41.2: Quantification of Temporal Threshold Noise in TV Display

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ABSTRACT

The time-varying speckle pattern due to temporal broadband noise presents an objectionable artifact in television viewing. This paper reports on research on that problem, performed on a video processing supercomputer at the National Institute of Standards and Technology (NIST). The research quantified the threshold signal-to-noise ratio (SNR) at which such temporal noise becomes visible, as a function of the mean and standard deviation of the background image. Data were taken using a large number of viewers, some trained and others untrained, observing both artificial and real TV images. It was found that the threshold SNR can vary between the limits of 29 and 39 dB, depending on the first two statistical moments of the background. Thus, for example, signal processing that changes image luminance levels can sometimes impose a system SNR penalty of up to 10 dB.

INTRODUCTION

"Noise" in television receivers takes on many forms such as ghosting, co-channel interference, chroma/luma interactions and random time-varying broadband noise [1]. Ghosting can be minimized by the use of modern ghost cancellation techniques [2]. If ghosting is eliminated, then the most objectionable noise, especially in fringe reception areas, is temporal broadband noise. This appears as a moving snow or speckle pattern, superimposed on the TV image. Most investigators who have sought a correlation between video signal-to-noise ratio (SNR) and the objectionability of the resulting image, have used measurements or appraisals based on static images derived from individually captured or simulated video frames [3,4]. That does not do justice to the complicated interactions that exist between the temporal and spatial acuity of human observers.

This paper presents preliminary results of an effort to characterize the relationship between broadband video noise and the threshold at which the resulting time-varying fine-pattern noise just becomes visible. For the purpose of this investigation, we divide the image seen on the monitor screen into a sum of two components. There is the desired image that we would like to see free of any noise disturbances. This we refer to as the "time-stationary background image." "Time-stationary" or static indicates that it generally changes much slower than the scintillation speckle pattern generated by broadband video noise. We were interested in the threshold of visibility at which the scintillation becomes just visible. We sought to measure the threshold as a function of two local image properties of the background image: the mean video luminance signal level and the standard deviation of the video signal that generates the static part of the image in a local region. In this research we took advantage of the real-time video simulation capabilities of the Princeton Engine supercomputer at the National Institute of Standards and Technology (NIST).

This relationship between the threshold SNR and the statistical moments of the image has practical importance in television systems. For example, video processing may change the mean video signal in a region of an image. We have found that under certain conditions this results in the pattern due to temporal noise appearing more objectionable. In such a case, even if the candidate video processing does not alter the raw video SNR, the psycho-physical effect on the observer would be equivalent to lowering the input video SNR. From preliminary qualitative experiments, we observed that under certain conditions the noise became more objectionable as the average video signal increased. We wanted to quantify that effect. We were also interested in quantifying the masking effect of the stationary image structure on the visibility of the temporal noise. Hence, we sought to generate plots of threshold SNR as a function of the mean and the standard deviation of the video signal that generated the background stationary image.

DEFINITION OF THRESHOLD SNR

This paper reports on experiments designed to measure the average threshold SNR of a group of observers. This threshold SNR is defined as the temporal video SNR at which the observer can just begin to see the temporally varying scintillating noise pattern against the background. Threshold is expressed in units of dB. The luminous video signal is usually scaled to vary between 0 and 0.7 volts. The convention is to express the amplitude of this video signal in IRE units. Zero volts equal 0 IRE units and 0.7 volts are 100 IRE units. Thus, a SNR of 40 dB would mean that the noise is 1 IRE unit, 1/100 of full scale.

An increase in this threshold value means an increase in the sensitivity of the eye to the temporal noise. For example, suppose that before some video processing this threshold is 30 dB. This means that the observer would not have seen the noise if the SNR were higher, such as 35 dB. If after such processing the measured threshold were to increase to 35 dB, this represents a 5 dB **increase in the noise sensitivity of the eye.** One result that the measurements reported on in this paper showed is that when the mean video level of the

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background is in the mid ranges, in the neighborhood of 50 IRE units, the eye is about 10 dB more sensitive to the noise (the SNR threshold is about 10 dB higher) than in the dark portions of the TV image.

