ADAPTIVE DIGITAL IMPULSE NOISE REDUCER

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Abstract

A newly developed adaptive digital signal processing system capable of eliminating most impulse noise from TV signals is described. Video is analyzed pixel by pixel. If the circuits determine that the pixel under analysis contains impulse-noise perturbations, and no motion is found in its vicinity, that pixel is replaced with an appropriate predicted value. The system cleans up impulse noise, FM sub-threshold noise, as well as video tape drop outs.

1. INTRODUCTION

A problem often encountered by cable television operators is interference in the television signal caused by power line leakages, industrial electrical equipment operating in the vicinity of the receiving site, and other RF energy entering the TV signal spectrum at the receiving antenna. This type of interference usually shows up in the TV picture as bright or dark speckles and streaks, and it is commonly referred to as impulse noise.

Until recently, the only way to clear up this type of interference was to locate the source of the electrical noise and to correct the cause of the problem. In some cases correcting the problem has been impossible, forcing the cable operator to transport video from a remote site or directly from the broadcaster, via fiber-optic or microwave links. Such extreme measures can be very expensive, and in small markets, or isolated sites, they can become economically impractical.

With the encouragement and support of Cable Television Laboratories, Inc., Intelvideo has developed an impulse-noise reduction system that can remove impulse noise from baseband NTSC color television signals and permit cable operators to deliver acceptable quality pictures for channels that otherwise would have been severely impaired by impulse noise.

2. NOISE AND VIDEO CHARACTERISTICS

To understand the operation of the impulse-noise reducer, it is necessary to understand the character of impulse noise. In general, impulse noise is the result of electrical discharges which generate broadband energy at RF. This energy can occur at particularly high levels at frequencies occupied by the VHF TV channels, and of course, broadband energy at RF converts into spikes and streaks in the demodulation process. These spikes can have any amplitude in the baseband video signal. They can have different shapes and either positive or negative polarity. They may have a duration from a few hundred nanoseconds to several microseconds. Some spikes may destroy the video signal of an entire TV line. When the interference is very severe, the picture becomes unwatchable or, at best, very annoying to the subscriber.

The first task in trying to remove this type of noise is to identify characteristics that would permit differentiating the impulse noise from normal NTSC color signals. The most important and useful characteristic of impulse noise is that it usually consists of isolated spikes, uncorrelated with the video signal, and normally uncorrelated from line to line and from frame to frame. Another characteristic of impulse noise is that it often exceeds the normal positive or negative range of the video signal. The third characteristic of impulse noise is that, because it is usually caused by power line leakages, it has a 60 Hz repetition component. This is clearly demonstrated by the fact that this type of impulse noise in a TV picture rolls slowly up the screen.

An NTSC color signal, unfortunately, also exhibits certain characteristics that cause difficulties in differentiating between impulse noise and wanted video. Because of the color subcarrier, a color NTSC signal appears to have a certain degree of uncorrelation from line to line and from frame to frame. This is due to the color subcarrier having 180° phase difference from line to line and from frame to frame. In addition, moving picture details, unless precisely tracked, appear to have the same frame-to-frame uncorrelation that is a characteristic of impulse noise.

The challenge in trying to remove impulse noise is to differentiate between impulse noise and video. The low spatial and temporal correlation of impulse-noise spikes can be used to identify potential impulse-noise errors. But, in addition, one needs to identify moving video details and differentiate between impulse noise and video details.

3. COLOR SUBCARRIER IMPLICATIONS

As mentioned, the presence of the color subcarrier in the video signal reduces pixel correlation, both spatially and temporally, because it causes neighboring video samples to have large level variations. However, samples that have the same color-subcarrier phase do exhibit similar amplitude levels. To analyze NTSC color signals and detect impulse noise using correlation methods, one must either use video samples that have the same color-subcarrier phase, or one needs to color decode, or at least separate, the luminance and chrominance of the NTSC color signal.

To achieve acceptable luminance-chrominance separation, one may use comb filters. Comb filters normally combine video information from two or more TV lines. That means that if video contains a noise impulse, comb filtering will spread that impulse to two or more TV lines. The impulse amplitude will also be reduced, making it more difficult to detect, and secondary impairments may result. More sophisticated comb filters use adaptive processes. An adaptive comb filter can help when the impulse noise is a fairly long streak, making it easily detectable as a luminance signal. But for very short duration pulses, practical comb filters have been found to react too slowly to permit a clean separation of the impulse and the chrominance. In some cases, the adaptive process can cause significant video perturbations.

We looked at a number of adaptive comb filters being used in professional equipment and we also analyzed other patented variations of adaptive comb filters. The hardware-implemented comb filters we tested performed poorly trying to separate impulse noise from chrominance. Some of the more complex comb filters that have been proposed may, on the surface, appear to be able to handle impulse-noise separation, but practical implementation of these systems requires selection of switching thresholds and controlled gating functions that can introduce secondary perturbations. Any error in the luminance-chrominance separation can result in imperfect impulse-noise detection as well as imperfect correction. We decided, therefore, to look for impulse noise in the composite color signal, taking into account the color subcarrier phase variations.

