Lossless Integer Color Transform for Four Color Components

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Abstract— **This report proposes an integer color transform for lossless coding of four color components of images. An existing color transform has a fixed set of coefficients and therefore it can't be adaptive to each image. We utilize eigen-vector of the covariance of the four components to increase data compaction performance. We also utilize fixed relation between two green components to simplify computational cost of the transform. It was confirmed that the proposed method reduces entropy rate by 0.4 bit comparing to the existing method.**

I. INTRODUCTION

Three color components R, G and B have been widely utilized as a standard format of image and video in digital signal processing technologies. It is originally obtained as four color components R, G0, G1 and B though the Bayer type mosaic filter array. These color components are interpolated to three colors by a demosaicing technique [1,2].

In this report, we propose an integer transform of the four color components for lossless coding of color images. The JPEG-LS is an international standard for lossless coding of images [3]. It utilizes correlation between neighboring pixels adaptively to the local context in an image. It was expanded to four color components [4]. However, these adaptive prediction based methods take much computational cost in encoding.

On the other hand, the transform based methods have been also developed. The integer DWT (Discrete Wavelet Transform) is adopted by the JPEG 2000 for lossless coding [5,6]. The integer DCT (Discrete Cosine Transform) has an advantage of compatibility to the conventional real valued DCT for lossy coding [7,8].

These transforms utilizes correlation among pixel values within a component after a color transform. It is well known that their coefficient values (basis functions) can be fixed since statistical characteristics of the input wave form can be approximated as the AR(1) model. However, it does not hold for coefficient values of a color transform.

For example, a reversible color transform (RCT) of three color components is defined in JPEG 2000. It converts RGB to YUV and utilized for lossless coding of color images [5]. A similar transform of four components was proposed (existing method I) [11]. It has fixed coefficients and therefore it can't be adaptive to, not always optimum for, each input image.

To make a color transform optimum, we utilize the integer Karhunen Loeve transform (reversible KLT) in the form of ladder structure [9]. Its coefficient values are given as the eigen-vector matrix of the covariance matrix of four color components. Its basis functions are optimum for each color input image. In this report, we simplify computational cost of an existing integer KLT with permutations for singular point avoidance (existing method II) [10].

Utilizing the fact that the optimum rotation angle between G0 and G1 can be fixed, we apply a pre-transform with fixed coefficients to these two color components first. Then we apply a three point KLT to one of output signals from the pre-transform and other color components G and B. Finally we confirm that the proposed method can reduce data volume than the existing method I under less hardware complexity of the existing method II.

II. EXISTING METHODS

Two existing methods I and II are described. The former is simple but not adaptive. The latter is adaptive but complex.

A. *Lossless Coding of Four Color Components*

Fig.1 illustrates a coding procedure. Firstly, a set of four pixels composed of one pixel from each of four color components R, G0, G1 and B is processed with the four point reversible color transform (4pt- Rev.CT). Next, a set of neighboring 8x8 pixels in each component are independently processed with the reversible eight point DCT (Rev.DCT).

In the figure, H0 and H1 denote the entropy before and after the Rev.CT respectively. H0 indicates how the data volume is compressed by an entropy coder without any transform. The value H1 minus H0 indicates significance of the Rev.CT described in the following subsections.

H2 and H3 are the entropies after applying the Rev.DCT. Only one component with the least variance is not processed by the Rev.DCT at H2. If H2 is almost same as H3, then it is not necessary to apply the Rev.DCT to all the components. It contributes to reduce total computational cost.

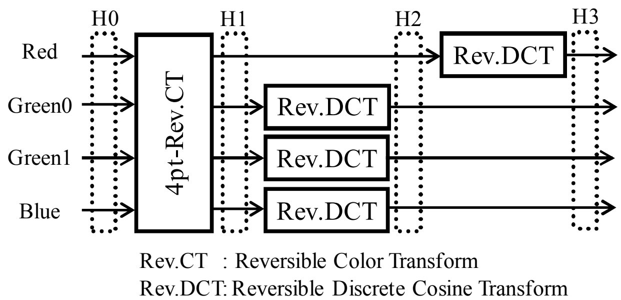

Fig.1 Lossless coding of four color components.

