Improvement of the dc-shift noise reducer with statistical noise separation method and adaptive area filtering method using local and global characteristics of video sequences

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ABSTRACT - Our developed noise reducer, called a dc-shift noise reducer, reduces noise by shifting the local signal level to minimize the noise level. A combination with a dc-shift technique and a median filter reduced the noise in a moving area effectively. We have successfully developed the dc-shift noise reducer for HDTV receivers to reduce the transmission noise. Detection of the noise level in a real moving picture is a problem that must be solved to utilize the dc-shift noise reducer for real moving TV pictures. However, we have developed the noise level detection method using a statistical distribution analysis. We also introduced the detection of global and local noise levels, which contribute to the dynamic threshold ε -filter instead of the median filter originally used. These newly developed techniques of statistical analysis for noise level detection and the dynamic threshold ε -filter improved the dc-shift noise reducer for the use of real moving TV sequences.

1. Introduction

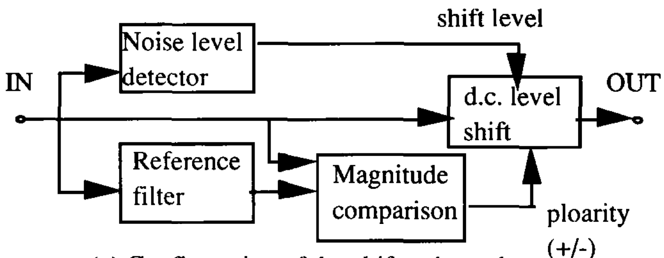
Noise reduction is a classical but an important technique to improve the picture quality of TV pictures. The importance of noise reduction has increased in recent digital TV broadcasting services which are commonly operated by the HDCT (Hybrid Discrete Cosine Transform) coding system. Entropy measurement and subjective evaluation of HDCT coded pictures revealed that the picture quality changes according to the picture contents, and most of the high entropy sequences, i.e. the most difficult or critical sequences, are found to be noisy. This indicates that noise reduction is increasingly important for digital TV systems.

For analogue TV, several noise reducers have been proposed and developed. Motion adaptive temporal noise reduction has been successful, but it offers no improvement in the moving area of pictures.

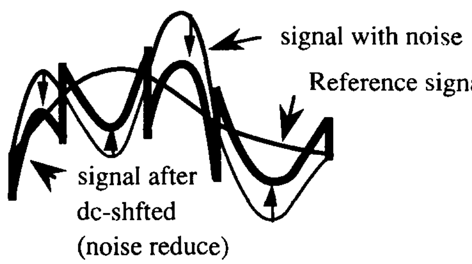
To overcome this shortcoming, we considered using a nonlinear filtering noise reducer called a "dc-shift noise reducer", which is combined with a median filter and a local level shifting technique to reduce the noise in the moving portion of pictures.

The principle of the dc-shift noise reducer is illustrated in

Figure 1.



(a) Configuration of d.c-shift noise reducer



(b) Principle of dc-shift noise reduction

Figure1. The dc-shift noise reducer -configuration and principle-

The noisy signal is compared with the reference signal and the polarity of noise, which corresponds to the direction of level shifting, is detected. Then the noisy signal is shifted to be close to the reference signal. The shifting level is set to be equal to the noise level to reduce the noise.

Let $\hat{x}_n$ be a reference level at n, and ΔN a noise level, then the output signal of the dc-shift noise reducer is as follows.

$$y_n = x_n - \Delta N \quad \text{if } x_n > \hat{x}_n$$

$$y_n = x_n + \Delta N \quad \text{if } x_n < \hat{x}_n$$

The median filter is used to utilize the advantage that the slope of the edge signal of the moving object tends to be maintained. The side-effect of the median filter is the production of an erroneous signal which does not exist in the original picture.

In order to minimize this problem we applied the median filter only for a reference signal which is used to detect the polarity of the noise in comparison with the reference signal.

We considered two technical solutions to improve the dc-shift noise reducer. One of them is to improve the accuracy of the local shift level, which is accomplished by improving the detection of the noise level, and the other is to improve the accuracy of the reference filter which does not cause any picture degradation instead of the median filter.

