COLOR-COMPONENT BIT ALLOCATION SCHEME FOR JPEG 2000 PARALLEL CODEC

Yoshihide Tonomura†, Takayuki Nakachi†, Daisuke Shirai†, Tatsuya Fujii†, Hitoshi Kiya‡

†NTT Network Innovation Laboratories,
Nippon Telegraph and Telephone Corporation, 239-0847 JAPAN
‡Department of Information and Communication Systems Engineering,
Faculty of System Design, Tokyo Metropolitan University, 191-0065 JAPAN

ABSTRACT

A new bit allocation scheme for JPEG 2000 systems in parallel-distributed environments is proposed. In recent years, super high-definition images are being used for not only digital cinema also alternative services e.g. real-time sports in theaters. In general, such high-definition images are divided into small segments, such as tiles or components, and compressed. However, this process leads to low coding efficiency. In contrast, our proposed scheme controls the bit allocation ratio for each color-component separately by using the quantizer properties available in the JPEG 2000 standard. Simulation results show that the proposed scheme achieves the same coding performance as the non parallel-distributed approach.

Index Terms— JPEG 2000, Bit allocation, Parallel processing, Rate distortion

1. INTRODUCTION

The popularity of digital reproduction is driving the number of image pixels ever upward. Symbolic of this trend is the standardization of digital cinema in digital cinema initiatives LLC (DCI)[1]. The DCI specification recommends super high definition (SHD) images (4096×2160 pixels) called "4K" as the highest quality of digital cinema. Since 4K is excessive for small screens, the DCI specification adopts the JPEG 2000 scheme which makes it possible to easily create 2K content from 4K content through the use of spatial scalability. According to the DCI specification, a 4K stream can be compressed using JPEG 2000 to 250[Mbps].

With this bit rate, and modern broadband networks, high quality content is being multicast by JPEG 2000 systems[3][4] to movie theaters. This new service is called "ODS: Other Digital Stuff/ Online Digital Source". ODS is starting to garner attention for new in-theater entertainment services including real-time sports, music, pre-show ads and more[5].

In this way, live streaming of SHD images is becoming a reality due to the standardization of digital cinema. However, SHD applications impose a huge computational load since the large data stream must be treated in real-time. The general solution is to divide the SHD image into small segments such as tiles or components. These components are compressed using parallel processing. Unfortunately, this separation leads to low coding efficiency because of the bit allocation problem. Some papers have tackled this problem and [6] proposed threshold-based RAIT (Rate Allocation for the Image Tiles) schemes, which allocates bit rates to each tile before encoding. However, the optimal threshold changes depending on the image used and is difficult to compute. This paper proposes a new bit allocation scheme for JPEG 2000 systems in parallel-distributed environments. Specifically, the bit allocation problem of each color-component is considered independently using the quantizer in the JPEG 2000 standard. However, since it is difficult to achieve pre-specified bit rates with this approach, we propose a near-optimal 2 pass rate allocation scheme that combines a quantizer and a post quantizer.

2. 4K REAL-TIME VIDEO STREAMING SYSTEM

In this section, we describe 4K real-time video streaming system and its JPEG 2000 coding process[4]. After this section, we examine a bit allocation method for this system.

2.1. Overview of the 4k video streaming system

Our JPEG 2000 video streaming system can treat a progressive 4K resolution image at 60 [fps] with 36 [bit] color separation in real-time. One of its most attractive features, its very low latency of 70 [msec], is achieved because the system employs parallel processing. Fig. 1 illustrates the encoder construction with parallel processing.

2.1.1. Input and tile division

The input part uses four HD-SDI Dual Links with four 2K signals from a 4K camera. These 2K signals are put into the tile divider, which separates the components as 1K images.

2.1.2. Color transform

The colour transform can exploit redundancies between the red, green and blue sample values of a colour image and

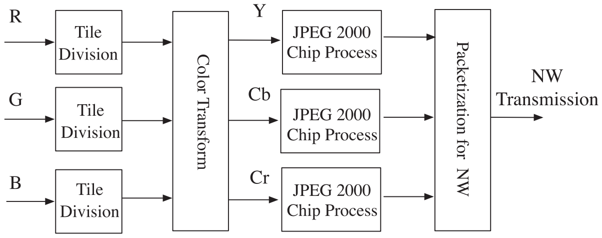

Fig. 1. Construction of 4K video streaming system with parallel processing codec.

yields compression based on the so-called Contrast Sensitivity Function (CSF).

2.1.3. JPEG 2000 chip

Each YCbCr component signal is compressed by one JPEG 2000 chip (Analog Devices INC. ADV202 ES5).

