Methods for Picture Quality Improvement : Aspects on Co-channel, Random, and Impulse Noise Cancellation

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ABSTRACT

With the industry wide adaptation of the Ghost Canceling Reference (GCR), commercial products for high quality video ghost cancellation have become practical for the cable operators at their headend. However, co-channel interference accounts for as much as one third of all reception problems. Further, both impulse and random noise related picture impairments are a concern for quality conscious operators. With the cost of high speed digital signal processing becoming more affordable, innovative and powerful real time processing techniques can now be applied for enhancing picture quality.

While mathematical modelling of co-channel interference is at its conceptual stage, it is well known that the primary impact on the picture degradation is related to carrier beat and horizontal line frequency harmonics. Significant improvement of co-channel interference impairments can be handled by addressing these problems.

Expensive studio quality products are available today for the reduction of both impulse and random noise impairment. These devices employ a combination of frame storage, impairment detection, and impairment concealment using substitution and/or averaging techniques.

With the progress being made in digital video compression and HDTV many of these techniques can be re-examined with the economy of the cable operators in mind. This paper examines the status of the technical community in these challenging areas.

INTRODUCTION

This paper describes specific methods for picture quality improvement for motion video in television signals with respect to co-channel, random, and impulse noise impairments. The first section deals with the effect of co-channel impairments and application of transversal filters for improvement. In the next section, a non-linear digital filtering technique is introduced, and its application in impulse noise filtering is explained. A recursive filter for random noise filtering is then introduced along with motion detection techniques for reducing the artifacts of such filters on video signals. Finally, the paper concludes with a proposal on a complete video enhancement system that applies the techniques discussed in the paper.

CO-CHANNEL INTERFERENCE SUPPRESSION

While co-channel interference would seem to be difficult to suppress due to the constantly-changing characteristics of the interfering signal's picture content, the most visually perceptible interference component is a "beat" which is the difference in RF carrier frequency between the desired and the interfering signals. Considering the frequency tolerance of each carrier plus the specified frequency offset (if any), the frequency difference can exceed 20 KHz. The simplest form of co-channel interference suppression could therefore be a sharp notch filter tuned to the interfering carrier.

In practical applications, the beat frequency varies constantly due to small changes in carrier frequencies; a sufficiently sharp notch filter is difficult to realize at RF; and the filter skirts may interfere with the desired signal.

These limitations may be overcome through the use of state-of-the-art digital transversal filters operating at baseband, such as those used for video echo cancellation. These adaptive digital filters are reconfigureable to follow a changing beat frequency, and they also permit additional filtering for removal of line-rate (15 KHz and harmonics) components in the interfering signal.

As in the echo-cancellation system, while the baseband video filtering must be done in real-time, the interference analysis and filter coefficient calculation may be done "off line" using conventional DSP processors and algorithms which operate at speeds which are inappropriate for real-time video applications. A real-time capture buffer permits the analysis routines to operate at a reduced speed appropriate to the echo's rate of change; typically, the filter coefficients are updated every two to eight seconds. This performance level would also be appropriate for the detection and suppression of beats generated by the co-channel interference.

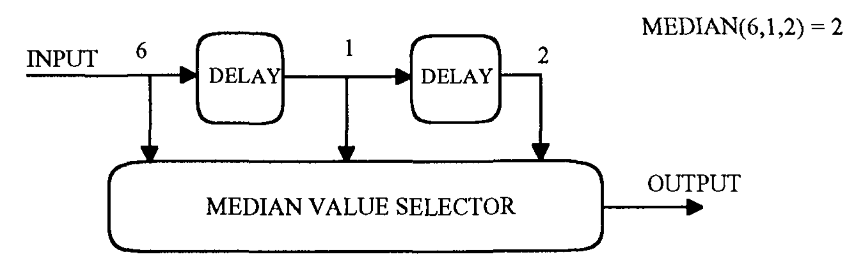

FIGURE 1: ONE DIMENSIONAL MEDIAN FILTER

NOISE REDUCTION USING NON-LINEAR SIGNAL PROCESSING

Impulse noise in video signals can come from film scratches and dust, film grain, drop-outs, tape noise, cross color and cross luminance . Application of common digital filters, like transversal and recursive, does not usually produce desired impulse noise reduction without band-limiting the video signal as well. *Median filtering* of video signals provides a powerful alternative for noise filtering in these cases. A median filter provides error concealment by detecting a picture element that is disturbed by noise and substituting it with a picture element from the neighborhood that is less disturbed. Non-linearity in a median filter comes from the fact that a substitution is done rather than averaging. Non-linearity in a signal processing chain generally produces distortions, harmonic waves, and other defects; however, three dimensional median filtering utilizing statistical linkage of neighboring picture elements is found to be suitable for video signal improvement without visible artifacts. It is also suitable for disturbances due to bit errors or drop-outs.

