CAN VIDEO NOISE REDUCTION SAVE MONEY?

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Abstract

In this paper we discuss the results of research aimed at making the reduction of signal impairments such as thermal noise, composite triple beats (CTB) and composite second order beats (CSO) inexpensive enough for inclusion in DVC set-top converters and other consumer equipment. Simple algorithms which reduce thermal noise, CTB, and CSO by approximately 7 dBs have been developed and demonstrated. Subjective visual improvement is frequently better than actual SNR measurements would imply. Several potential implications of this development on the operations and economics of cable systems are briefly discussed.

Introduction

Inspired by support from Rogers Canadian Cable Labs Fund, the group at U.B.C. which is headed by one of us (Ward) has been researching and developing techniques to detect, measure, and reduce a number of common visual impairments to television signals since 1990. Some of the earlier theoretical and experimental work has been reported elsewhere.[4, 5, 6]

In the past three and a half years we have employed digital signal processing techniques to detect, measure and reduce thermal noise, composite triple beats (CTB), composite second order beats (CSO), impulse noise, co-channel interference and single frequency interference.

Our previous publications have focussed on the theory behind the processes and have reported on our ability to detect the presence of the impairments automatically. Our work during the past year has been directed primarily towards noise reduction. This is because both we and our sponsors, Rogers Cablesystems, sensed that with the advent of Digital Video (de)Compression (DVC) set-top converters, the rather complex digital electronics which these devices embody might be put to good use improving ordinary TV pictures when subscribers were tuned to conventional analog broadcast stations, or were watching programming played back on conventional VCR's.

In this paper we discuss some results of this work, and finish with a brief consideration of some of the implications for cable television service providers and their subscribers.

Background

A variety of techniques for reducing Gaussian (or thermal) noise in television and motion picture signals have been developed and applied over the years. For the most part, as with the digital compression process, these algorithms have not been applied in real time. Rather the process has taken place off line, with the results recorded for later play-back in real time. Notwithstanding, some real time studio and head end equipment targetted at some specific signal impairments, such as impulse and thermal noise, has recently appeared on the market.

Our research group had, in the past, been more interested in developing accurate video signal impairment detection and measurement algorithms, a process which does not involve real time processing of sampled video data. The question we asked was whether the algorithms we had developed for these tasks could be simplified enough to work in real time using a low cost chip or chip set affordable by cable subscribers.

Procedure

Working with calibrated Betacam tapes produced with the assistance of Brian James at the Cable Television Laboratories Inc. test facility in Alexandria, Virginia, we developed efficient techniques which reduce the visual appearance of the major video impairments encountered in cable distribution plants. We have studied each impairment and found appropriate algorithms which cancel or significantly reduce the visual appearance of each of these impairments or a combination of them. Our universal algorithm also slightly enhances the picture's visual appearance. None of our algorithms introduces any visible changes in the picture. Our techniques involve processing the frames in the spatial and time dimensions. Each frame is first processed spatially, and then consecutive frames are processed together. The inter-frame processing involves detection of motion in the sequences. The algorithm specifically developed to cancel composite second order beats when incrementally related carriers (IRC) or harmonically related carriers (HRC) transmission systems are used requires finding the frequency spectrum of sequential lines of the video signal.

The rationale behind cancelling the CTB impairment depends on the idea that over a small region of any line of the picture, the CTB may be approximated as a constant luminance signal. Thus the effect of the CTB impairment over such a small segment of a line in the image may be modelled as a change in the DC luminance by an (unknown) constant over that signal. To filter out that constant, the digital signal is divided into vertical stripes or sub-pictures. The average intensity of the signal in each line of the sub-picture is determined. These average intensities are then filtered by a sliding averaging window of length equal to 3 or 5 pixels. The filtered value of each average intensity is then assumed to be the corrected DC level of the corresponding line in the sub-picture. In order to further improve the noise reduction, one can apply a multiframe CTB removal scheme. The average of the DC level in a given line in a given sub-picture is based on the average of the same line in the consecutive frames of the sequence. This method, and a slightly modified version of it, are also found to be able to measure the carrier to noise ratio of CTB-impaired pictures within ±2 dB's. For measurement purposes, the advantage of this technique is that it is non-intrusive.

To reduce thermal noise, inter-frame averaging is most efficient. One of the practical constraints is the number of frame buffers used. In order to achieve 10 dBs reduction in the signal-to-noise ratio using direct averaging, ten frames are required (provided there is no motion in the scene). We have modified the direct averaging process so that similar performance can be obtained using only four video frames.

The algorithm for reducing CSO also uses spatial and time directions filtering. However for IRC or HRC transmission systems, much better results are obtained using a notch filter in the frequency domain. When notch filtering is used, algorithm parameters have to be chosen so that the continuous Fourier transform and the discrete Fourier transform yield exactly the same results within a scaling constant.