We have developed a reliable method of noise level measurement which uses a statistical analysis, and modified an ϵ-filter with an adaptive threshold in accordance with the measured local noise level and global noise level. The results of the computer simulation showed good improvement for dc-shift noise reducer.

2. Noise level detection

The developed dc-shift noise reduction showed good performance on reducing the noise in the moving area of the video signal, however it is necessary to detect or estimate the noise level in a video signal accurately for application to the real moving TV pictures.

Various algorithms have been presented to calculate the SN ratio in a TV picture. One is based on the measurement of the PSD (Power Spectrum Density), as the PSD between picture and noise are different. On the other hand, a commercialized video noise meter calculates noise level in a selected area of the known level manually.

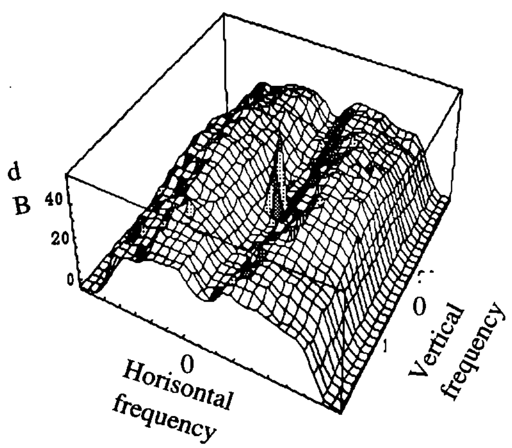


Fig.2 Frequency characteristics of measured noise

First, we investigated the characteristics of the noise signals of studio-quality HDTV signals using the same algorithm as the video noise meter. In this experiment we separated the noise signals in frame difference signals manually, taking into account the frame difference caused by motion. The result showed that the frequency characteristics of the noise are band-pass frequency characteristics, which as has been explained by other references, are the result of the effect of the aperture correction. The distribution of the noise is found to be a gaussian distribution.

And the example of the results of the experiments is shown in Figure 2, which shows the frequency characteristics, and Figure 3, which shows the occurrence distribution of the noise level.

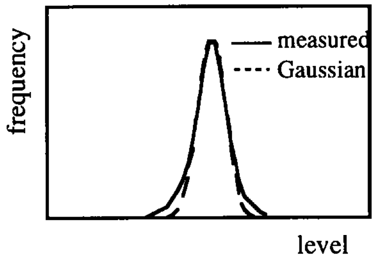


Fig.3 Measured noise distribution

It is well known that gaussian distributed noise can be reduced effectively by a linear low pass filter. This implies that the linear high pass filter is adequate to extract a gaussian distributed noise from real moving pictures. However, the picture contents might affect the performance of detection of the noise.

One particular problem is the existence of the edge in a picture, which tends to be regarded as noise and the other is the frame difference caused by a moving object, which also tends to be regarded as noise. To avoid these kinds of failures, we introduced statistical analysis of the occurrence of noise from edges or moving objects.

The basic algorithm of the noise level detection which we considered is based on that of the video meter. First we calculate the two-dimensional average of 7 by 7 pixels in a block.

$$x_{m,n}^{2Daverage} = \frac{1}{k} \sum_{i=-3}^{3} \sum_{j=-3}^{3} x_{m+i,n+j}$$

Then we calculate the differences between the two-dimensional average of pixels and each pixel in a block.

$$N_{rms2D} = \sqrt{\frac{1}{k} \sum_{i=-3}^{3} \sum_{j=-3}^{3} \left(x_{m,n}^{2Daverage} - x_{m+i,n+j}\right)^2}$$

We also calculate the frame difference between the pixels of the present frame and the past frame.

$$N_{rms3D} = \sqrt{\frac{1}{k} \sum_{i=-3}^{3} \sum_{j=-3}^{3} \left(x_{m+i,n+j,l} - x_{m+i,n+j,l-1}\right)^2}$$

The distributions of two 49 differences (2D noise and 3D noise) are examined by the chi square method.

