A NEW VIDEO NOISE REDUCTION ALGORITHM USING SPATIAL SUBBANDS

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ABSTRACT

Noise filtering in television receivers provides an attractive feature, especially under sub-optimal reception conditions. This paper describes a concept of temporal recursive noise filtering in video signals for a standard interlaced TV environment based on the visual noise perception characteristics and on different processing modules in the spatial subbands. The subband (highs and lows channels) oriented algorithm allows optimal noise filtering based on a 2-channel-model of the human visual system. An adequate combination of two different subband based motion detection techniques is proposed. Therefore, different procedures in the highs and lows channels lead to results well matched to the requirements of the human visual system. An evaluation of the new concept is included. A comparison to known motion adaptive noise filter techniques shows a significant improvement of the scheme. Experiments using the new noise reduction scheme on MPEG-received video images show that a good quality improvement of noisy source materials can be achieved.

1. INTRODUCTION

Image quality improvement by noise reduction is a fundamental problem in video image processing (Fig. 1). Noise reduction is an image restoration problem in that it attempts to recover an underlying *perfect* image from a degraded copy. Accordingly, in a noise reduction process assumptions should be made about the actual structure of the *perfect* image. Various noise reduction techniques make various assumptions, depending on the type of images and the goals of the image restoration.

Depending on the application, various types of noise can be distinguished (Table 1). Noise may be generated by signal pick-up in the television camera or by film grain in the cine camera. Further noise can be added to the signal by recording or transmission. Channel, recording, film grain and camera (CCD) noise can be modelled as white noise which is usually of low amplitude. High amplitude noise like impulse noise generated through e.g. motor vehicles or satellite transmission requires an individual approach in order to get optimal performance.

This paper descripes a subband (high and low frequency channels) based image restoration algorithm to enhance video images corrupted by white additive noise which can reduce the efficiency of e.g. image compression or object recognition.

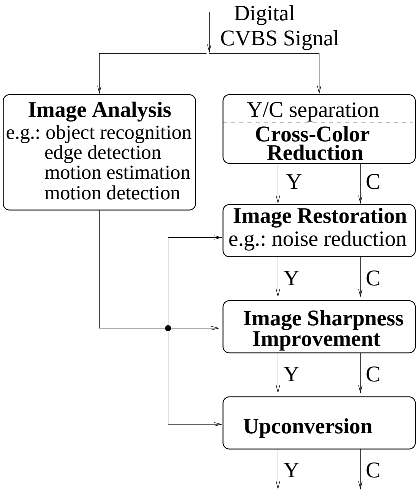

Figure 1. Video image enhancement

The goal of the new algorithm is to 'clean' image sequences from noise so that the subjective quality of transmitted video will be improved in order to get a clear detail and object representation:

1) Lines, details and edges are sharp,
2) Object motion is not blurred.

Assumption 1) is fundamental for the performance of many image restoration techniques. The second assumption is important especially for temporal recursive image restoration techniques. To minimize the conflict between the aforementioned goals, several motion and signal adaptive noise filtering algorithms have been investigated [5, 8]. Oriented on these goals the new motion adaptive and subband based noise reduction algorithm was developed.

2. NOISE REDUCTION ALGORITHMS

In general, noise reduction of image data is realized by linear or nonlinear operations on correlated picture elements. This can be achieved by temporal, spatial or hybrid algorithms (Fig. 2).

Many spatial noise filter techniques replace each pixel using functions of the pixel's neighborhood. Because image detail and noise usually have common frequency components, they are not separable in the frequency domain. Linear filters therefore tend to blur edges of objects and details. To minimize the conflict between sharpness, smoothing and motion blur, several signal adaptive and object

Origin	Interference type
Sampling • camera (CCD), film grain	 white noise
Recording • video tape noise • tape dropout, film damage	 white noise impulsive noise
Analogous transmission • channel • satellite	 white noise pattern noise
Digital coding (MPEG)	blocking, dirty window, ringing, mosquito effects
Digital transmission (DVB)	Gaussian noise ($\rightarrow$ faulty bits)

Table 1. Noise and artefacts in video signals

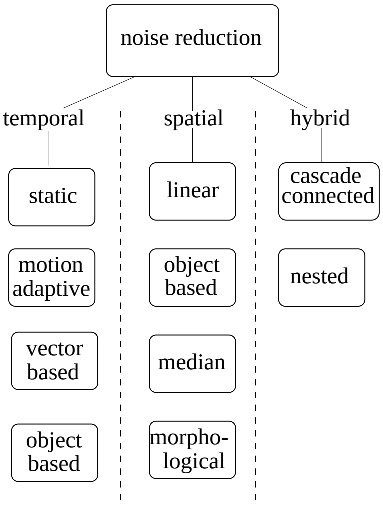

Figure 2. A classification of noise filter

based noise filter algorithms have been introduced.

