Picture Quality Control Method among Multiple Video Sources

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Abstract

When the multiple video sources are together transmitted through the channel of fixed bandwidth, the efficiently picture quality control method is necessary. This paper presents the picture quality control method to keep the same distortion level among the video sources. We first find a model of distortion and bitrate for the multiplexing system of multiple sources. Then we obtain the bitrate for each source to have same distortion level among the sources by using the approximated model parameters for simple implementation.

Keywords:

Quality; Bitrate; MPEG

I. Introduction

The video source can be transmitted through the conventional media by the video compression schemes such as MPEG-1 and MPEG-2[1]. In the environments of satellite, terrestrial, and cable TV broadcasting channels, the several compressed video sources can be transmitted together within one channel. For example, the digital NTSC video source can be compressed to 3-6 Mb/s while still providing acceptable picture quality. Hence, it is possible to transmit 3-6 NTSC sources over a conventional terrestrial TV channel of 19Mb/s and 5-12 sources over a cable TV channel of 27-38Mb/s[8]. Thus, the total bandwidth of a channel should be divided to each video effectively. The bandwidth for each video can be allocated by independent method which divides total bandwidth by only considering the spatial resolution. However the independent allocation method does not distribute the picture quality to each video uniformly and also does not have the picture quality within each video constantly.

To overcome the problems, the joint bandwidth allocation method is required to keep the uniform picture quality among multiple video sources by considering the video characteristics. Keeping the uniform picture quality, we can also take the additional advantage of the constant picture quality within each sequence [7,8].

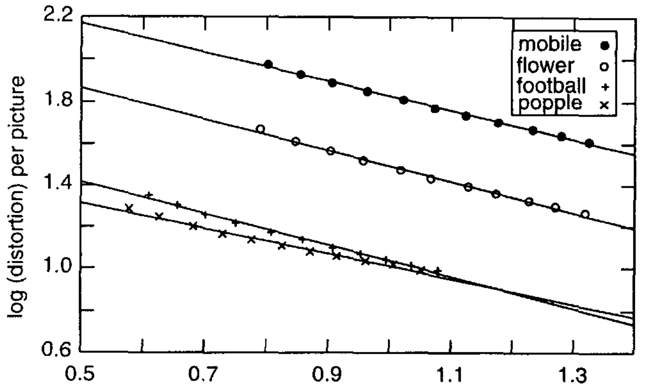
For the bandwidth allocation, the relationship of distortion and bitrate should be firstly defined. In the some literature [3,4,5,6], the relationship of distortion and bitrate has been presented. This relationship is large dependent on the each particular coding system, so it is necessary to define a best suitable relationship for the coding system.

In this paper, we propose the uniform picture quality control method among sources in the condition of the fixed total bitrate. We first find the model of distortion and bitrate according to the video sequence and the coding picture-type. Then we obtain the bitrates of the pictures within the sources to keep the same distortion level by adaptively using the model parameters and the coded results of previous pictures.

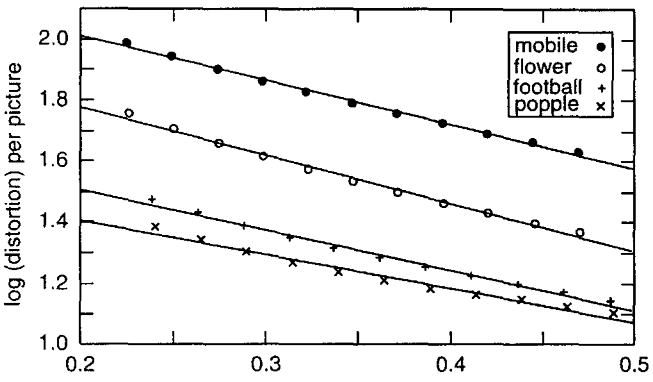
II. Distortion-bitrate Model

By computer simulation, we investigate the distortion-bitrate relationship of MPEG-2 video coding. The sequence is set to the interlaced 30 pictures per second of 704 pixels x 480 lines for luminance component and 352 x 240 for each chrominance component from each of four test sequences, "Flower Garden", "Football", "Mobile & Calendar", and "Popple". The coding procedure is based on the TM5 method[2], where a GOP (group of pictures) consists of 15 pictures without B-picture. Since the distortion is dependent on the assigned bitrate, we investigate the effect on the distortion according to the variation of bitrate. We here vary the bitrates from 4.0 ~ 8.0Mb/s at 0.4Mb/s intervals. We also use the two-steps of the TM5 rate control algorithm in which the target bit is allocated for the picture-type by the complexity measure and then the quantizer step size is selected for each macroblock within the picture by the virtual buffer fullness.