The PDF (Probability Density Function) of gaussian distribution $N(\hat{\mu}, \hat{\sigma}^2)$ is well known as

$$\text{PDF} = \frac{1}{\sqrt{2\pi}\,\hat{\sigma}} \exp\left\{\frac{(x-\hat{\mu})^2}{-2\hat{\sigma}^2}\right\}$$

Then the CDF (Cumulative Density Function) is calculated by summing up the PDF for each noise level category.

Hence χ^2 is calculated as

$$\chi^2 = \sum_{j=1}^{k} \frac{(x_j - k \times \text{CDF})^2}{k \times \text{CDF}}$$

The 5 % probability level of the χ^2 distribution ($\chi^2(0.05, k-1)$) is used to test the validity of the distribution of the local noise level.

At the end of the calculation of the frame, the maximum occurrence of the valid noise level is adopted as the noise level of the frame.

$$N^{Global} = \max(\text{histogram}(N_{rms-valid}))$$

Figure 4 illustrates the basic algorithm for the estimation of noise ratio.

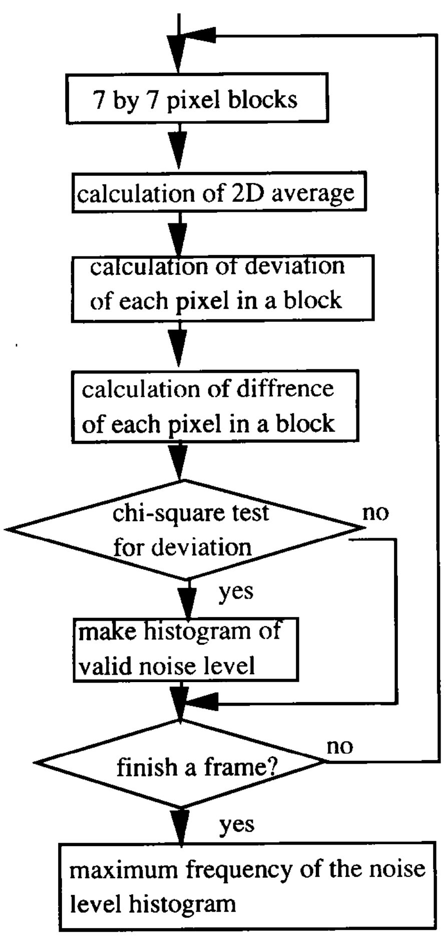


Fig.4 Flow chart of the algorithm for detection of noise level

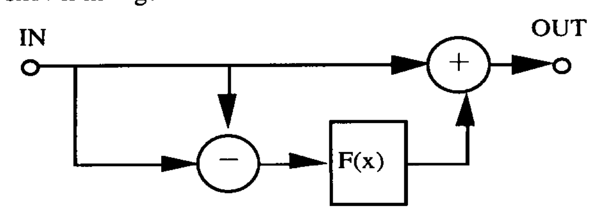
3. Improvement of the reference filter for moving areas

A median filter is used as the reference filter in order to applied to the moving areas in the original dc-shift noise reducer. The advantage of the median filter is its edge preservation characteristics. However, as is well known, an erroneous signal might be produced by the median filter, which degrades the picture quality. One candidate to improve the median filter is an ε -filter, which is basically a low pass filter but has threshold criteria to select the pixels within a filtering window, hence only small deviated pixels within a window are used filtering and large deviated pixels like edge signals are not used for filtering.

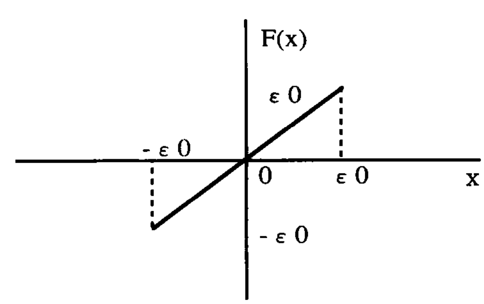
The function of the ε -filter is expressed as follows.

$$y_n = x_n - \sum_{k=-N}^{M} a_k F(x_n - x_{n-k}) \quad (1)$$

$F(x)$ is a nonlinear function and its characteristics are shown in Figure 5.