THE EXPERIMENTAL PROCEDURE

The Princeton Engine was programmed to simulate an NTSC (National Television Systems Committee) television system. Temporal Gaussian random noise of known standard deviation was generated via software. This noise was added to a local region of the video image. This region was of programmable size. The standard deviation of the added temporal noise was decreased from a high value until the scintillation of the region of noise, as perceived by an observer, disappeared into the background. The experiment was then repeated by increasing the standard deviation of the noise until it just became visible. These two threshold readings were averaged for each observation. Both trained and untrained observers were used and no effort was made to separate the reactions of the two groups of observers.

An effort was made to have the experiment approximate as closely as possible the conditions specified in the CCIR Recommendation 500-4 [5]. A Sony 19 inch monitor with a pitch of 0.4 mm and a gamma of 2.2 was viewed at 5 times vertical screen height. The monitor had a peak white output of 75 cd/m^2. The output for 0 IRE input was 0.05 cd/m^2 and for 7.5 IRE units the output was 0.29 cd/m^2. The room lighting was incandescent, with 4 cd $/m^2$ of illumination falling on the monitor face. The wall behind the monitor was at approximately 15% of peak monitor luminance.

This paper reports on two experiments. In the first case, the background was a time-stationary, monochromatic, synthetic "image" generated by superimposing onto a uniform illuminance level, a single frame of captured, stationary video noise derived from broadband (4.2 MHz bandwidth) Gaussian noise, displayed over the entire screen. A second speckle pattern, this one temporally varying, was continually generated by broadband Gaussian noise. This was superimposed over the center of the time-stationary background "image," covering an area of size equal to 10% of the screen dimensions, both horizontally and vertically (76H by 48V pixels). The observer controlled a console by which the standard deviation of the temporal noise was varied until threshold was reached. This was repeated for different values of the mean and standard deviation of the video signal of the background. This mapped out a two-dimensional space where one axis is mean background video signal, and the other axis is the standard deviation of the video generating the background pattern. This space was sampled with a grid of 25 points. These 25 points were chosen to cover a gamut so that the mean background varied from 5 to 95 IRE units, whereas the standard deviation of the non-changing background went from 0 to 18 IRE units. Each of 5 observers sampled all 25 points, for a total of 125 observations.

A second experiment used as a background a sequence of local regions from actual captured color video images. Here, a total of 9 regions, of 76 horizontal by 48 vertical pixels, were chosen. The complete set was viewed by 9 observers for a total of 81 observations. The mean and standard deviation of each sample region were computed.

EXPERIMENTAL RESULTS

The results of the first experiment are shown in Figure 1. This was the experiment where some fixed broadband masking pattern was added to the uniform background. The observers noted the threshold of the temporal noise as a function of mean and standard deviation of the background. In this contour plot, the horizontal axis is the mean value of the background in IRE units. The vertical axis is the standard deviation of the background structure, also in IRE units.

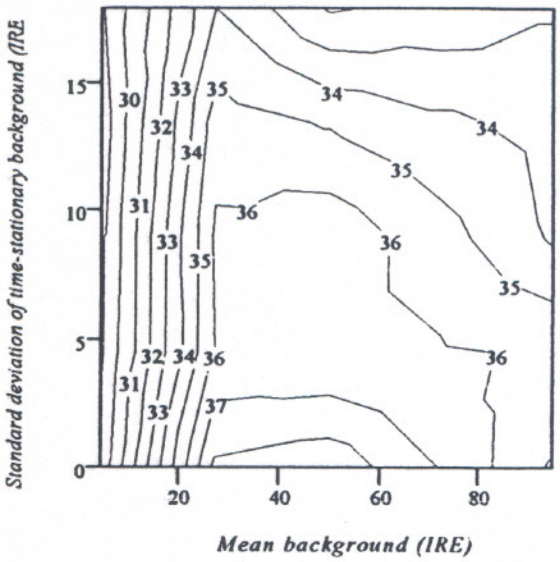

Figure 1. Contour plot of the SNR threshold as a function of mean and standard deviation of time-invariant background.

A cut of this plot, at a standard deviation of zero, is shown as Figure 2. It shows that for dark areas, the threshold starts out low. The results show that the eye is relatively insensitive to noise against a dark background, as compared to a bright background. As the background luminance increases from a level due to 5 IRE units of video signal to about 50 IRE, the noise threshold increases by about 9.4 dB, from 29.3 to 38.7 dB. Thus, this increase in background luminance is equivalent to an increase of the noise level by 9.4 dB. As the background increases further, the noise threshold falls to about 35 dB at 95 IRE units of background signal.