4. NOISE DETECTION AND CORRECTION

To determine whether a particular video pixel has impulse noise or is in error, it is spatially and temporally correlated with surrounding pixels having the same color-subcarrier phase. Thus, looking at a limited spatio-temporal array of video samples, we first define equi-phase samples surrounding the sample to be analyzed. Figure 1 shows such a spatio-temporal array of video samples that have the same color-subcarrier phase (the samples identified with a star). The video sampling frequency used is 14.3 MHz (four times color subcarrier).

Note that the array of Figure 1 has samples from a number of lines from the same field (field 2) as well as from lines of the previous field (field 1) and the following field (field 3). In addition, this relationship repeats every two TV frames. The

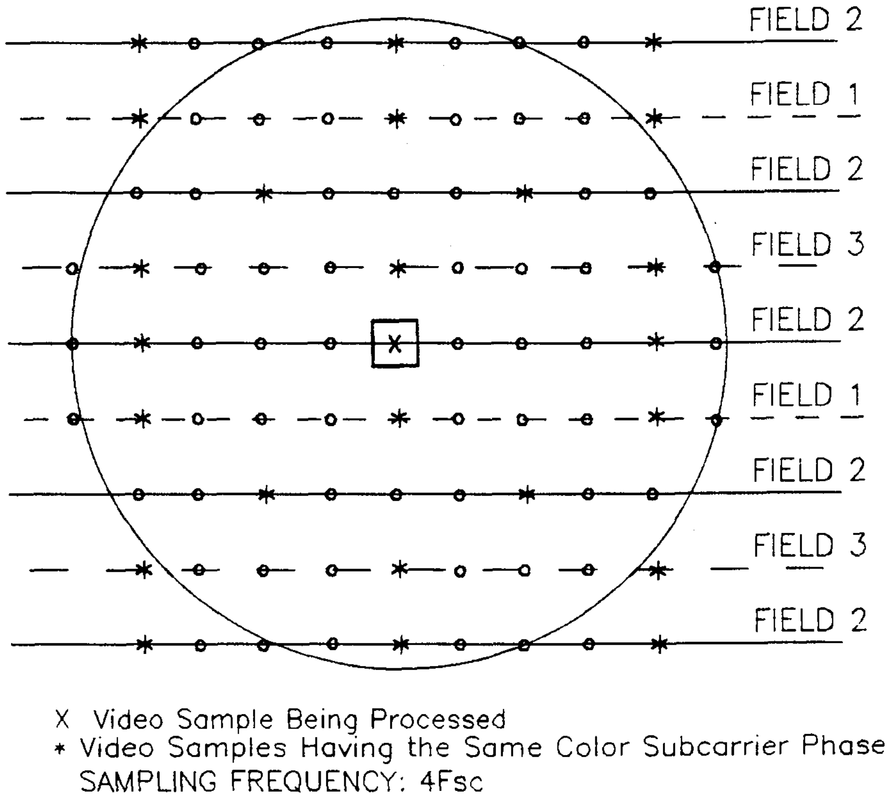

Figure 1. Spatio-Temporal Array of Video Samples

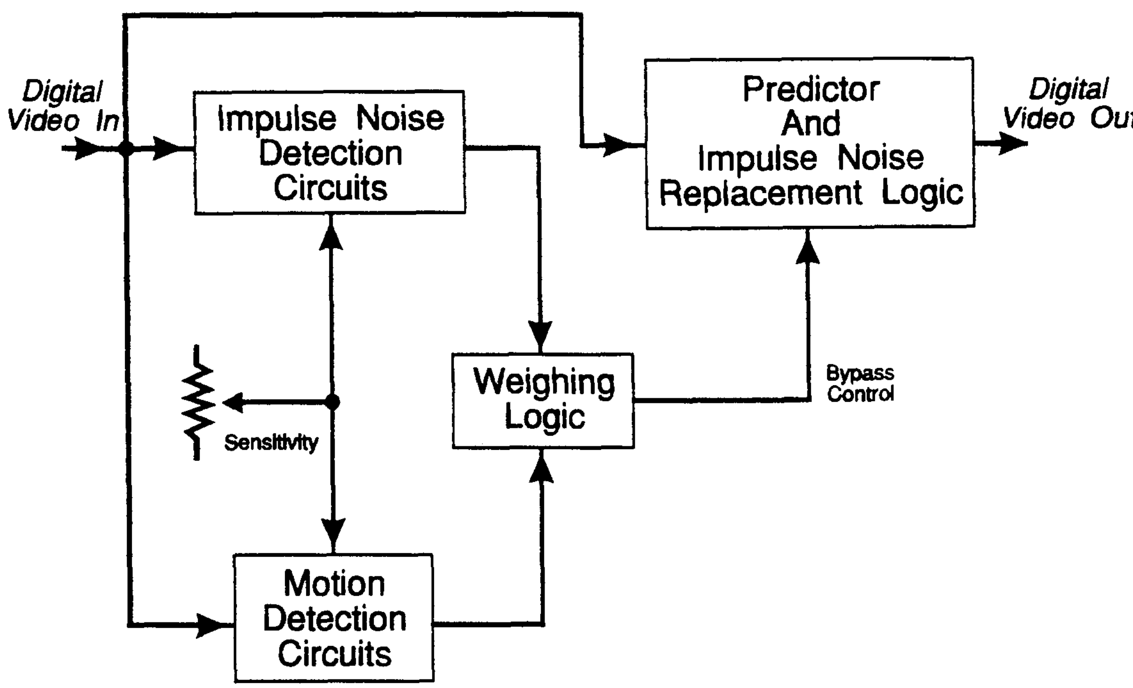

Figure 2. Impulse Noise Reducer - Digital Processor

process of determining whether the sample under consideration (sample X) has impulse-noise perturbation consists of comparing that sample with a number of other equal phase samples (as identified in Figure 1). Using some empirically determined priority rules, one can decide whether pixel X is sufficiently uncorrelated with respect to the other samples and can be labeled impulse noise.

Since moving video details, when analyzed by the same method used for impulse-noise detection, may give the same reading as impulse noise, a different analysis is performed on a number of surrounding pixels from different video frames to determine whether motion is present in the vicinity of pixel X. The process of motion detection is also a correlation process similar to the process used to detect impulse noise. The significant difference here is that pixel X is not included in the motion detection process, and thus the motion detector is not affected by the possible presence of impulse noise in pixel X.

When the noise-detection circuits determine that a given video pixel appears to have an impulse-noise perturbation or is in error, and the motion detection circuits determine that no significant motion exists near that pixel, the decision is made to replace that pixel with a video value that is believed to be the correct level for that pixel had it not been altered by the impulse noise or other perturbations. That value is obtained by predictive techniques using spatio/temporal surrounding pixels. The resulting noise-corrected picture is excellent. Under many conditions, it is nearly impossible to detect residual distortions or impairments that may be introduced by this correction process.

5. SYSTEM IMPLEMENTATION

