Encoding *Y,I,Q* Component Estimates of an NTSC Composite Signal

David A. Border*
Digital Automation Associates, Bowling Green, Ohio
and
S. C. Kwatra†
University of Toledo, Toledo, Ohio

Several new techniques for reducing the entropy of a *Y,I,Q* component digital transmission are presented. A discussion of each technique is presented along with objective and subjective analysis. For a set of four test pictures, the average *Y,I,Q* entropy/pixel was reduced by nearly 80%. An initial component system entropy of 11.08 bits/pixel was reduced to 2.33 bits/pixel. Although exact numeric results are dependent on the separation technique used, the methods presented may be applied to systems using other component separation methods.

Introduction

MAJOR functional elements of a digital component television transmission system include the analog NTSC composite signal digitizer, the composite-to-component separator, and the component signal encoder. In earlier papers,[1,2] the authors presented new techniques to separate the NTSC composite signal into the *Y,I,Q* components. In this paper, four major steps toward reducing the transmission bit rate of the component transmission system are considered. The first step is the reduction of redundant component information by subsampling the component values (choosing every *N*th value and discarding the remaining values) prior to transmission. The second bit-rate reduction step provides additional reduction in transmitted samples by replacing the previous uniform-rate chrominance transmission with a variable-rate chrominance transmission (VRCT).

The third bit-rate reduction step enables the subsample rate to adjust adaptively to scene statistics. This technique is called "adaptive-rate component transmission" (ARCT). It provides for low subsample rates in low-detail scene regions while imposing a higher subsample rate in high-detail scene regions. The fourth, and final, bit-rate reduction step is the nonuniform quantization of component values following component subsampling. All methods assume transmission of differential pulse code modulation (DPCM) values using intraframe adjacent pixel first-order predictors.

Subsampling Component Estimates

Commonly, the *Y,I,Q* components are subsampled at a rate that preserves transmission bandwidth and picture quality. If the *Y,I,Q* signals are obtained at the television camera (prior to encoding into the composite signal), the subsampling rates are determined by the characteristics of the components. For this case, the luminance component has spectral elements up to 4.2 MHz, the *I* component has spectral elements up to 1.5 MHz, and the *Q* component has spectral elements up to 0.5 MHz. Because of the ease of sampling at a multiple of the color subcarrier frequency, convenient *Y,I,Q* sampling rates are 14.3, 3.57, and 1.8 MHz, respectively.[3] By sampling the components at these rates, the luminance component must be sent every transmission, the *I* component every fourth transmission, and the *Q* component every eighth transmission.

When components are not derived by digitizing the source component signals, the component samples are not "true" component values but estimates of the actual components. In obtaining the *Y,I,Q* estimates from the composite signal, component estimation error is introduced especially in picture regions containing "edges" or "boundaries." Within these regions, subsampling schemes may adversely affect picture reconstruction quality.

For the separation method used in this investigation, a constraint for accurate reconstruction of the composite signal is that *Y,I,Q* be updated simultaneously to the receiver in high-error regions. A *Y,I,Q* subsampling rate of 3:1 resulted in pictures considered to be of excellent quality although, at extremely close viewing distances and with very critical analysis, picture differences did appear. This rate is below the Nyquist rate (8.4 MHz) for sampling a luminance signal at the television camera source. Picture quality at the sub-Nyquist rates is determined by the amount of critical luminance spectral energy in the aliasing region, the effect of aliasing on this signal content, and the tolerance of the human eye to high-frequency video interference.[4]

Four test pictures were subsampled at a rate of 3:1. The subsampled values were converted from floating point to the nearest integer value and DPCM encoded for transmission. At the receiver, the data were decoded and processed for display on a TV monitor. The processed pictures were evaluated subjectively, and entropy measurements were taken of the DPCM-encoded data. The results of the entropy measurements are shown in Table 1. The last column in Table 1 contains the average entropy per pixel necessary for transmission of complete *Y,I,Q* information. Certain scene-specific details account for the entropy distribution. Examples of such details are large regions of background tropical foliage within the beach scene and low chrominance saturation within the soap opera scene. The last row entry of the last column in Table 1 shows the average entropy of 4.48 bits/pixel for the four broadcast-quality scenes (beach, makeup, soap opera, and Star Trek). This number is a significant reduction from the average entropy of 11.08 bits prior to subsampling, and represents a bit-rate reduction from 127 to 51 Mbits/s (assuming ideal entropy encoding) for active video information (NTSC sync information not transmitted).