B. *Existing Method I*

Fig.2 illustrates the existing 4pt-Rev.CT proposed in [11]. Its forward transform is described as

$$\begin{bmatrix} Y \\ C_r \\ C_b \\ C_g \end{bmatrix} = \begin{bmatrix} F\big[\big(R + 2 \cdot F[(G_0 + G_1)/2] + B\big)/4\big] \\ R - F[(G_0 + G_1)/2] \\ B - F[(G_0 + G_1)/2] \\ G_0 - G_1 \end{bmatrix} \quad (1)$$

$$F[x] = x - (x \bmod 1)$$

where F[x] denotes flooring of a value x to an integer. It converts four components (R, G0, G1, B) to luminance Y and three color difference (Cr, Cg, Cb). Note that both of input and output values are integers, and its backward transform reconstructs the input value without any loss.

This existing method I is simple to implement since coefficients are fixed. However it is not adaptive to correlation between components in, not always optimum for, each of input images.

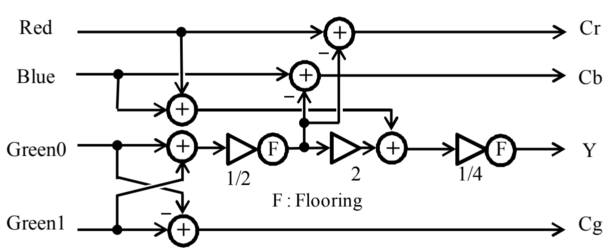

Fig.2 Existing method I

C. *Existing Method II*

The forward transform of KLT converts a set of four color components X to Y as

$$\mathbf{Y} = \mathbf{K}^T \mathbf{X} \quad (2)$$

where K is a 4x4 eigen-vector matrix of the covariance matrix of X. As a result, the covariance matrix of Y becomes diagonal matrix composed of eigen-values, and therefore the components are de-correlated.

Fig.3 illustrates a four point Rev.KLT which is straightforwardly extended from the three point Rev.KLT proposed in [10]. It is composed of six rotations:

$$\mathbf{F}(\theta_i) = \begin{bmatrix} \cos\theta_i & -\sin\theta_i \\ \sin\theta_i & \cos\theta_i \end{bmatrix}, \quad i \in \{1,2,\cdots,6\}. \quad (3)$$

where θ_i denotes the rotation angle. This existing method II is adaptive to each of input images. Its data compaction performance is expected to be superior to the existing method I. However it takes larger computational cost to calculate the eigen-vector. It should be attached to the data as an overhead.

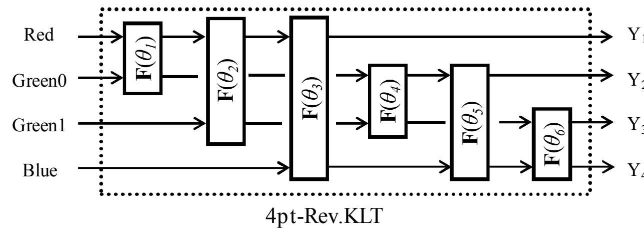

Fig.3 Existing method II

III. Proposed Method

A simplified KLT is proposed utilizing the fact that correlation between two green components is almost fixed.

A. *Correlation between Two Green Components*

Fig.4 summarizes the optimum rotation angle of a two point KLT for two color components in the sample images in Fig.5. Cross correlations are summarized in Fig.6. It is observed that the two green components G0 and G1 have a fixed rotation angle. Utilizing this fact, we reduce the KLT size from four to three to reduce computational cost.

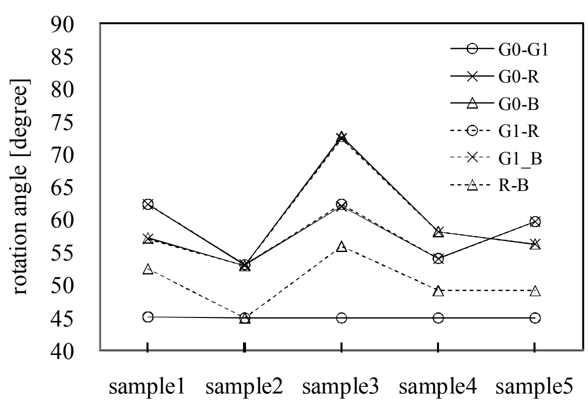

Fig.4 The optimum rotation angle of two components

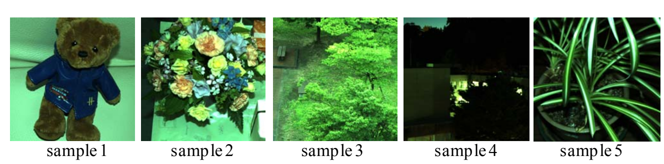

Fig.5 Sample images (8 bit, 4 colors)