Figure 2 shows a block diagram of the digital processes implemented in the impulse-noise reducer. Its operation is essentially as already explained. The block diagram has one particular that has not been mentioned yet. That is a sensitivity control. There are, obviously, different levels of impulse-noise perturbations, some are mild, some more severe. In some extreme situations, impulse noise is so severe that the TV picture is practically unwatchable. Under those conditions, the noise detection circuits will easily detect the noise, but the motion detection circuits will also be fooled by the noise into believing that there is motion and thus prevent the noise correction. Thus is necessary for the system to be able to operate at different sensitivity thresholds for both noise detection and motion detection. The sensitivity control shifts detection priority between noise detection and motion detection.

For severe noise cases, the motion-detector sensitivity is reduced so as not to be triggered by impulse noise, while the noise-detector sensitivity is increased so as to permit positive noise identification even as the level of uncorrelation between the pixel under analysis and the surrounding pixels (which may also have some noise) is reduced. This makes it possible to clear up severe impulse-noise conditions. A minor penalty to be paid under those conditions is that the noise-reduction process may introduce some motion impairments. But, given the choice between pictures with severe impulse-noise impairments and pictures with no noise impairments, but some occasional motion artifacts, the choice will always, unequivocally, be for the impulse-noise-free picture. In fact, the quality improvement achieved is so dramatic one needs to see it demonstrated in order to appreciate its effectiveness.

6. OTHER APPLICATIONS AND CONCLUSION

A useful alternative application of the noise-reducer technology is to correct FM sub-threshold noise. This noise appears as bright or black dashes or sparkles on a picture. They are usually caused by a signal reduction of the FM carrier. The impulse-noise reducer has a rather easy time of detecting those types of errors and replacing the errors with a proper video level. Thus one may look at the impulse-noise reducer as a means of extending the

FM threshold in an FM microwave or satellite link. It also can be effective in reducing the impulse-noise effects of terrestrial interference (TI) in satellite TVRO installations.

Yet another use of the impulse-noise reducer is as a tape drop-out compensator. Of course, it is preferred to perform drop-out compensation at the video tape recorder during playback using the drop-out detector control signal. Some tape recorders, however, do not have a drop-out compensator, and one is at times saddled with video signals that contain drop outs. Because the drop outs have characteristics similar to impulse noise, the impulse-noise reducer will automatically detect drop outs and correct them.

The impulse-noise reducer we described is available as a product from Intelvideo. Several cable companies are already using the device to eliminate the effects of impulse noise at some of their worst reception sites. Reports from users of the device have been enthusiastic.