Variable-Rate Chrominance Transmission

Further data-rate reduction is possible by selectively transmitting the chrominance terms on demand. One method

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*Project Manager.

†Professor, Department of Electrical Engineering.

Table 1 DPCM component entropy values

	Component entropy				
Scene	Y	I	Q	Y,I,Q sum	Average Y,I,Q sum, per pixel
Beach	5.42	5.06	4.59	15.07	5.02
Makeup	4.34	5.12	4	13.46	4.48
Soap opera	4.65	3.97	3.24	11.86	3.95
Star Trek	4.24	4.96	4.23	13.43	4.47
Overall average entropy	4.66	4.77	4.01	13.44	4.48

Table 2 DPCM component entropy with conditional transmission of I,Q terms

	Component entropy			Allocation of transmission type,[a] %				Entropy, bits/pixel
Scene	Y	I	Q	A	B	C	D	
Beach	6.7	5.3	5.2	11	15	15	59	4.86
Makeup	5.9	4.6	4.6	33	19	17	31	3.49
Soap opera	6.1	4.6	4.6	28	17	18	37	3.75
Star Trek	5.8	4.5	4.5	33	18	17	32	3.45
Overall average entropy	6.1	4.7	4.7					3.88

[a]Transmission types herein defined as follows: A = percentage of luminance-only transmissions ($I \leq 1$ and $Q \leq 1$); B = percentage of Y,I transmissions ($Q \leq 1$); C = percentage of Y,Q transmissions ($I \leq 1$); D = percentage of Y,I,Q transmissions necessary.

of selective transmission is the inclusion of a flag just prior to luminance transmission that notifies the receiver of the components that follow. The flag inserted prior to the luminance component, called a component flag, can be defined as having four possible values. The four-value component flag tells the receiver to expect a Y term only, or Y,I terms only, or Y,Q terms only, or Y,I,Q terms. The determination of whether chrominance components need to be transmitted would be based on the amount of chrominance change that had occurred since the last chrominance transmission.

Consider the transmission of luminance information and component flag information. When they are encoded separately, the total entropy of transmission is

$$H(T) = H(L) + H(F) \tag{1}$$

where $H(L)$ is the luminance term entropy, and $H(F)$ is the component flag entropy. By jointly encoding (embedding) the luminance and component flag, the entropy of the source may be written as

$$H(T) = H(L,F) = H(L) + H(F) - I(L;F) \tag{2}$$

where $I(L;F)$ is a measure of the mutual information between the luminance terms and component flag.

Equations (1) and (2) will result in the same entropies only when $I(L;F)$ is equal to zero. Mutual information, $I(L;F)$, will be zero only when the luminance terms and component flag are statistically independent. However, testing shows this not to be the case and, therefore, $I(L;F)$ will be nonzero and Eq. (2) will have lower entropy than Eq. (1). Therefore, embedding the luminance DPCM term and the component flag into one term (which will still be called the luminance term) will decrease the cost of the overhead information.

This transmission scheme was implemented and tested for each of the four test pictures. Transmission of a chrominance term was suppressed only when the absolute chrominance value changed was ≤ 1. This threshold restriction was chosen to insure high-quality picture processing. The results are given in Table 2.

The usefulness of variable-rate chrominance encoding is shown by the decrease in the entropy per pixel for each of the test scenes. The overall total average entropy decrease was 0.6 bits for the four scenes. This corresponds to a 6.8 Mbits/s average decrease in the active video rate. Thus the 51 Mbits/s average bit rate from the previous section is reduced to a 44.2 Mbits/s active video rate.

