Statistical Feedforward/Feedback Buffer Control for Transmission of Digital Video Signal Compressed by The JPEG Algorithm

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Abstract- **A new buffer control policy for intrafield coding of video signals is introduced. The proposed method employs two statistical bit rate predictors, feedback and feedforward, and uses the feedback predictor in stationary portions of an image sequence and the feedforward predictor at scene changes. It is shown that the proposed buffer control policy is reasonably simple to implement and can efficiently control the ouput bit rate even at scene changes.**

I. Introduction

The use of variable bit rate (VBR) coders for compressing video signals in a constant bit rate transmission environment requires a transmission buffer and buffer control policies that adaptively control the output bit rate of the encoder. The buffer control directly influences the picture quality, and has been investigated in many digital image compression systems [1]-[8]. Conventional buffer control methods in [1]-[4] are based on observations of buffer occupancy and controls the bit rate in a feedback manner. More sophisticated feedback buffer control methods, which have been proposed recently in [5],[6], exploits appropriate statistical information about the encoder output along with buffer occupancy observations. It has been observed that the statistical approaches provide some improvement in picture quality. A drawback of feedback methods is their inability for rate control at scene changes. In an effort to overcome the difficulty, feedforward buffer control policies have been introduced in [7],[8] These methods, however, are considerably more difficult to implement than feedback methods, because they require to produce several output bit streams having different bit rates.

In this paper, we introduce a new buffer control method for intrafield(frame) coding of video signals. The proposed method incorporates a feedback approach with a simple feedforward approach and is called the statistical feedforward/feedback buffer control. It employs two predictors, feedback and feedforward, for the output bit rate prediction. The feedback prediction is used in stationary portions of an image sequence and the feedforward prediction is used whenever scene changes occur. Both the predictors exploit statistics of the encoder inputs and outputs: the feedback predictor is essentially the same as the one in [6], and the feedforward predictor uses the statistical relation between the input picture complexity and the output bit rate. The computational load required for the feedforward prediction is somewhat heavier than that for the feedback prediction. We shall show that the proposed policy is resonably simple to implement and can efficiently control the bit rate even at scene changes.

In what follows, the buffer control policy is presented using the JPEG encoder [9] which is applied to intrafield coding of video signals. It is assumed that the rate is controlled once for each field.

II. Intrafield Coding Using The JPEG Baseline Algorithm

Fig. 1 illustrates the JPEG baseline algorithm proposed by ISO for still picture coding. This algorithm partitions the input picture (luminance and chrominance components) into 8×8 blocks, performs two-dimensional discrete cosine transform (DCT) on each block, and independently quantize the DCT coefficients using a set of uniform quantizers. The quantization step-size applied to each coefficient is determined from the contents of a 64 element quantization table presented in the system (two such tables for luminance and chrominance components are given). The quantized DC coefficients of DCT are encoded by interblock DPCM. The prediction errors are coded using a variable-length coding (VLC) technique. The quantized AC coefficients of DCT are converted into a 1-D array through zig-zag scanning, run-length (R-L) coded, and then encoded by VLC. Four Huffman tables are given in the JPEG system for VLC of luminance DC, AC, chrominance DC, and AC coefficients.

When the JPEG algorithm is applied to compress an image, the elements of the quantization tables are divided by a constant, which will be referred to as the division factor (DF), and then used as step-sizes of the uniform quantizers. Note that DF and step sizes are inversely proportional to each other. Thus increasing DF results in an increase in the output bit rate, and *vise versa*. Throughout this paper the bit rate of the JPEG encoder will be controlled by adjusting DF. For luminance and chrominance quantization tables we shall use the same DF value.

III. The Statistical Feedforward/Feedback Buffer Control

The system block diagram of the statistical feedforward/feedback buffer control is shown in Fig. 2. For a given field, two DF values are produced from the feedforward and feedback DF estimators, and one of them is chosen by examining whether the scene change occurs or not. Details of each block are described as follows.