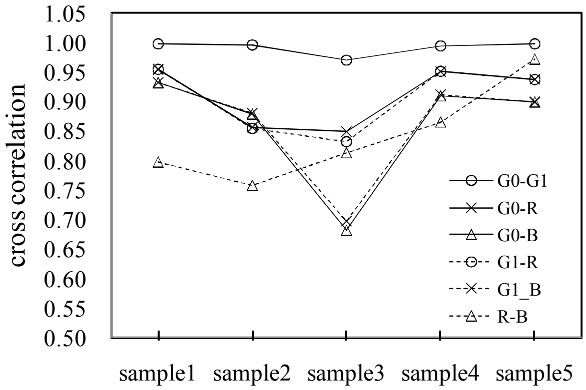

Fig.6 Cross correlation between two components

B. Proposed Method and its Variations

(Type 1)

Fig.7 illustrates the proposed method (type 1). We apply the two point Haar transform defined by

$$\begin{bmatrix} Y_1 \\ G_1' \end{bmatrix} \approx diag[2^{-1/2} \quad 2^{-1/2}] \cdot \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} G_0 \\ G_1 \end{bmatrix} \tag{4}$$

to the two green components G_0 and G_1 first. We implement this two point transform in the ladder form [9] to make it reversible as illustrated in the figure. Since they have strong similarity, we set the parameters $f_1 = f_2 = tan(\pi/8)$ and $f_3 = tan(\pi/4)$. Then we apply the three point Rev.KLT to (Y_1, R, B). Now the KLT size is reduced from four to three.

(Type 2)

Fig.8 illustrates the proposed method (type 2). The two point reversible transform is replaces by the DPCM as

$$\begin{bmatrix} Y_1 \\ G_1' \end{bmatrix} = \begin{bmatrix} 1 & -1 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} G_0 \\ G_1 \end{bmatrix} \tag{5}$$

where G_1' is exactly the same as G_1. This is the simplest implementation since it has no scaling factor.

(Type 3)

Fig.9 illustrates the proposed method (type 3). The two point reversible transform is replaces by the S transform proposed in [12] as

$$\begin{bmatrix} Y_1 \\ G_1' \end{bmatrix} = \begin{bmatrix} G_0 - G_1 \\ F[(G_0 + G_1)/2] \end{bmatrix} \approx diag[1 \quad 2^{-1}] \cdot \begin{bmatrix} 1 & -1 \\ 1 & 1 \end{bmatrix} \begin{bmatrix} G_0 \\ G_1 \end{bmatrix}. \tag{6}$$

C. Advantage of the Proposed Method

All the variations of the proposed method use three point Rev.KLT instead of four in the existing method II. Since its size is reduced, its computational cost and overhead are also reduced.

Table I summarizes comparison results between the two methods. Matrix size is reduced from 4x4 to 3x3 (56 %). When the rotation angles are used as the overhead, it is reduced from 6 to 3 (50 %) [10]. Computational speed for eigen-value calculation is reduced to 92 %. Since each of the rotation contains three lifting steps which bring about the lifting latency [12], it is reduced from 18 to 12 steps in type 1. It also contributes to reduce the number of rounding or flooring operations which generate rounding errors.

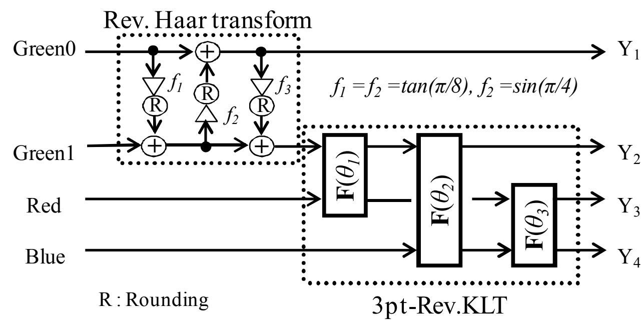

Fig.7 Proposed method (type 1)

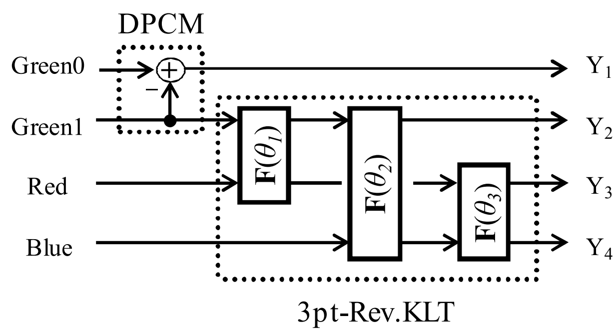

Fig.8 Proposed method (type 2)