Block diagrams of a first order median filter and its response to an input with a spike are shown in Figures 1 & 2. Properties of a median filter are better analyzed in time domain as frequency domain will not make much sense. As can be seen from the figures and from the functional properties, the transfer function for a step response of a median filter is unity, and its impulse response is zero. While a conventional low-pass filter affects the rise time or overshoot, a median filter

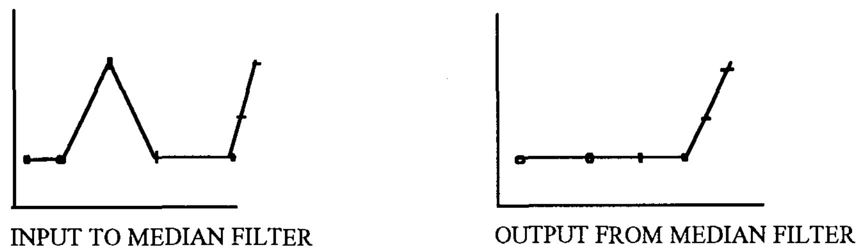

FIGURE 2 : IMPULSE NOISE SUPRESSION IN MEDIAN FILTER

response is dependent on the input signal waveform with unity transfer function or "zero" transfer function; here the zero transfer function will result in substitution establishing a correlation of adjacent picture elements that were lost or disturbed due to noise.

The application of a one-dimensional median filter, while providing a noise reduction of about 3 dB, also attenuates higher horizontal spatial frequencies and presents aliasing problems. Most of these problems are overcome in a two dimensional median filter where picture element susbstitution is influenced by both horizontal and vertical neighbors. The selection of adjacent picture elements from a cross-shaped window is known to give a good compromise between noise filtering magnitude and undesirable aliasing effects. This is due to the fact that any horizontal or vertical structure or outline in a picture automatically produces unity transfer function (or transparently passes through) in a median filter. If the window were to be a square, this would not be the case resulting in artifacts. The two types of windows for two dimensional median filtering and their noise reduction factors are shown in Figure 3.

A three dimensional median filter further reduces the artifacts as the central value is correlated in horizontal, vertical, and in time. The temporal filtering in this case generally will not produce smearing effects of moving pictures as there is no feedback; further as temporal direction assumes an extreme amplitude rank in the filter window, the median value sought is closely correlated to local surroundings. However, the median filter does have a problem in the case of moving pictures with high content detail; this may not be a big factor due to the fact that there is reduced local resolution in the eye while observing motion. In any case, 2 to 1 interlacing in television signals produces motion aliases for high vertical frequencies.
The resolution of three dimensional median filter can be improved by using sub-pixel averaging for neighboring signals. Here a sub-pixel value is determined by interpolation and can be thought of as an FIR filter in the horizontal direction, a line comb filter in the vertical direction, and a frame comb filter in the temporal direction. By special design of the filter window, even regular disturbance

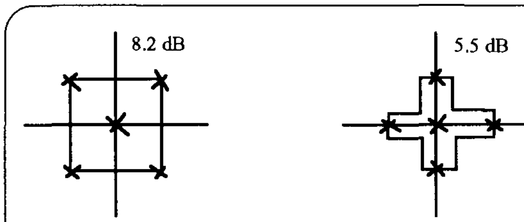

FIGURE 3 : MEDIAN FILTER WINDOWS

structures like cross color and cross luminance can be suppressed.

NOISE FILTERING USING LINEAR SIGNAL PROCESSING

The addition of noise to a video signal happens at the source (e.g. thermal noise in a camera), the transportation system (e.g. signal-to-noise ratio of distribution amplifiers), and by the receiver circuits. Noise reduction can be accomplished in video signals without any impairment to spatial resolution by averaging successive pictures. Such an averaging amounts to a temporal low-pass filtering which is easily implemented using digital transversal filters as shown in Figure 4. The noise reduction factor can be increased simply by adding many picture delay elements.

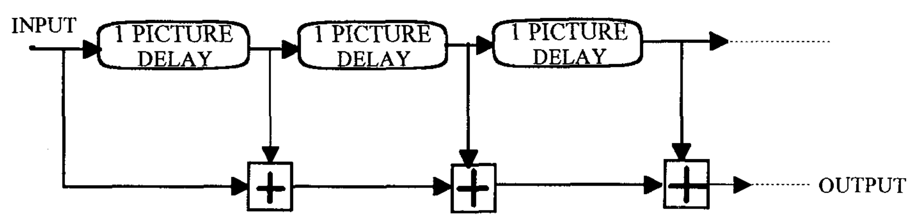

FIGURE 4: DIGITAL TRANSVERSAL FILTER FOR NOISE REDUCTION

Alternatively, a recursive filter that requires a single picture element delay can be used as shown in Figure 5. Here a fraction ***K*** of input and a fraction ***1- (1/K)*** of the previous output are combined to form the present output. Notice that when ***K = 1***, the effect of temporal low-pass filtering is eliminated and the input is transparently passed to the output. Noise power reduction around 8 dB can be achieved for a ***K*** value of four.