To reduce the computational complexity in order to meet demanding cost constraints on the hardware if it is to be implementable in DVC set-top converters, the different algorithms for reducing CTB, CSO, and thermal noise have been modified, significantly simplified, and combined into one algorithm. The resulting universal algorithm achieves different values of noise reduction depending on the allowed cost of the hardware, the SNR, and the type of signal impairment, but a good working performance improvement estimate would be 7 dBs. Video clip samples of the results obtained will be presented during the paper presentation. Those reading the paper will have to rely on the less satisfactory evidence of the still photographs of frames included in this paper.

Results

The photographs shown on the next four pages of this paper illustrate the results of the noise reduction process. All the pictures presented herein are modified by the same universal algorithm. Our process works equally well with colour and black and white sequences. Regretably, the static nature of the photographs, combined with noise introduced by the page reproduction process, make it difficult for the viewer to gain a true appreciation of the degree of noise reduction from the photographs. Those present at the paper presentation will be able to view complete video sequences from which these results are drawn.

It should be noted that employment of these noise reduction techniques frequently results in the addition of "noise" elsewhere in the signal, usually in a fashion which is not visually objectionable, and which may even be picture enhancing. Indeed, the image enhancement process is, by definition, the addition of some carefully constructed "noise", in the sense that it is not a part of the signal. Thus, when considering the performance of noise cancellation algorithms, improvements in SNR are not usually good metrics of performance. It is essential to view the actual results.

Discussion

The signal processing techniques described above require the following:

- an A/D converter;
- a microprocessor,
- up to 2 Mbytes of memory,
- special purpose custom circuitry,
- a D/A converter

MPEG-2 DVC set-top converters already contain a microprocessor of adequate power, a D/A converter, and 2 Mbytes (or 16 Mbits) of memory if they comply with the Main Profile, Main Level of the standard (i.e. are B-frame compatible). These are likely the most expensive components if a stand-alone analog video signal noise reduction system were to be developed.

Our experimental results leave us confident that custom silicon circuitry comprising 30,000 to 50,000 gates would be adequate to provide well over 6 dBs of noise reduction for thermal noise, CTB, CSO, and potentially some other impairments. Using current technology, this can easily be accommodated on a single chip, or even a part of a chip. Chip clock speeds of about 40 MHz. are believed to be adequate for the task. Appropriate A/D converters are inexpensive. It is thus feasible to think in terms of a $20 incremental selling cost for MPEG-2 set-top converters fitted with analog video noise cancellation for these impairments.

When IRC or HRC transmission systems are used, CSO noise reduction (almost to the point of total elimination) is possible, but the process presents a greater technical challenge. Although CSO noise reduction of 10 dB's or more can be obtained, today at least, the algorithm requires the use of high speed FFT chips which are costly even in mass production.

The ability to reduce video noise at the set-top converter (or further upstream in the cable system) has some interesting economic and service implications. Among them are:

Picture with Thermal Noise (C/N = 35 dbs)

Cleaned Picture

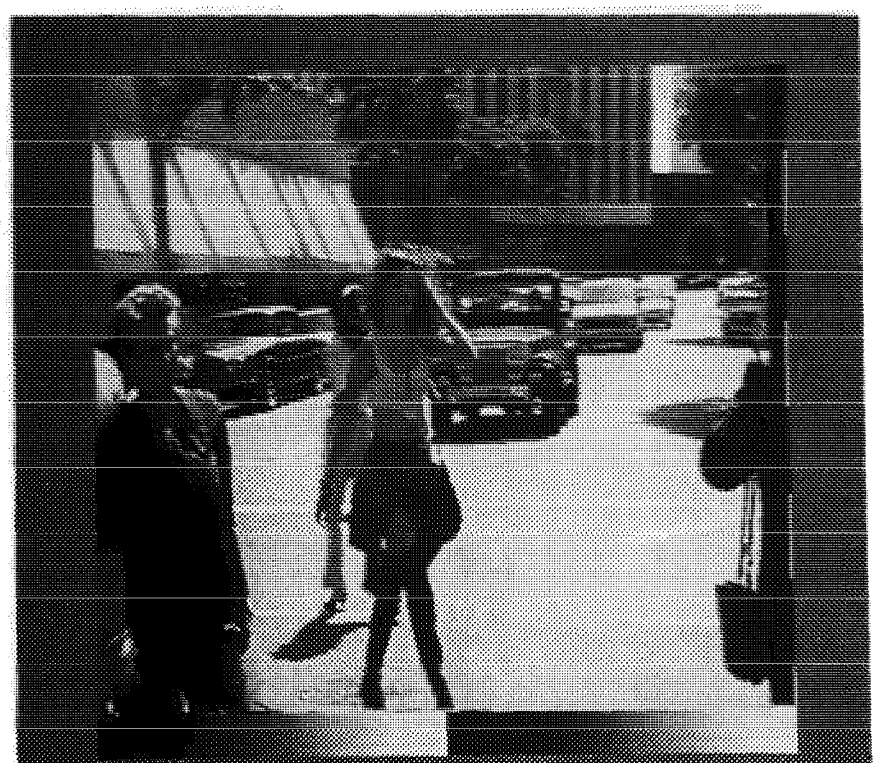
Picture with CTB and Thermal Noise (C/N = 35 dbs)