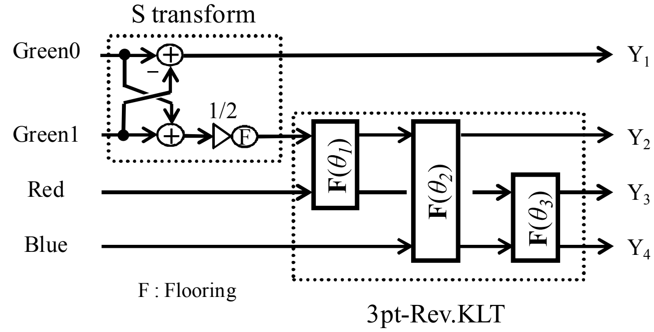

Fig.9 Proposed method (type 3)

TABLE I Comparison of the methods in utilities.

<table>
<tr><th rowspan="2"></th><th colspan="2">over head</th><th rowspan="2">eigen value calculation [μsec]</th><th rowspan="2">lifting step</th><th rowspan="2">number of rounding</th><th rowspan="2">optimi-zation</th></tr>
<tr><th>angle</th><th>matrix</th></tr>
<tr><td>existing I</td><td>0</td><td>0</td><td>0</td><td>3</td><td>2</td><td>Not Available</td></tr>
<tr><td>existing II</td><td>6</td><td>16</td><td>84.3</td><td>18</td><td>18</td><td rowspan="4">Available</td></tr>
<tr><td>proposed (type 1)</td><td rowspan="3">3</td><td rowspan="3">9</td><td rowspan="3">77.8</td><td>12</td><td>12</td></tr>
<tr><td>proposed (type 2)</td><td rowspan="2">10</td><td>9</td></tr>
<tr><td>proposed (type 3)</td><td>10</td></tr>
</table>

TABLE II Comparison of the methods in entropy.

H3	sample1	sample2	sample3	sample4	sample5	average
existing I	4.18	4.27	5.37	3.52	3.81	4.23 (0.00)
existing II	4.10	4.21	5.17	3.48	3.72	4.14 (-0.09)
proposed (Type1)	4.10	4.21	5.16	3.48	3.72	**4.13 (-0.10)**
proposed (Type2)	4.21	4.30	5.26	3.58	3.80	4.23 (-0.00)
proposed (Type3)	4.12	4.22	5.16	3.50	3.73	**4.14 (-0.09)**

IV. SIMULATION RESULTS

Fig.10 illustrates the entropy rate at H0, H1, H2 and H3 in Fig.1 for sample 1. It is averaged over all the components. As H0 indicates, the original 8 bit signal is compressed to 6.5 bit without any transform. H1 indicates that the existing method II and the proposed method compresses to 5.7 bit per pixel component. It is less than the existing method I by 0.4 bit. Effectiveness of the Rev.KLT is confirmed. It was also observed that the proposed method does not degrade coding performance of the existing method II. Adding the Rev.DCT, the entropy is furthermore reduced to 4.2 bit. Data volume is then compressed to 52%. Difference between H2 and H3 is observed to be 0.03 bit.

Table II summarizes entropy rate at H3. It is observed that type 1 is the best among variations of the proposed method. It was confirmed that entropy rate was reduced by 0.1 bit per pixel component comparing to the existing method I with fixed coefficients. This is equivalent to the existing method II with the optimum coefficients. As indicated in table II, computational costs were reduced comparing to the existing method II.

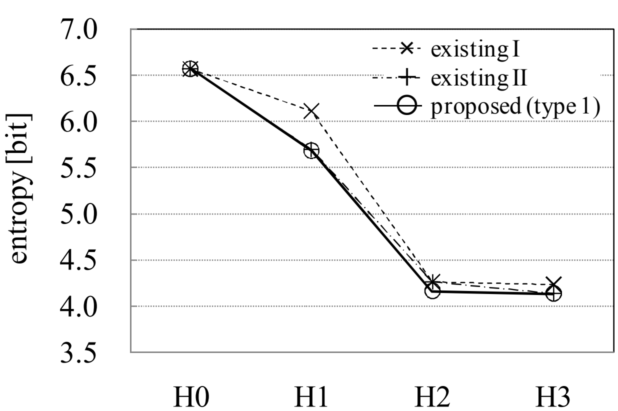

Fig.10 Lossless coding performance

V. CONCLUSIONS

An integer transform for lossless coding of four color components is proposed. Eigen-vector of the covariance of the components was utilized to increase coding performance. Fixed correlation between two components is confirmed and utilized to simplify its computational cost. It was confirmed that entropy rate was reduced by 0.1 bit per pixel component comparing to the existing method I and computational costs were reduced comparing to the existing method II.

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