A. The Feedback DF Estimator

The DF value is estimated following the procedure proposed in [6]. The estimation requires the statistical bit rate curve, called the $DF - Rate$ curve, showing the mean and average absolute deviation of the output bit rate (bits/pixel) as functions of DF. Fig. 3 illustrates a $DF - Rate$ curve which is obtained by compressing six CCIR 601 test images (Ping-Pong, Flower Garden, Suzie, Popple, Mobile & Calendar, Tempest) using the JPEG baseline algorithm. Here the DF values are increased from 0.1 to 12.0 with increment 0.1. The output bit rate can be predicted using the DF-$Rate$ curve. Let $n_k(m)$ be the bit rate of the k_{th} field when $DF = m$. If the value of $n_k(m)$ is given, then for some p, $p \neq m$, $n_k(p)$ is estimated as follows:

$$\hat{n}_k(p) = d(p)\frac{n_k(m) - a(m)}{d(m)} + a(p) \qquad (1)$$

where $a(i)$ and $d(i)$, respectively, are the mean and the average absolute deviation of the rate corresponding to $DF = i$. In stationary portions of an image sequence $\hat{n}_k(p) \approx \hat{n}_{k+1}(p)$. Therefore we may write

$$\hat{n}_{k+1}(p) = d(p)\frac{n_k(m) - a(m)}{d(m)} + a(p). \qquad (2)$$

The feedback DF estimator predicts $n_{k+1}(p)$ for all p, $0.1 \leq p \leq 12$, and set $DF = p_0$ if $n_{k+1}(p_0)$ is closest to the transmission (target) bit rate. The estimation procedure is summarized as follows.

Step 1: From the buffer, obtain the bit rate $n_k(m)$ and the corresponding DF value m assocaited with the compressed field at time k.

Step 2: Using (1) predict $n_{k+1}(p)$ for all p, $0.1 \leq p \leq 12.0$ (p is icreased from 0.1 with increment 0.1).

Step 3: Set $DF = p_0$, for some p_0, if $n_{k+1}(p_0)$ is closest to the transmission bit rate.

B. The Feedforward DF Estimator

The feedforward prediction of the bit rate is based on the fact that the amount of data produced by the JPEG encoder with a fixed DF value is roughly proportional to picture complexity. A simple measure that we use for examining complexity of each 8×8 block is the sum of squred absolute difference ($SSAD$) defined as

$$SSAD = \sum_{i=0}^{7}\sum_{j=1}^{7}\sqrt{|f(i,j) - f(i,j-1)|} + \sum_{i=1}^{7}\sum_{j=0}^{7}\sqrt{|f(i-1,j) - f(i,j)|} \qquad (3)$$

where $f(i,j)$ is the gray level of i-th row, j-th column within an 8×8 block. The feedforward predictor utilize the statistical relation between the rate and $SSAD$. To obtain the statistics, the bit rate and $SSAD$ are evaluated for every block of the six test images (Ping-Pong, Flower Garden, Suzie, Popple, Mobile & Calendar, Tempest) and then the bit rates of the blocks having identical $SSAD$ values are averaged. Here the JPEG algorithm with $DF = 2.0$ is used, and the luminance and chrominance components are independently treated. The results are shown in Fig. 4. It is seen that the rate is roughly proportional to the $SSAD$.

For a given field to be compressed, the feedforward DF estimator evaluates the $SSAD$s of all blocks and predict the bit rate of each block using Fig. 4. The bit rate of the field for $DF = 2.0$ is predicted by averaging the predicted values from blocks. Here the rates for luminance and chrominance are predicted independently, and then added to get the bit rate of the field. The rates for $DF \neq 2.0$ are predicted using (1) and Fig. 3. Specifically, in (1) we assume $n_k(m)$, $m = 2$, is the predicted value for $DF = 2.0$ and calculate $\hat{n}_k(p)$. Finally, the DF is selected as in the case of feedback DF estimation. The feedforward DF estimation is summarized as follows:

Step 1 For a given field evaluate $SSAD$s of all 8×8 blocks and predict the bit rate of each block using Fig. 4.

