIR filtering causes time delay and requires many frame memories.

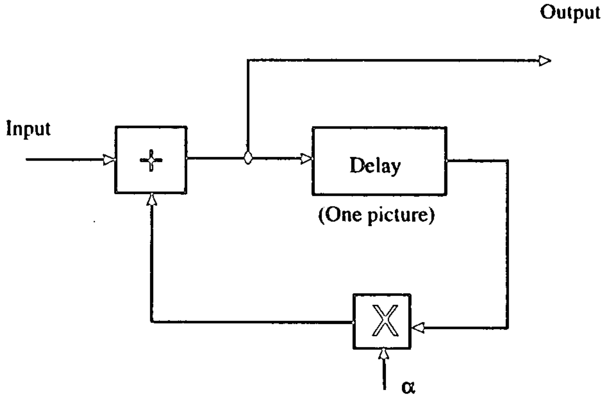

Fig. 1. A recursive filter for noise reduction.

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Thus recursive filtering with only one frame memory is preferable for real time application, and there is commercially available one with adaptive filter coefficients [1]. The system is a low-pass filter which is consisted of first order recursive filter and a simple motion detecting circuit for coefficient adaptation. But as noted by Girod [15], low pass filtering causes annoying effects on moving objects because it brings lag-like smearing like a display with long-persistent phosphor. Hence, in order to reduce these effects, the filter coefficients should be adjusted according to the amount of motion. More precisely, the filter is adjusted to have narrow bandwidth for video signal with small motion, and wide bandwidth for image with large motion. But the adaptation requires more computations and expensive hardware. Thus we propose a recursive BSF (band stop filter) which reduces bandwidth of the video sequences while preserving high frequency components consisting of moving objects. By applying the proposed filter for the pre-filtering of video sequences which are encode by MPEG2, the coding performance is increased while annoying effects of filtering is reduced compared to the case of applying low-pass filters. The organization of this paper is as follows. In section 2, recursive low-pass filter is introduced, and in section 3, a recursive band-stop filter is proposed and simulation results are presented. Finally, section 4 gives conclusions.

Ⅱ. Pre-filtering of Image Sequences by Recursive Low-Pass Filters

The structure of the recursive low-pass filter introduced in [1] is shown in Fig. 1, and its transfer function is given by

$$H(z)=\frac{1}{1-az^{-1}}\,. \tag{1}$$

However, since the filter gain for image processing should be 1 at $\omega=0$, it should be modified as follows.

$$H(z)=\frac{\frac{1}{K}}{1-(1-1\,K)z^{-1}}\,. \tag{2}$$

We can verify that the gain of the above filter at $z=1$ ($\omega=0$) is 1.0, and it can be implemented as shown in Fig. 2. The function of (2) in time domain can be interpreted that the weight for the old data increases as K increases. For more general expression used in digital signal processing, the transfer function can be rewritten as

$$H(z)=\frac{1-a}{1-az^{-1}} \tag{3}$$

and the magnitude response of the filter is shown in Fig. 2. with several values of $a=(1-1/K)$. As shown in the figure, the cut-off frequency decreases as a approaches 1, *i.e.*, as K increases. Hence, as K increases, the correlation of data increases and coding performance also increases.

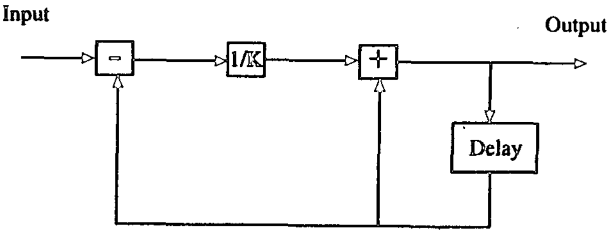


Fig. 2. A recursive low-pass filter with DC gain 1.0

In order to demonstrate the effect of bandwidth reduction by LPF on coding performance, 60 frames of "Flower Garden" video sequences are filtered pixel-wise by the above recursive temporal low-pass filter and the result is encoded according to MPEG2 scheme [14]. The average of PSNR of 60 frames for comparing the original and reconstructed image sequences is shown in Table 1, for several values of K. In the simulation, the bit-rate for all cases is 2.0Mbps. The talbe shows that reducing the bandwidth of the signal results in higher coding gain. In other words, for obtaining the same PSNR as the original image sequence, less bits are required for the pre-filtered one. It is verified in Table 2 with the example of $K=2.0$. It shows that reducing the bit rate results in decrease of PSNR, and the coding gain over the case of $K=1.0$ (no filtering) is also shown in the table. It can be observed that 0.75Mpbs are required for obtaining the same performance, in terms of PSNR, whereas original sequence requires 2.0Mbps.