(a)Wavelet transform: In the first JPEG 2000 process, each component signal is transformed into sub-bands using the discrete wavelet transform (DWT).

(b)Scalar quantization: After DWT, the DWT coefficients are quantized with their own step sizes. The step sizes of each sub-band are given by

$$\Delta_b = 2^{-\epsilon_b}\Big(1 + \frac{\mu_b}{2^{11}}\Big) \tag{1}$$

where, ϵ, μ are nonnegative integers; normalized DWT coefficients are adopted. The error signal assumes white additive noise, and the optimal quantization step size is approximately given by

$$\Delta_b = \Delta_0 \cdot \sqrt{\frac{1}{G_b}} \tag{2}$$

where G_b is the sum of all L2 norm values of the synthesis filter and Δ_0 is base step size.

(c)EBCOT(Embedded Block Coding with Optimized Truncation): In EBCOT, quantized coefficients are divided among each code block and each value is converted into binary signals in conformance with bit modeling. The binary signals are compressed by an arithmetic coder. Coded data is sent to the post quantizer and optimal bit rate is allocated by the PCRD (Post-compression rate-distortion) algorithm.

In the PCRD algorithm, optimal truncation points are found in the coded data; note that these points should have the same rate-distortion (RD) slope value. The RD slopeλ_i of each code block is approximately given by

$$\lambda_i(z) \simeq \frac{D_i^{(z')} - D_i^{(z)}}{L_i^{(z)} - L_i^{(z')}} \tag{3}$$

where z and z' are a truncation and ex-truncation point, respectively, in each coding modeling pass, L is the exact bit rate and D is the variance of the error signal in the coded image.

2.1.4. Packetization

In this part, the JPEG 2000 file is packetized for IP network transmission. Our system uses TCP or UDP unicast or UDP multicast. In the case of multicast, this part sets the network interface for packet multicasting and sends packets to the multicast address.

3. BIT ALLOCATION SCHEME FOR JPEG 2000 PARALLEL CODEC

3.1. Bit allocation method using fixed ratio in parallel-distributed environment

The goal of this paper is to assign the optimal bit rate to each component separately. As noted Section 2, to assign the specified bit rate, we need to allocate the bit rate of each component before entering the JPEG 2000 process.

We evaluated the fixed assignment ratio method assuming the use of the JPEG 2000 parallel codec. In this simulation, we compare two environments, one is simultaneous encoding, i.e. the components are processed together using the PCRD algorithm; the other is independent encoding using the fixed ratio which provides average allocated ratio. We used the kakadu JPEG 2000 program [7], Kodak 4 test images and StEM 4 images [1]. The results are shown in Fig. 2 and Table1. Figure 2 plots the average PSNR of each image as calculated by

$$\text{PSNR} = 10\log_{10}\frac{(2^{\text{Bitdepth}} - 1)^2}{\text{MSE}} \tag{4}$$

$$\text{MSE} = \frac{1}{N_1 N_2 N_3}\sum_{n_1=0}^{N_1-1}\sum_{n_2=0}^{N_2-1}\sum_{n_3=0}^{N_3-1}(x[n_1,n_2,n_3] - x'[n_1,n_2,n_3])^2 \tag{5}$$

where N_1, N_2 are pixel sizes and N_3 is the number of components (RGB color space).

In Fig. 2, the fixed ratio method shows a drop in coding efficiency for all test images. This means that the fixed ratio method could not allocate the bit rate optimally. The average drop was about 1[dB] for the Kodak images and 2[dB] for the StEM sequence. In the worst case (Kodak 1st image) the drop was 2.7 [dB].

3.2. Bit allocation method utilizing JPEG 2000 quantizer property

The fixed ratio method fails to allocate bit rate optimally. One reason is that each image has many unique characteristics, such as the correlation between components.

To allocate each bit-rate optimally, we consider using the JPEG 2000 quantizer properties. Unlike the PCRD optimization in Eq.(3) which requires the knowledge of each λ for each code-block, the quantization optimization in Eq.(2) does not require knowledge of the image characteristics. However,