We obtained the measured distortion (Mean of Square Errors between the original and reconstructed pixels for luminance and chrominance components) averaged over 45 pictures with respect to the bitrates in bits per pixel for I-picture and P-picture of the test sequence. Figure 1 shows the measured data of actual distortion-bitrate and fitting lines among those data.



(a) I-picture



(b) P-picture

Figure 1. Observed relationship of distortion and bitrate for the bitrates from 4.0Mb/s to 8.0Mb/s.

We found that the relationship in picture-types for each sequence can be accurately approximated by the following model[4] in the practical range of bitrates,

$$\log D_{10} = m - nR \tag{1}$$

where D is the distortion (Mean of Square Errors between original and reconstructed pixels), R is the bitrate in bits per pixel, and m, n are model parameters which are dependent on the characteristics of test video sequences as summarized in Table 1 for I-picture and Table 2 for P-picture. We notice in Tables that the slope term n is less dependent on test sequence. However, the value of the slope term n for P-picture is about two times larger than I-picture, since the different quantizers are used for both picture-types (a quantizer without dead-zone for I-picture, a quantizer with dead-zone for P-picture) and the quantized DCT coefficients are coded by the variable length coder. Thus we notice that the term n can be approximated to a constant for each picture-type, independently of the sequence. We choose approximated (average) value n for each picture-type, n =0.7 for I-picture and n =1.4 for P-picture.

Table 1: Comparison of observed *m*, *n* values in I-picture for sequence

Test sequence	I-picture	
	m	*n*
Flower Garden	2.239	0.745
Football	1.795	0.757
Mobile & Calendar	2.512	0.685
Popple	1.620	0.608
average	-	0.7

Table 2: Comparison of observed *m*, *n* values in P-picture for sequence

Test sequence	P -picture	
	m	*n*
Flower Garden	2.088	1.559
Football	1.773	1.320
Mobile & Calendar	2.297	1.441
Popple	1.628	1.107
average	-	1.4

III. Picture Quality Control Method

1. Bitrate Allocation for Uniform Picture Quality

When the total bitrate for multiple video sources is fixed, we propose the uniform picture quality control method which keeps the same distortion level among the video sources.

The total bitrate R_t is given by

$$R_t = \sum_{i=1}^{N} R_i \tag{2}$$

where R_i is bitrate in bits per pixel for the *i*-th video source. For uniform picture quality, the requirement equation is given by

$$D_i = D_j, \text{ for } 1 \le i, j \le N \tag{3}$$

where D_i is distortion of the *i*-th video source. Using the distortion-bitrate model of Eq. (1), Eq. (3) can be rewritten by

$$10^{m_i - n_i R_i} = 10^{m_j - n_j R_j}, \text{ for } 1 \le i, j \le N \tag{4}$$

Eq.(4) can be presented for the term of R_i as follows:

$$R_i = \frac{n_j R_j + (m_i - m_j)}{n_i} \tag{5}$$

Substitution of Eq.(5) into Eq.(2) yields

$$\begin{aligned} R_t &= \sum_{i=1}^{N} \frac{n_j R_j + (m_i - m_j)}{n_i} \\ &= n_j R_j \sum_{i=1}^{N} \frac{1}{n_i} + \sum_{i=1}^{N} \frac{(m_i - m_j)}{n_i} \end{aligned} \tag{6}$$

From exchanging j to i in Eq.(6), we can obtain the following bitrate R_i for uniform picture quality.

$$R_i = \frac{R_t - \sum_{j=1}^{N} \frac{m_j - m_i}{n_j}}{n_i \sum_{j=1}^{N} \frac{1}{n_j}} \tag{7}$$