Step 2 Predict the bit rate for $DF = 2.0$ by averaging the predicted rates from blocks.

Step 3 Using (1) and the DF-$Rate$ curve in Fig. 3 predict bit rates for all DF values between 0.1 and 12, $DF \neq 2.0$.

Step 4 Select the DF value corresponding to the predicted bit rate which is closest to the transmission rate.

Due to Steps 1 and 2 the feedforward DF estimation require more computation compared to feedback estimation, but the additional computational load is not heavy; the implementation of the feedforward estimation is reasonably simple.

C. Scene Change Detector

A scene change is claimed at $(k+1)$-*th* field if the absolute difference between the feedforward prediction values at $(k+1)$-*th* and k-*th* fields, for $DF = 2.0$, is greater than a threshold value. In our simulation, the threshold is set to 10% of the transmission bit rate.

IV. Simulation Results

The image sequence used for examining the performance of the proposed buffer control policy consists of four different types of CCIR 601 images. Specifically, the sequence has ten flower garden fields followed by ten Suzie, ten Mobile & Calendar, and ten Ping-Pong fields; it contains a total of forty fields with three scene changes.

The JPEG algorithm is applied to the image sequence under the assumption that the transmission bit rate is 0.8 bits per pixel (bpp). The DF value of the JPEG algorithm is adjusted once for each field by using the proposed buffer control policy. For comparison, the statistical feedback buffer control method employing only the feedback DF estimator, after removing the feedforward DF estimator from Fig. 2, is also applied.

Fig. 5 shows the evolution of output bit rates of the JPEG encoders employing the proposed feedforward/feedback and feedback buffer control methods. It is seen that both methods perform well in stationary portions of the image sequence. At scene changes, however, only the proposed feedforward/feedback method controls the bit rate, while the feedback method cannot. The buffer occupancy observation shown in Fig. 6 indicates that the probability of buffer overflow and underflow associated with the proposed method is considerably lower than that associated with the feedback method.

V. Conclusions

The statistical feedforward/feedback buffer control method employing two statistical bit rate predictors, feedforward and feedback, is introduced. It is shown that the proposed method is reasonably simple to implement and can control the bit rate even at scene changes.

The proposed buffer control policy can be directly applied to some other DCT-based intrafield coding techniques such as the ones in [6],[7]. Futhermore, it is expected that the concept of the statistical feedforward/feedback control can be applied to various image compression systems which are not based on DCT. Research in this direction is being pursued.

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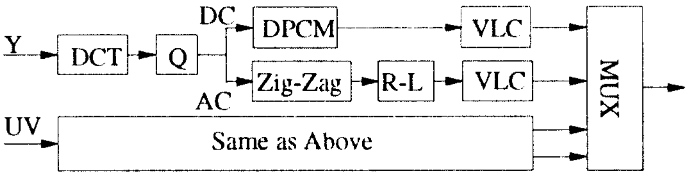

Q : Quantization
R-L : Run-Length Coding
Zig-Zag : Zig-Zag Scanning

Fig. 1. JPEG baseline algorighm.

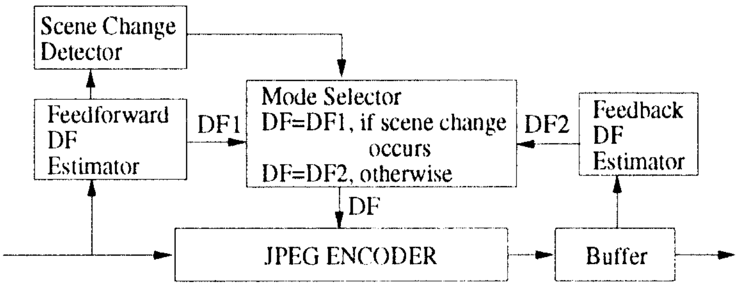

Fig. 2. Statistical feedforward/feedback buffer control system.