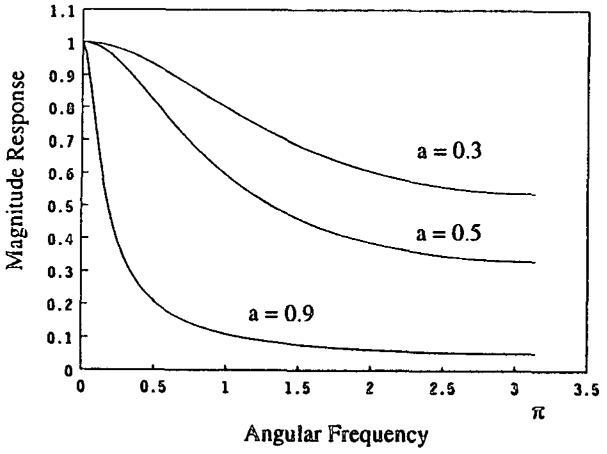


Fig. 3. Magnitude response of the recursive filter with several values of a.

However, in the above result, the reconstructed images are compared with the filtered images, not with the original one. But, comparing the results with the original images is also not always a good idea, because human visual aspects should be considered in comparing filtered images. Hence, the above results do not always mean that the large K, which gives large coding gain or small bit-rate, is desirable.

Table 1. PSNR of reconstructed images which are processed by recursive low-pass filters.

K	α	PSNR (dB)	coding gain (dB)
1.0 (no filtering)	0.0	27.5	0.0
2.0	0.5	32.12	4.62
4.0	0.75	35.38	7.88

As shown in (2) and Fig. 3, large K means large weight on old data and small cut-off frequency. It is obvious that the filter cuts off larger bandwidth with larger K and this results in better coding performance. Also, noise with high frequencies are removed by the low-pass filter. However, removing the high frequencies causes very annoying effects when there are moving objects in the sequences. That is, it brings lag smearing of moving objects like a display with a long-persistent phosphor [1]. Conversely, if K is small, though there is less smearing, noise is not much reduced and the correlation of the images does not increase, resulting in poor coding performance.

Table 2. Bit rate vs. PSNR of reconstructed images which are processed by recursive low-pass filter K = 2.0, where the reconstruction of the images without pre-filtering shows PSNR of 27.5dB.

Bit rate (Mbps)	PSNR	PSNR-27.5
2.00	32.12	4.62
1.75	31.36	3.82
1.50	30.52	3.02
1.25	29.57	2.07
1.00	28.43	0.93
0.75	26.86	-0.64

Thus adaptive scheme is required, which imposes large value on K for the parts of images with large motion, and small value for the parts with small or no motion. Thus the recursive filter in Fig. 3 should be replaced by an adaptive one as shown in Fig. 4(a), where the circuit for coefficient adaptation is shown in Fig.4(b). In this figure, H is just a rectifier which gives larger output for larger picture difference. The multiplier value is continually adjusted by multiplying the previous value with the output of H. Also, this result is saturated to be in the pre-defined lower and upper bound by the function G in the figure. Usually, this function is experimentally determined [1], and determination of the function H and G is very important.

The adaptive recursive low-pass filter discussed above has some drawbacks. First, the adaptive circuit is very expensive and also it should be applied to each pixel. Secondly, though the coefficient is adjusted to be small for the parts with large motion, it is still a low-pass filter which causes annoying effects of smearing. For example, Fig. 5(a) shows 30th frame of "Flower Garden" image sequence, and (b) is the result of filtering this image sequence by the recursive filter of (2) or (3), with $K=2.0$ ($\alpha=0.5$). It can be observed that there is lag of tree and moving parts are seriously blurred. Hence, it is required to develop new pre-filtering techniques to improve these effects.