Cleaned Picture

Picture with CSO and Thermal Noise (C/N = 35 dbs)

Cleaned Picture

Picture with CSO, CTB and Thermal Noise (C/N = 35 dbs)



Cleaned Picture

1. DVC Converter Penetration Rate Enhancement

Initial penetration of DVC converters will be small, but there are strong financial incentives for cable service providers to move rapidly towards higher penetrations. There are some who predict that subscribers who have access to good quality digital satellite video signals will become dissatisfied with the technical quality of analog video signals currently delivered by cable. We believe that the techniques described in this paper could provide the cable industry with a practical response to this criticism, while at the same time giving subscribers yet another reason to obtain a DVC set-top converter.

Paradoxically, another potential incentive for boosting penetration may be to offer subscribers a feature which reduces the noise on a competitor's product, i.e. VCR cassettes obtained from video rental stores! Viewers of these cassettes typically experience thermal-like carrier to noise ratios of 30 to 40 dB, depending on the quality of the cassette and of their playback machine. By providing for a VCR input to the converter (and using the same noise reduction algorithm), subscribers could have access to cleaner rental videos. The potential effect of such an incentive on the penetration rate of DVC converters, and on the sale of DVC pay TV products is highly speculative, but, in our view, is likely to be significant, especially once viewers become accustomed to virtually noise-free digital TV programming.

2. Noise Cancellers at Nodes

The installation of increasing amounts of fiber trunking has led to a corresponding increase in concern about CSO, especially in the mid-band frequencies. A bank of noise reduction filters located at critical nodes offers a potentially attractive means of meeting noise specifications at a low cost per subscriber, while simultaneously obtaining a noise measurement and performance monitoring capability. However, while technically feasible, the additional cost of down conversion and subsequent up conversion of channels selected for noise reduction could render this approach economically infeasible in practice.

3. Noise Reduction through In-Home Noise Cancellation

As the penetration of DVC converters increases, it becomes possible to factor the noise reduction from set top converters into plant engineering calculations. For example, it may be possible to engineer capacity upgrades (e.g. from 330 MHz to 450 MHz) while conserving existing amplifier spacings (for cost savings of from \$15-\$25 per home passed or roughly \$24-\$40 per subscriber[7]). This could be done through the provision of DVC converters to the relatively small percentage of customers in high noise segments of the system, thus postponing expensive plant rebuilds to a more propitious time from a business point of view. System operators could, in such circumstances, de-activate the digital pay per view function of the DVC converters for non-subscribers to the service.

Conclusion

It would appear that the utilization of analog video noise reduction systems could have a substantial favourable impact on cable plant financial returns and investment, as well as on subscriber satisfaction.

We are of the opinion that there is a good parallel to be drawn between the audio noise reduction circuitry which is now widespread in the audio industry and the kind of video noise reduction circuitry which is discussed in this paper. In time, such circuitry will be incorporated into television sets and VCR's. Of course eventually, and perhaps as early as 2004, analog TV signals will be replaced by much more noise-free digital TV.

But at least until 2004, and perhaps well beyond that time, there will be noisy analog video signals which will be improved by noise reduction.

We believe that it is best for the industry if noise reduction know-how be made generally available in a fashion which enhances the speed of its development and promotes a commonality of approach. To that end, a new company (Ward Laboratories Inc.) has been established which has negotiated a licensing agreement with the University of B.C. for the purpose of accelerating the development of video noise reduction techniques in collaboration with interested commercial entities.

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Footnotes and References

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[4] R. K. Ward and Q. Zhang, "Automatic Identification of Impairments Caused by Intermodulation Distortion in Cable Television Pictures", *IEEE Trans. on Broadcasting, vol. 38, no. 1,* March, 1992, pp. 60-68.

[5] Q. Zhang and R. K. Ward, "A Non-Intrusive Scheme for Measuring the Signal-to-Noise Ratio of Television Pictures", *Proc. of the Can. Soc. of Elect. & Comp. Engineers Conf.,* Vancouver, Sept., 1993, pp. 656-659.

[6] P. Shi and R. K. Ward, "Automatic Recognition of Intermodulation Beat Products in Cable TV", *IEEE Trans. on Broadcasting, vol. 39, no. 1,* Sept., 1993, pp. 318-326.

[7] A penetration rate of 63% has been assumed.