(a) Configuration of ε -filter



(b) Nonlinear function of ε -filter F(x)

Fig.5 ε -filer -configuration and nonlinear function F(x)-

The criteria ε_{th} used in the ε -filter is necessarily dependent on the noise level.

Another improvement can be made adopting the criteria ε_{th} dependent on the picture contents locally. For this purpose we introduced local and global noise level detection.

We define the local noise level and global noise level as follows. The local noise level is measured by the minimum difference between the two-dimensional average and the temporal average.

The global noise evel is measured by the statistical maximum of the histogram of the local valid noise levels. To avoid mistaking the edge signal for noise, or the temporal difference of a moving picture for noise, the statistical chi-square (χ 2) analysis technique is applied to separate the edge of a moving object and the noise signal as mentioned in section 2.

$$N_{rms-global} = \text{MaxHistogram}(N_{rms-local} \times f(\chi^2))$$

$$f(\chi^2) = 1 \ \text{if} \ \geq \chi^2 (0.05, k-1)$$

$$= 0 \ \text{if} < \chi^2 (0.05, k-1)$$

However, the original local noise level includes the edge signal and frame difference of the motion. The logical combination of the global noise level and the local noise level compensates for each noise by the use of minimum selections.

$$\varepsilon_{th} = k \times \min(n_{rms-global}, n_{rms-local})$$

If there is an edge signal or motion, then the global noise should be smaller and selected as ε_{th}. If the local noise level is smaller than the global noise, then smaller criteria are applied, which is preferable to prevent some blur.

4. Experiments and results

The proposed process was examined by computer simulation.

Figures 6,7 and 8 show an example of an original noisy picture, median filtered picture and the proposed ε -filtered reference picture respectively.

The false edge of the median filter in Figure 7 is improved in a proposed ε -filter in Figure 8. The noise suppression is almost equal in Figures 7 and 8.

The resultant noise reduced pictures of the median type dc-shift noise reduction and proposed ε -filter type dc-shift noise reduction are presented in Figures 9 and 10. The effect of the false edge is improved in Figure 10.

Sequence name		Before NR	After NR	ratio
baseball	41	1.29	1.16	0.9
openig ceremony	31	1.785	1.22	0.68
leaves	43	2.03	1.88	0.92
openig ceremony II	34	2.55	1.558	0.61
soccer	27	1.776	1.2	0.67
	S/N (dB)	entropy(bps)	entropy(bps)	after NR/before NR

Table 1. Entropy reduction ratio before and after noise reduction for HDCT codec

The entropy reduction for the HDCT codec is also measured and the result is shown in Table 1.

The entropy reduction by the proposed noise reduction is achieved by comparison of the entropy for the HDCT codec before and after the noise reduction. An ratio of entropy reduction of about 3/4 is obtained for several sequences.

The application of the proposed filter not only for the pre-processing of the digital codec but also for the post-processing of the video transmission system thus appears to be promising.

5. Conclusion

The introduction of the statistical technique for the separation of the noise and the picture improved the accuracy of the detection of the noise level in real TV pictures. By setting the noise level, the dc-shift noise reducer can be used for real moving TV pictures.

The nonlinear filter used for the moving area is based on the ε -filter, which reduces noise by averaging the neighboring pixels within a small difference from the target pixel.

We modified a dynamic optimization method for the threshold criteria of the ε -filter using the local and global noise levels. The logical selection of local and global noise levels gives better criteria for the ε -filter. The combination of these two developments improves the performance of the dc-shift noise reducer. The entropy measurement showed promising results for improving the picture quality of digital codecs. The new noise reducer was found to be promising not only for analogue TV systems, but also for digital TV systems.

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[illegible] (SUMO sequence

Fig.7 Median filtered image

Fig.8 ε -filtered image

Fig.9 DC-shift noise reduced image with median filter

Fig.10 DC-shift noise reduced image with ε filte