Median filters are nonlinear operators causing no edge sharpness loss in the smoothed image. Depending on the structure of their masks median noise filters can degrade small details at the same time suppressing impulse noise [5].

The fundamental idea behind morphological image restoration is the opening and closing [5] of the input image in a way that object structures and noise can be distinguished. But the use of morphological filters is limited by their tendency to degrade important details.

For high quality video applications motion based (adaptive or compensative) temporal recursive noise filters are proposed [2] [3]. Fig. 3 shows the basic concept of a first-order temporal recursive noise filter where MAC is the motion adaptive control unit which increases or decreases the parameter k according to the detected motion. The filter output $g(t)$ is defined as given in eq. (1)

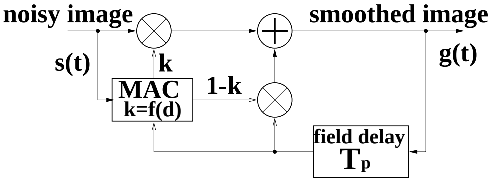

Figure 3. Temporal noise reduction

$$g(t) = ks(t) + (1-k)s(t-T_p) \qquad (1)$$

where $s(t)$ is the input luminance signal and T_p is the picture period of the video signal, which is 20ms in a 50Hz video system.

The parameter k can be controlled with a motion detector or a motion estimator which determines the motion between an image and its predecessor. The amount of (unweighted) noise reduction R in dB can be given [2] as in eq. (2).

$$R = 10\lg\left(\frac{2}{k} - 1\right) \qquad (2)$$

In motion compensating algorithms [3] motion vectors are estimated and used to displace the pixels of the previous image to generate an approximation of the current one. Then the remaining differences between these images are processed to control the filter. The advantage of compensating techniques is that they eliminate the blurring due to non-compensating temporal concepts suppressing e.g. fine details.

Because of the expensive implementation of vector based noise filtering techniques motion adaptive filters are necessary to prevent smearing of moving objects using temporal recursive filters. The image difference $d(t)$ can be expressed in general as given in eq. (3) where N describes an area around the current pixel and LP gives a low pass function.

$$d(t) = \mathrm{LP}\left(\sum_N |[s(t) - s(t-T_p)]|\right) \qquad (3)$$

High performance hybrid spatio-temporal 3-D noise filter are used to achieve results that highly meet the requirements of high-end video sets. In high quality cascade based noise filters spatial filters can be connected with motion based temporal filters. For error tolerante motion based techniques hybrid nested noise filters can use spatial filter as fall back mode.

3. VISUAL NOISE PERCEPTION

A spectral weighting function for image noise describes the perception of noise with respect to its spectral distribution. For different video systems the image quality degradation by noise has been subjectively evaluated and several weighting functions have been proposed [4] [6].

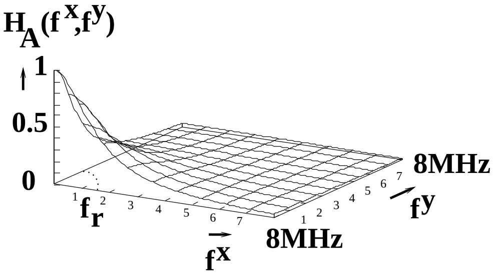

Figure 4. Random noise weighting function

In general, noise impairing a video signal has a flat spectrum for both the spatial and the temporal frequency domains as it is given e.g. for a CCD camera. Consequently, a weighting function should be expanded to 2-D or 3-D domains. Eq. (4) und Fig. 6 illustrate the 2-D weighting function proposed in [6]. Here f_r is the cutoff frequency, f^x and f^y are the spatial vertical and horizontal frequencies. Here, vertical as well as horizontal frequency components have been taken into account.

$$H_W(f^x, f^y) = \frac{1}{1 + \frac{f^{x2} + f^{y2}}{f_r^2}} \qquad , f_r = 1.5\text{MHz} \quad (4)$$

According to the scheme of the aforementioned noise weighting function the perception of the human eye with respect to spatial lower frequencies is more sensitive for noise or artefacts than in high frequency directions. Therefore, for a perception based adapting and optimization of noise filter the reduction process can be splitted in two parts: the low and the high frequency processing (in the following also called 'lows' and 'highs').