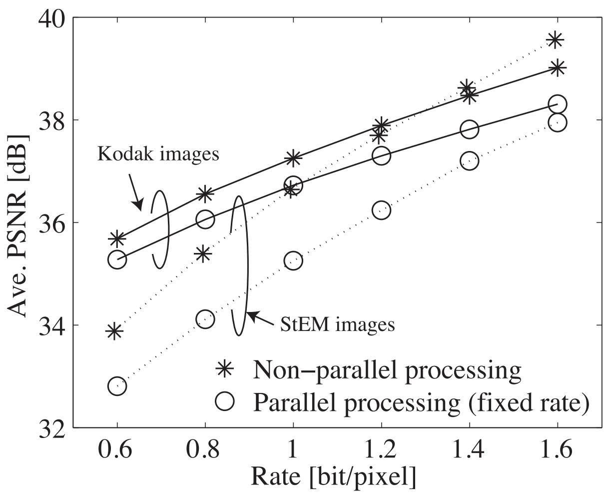

Fig. 2. Average PSNR for Varying Total Bit Rate when the YCbCr components are Encoded both Independently and Simultaneously (Existing method)

Table 1. Allocated Bit-rate Ratio using PCRD algorithm.

image	Kodak(No.01)	Kodak(No.02)	Kodak(No.03)
Y	0.9491	0.7694	0.8207
Cb	0.0150	0.0697	0.1006
Cr	0.0300	0.1547	0.0698
image	Kodak(No.04)	StEM(No.02741)	StEM(No.003869)
Y	0.8043	0.4591	0.4496
Cb	0.0394	0.4129	0.4072
Cr	0.1511	0.1276	0.1429
image	StEM(No.6050)	StEM(No.8617)	Average ratio
Y	0.4692	0.2588	0.6225
Cb	0.4511	0.6594	0.2694
Cr	0.0795	0.0814	0.1046

it is unclear if quantization optimization can yield optimally bit-rate allocation or not. Moreover, if the quantization optimization works well, it is quite difficult to be able to predict the encoding bit rate for a given image component from its quantization step size. Therefore, we split the encoding process into two stages in order to optimally encode each YCbCr component independently. We call this method the "2 pass method" and illustrate it in Fig.3.

The first stage is the analysis part; each component is encoded using the scalar quantizer to alter the encoding rate. The rates at which each component is encoded at this stage are used to determine the percentage of the total bit rate allocated to each component in the second stage of the encoding process. The quantization step size used to encode each component is determined using Eq.(2) and we set the base step size to ($\Delta_0 = 0.0195312$) for normalized DWT coefficients. In the final portion of the first pass, we analyze the coded j2c files of each component and extract the rates at which each of them are encoded. We can use these rates to find the ratio

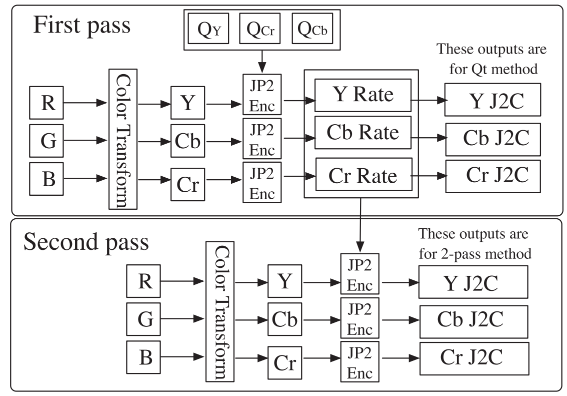

Fig. 3. 2-pass encoding process for proposed encoding scheme.

of the total bit-rate and allocate the optimal bit rate to each component as shown in

$$\left[\text{Ratio}_Y, \text{Ratio}_{Cb}, \text{Ratio}_{Cr}\right] = \frac{\left[R_Y, R_{Cb}, R_{Cr}\right]}{R_Y + R_{Cb} + R_{Cr}} \qquad (6)$$

After determining the rate for each component, we use these results in the second pass to encode each component. The reasoning behind this bit rate allocation scheme is that previous results revealed that if the image components are encoded independently using the quantization step size as the control variable for encoding, then the average RGB PSNR at all rates are maximized and the bit rate allocation for each component is near optimal. However, the computational load of this operation may be a problem. Therefore, we also propose a method that can remove the second encoding process by utilizing JPEG 2000 quality scalability. We call this method the "Quantization-truncation method (Qt method) ". In the Qt method, rate control is done after the first pass and it is simple to cut some layers according to the analysis results obtained in the first pass. The weakness of this method is the increased overhead drive by the layer structure of the code-stream. We address the concern presented by this increased overhead at the end of this section.