Adaptive-Rate Component Transmission

The use of the luminance term for transmission of receiver information, other than strictly luminance DPCM values, can be used to advantage in further reducing transmission bit rates. Because of the popularity of adaptive bandwidth compression techniques in digital television research,[5] it was decided to explore a transmission encoding scheme that operates at two different update rates: a 4:1 subsample rate for low-detail regions and a 3:1 subsample rate for high-detail regions. The information as to which subsample rate was used would be embedded into the luminance term (similar to the previous section).

Various algorithms were tested, each based on testing the amount of reconstructed signal absolute error and squared error over the subsampled region. The algorithm chosen preserves picture quality while allowing for the frequent use of the 4:1 subsample rate. The algorithm determines when a rate change (to 3:1) is necessary for retention of picture quality.

Adaptive rate change eliminates the visual scene impairments that are otherwise noted in the subjective evaluation of the straight 4:1 subsample rate. This method yields subjective results very close to those of the 3:1 uniform subsampling rate, but the rate obtained is close to the 4:1 subsample rate.

Table 3 shows the entropy measurements for each component along with the average entropy after the addition of adaptive rate coding to the VRCT coding. By addition of ARCT and VRCT techniques, the average entropy of the component transmission system presented earlier in the Subsampling Component Estimates section is reduced from 4.48 to 3.18 bits/pixel. The bandwidth savings, on average (for ideal entropy coding), is 14.8 Mbits/s and cuts the DPCM bandwidth of 51 Mbits/s by 29% to 36.2 Mbits/s.

Component Quantization

The final stage of entropy reduction for component transmission prior to code-word assignment is component quantization. By limiting the DPCM values of each component to a few predetermined levels, it is possible to reduce the entropy of each component and thereby further reduce the transmission rate.

A starting point for component quantization was the quantizer design by Max.[6] For a given number of quantizer levels,

Table 3 Component entropies and entropy-per-pixel measurements with adaptive rate transmission

	Component entropy			Allocation of transmission speed, %		
Scene	*Y*	*I*	*Q*	High	Low	Entropy, bits/pixel
Beach	7.5	5.4	5.3	15.3	84.7	4.07
Makeup	6.6	4.7	4.6	6.1	93.9	2.83
Soap opera	6.9	4.7	4.7	6.5	93.5	3.01
Star Trek	6.5	4.7	4.5	7.0	93.0	2.84
Overall average entropy	6.8	4.8	4.7			3.18

Table 4 Entropy for system with component quantization

Scene	Entropy, bits/pixel
Beach	3.19
Makeup	1.98
Soap opera	2.14
Star Trek	2.01
Average entropy of four scenes	2.33

the Max quantizer minimizes the mean-squared error between the quantizer output and the signal described by the nonuniform probability density function.

Following the establishment of minimum-level Max quantizers, an empirical design procedure was followed to obtain a lower number of quantizer levels. This replacement is expected to occur in digital television quantizer design because Max quantizers are optimum only in the mean-squared-error sense. The correlation between mean-squared error and subjective picture-viewing results is not sufficiently strong to preclude other design approaches. The empirical design procedure was based on maximizing the number of DPCM components quantized to zero, maximizing the input range for low-magnitude quantizer levels, and retaining broadcast-quality pictures.

Based on several test picture sets, a 21-level luminance quantizer was determined along with a 13-level *I*-component quantizer and a 13-level *Q*-component quantizer. These nonuniform quantizers were tested with the original four test pictures. As shown in Table 4, an overall average entropy of 2.33 bits/pixel was achieved, representing an active video rate of 26.6 Mbits/s. Note that, due to the extreme sensitivity of the system in high-activity scene regions, uniform quantizers (range: -255 to $+255$) are substituted for the nonuniform quantizers when the subsample rate is raised from 4:1 to 3:1. The subjective results remained at a level very near that of the previous section. Only slight differences were noted at close viewing distances.

Conclusions

Each of the techniques developed can be implemented in a component transmission system to lower transmission rate measurements. The techniques may be employed separately or jointly, depending on the allowable encoder design complexity. Prior to encoding, the composite-to-component separation network used in this research provided a DPCM entropy measure of 11.08 bits/pixel. With the inclusion of subsampling, variable-rate chrominance transmission, adaptive-rate component transmission, and component quantization, the entropy measure was decreased to 2.33 bits/pixel.

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