In order to use the above Eq. (7), we should know the real values of model parameters m, n. The real values can be known from the several coded results (distortions and bitrates) of the same picture. It introduces the picture delay and processing complexity. For simple implementation, we select the approximated constant value n which is not dependent on the video and m is updated by the coding results of the previous pictures within same video source. For simple implementation, the bitrate of k-th picture of i-th source can be obtained by

$$R_i(k) = \frac{R_t}{N} - \frac{1}{N} \sum_{j=1}^{N} \frac{m_j(k-1) - m_i(k-1)}{\bar{n}} \tag{8}$$

where $m_j(k-1)$ is calculated from $R_j(k-1)$, the bitrate of previous (k-1)-th picture, and $D_j(k-1)$, the average distortion of previous (k-1)-th picture by using the model Eq.(1), i.e.,

$$m_j(k-1) = \log D_j(k-1) + \bar{n} R_j(k-1) \tag{9}$$

2. Effects of Approximated Model Parameters

Now we consider the effect of the approximation of $\bar{n}$ on the user requirement of Eq. (3) in video variation such as scene change. Under the distortion-bitrate model of Eq. (1), $D_i(k)$ is given by

$$\log D_i(k) = m_i(k) - n_i(k) R_i(k) \tag{10}$$

In order to find the effect of approximation, we consider the stationary sources in which the pictures of same picture-type in each source have same values of real m and real n in Eq. (1), i.e., $m_i(k-1) = m_i(k) = \dots = m_i$, $n_i(k-1) = n_i(k) = \dots = n_i$. Eq. (10) can be rewritten by

$$\log D_i(k) = m_i - n_i R_i(k) \tag{11}$$

By replacing m_i with the distortion-bitrate pair of (k-1)-th picture, Eq. (11) is given by

$$\begin{aligned} \log D_i(k) = \log D_i(k-1) + n_i R_i(k-1) \\ - n_i R_i(k) \end{aligned} \tag{12}$$

Then, substitution of Eqs. (8) and (10) obtained by the approximated $\bar{n}$ instead of real n into Eq. (12) yields

$$\begin{aligned} \log D_i(k) &= \log D_i(k-1) + n_i R_i(k-1) - n_i \frac{R_t(k)}{N} \\ &+ \frac{n_i}{N} \sum_{j=1}^{N} \frac{(\log D_j(k-1) - \log D_i(k-1))}{\bar{n}} \\ &+ \frac{n_i}{N} \sum_{j=1}^{N} (R_j(k-1) - R_i(k-1)) \end{aligned} \tag{13}$$

From the constraint of constant total bitrate, $R_t(k) = R_t(k-1) = \sum_{j=1}^{N} R_j(k-1)$,

$$\begin{aligned} \log D_i(k) &= \log D_i(k-1) \\ &+ \frac{n_i}{N} \sum_{j=1}^{N} \frac{(\log D_j(k-1) - \log D_i(k-1))}{\bar{n}} \\ &= \frac{\bar{n} - n_i}{\bar{n}} \log D_i(k-1) \\ &+ \frac{n_i}{N} \sum_{j=1}^{N} \frac{\log D_j(k-1)}{\bar{n}} \end{aligned} \tag{14}$$

Eq. (14) shows the relationship of distortion-bitrate pairs between (k-1)-th and k-th pictures. From this equation, we can find the variations of distortion among the sources, i.e., the distortion ratios.

In order to satisfy the Eq. (3) which is requirement for same distortion among the video sources, the distortion ratio among the sources should be converged to the desired value. That is,

$$\sum_{j=1}^{N} \left(1 - \frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \sum_{j=1}^{N} \left(1 - \frac{D_j(k)}{D_i(k)}\right)^2 \tag{15}$$

Above convergence condition can be satisfied if the following condition is satisfied between two sources of N sources.

For $1 \le i \ne j \le N$,

$$\left(1-\frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \left(1-\frac{D_j(k)}{D_i(k)}\right)^2 \qquad (16)$$

By considering only two sources *i*, *j*, Eq. (14) can be presented by

$$\log D_i(k) = \frac{\bar{n}-n_i}{\bar{n}}\log D_i(k-1)$$

$$+\frac{n_i}{2}\frac{\log D_i(k-1)+\log D_j(k-1)}{\bar{n}}$$

$$=\frac{2\bar{n}-n_i}{2\bar{n}}\log D_i(k-1)$$

$$+\frac{n_i}{2\bar{n}}\log D_j(k-1) \qquad (17)$$

Similarly,

$$\log D_j(k) = \frac{2\bar{n}-n_j}{2\bar{n}}\log D_j(k-1)$$

$$+\frac{n_j}{2\bar{n}}\log D_i(k-1) \qquad (18)$$

From Eqs. (17) and (18), distortion ratio between *i* and *j* sources can be presented by

$$\frac{D_j(k)}{D_i(k)} = \left(\frac{D_j(k-1)}{D_i(k-1)}\right)^F \qquad (19)$$

where

$$E = \frac{n_i+n_j}{2\bar{n}} \qquad (20)$$

$$F = \frac{2\bar{n}-(n_i+n_j)}{2\bar{n}} \qquad (21)$$

Then substitution of Eq. (19) into Eq. (16) yields

$$\left(1-\frac{D_j(k-1)}{D_i(k-1)}\right)^2 > \left(1-\left(\frac{D_j(k-1)}{D_i(k-1)}\right)^F\right)^2 \qquad (22)$$