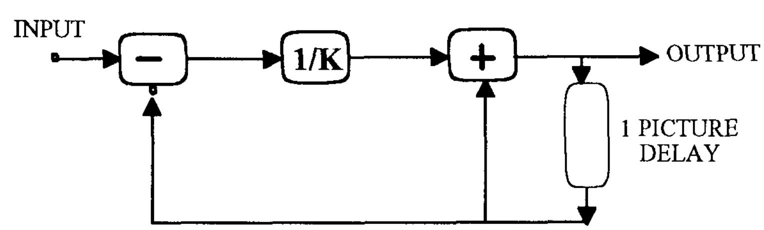

FIGURE 5 : RECURSIVE DIGITAL FILTER FOR NOISE REDUCTION

The filters shown in Figures 4 & 5 perform adequately for still pictures; however, smearing effect similar to long persistence picture tubes will occur for motion pictures, making these simple approaches generally unacceptable. By using motion detection techniques, the digital filtering circuit shown in Figure 5 can be modified to include a control circuit that produces a smooth variation of factor ***K*** from the set value to unity at areas of the picture where a degree of motion is sensed. A block diagram of a filter that compensates for motion while accomplishing noise reduction in stationary areas is shown in Figure 6.

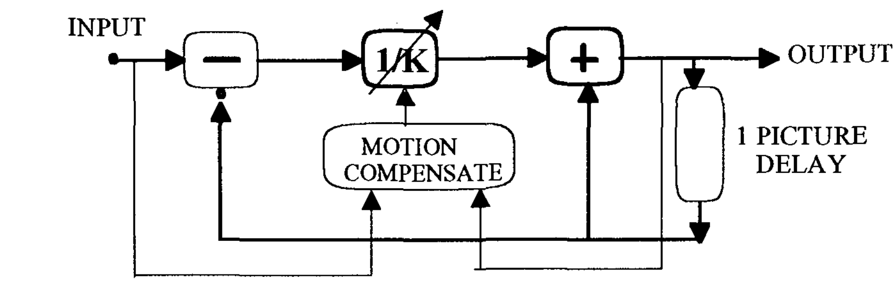

FIGURE 6: NOISE REDUCTION FILTER WITH MOTION COMPENSATION

The motion detector works on the principle that when adjacent pixels are averaged, the probability distribution of white noise which is Gaussian will have its variance shifted due to movement amplitudes in picture. The spatial filter that forms an equal-weight sum of ***n*** terms , triggers a control function for ***K*** which provides a smooth variance to unity from the set value, thus reducing the effect of noise reduction filtering in areas of motion.

A COMPLETE VIDEO ENHANCEMENT SYSTEM

A complete video enhancement system that can be built on top of a Philips VECTOR Video Echo Canceller is shown in Figure 7. Such a system adds only incremental cost to the existing hardware while providing extensive performance enhancements. The additions to the current echo cancelling system are the co-channel trap filters, 3-D median filters, and possibly a noise reduction filter with motion sensing and compensation. The co-channel trap filters can be realized using the same powerful and flexible integrated circuits used in the VECTOR product. These filters are programmable in both FIR and IIR configurations, and contain an extensive number of taps for complex transfer function implementation. Algorithms for co-channel beat product trap filters are currently under

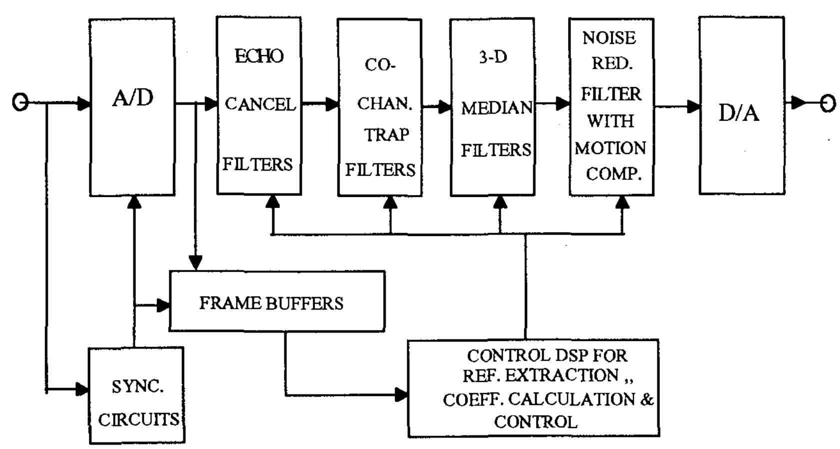

FIGURE 7 : A COMPLETE VIDEO ENHANCEMENT SYSTEM

investigation. The addition of a three dimensional median filter will provide noise reduction but will require hardware for a real-time frame memory architecture. Hardware for noise reduction using linear filters with motion detection and controls is under consideration.

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