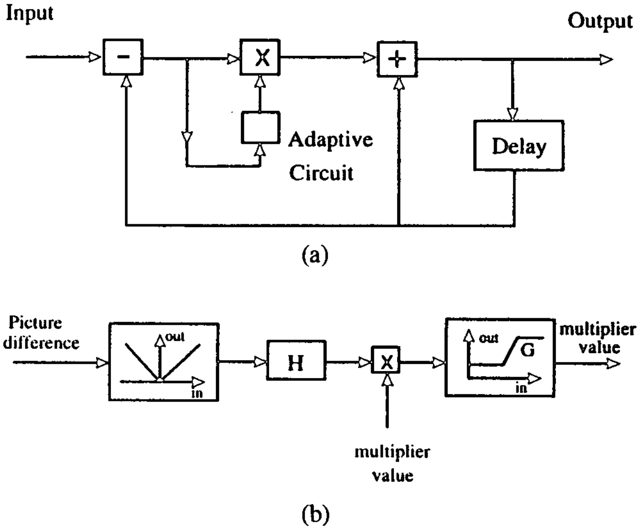


Fig. 4. Structure of recursive low-pass filter (a) Overall structure (b) Coefficient adaptation part

III. A Recursive Band Stop Filter for Pre-filtering of Image Sequences

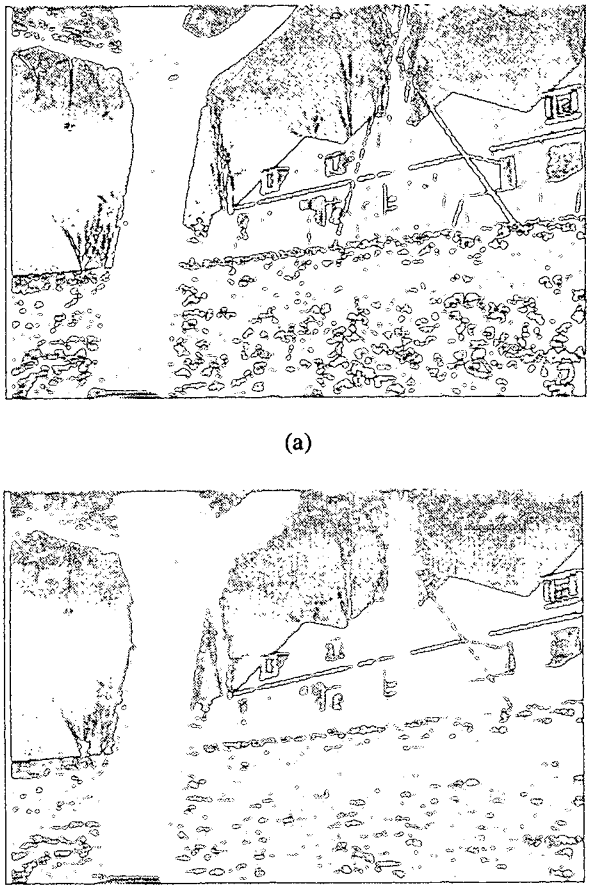
In this section, we propose a band stop filter which does not blur the fast moving parts while increasing the correlation of the overall images by removing components in the middle frequencies. In the case of the low-pass adaptive filter which adjusts the coefficient α in (3) to be close to 1 for the parts with small or no motion and 0 for large motion, the computational load or hardware complexity is high. But in the proposed scheme, instead of adjusting the coefficients, we employ a BSF which can keep the parts of the images with very small and very large motion. Thus there is less lag smearing in the image and only components in the middle range are deleted, which do not much affect the image quality in view of human visual system [15].

The band stop filter is designed based on the recursive low-pass filter in (3). Since (3) has its pole on $z=\alpha$ and $0<\alpha<1.0$, it works as a low-pass filter. Hence, we need a filter with a pole on the opposite side $z=-\alpha$, which works as a high-pass filter. By cascading these filters we obtain a band stop filter given by

$$H(z) = \frac{(1-a)(1+a)}{(1-az^{-1})(1+az^{-1})} \tag{4}$$

$$= \frac{1-a^2}{1-a^2z^{-2}}, \tag{5}$$

which has unity gain at $\omega=0$ and $\omega=\pi$. The magnitude response of the filter for several a is shown in Fig. 6. In order to investigate the effects of the filter on image sequences, the 30th frame of the output of the band stop filter with the input of "Flower Garden" image sequence, is shown in Fig. 7. Compared to the picture shown in Fig. 5(b), the lag of the tree is not so much annoying, and the overall picture is less blurred. This effect is more clearly perceived when actually displaying the image in sequences, which cannot be shown in the paper, but verified by subjective tests that we have performed.