Therefore, for being satisfied the convergence condition of Eq. (22), *F* shoud be in range of

$$-1 \le F \le 1, \qquad (23)$$

that can be rewritten as following by using Eq. (21),

$$0 < \frac{n_i+n_j}{2} < 2\bar{n} = \bar{n}+\bar{n} \qquad (24)$$

We notice from Eq. (24) that if the sum of approximated *n* values is greater than one half of the exact sum, then the distortion ratio converges to the desired ratio

IV. Results

We compare the performance of the proposed method in the distortion and the bitrate with that of an independent bandwidth allocation method. The resolutions for test sequences are the same as those for Figure 1. The sequences are coded by TM5 method, but without adaptive quantization scheme. We use the GOP structure with 15 pictures of no B-picture. The total bitrate for four test sequences is fixed as a constant bitrate 24.0Mb/s. In the independent bandwidth allocation method, the bitrate for each sequence is allocated as the constant bitrate 6.0Mb/s which is divided the total bitrate by the number of multiplexed sources.

Figure 2 shows the PSNR (Peak Signal to Noise Ratio) and the generated bits per picture of the sequence for the independent bitrate allocation method. The PSNR is calculated as following,

$$PSNR_i(k) = 10\log(255^2 / MSE_i(k)) \qquad (25)$$

$$MSE_i(k) = \frac{1}{(N_x \times N_y)}\sum_{x=1}^{N_x}\sum_{y=1}^{N_y}\left(f(x,y,k)-f'(x,y,k)\right)^2 \qquad (26)$$

where, $f(x, y, k)$ is a pixel of *x*-th and *y*-th position in horizontal and vertical direction respectively, and *k*-th picture, $f'(x, y, k)$ is the reconstructed pixel of $f(x, y, k)$, and N_x, N_y are the number of pixels for horizontal and vertical directions, respectively.

Since the bitrate for each sequence is allocated as same value, the PSNRs among the sequences are large different according to the video characteristic. Also, there are some different among the PSNRs of the pictures within each sequence as shown in Figure 2(a).

Figure 3 shows the simulation results for the proposed bitrate allocation method. We notice that the proposed method makes significant difference in bitrate depending on the characteristics of video sequence. However the proposed method keeps almost the uniform PSNR among the sequences and also gives almost the constant PSNR among the pictures within each sequence.

Table 3 also shows the averaged values of distortion for the conventional and proposed methods and compares the deviation factors of average distortion among the tested four sources. The average distortion(M) and deviation factor(ΔM) is calculated by

$$M_i = \left(\sum_{k=1}^{45} MSE_i(k)\right)/45 \qquad (27)$$

$$\Delta M_i = \left(M_i - \left(\frac{1}{4}\sum_{i=1}^{4} M_i\right)\right) / \left(\frac{1}{4}\sum_{i=1}^{4} M_i\right) \qquad (28)$$