Concepts using separated channels for video applications (e.g. upconversion techniques) have been proposed [7, 1]. In general the separated highs and lows processing techniques are oriented to a 2-channel model of the human visual system yielding for the spatial highs a low temporal resolution and a higher temporal resolution for the lows [7]. This general concept combined with the weighting noise function approach meets the characteristics of the human noise perception so that effective noise reduction can be achieved.

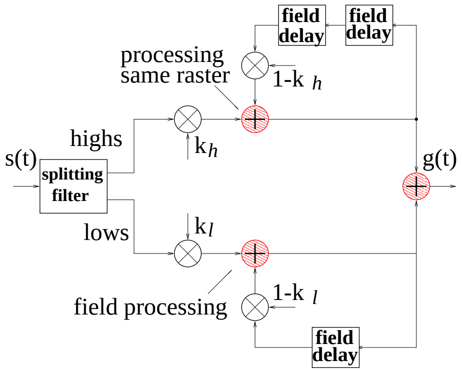

Figure 5. Subband noise processing

Fig. 5 shows a basic proposal of subband based noise filter where k_h and k_l are the reduction parameters in the highs respectively lows. Video signal processing in standard interlaced systems has to be performed taking into account the different field rasters. Since the highs hold high spatial resolution field processing using the same rasters is proposed. Because of the high temporal resolution in the lows a first-order recursive noise filter is preferred. Owing to the described weighting noise function the variables k_h and k_l can be separately determined.

4. A SUBBAND BASED NOISE FILTER

A motion adaptive noise filter averages similar areas in successive images. The proper image information is highly correlated and added linearly, whereas the noise is uncorrelated and fails by adding. However, image correlation breaks down when there is movement in the input sequence. Hence, it is important to use a motion detector to reduce the recursive portion when motion appears. The MAC (Fig. 3) detects the amount of motion between the actual input image and the delayed image and translates it monotonously into k. Fig. 6 shows a proposal of several curves for the translation where k is a function of the field difference d. Here d_{max} is the maximal image difference.

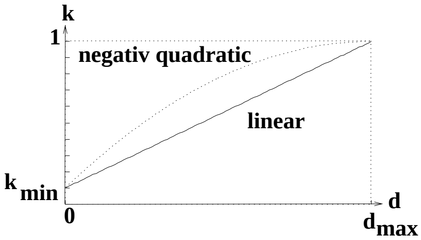

Figure 6. The applied MAC characteristics

The subband based process is controlled by the underlying image informations. The highs channel contains vertical high frequency image details which can't be optimally represented in an interlaced field based procedure. Therefore, a processing using the same field raster is preferably implemented in order to preserve especially the vertical high frequency details. Seeing that the human eye has a low sensitivity for spatial high frequency noise less noise reduction is realized e.g. using the negativ quadratic curve. The remaining noise is compensated of the eye according to the noise weighting function.

As the lows with high temporal resolution are essential for the human visual perception a field processing is carried out so that the temporal lows are recovered by averaging in direct successive fields. Because the human eye perceives strongly noise and artefacts in the lows channel the filtering in the lows is strengthened using a fitting lows MAC (e.g. using the linear curve). For the compensation of the interlaced recursive part in lows field processing a spatially or interfield dominated median reinterpolation is feasible.