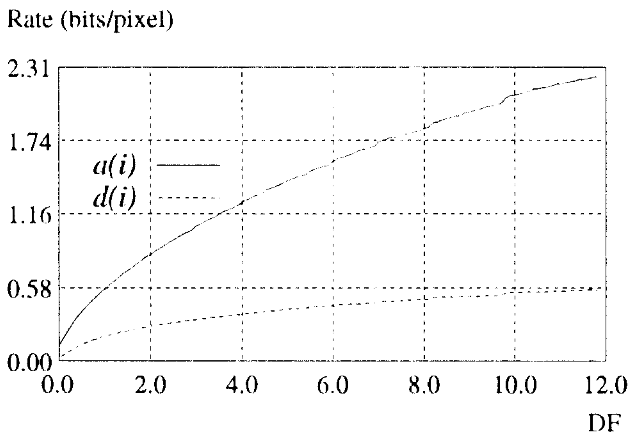

Fig. 3. DF-Rate curve

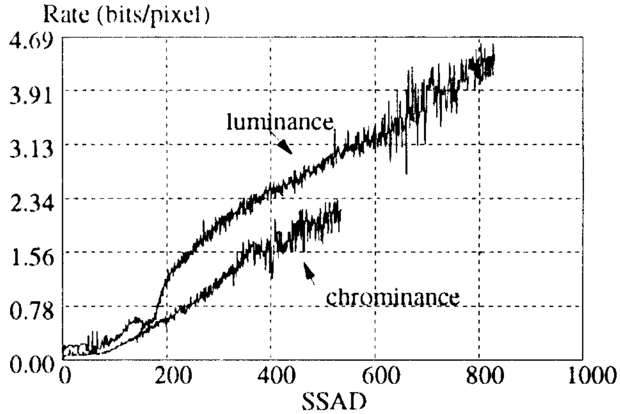

Fig. 4. SSAD-Rate curve.

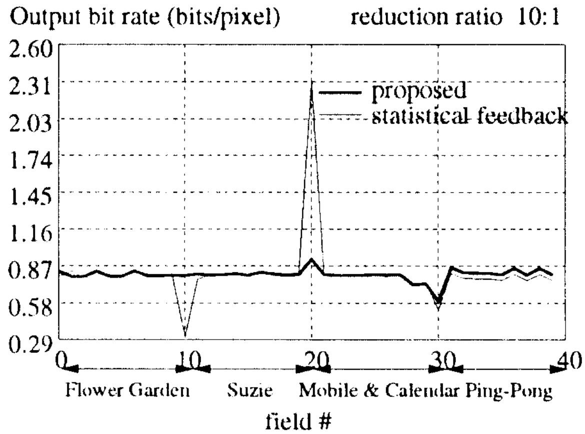

Fig. 5. Output bit rate.

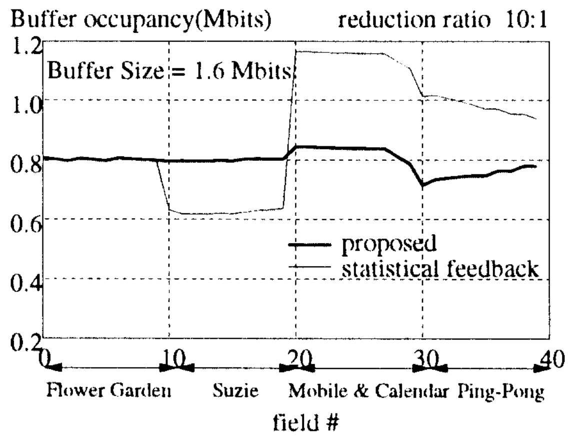

Fig. 6. Buffer occupancy