VIDEO ENCODING FOR THE SPACE SHUTTLE

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ABSTRACT

The Space Shuttle will initially be using a field sequential color television system but it is possible that an NTSC color TV system may be used for future missions. In addition to downlink color TV transmission via analog FM links, the Shuttle will use a high resolution slow-scan monochrome system for uplink transmission of text and graphics information. This paper discusses the characteristics of the Shuttle video systems, and evaluates digitization and/or bandwidth compression techniques for the various links. The more attrative techniques for the downlink video are based on a two-dimensional DPCM encoder that utilizes temporal and spectral as well as the spatial correlation of the color TV imagery. An appropriate technique for distortion-free coding of the uplink system utilizes two-dimensional HCK codes.

INTRODUCTION

Developments in digital television coding techniques have established that significant compression of digital television data can be achieved at moderate cost, while maintaining extremely low distortion. This is done by exploiting the high degree of spatial, temporal, and spectral correlation in black and white or color video data. Most coding algorithms require substantial amounts of memory and high computational rates; however, with the advent of high-speed digital logic, a high degree of signal processing is currently possible at reasonable cost, size, weight, and power. New technology makes possible the development of relatively sophisticated data compression systems which promise to bring the digital transmission of television into the same bandwidth regime as analog.

The early Shuttle missions are scheduled to fly a refurbished Apollo color television system. This system will use a black and white camera which is converted to field-sequential color by the addition of a rotating color wheel. The bandpass of the camera is approximately 4.5 MHz which would require a digital sampling rate of 9 Msps (minimum). Assuming a minimum of 6 bits per sample, the system would require about 54 Mbps for

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downlink data transmission if conventional PCM data were used. Should the Shuttle Orbiter switch to a standard three-gun color television camera in the future, the digital transmission rate requirements (using PCM) for an NTSC color TV system would be about 130 Mbps. The goal is to reduce the required data rates of the two systems by a factor of 5 to 10 while limiting spatial, spectral, and temporal distortion to levels acceptable to an average viewer.

By taking advantage of the high degree of correlation in both the spatial and temporal domains, the required bandwidth for digital transmission of the video data can be reduced from that associated with PCM. A number of coding algorithms that exploit these correlations have been developed in recent years. Efficient coding of the color television signal requires use of sequential color fields in the field-sequential system to generate the usual illuminance (Y) and the chromaticity (I, Q) components. This would involve on-board preprocessing of the data and would result in additional weight and power above that of other realtime television applications. In an NTSC color television system, the color composite signal would have to be demodulated to generate Y, I, and Q components prior to the application of a bandwidth compression method. However, demodulation of the color composite signal could be avoided by modifying the camera to provide the Y, I, and Q components directly.

In addition to downlink color television transmission, the Shuttle will utilize (on the later flights) a high resolution slow-scan monochrome system for uplink transmission of text and graphics information. The uplink system will utilize a 128 kbps channel. Distortion-free coding of the high resolution imagery could be utilized to increase the transmission capacity of the uplink system, although such coding is not currently planned.

BANDWIDTH COMPRESSION OF SHUTTLE VIDEO

Both NTSC and field-sequential color TV exhibit significant spectral, temporal, and spatial correlation. An efficient bandwidth compression technique must utilize all three types of correlations. However, this results in sophisticated bandwidth compression algorithms with fairly large hardware complexity.

To reduce the hardware complexity we separate the problem of spatial bandwidth compression from that of spectral/temporal bandwidth compression. This section discusses possible techniques of utilizing spectral and temporal correlation of field-sequential and NTSC color television signals.

TEMPORAL AND SPECTRAL REDUNDANCY REDUCTION OF FIELD SEQUENTIAL COLOR TV

The salient feature of the field-sequential color TV signal is that the sequential fields exhibit temporal as well as spectral correlation, and exploiting these correlations in addition to spatial correlation is essential to obtaining efficient bandwidth compression. Spectral correlation is best utilized by using red, green, and blue fields to generate the illuminance (Y) and the chromaticity components (I, Q).

In field-sequential color TV, the sequential fields are composed of odd and even lines. The odd red field exhibits spectral similarity with the odd blue and green fields. These samples are separated, however, by a temporal distance of 4/60th of a second and this causes some spectral decorrelation due to temporal motion. The Y, I, and Q signals formed from all odd or even frames, which require storing a minimum of four fields, are particularly susceptible to spectral decorrelation from rapid temporal motion. An alternate procedure is to mix the odd and even fields in generating the illuminance and chromaticity components. This requires storing only two fields. The mixing of odd and even fields results in a smaller correlation among the spectral components but a large temporal correlation, since the three fields used in generating Y, I, and Q are only 2/60th of a second apart. This gives a larger or smaller compaction of energy in the illuminance signal depending upon the comparative size of the spectral similarity and temporal motion. In this study we chose a mixing of odd and even fields to generate the illuminance and chromaticity components, mainly to reduce the memory requirements.