(a)

(b)

Fig. 5. 30th frame of "Flower Garden" image sequence (a) original (b) result of recursive low-pass filtering with a =0.5

For comparison, the coding performances obtained by employing the proposed band stop filter and by low pass filter are presented in Fig. 8. The first figure implies that the PSNR of low pass filtered image, compared to the original, is 21.97dB and MPEG2 reconstructed image has PSNR of 31.12dB compared to the input to the MPEG2 encoder. However, compared to the original image, the reconstructed image shows PSNR of 21.27dB. Likewise, the second figure shows simulation results for each case addressed above, with the proposed band stop filter. Though coding gain is lower than the case of using LPF, the processed image is more close to the original in terms of PSNR. Also, we have verified through subjective tests that the result of band stop filtering shows better image quality as compared in Fig. 5 and Fig. 7, and there is less smearing in moving objects

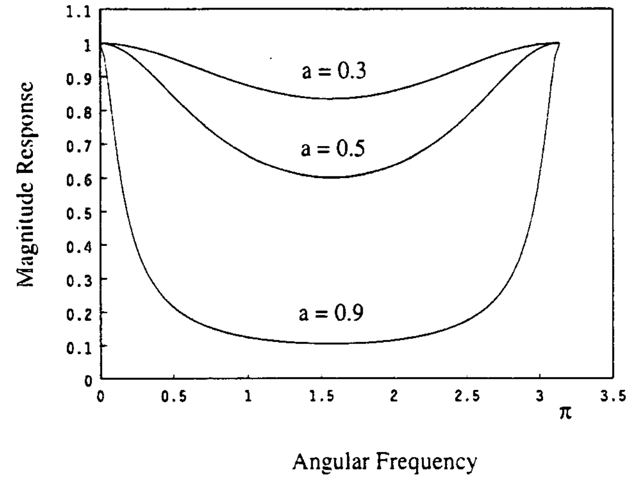


Fig. 6. Magnitude response of band stop filter for several values of a

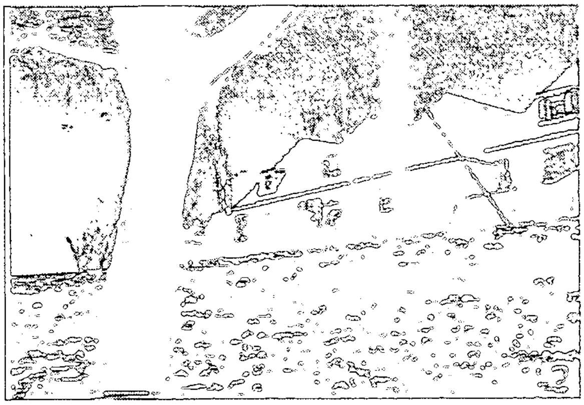
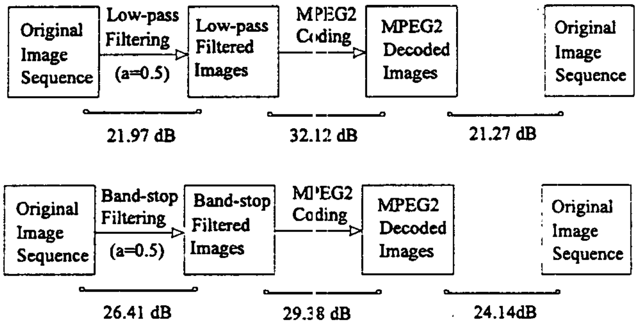


Fig. 7. 30th frame of the output band stop filter (BSF of "Flower Garden" image sequences with a =0.5).

We have also performed simulations for $a=0.3$ and the results are summarized in Fig. 9. The 30th frames for the case of using LPF and BSF are shown in Fig. 10(a) and (b), respectively. Like the case of $a=0.5$, the image with LPF are severely blurred and has smearing around the moving objects, whereas the image with BSF shows less blurring.