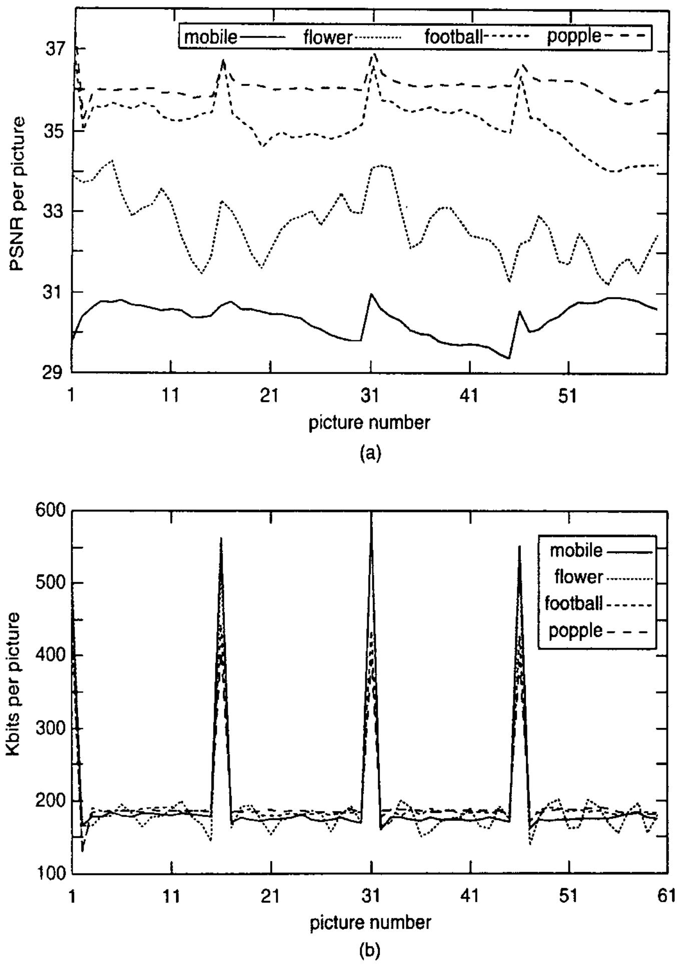


Figure 2. Performance of an independent bitrate allocation method; (a) PSNR per picture, (b) generated bits per picture.

Table 3: Average distortion(M) and deviation factor(ΔM) among the average distortions

Test sequence		Flow	Foot	Mobile	Popple
conventional method	M	36.89	20.36	61.26	15.81
	ΔM	9.8%	-39.3%	82.4%	-52.9%
proposed method	M	31.60	31.66	30.87	31.53
	ΔM	0.6%	0.7%	-1.7%	0.3%

From Table 3, we can notice that the distortion of "Mobile & Calendar" sequences is deviated the maximum 82.4% from the averaged value for the conventional method, but is deviated the maximum 1.7% only for the proposed method.

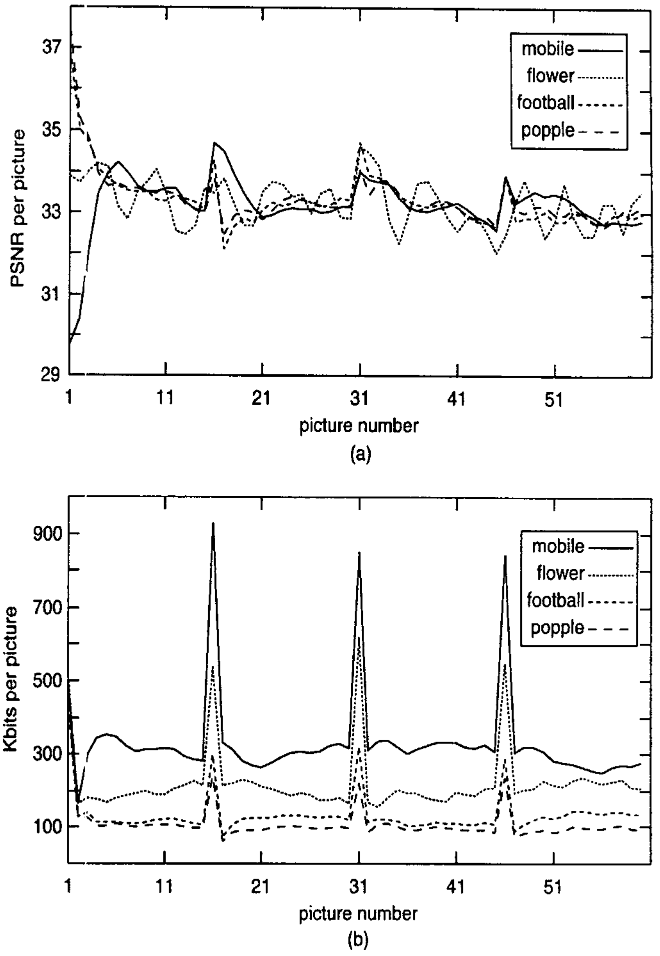


Figure 3. Performance of the proposed picture qulaity control method; (a) PSNR per picture, (b) generated bits per picture.

V. Conclusion

For the multiplexing system of multiple video sources, it is required to control the picture quality among the sources under the condition of fixed total bandwidth. In this paper, we investigate the approximated model of distortion and bitrate for the video source, and then we propose a picture quality control method based on the model for the same distortion level among the sources. By adaptively using the approximated model and the coded results of the sequences, we can see that the distortions among the sources are almost same and the distortion of a source is almost constant.

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