In addition to the mixing of even and odd fields, other modifications can be made to reduce the memory requirements further. Although the Y, I, and Q signals used in United States commercial television lead to the most efficient analog TV bandwidth compression; European TV system uses a different set of chromaticity components (C_1, C_2) which are useful alternatives for digital bandwidth compression applications. These are related to the red, blue, and illuminance components as follows:

$$C_1 = R-Y \tag{1a}$$

$$C_2 = B-Y \tag{1b}$$

The attractive feature of these chromaticity components is that they can be generated using only a single field of memory if the illuminance signal is directly available from the camera. This presents two sets of alternatives that can be explored for design simplifications. The first alternative is to replace the green filter in the color wheel by a “colorless” filter to obtain the illuminance signal directly. The second alternative uses the standard color wheel and substitutes the green for the illuminance signal. Then the chromaticity components are obtained by subtracking the green from the red and blue components. This approach is based on the fact that the green spectral component is very similar to the illuminance component.

Using the green component instead of the illuminance, the transmission tristimulus signals (Y, C_1, C_2) are:

$$Y = G \tag{2a}$$

$$C_1 = R-G \tag{2b}$$

$$C_2 = B-G \tag{2c}$$

C_1 and C2 possesses a much smaller bandwidth and smaller fraction of the signal energy than the G component; therefore, they can be transmitted in a subsampled form utilizing a smaller fraction of the available bit rate. A block diagram of the proposed system is shown in Figure 1. The proposed system uses a 2:1 subsampling of C_1 and C_2 components and employs a two-dimensional DPCM encoder for compressing the bandwidth of luminance and chrominance signals.

SPECTRAL REDUNDANCY REDUCTION OF NTSC COLOR TV

In the analog transmission of I and Q signals, they are lowpass filtered and multiplexed with the luminance signal. This technique is practical since human vision is very insensitive to high frequency components of I and Q signals. Taking advantage of this property, we also propose lowpass filtering of the I and Q signals. The passbands of these filters are about one-fifth of the illuminance signals. Maintaining a spatial resolution of 512 samples per line gives a spatial resolution of about 100 samples per line for I and Q signals. A further bandwidth compression can be achieved by alternating the transmission of the I and Q signals with each line of luminance signal. The receiver then restores the missing color component for each line by interpolating between the transmitted components for the previous and future lines. The performance of such a system results in no noticeable color degradation.

A block diagram of the proposed encoder is shown in Figure 2. The luminance signal is sampled at a rate of 7.8 Mbps and transmitted during the active period of the line scan. During the periods of blanking, flyback and the interval which is normally used for analog transmission of the modulated color signal; we propose to transmit either I or Q signals This arrangement gives sufficient time for transmission of 100 chrominance samples in the nonactive interval. Both luminance and chrominance signals can use the same encoder.

SPATIAL REDUNDANCY REDUCTION OF A LUMINANCE AND THE CHROMINANCE SIGNALS

The above processing of the field-sequential and NTSC video results in some reduction in the bandwidth. This is achieved by subsampling the chromaticity signals. To achieve additional bandwidth compression, the luminance and the chromaticity signals must be encoded. Four candidate bandwidth compression techniques were evaluated and compared for this application. These are:

1) Two dimensional DPCM encoder
2) Block-adaptive two-dimensional DPCM (single loop)
3) Block-adaptive two-dimensional DPCM (multi-loop)
4) Hybrid encoder using Hadamard transform with DPCM encoder.

The details of these techniques are discussed in Reference 2. The two adaptive DPCM Systems have essentially identical performances. The performance of the hybrid encoder, on the other hand, is almost the same as the performance of the nonadaptive DPCM encoder. The difference in the performance of the adaptive and nonadaptive DPCM encoder is fairly small at 3 bits per sample. AT 2 bits per sample, the difference is about 3 dB in signal-to-noise ratio and may be significant for some applications. On the other hand, the complexity of the adaptive DPCM encoder is much greater than the complexity of the nonadaptive DPCM encoder. For this reason and because the lighting will be well controlled in the Shuttle, the nonadaptive DPCM encoder would be preferred over the adaptive DPCM system. The hybrid encoder was rejected because it requires more than twice the parts count of the nonadaptive DPCM encoder.

DISTORTION-FREE CODING OF UPLINK TV

Most documents and line drawings contain a large amount of white space. One approach to their efficient coding is to skip the white space. A simple way of doing this was suggested by de Coulon and Kunt and Horlander[3,4]. This technique has a performance similar to that of run-length coding. The performance of this system as well as its hardware complexity was evaluated for Shuttle application. For details of the analysis the readers are referred to Reference 2. The highlights of the results are listed in Table 1.

SUMMARY AND CONCLUSIONS

Image bandwidth compression techniques are feasible for Shuttle television and we have identified suitable bandwidth compression techniques for the uplink as well as two downlink systems. The characteristics of these techniques are summarized in Table 1. The performance of these techniques for the downlink systems was evaluated by using mean square error and signal-to-noise ratio between the original and reconstructed compressed imagery, subjective quality of single frames after bandwidth compression, and finally by generating a video tape of 10 seconds of field-sequential color TV imagery before and after bandwidth compression. These results showed that such techniques might be used to achieve bandwidth compression for the Shuttle TV system, and maintain high fidelity in the reconstructed compressed imagery.