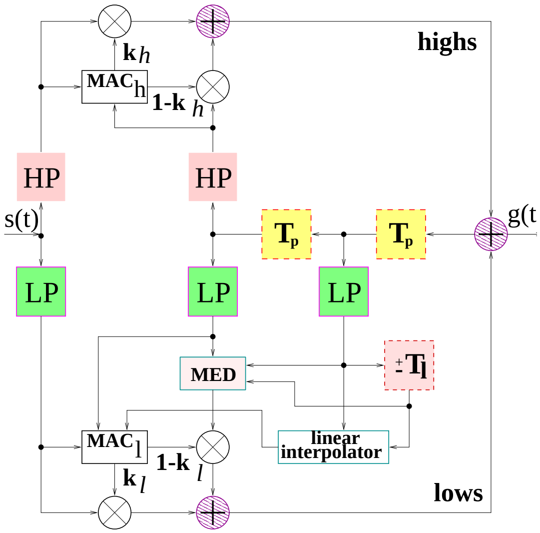

Figure 7. Block diagram of the new Filter

The whole filtering concept is summarized in Fig. 10 where LP, HP are the low respectively high pass for the subband splitting, T_l is a line memory, MAC_h, MAC_l are the motion adaptive control units in the highs respectively lows and MED is a 3-tap intrafield dominated median filter for the reinterpolation of lines.

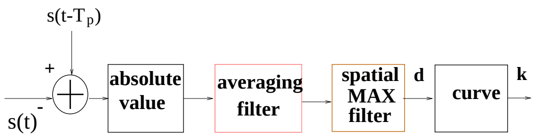

Figure 8. Basic concept of motion detection

The concept of the applied control units (Fig. 8) is a spatial filtering of the signal difference firstly by averaging and secondly by maximum filtering. The averaging causes a linear addition of the correlated true image data, whereas the noise is uncorrelated and fails by adding. Hence, the motion detection becomes less sensitive for existing noise. The maximum filtering causes that the motion detection is bounded to a certain area around the current pixel. Thus, the motion detection becomes robust.

5. EVALUATION OF THE FILTER

The Peak Signal to Noise Ratio PSNR as defined in eq. (5) is a standard criterion for objective noise measuring in video systems. Here NM denote the image size, $s_p(i,j)$ and $s_r(i,j)$ denote the pixel amplitudes of the picture and the reference image at the position i,j. The PSNR gives here the Signal-to-Noise-Improvement in dB (unweighted with respect to the visual perception).

$$\mathrm{PSNR} = 10\lg \frac{(255)^2}{\frac{1}{NM}\sum_{i=1}^{N}\sum_{j=1}^{M}\left(s_p[i,j]-s_r[i,j]\right)^2} \qquad (5)$$

The new filter has been tested using the PSNR-method in the way that white noise is added to a 'clean' reference image sequence. The resulting PSNR of the noise reduced image sequence gives the average PSNR over the images of the sequence. Fig. 9 shows that compared to basic adaptive noise filters the separeted highs and lows concept yields an improvement of about 3dB. Even when video sequences are corrupted by strong noise levels the filter stays robust (e.g. by PSNR$\approx$ 26dB, $R \approx 3.5$dB).

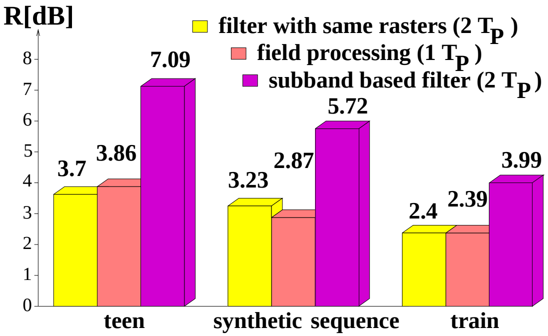

Figure 9. Objective results of the noise filter

Considering the human visual system which is a nonlinear system a lot of visual phenomena can't be described totally by an objective criterion. Therefore, subjective tests are important for a fair evaluation of enhancement filters. Subjective tests of the new algorithm showed that image sequences are improved according to the goals given in section 1.

The new subband based temporal filter has also been tested in a digital transmission environment, showing that a good quality improvement of noisy source materials decoded with MPEG-2 decoder is achieved. Experimental tests showed that decoded noisy sequences are still noisy so that a subsequent noise reduction process is feasible. The proposed noise reduction scheme delivers fair results as first experiments have shown.

6. CONCLUSION

This paper has presented a subband based algorithm for image noise reduction oriented to the requirements of the human visual system and on the human noise perception characteristic by adequate different processing techniques for the separated high frequency and low frequency branches.

The objective evaluation of the new algorithm and the comparison with known temporal noise filter has show a significant quality improvement. The robustness of the new filter is achieved even when the video sequence is corrupted by strong noise levels.

The subband based filter has also been tested in a digital transmission environment (MPEG), showing that a good quality improvement of noisy source materials can be achieved.

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