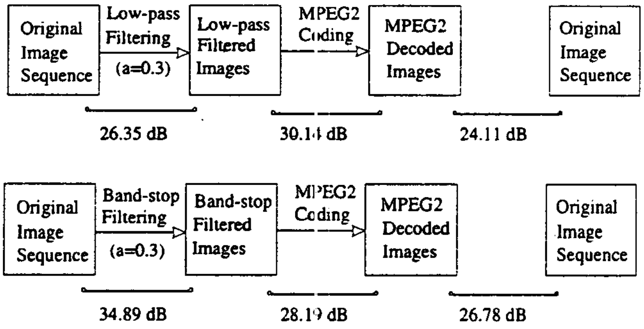


°Original vs MPEG2 code-decode result of original = 27.5 dB

Fig. 8. Simulation results for a =0.5.

IV. Conclusions

In this paper, we have studies the pre-filtering of image sequences for noise reduction and improvement of coding performance. One of the conventional methods for pre-filtering the video signal is to use an adaptive recursive low pass filter. Though the architecture of this filter is very simple, computational load or hardware complexity is relatively high because motion detection should be performed for each pixel. Also, it causes blurring and annoying effects such as lag smearing, especially for moving objects on the simple background.

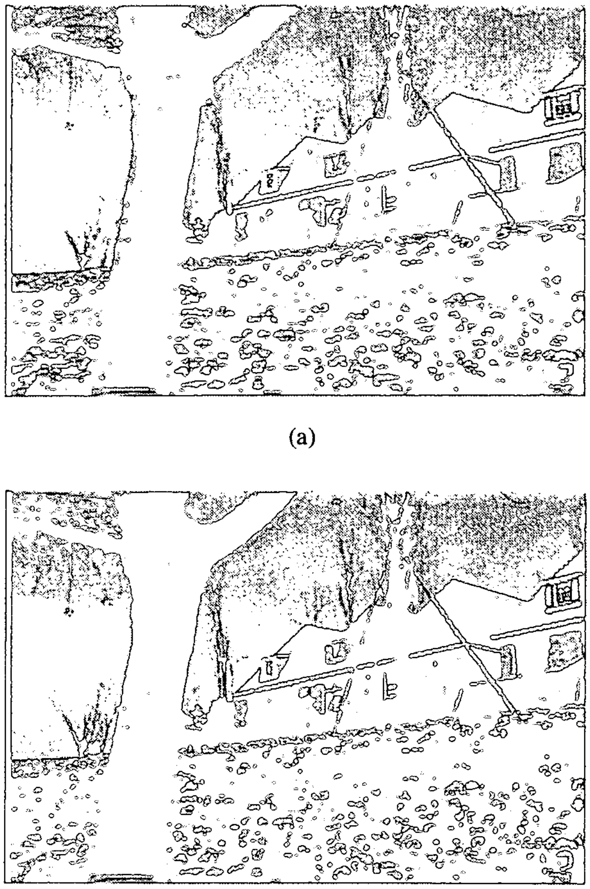


°Original vs MPEG2 code-decode result of original = 27.5 dB

Fig. 9. Simulation results for a =0.3.

Thus we have proposed a recursive band stop filter which has as simple structure as the conventional recursive low pass filter. By applying the BSF for the pre-filtering of image sequences, we could verify that there is very little lag and blurring compared to the case of using LPF. Also, the coding performance increases in proportion to the reduced bandwidth. Simulation results show that the PSNR of the MPEG2 encoded/reconstructed image, which was first processed by the BSF, is lower than that processed by LPF. However, the image processed by BSF is more closer to the original one, and the difference is more clearly perceived when it is actually displayed in sequences.

Though we have compared the images in terms of PSNR in this paper, subjective tests and weights based on human visual perception should be included for fair comparison [15, 16]. Also, the reconstruction PSNR (the PSNR of the MPEG2 encoded/decoded image compared to the original before pre-filtering) of the pre-processed image can never have higher PSNR than that of the original image, even if it were a process for removing noise. More specifically, as in our simulation results, the reconstruction PSNR of the pre-filtered image was always lower than 27.5dB, which is the reconstruction PSNR of the original image in certain conditions. But in subjective test, the quality of the reconstructed video, which had been processed by the proposed BSF, was as good as that of the original sequences.



(a)

(b)

Fig. 10. 30th frame of "Flower Garden" image sequence processed by (a) LPF (b) BSF (a =0.3).

Thus in our future study, more comparison through subjective tests will be performed and the comparison based on human visual perception will be investigated. Also, the pre-filtering based on temporal human visual transfer function will be studied.

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