The evaluation of the proposed method is outlined as follows. First, we investigated the relationship between bit rate allocation for each YCbCr component and the total bit rate as determined from the JPEG 2000 quantization property. The result is shown in Fig. 4. From the data seen in Fig.4, it is quite clear that the quantization method assigned the near-optimal bit rate to each component. Furthermore, the relationship between the component bit rate allocation for a given total bit rate is approximately linear. In other words, it is possible to approximate the target bit rate through linear regression using one observed bit rate. This makes it possible for our proposed method to estimate the allocated bit rate by Eq.(6). Interestingly, Fig.4 also shows the fact that if we use

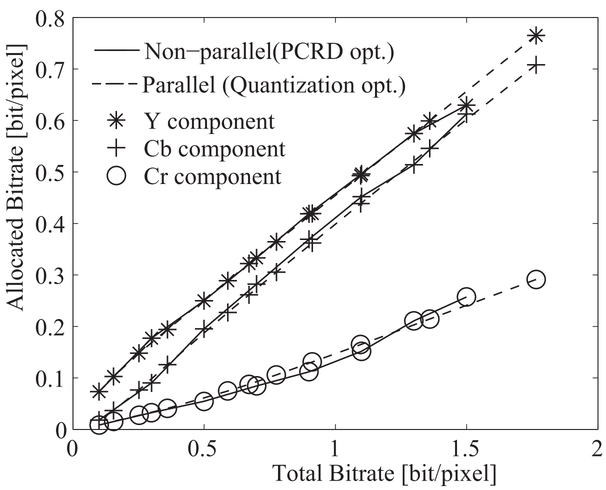

Fig. 4. Bit Rate Allocation for each YCbCr Component as the Total Bit Rate Varies. (StEM Day Scene)

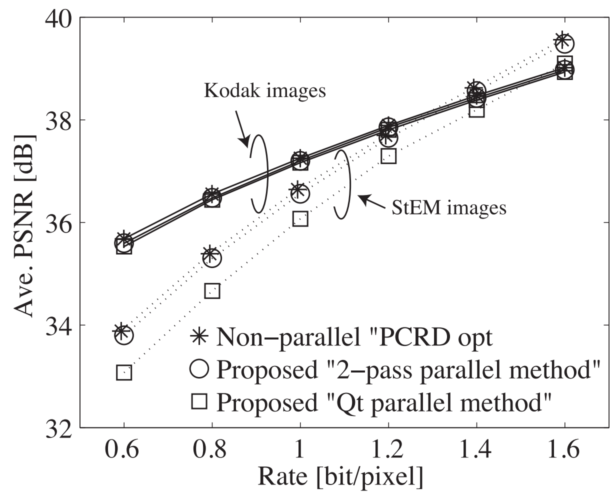

Fig. 5. Average PSNR for a Varying Total Bit Rate when the YCbCr components are Encoded both Independently and Simultaneously.

almost the same base step size for each component, the RD slopes for each component λ_c have almost the same values. Due to space limitations, we do not show all results, but we have confirmed that the proposed method, which uses proper quantization, can allocate near-optimal bit rates in all images.

Next, we evaluated the 2-pass and Qt methods using the conditions of Section 3.1 and the results are shown in Fig.5. As seen in Fig.5, using the 2-pass encoding process yields near-optimal component bit rate allocation for all test images. The worst drop in efficiency is less than 0.20[dB]. One explanation for the quality differences is the selection of the base quantization step size. In this experiment, base step size was fixed at $\Delta_0 = 0.0195312$. This approach may not maximize the image quality and further investigation is required in order to select the most effective initial step size for each image. Fig. 5 also shows that the Qt method allows efficiency to drop by about 0.1 [dB] for Kodak images and about 0.6 [dB] for StEM images when the bit-rate of each layer is set at 0.05 [bit/pixel]. This method sacrifices image quality to greatly reduce the overall computational load. The drop in efficiency can be attributed to the reduction of quality layers when encoding, as increasing the number of layers increases the amount of overhead, but allows us to allocate bit-rates that are much closer to optimal. This is one of the trade-offs to consider when using this method and is the subject of ongoing work. We have confirmed that our scheme shows almost the same characteristics as Fig.5 for all images.

4. CONCLUSION

This paper proposed a new 2-pass method that offers near optimal allocation of JPEG 2000 component bit rates via the scalar quantizer used for encoding. The proposed method utilizes the JPEG 2000 quantizer property to control the exact bit allocation rate for each color-component. We evaluated the proposed method and confirmed that the proposed scheme achieves coding performance comparable to that achieve by non parallel-distributed schemes. The proposed method shows a reduction in coding efficiency of less than 0.20 [dB] at the cost of doubling the computational load of encoding. On the other hand, the Qt method, which utilizes JPEG 2000 scalability, allows an efficiency reduction of 1.2 [dB] but requires only one encoding pass. Theoretical analysis of the proposed method, a method of deciding base step size and the division of optimal layers are to be considered in the future.

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