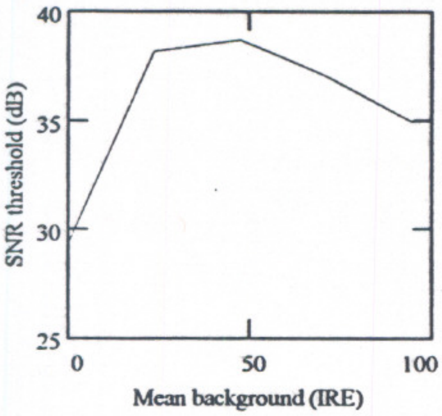

Figure 2. Plot of SNR threshold as a function of mean background, for background standard deviation of zero.

We would like to suggest an explanation of Figure 2. The rising part of the curve may be due to Porter's Law [6], which states that the cutoff temporal frequency at which time-varying flicker disappears is linearly proportional to the logarithm of the mean background luminance level. Thus, as the background luminance increases, the bandwidth of the eye's sensitivity to time varying noise increases, increasing the temporal noise threshold of the eye. Since Porter's Law is logarithmic in luminance, the increase in bandwidth saturates at higher luminance. At the same time, the noise contrast against the background decreases as the background luminance rises. The consequence is that the noise threshold falls for backgrounds due to mean video signals exceeding 50 IRE.

We were able to rule out dark adaptation as a relevant mechanism in these experiments, since we presented to the viewers mean video levels (as well as the standard deviations) in a randomized order.

Returning to Figure 1, it can be seen that the contour lines are nearly vertical and parallel at mean video levels below about 20 IRE. This indicates that a busy stationary background of increasing standard deviation fails to mask time varying noise when the mean background is dark. However, for brighter mean backgrounds in the range of about 25-95 IRE units, the busy structure of the background does indeed mask some of the temporal noise. Therefore, the temporal noise threshold falls by up to about 5 dB as the standard deviation of the stationary background rises from zero to 18 IRE units.

In the first experiment, whose results were given in Figures 1 and 2, the stationary background was completely and adequately specified by the mean and standard deviation of the video signal. In the second experiment, we used 76 by 48 pixel neighborhoods of actual captured TV images. The diversity of the backgrounds cannot be sufficiently characterized by the first two moments of the non-time-varying part of the background image. Nevertheless, most of the results agreed fairly closely with Figure 1. These results are given in Table 1. The first two rows of Table 1 give the two axes of Fig. 1, the mean and standard deviation of the time-stationary background. The third row is the average threshold SNR measured experimentally. The fourth row gives the prediction from Figure 1. Of the 9 values of Table 1, 7 fall within the span of Figure 1. These 7 deviate from values predicted by Figure 1 by a mean value of only 1.97 dB (data sigma=1.56).

Mean (IRE)	93	32	37	31	32	17	53	68	53
Std. Dev.	6.2	26	1.2	13	11	1.5	25	9	16
SNR Thr.	34.6	29.9	37.6	30.8	32.8	30.6	33.1	34.2	33
Fig. 1 Thr.	35.2	*	38	35.5	35.8	34	*	35.5	33.8

** These data points are out of the range of Fig. 1*

Table 1. SNR thresholds for actual TV images.

CONCLUSIONS

Based on the limited experiments with general captured TV images, we suggest that Figure 1 can be used as a general first-order quantitative predictor of the variation of human sensitivity to broadband temporal noise as a function of background statistics. This has particular significance in video processing methods that change such background statistics. Such changes can also be represented as changes in the effective input SNR.

Our interpretation of Figures 1 and 2 was not meant to be authoritative and conclusive. The authors welcome comments on that interpretation, as well as other aspects of this paper. Such constructive comments can help guide future continued research.

We have found the Princeton Engine to be a very versatile tool in simulation of TV systems. In particular, it was very easy to carry out the noise threshold experiments described herein. We plan in the future to explore other aspects of temporal noise sensitivities in TV viewing, using similar threshold experiments.

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