REFERENCES

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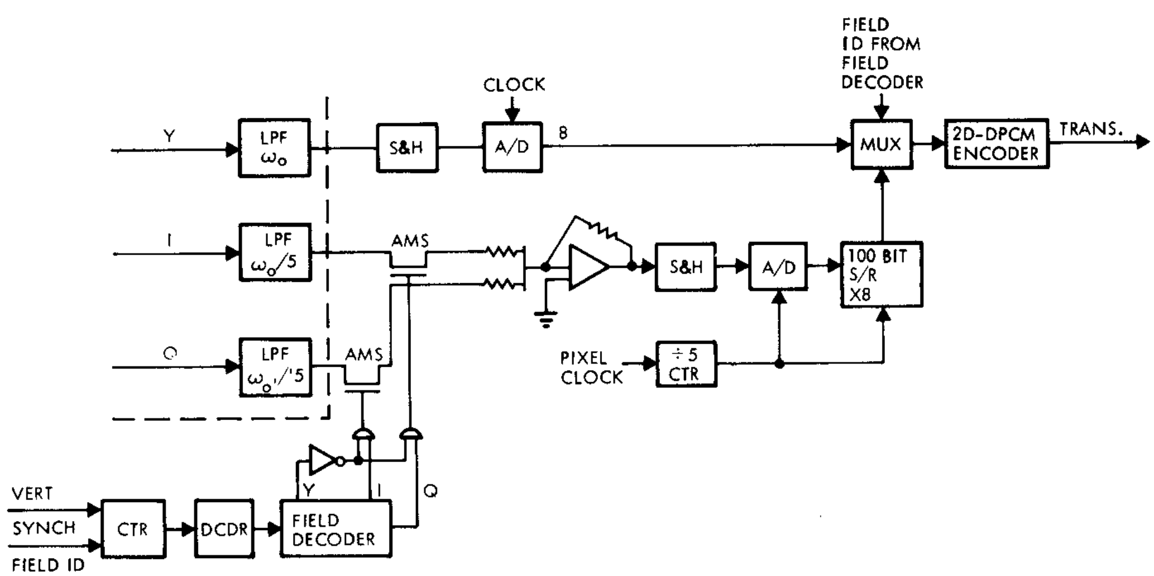

Figure 1. Block Diagram of the Proposed Bandwidth Compression Technique for Field-Sequential Color TV

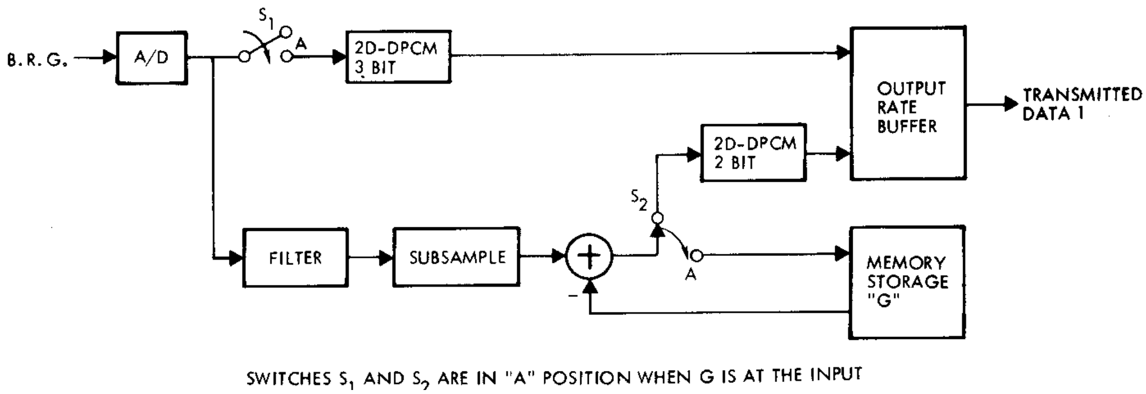

Figure 2. Block Diagram of Proposed Bandwidth Compression System for NTSC Color TV

Table 1. Characteristics of Recommended Bandwidth Compression Techniques

TV SYSTEM	ALGORITHM DESCRIPTION	BANDWIDTH OF THE COMPRESSED SIGNAL (MEGABITS/SEC)	COMPRESSION RATIO	POWER (WATTS)	NO. OF PAGES
FIELD-SEQUENTIAL COLOR TV SYSTEM	G, R-G, AND B-G ARE ENCODED USING 2D-DPCM	13.1	4.8	60⁺	348⁺
	G, R, B ARE ENCODED USING 2D-DPCM	24	2.66	60⁺	85⁺
NTSC COLOR TV SYSTEM	Y, I, AND Q (I AND Q SUBSAMPLED 5:1) ARE ENCODED USING 2D-DPCM	28	6.7	30⁺	100⁺
SLOW-SCAN UPLINK SYSTEM	CODING BY SHIPPING WHITE 2D HCK CODE IS USED	0.144	3	19*	102*

⁺ENCODER *DECODER