Lossless Color Coordinate Transform for Lossless Color Image Coding

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Abstract

This paper proposes a lossless color coordinate transform for lossless color image coding. Lossless color coordinate transforms are used to remove the correlation and to bias the signal energy ratio between the color signal components. In order to form the lossless coding, the ladder network is used. It is confirmed by the numerical simulations that the performance of the lossless coding scheme with the lossless color coordinate transform is better than that without the lossless color coordinate transform.

1. Introduction

Lossless image coding that can restore an image without distortion is required for example for treating high definition images such as medical images or satellite images. In areas of research on lossless coding that has been reported so far, it has dealt only with grayscale or continuous tone images [1]-[3]. For color images, lossless coding is implemented independently to each component of R (Red), G (Green) and B (Blue) [4].

In general, it seems that color images have a correlation between each component. Therefore we can carry out a color coordinate transform on a color image. If we do this before conventional lossless coding for continuous tone images, we can expect the coding efficiency to improve.

In this paper, we propose lossless color coordinate transforms for lossless color image coding. The proposed lossless color coordinate transforms are based on the YUV transform [4] or YIQ transform [5] used in lossy image compression. We use the transforms to remove the correlation and to bias the signal energy ratio between the color signal components. By forming the transforms using the ladder networks [8], the proposed coordinate transforms are implemented as lossless (reversible) color coordinate transform with suppressed increment of the number of transform sequence level. Since the proposed transform is performed before lossless coding, it can be easily combined to conventional lossless coding for continuous tone images such as JPEG-LS. It is also confirmed by the numerical simulations that the performance of the lossless coding scheme with the lossless color coordinate transform is better than that without the lossless color coordinate transform.

In this paper, we will assume that the input image is a RGB color image with integer values.

2. Color Coordinate Transform

Figure 1 shows the coding scheme used in this paper. Encoder shown as Figure.1 (a) is composed one color coordinate transform and three component encoders. The encoding procedure is as follows. First, by using lossless color coordinate transform, RGB color space is mapped to new $Y_0\ Y_1\ Y_2$ color space. Here, we can exploit correlation between R, G and B component in order to take higher compression efficiency. And then, Y_0, Y_1, and Y_2 component are encoded by traditional lossless coding method for continuous tone images respectively. For the decoder, which is shown as Figure.1 (b), its procedure follows the reverse of encoding procedure. Output image from decoder is equal to input image to the encoder completely because both the color coordinate transform and the component encoder are implemented as lossless process. The implementation of lossless color coordinate transform will be described in Section 3.

Optimum color coordinate transform with respect to compression efficiency is a transform that removes correlation between RGB component and biases the signal energy ratio as large as possible between the color signal components have been transformed. This transform is known as Karhunen-Leove transform (KLT) [5]. However, KLT depends on input signal obviously.

In JPEG [4], which is lossy compression scheme, it doesn't encode RGB component directly; color images are encoded after the color components have been transformed by using YUV transform. YUV transform has no dependency on input signal and it is given by the following equation [4]:

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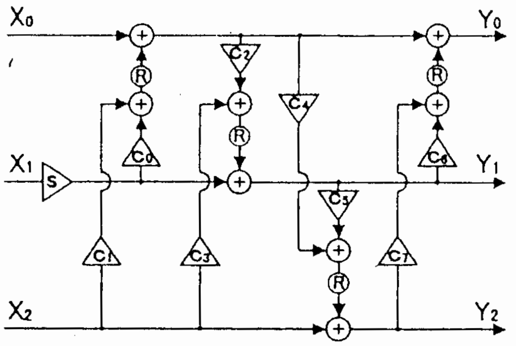


Figure 2: 3-point lossless transform using the ladder networks. R denotes "rounder".

$$P_2 = \begin{bmatrix} 1 & 0 & 0 \\ c_2 & 1 & c_3 \\ 0 & 0 & 1 \end{bmatrix}, P_3 = \begin{bmatrix} 1 & c_0 & c_1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, S = diag[1, s, 1].$$

The diagonal element s determines the sign of determinant of T, so s is 1 or −1. Therefore, to allow implementation of transform matrix T as lossless transform by using the ladder networks, we are required the following condition:

$$\det T = \pm 1 . \tag{4}$$

Let T_{YUV} denote YUV transform matrix in Eq. (1). The determinant of T_{YUV} then is 0.236. Therefore YUV transform matrix can not be implemented by the ladder networks directly, we must be scaled the color coordinate transform matrix in order to be equal the determinant to 1. In this paper, it is achieved by scaling the second- and third row. Therefore, we obtain

$$\overline{T}_{YUV} = Sc \cdot T_{YUV}$$

$$= \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.346 & -0.682 & 1.028 \\ 1.028 & -0.861 & -0.167 \end{bmatrix} \tag{5}$$

where

$$Sc = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \left|\det T_{YUV}\right|^{-1/2} & 0 \\ 0 & 0 & \left|\det T_{YUV}\right|^{-1/2} \end{bmatrix} . \tag{6}$$

We refer this modified YUV transform as LsYUV transform. The ladder networks coefficients of LsYUV transform can be obtained by compared the elements of triangular matrix product $P_0 P_1 P_2 P_3 S$ and the elements of LsYUV transform matrix $\overline{T}_{YUV}$. Also YIQ transform in Eq. (2) can be similarly obtained, and coefficients of both transforms are given in Table 1.

Inverse transform of these transforms is given by

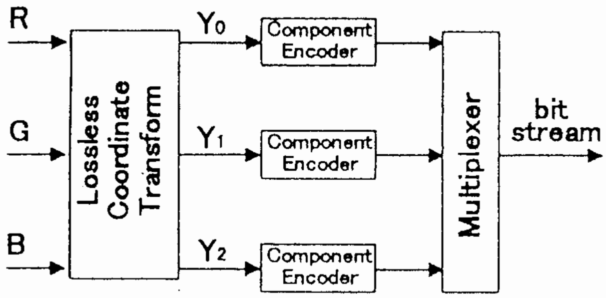
$$T^{-1} = S^{-1} P_3^{-1} P_2^{-1} P_1^{-1} P_0^{-1} . \tag{7}$$

However, since the inverse of triangular matrix with unity diagonal elements becomes triangular matrix with reverse of sign of the non-diagonal elements, it can be implemented by using the ladder networks similar to forward transform.

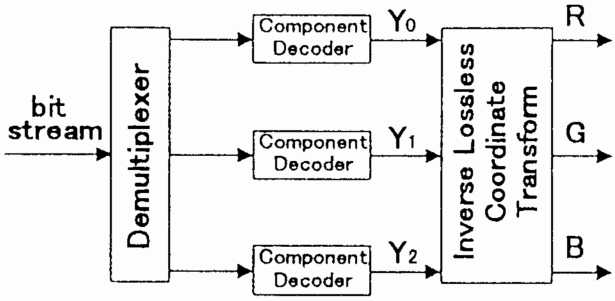
4. Simulation

In this section, the compression performance of lossless coding with lossless color coordinate transform for some standard images will be demonstrated. Pulse Code Modulation (PCM) and Lossless JPEG [4] with Static Huffman coding are used for lossless coding of transformed color signals. Lossless JPEG has eight predictors and choices the best predictors followed by minimum code Huffman coding of the prediction errors. These lossless coding are independently performed at each color components according to Figure 1. The compression performance is evaluated by bit rate (bits per pixel). Test images used for simulation contain "lenna", "baboon", "airplane", "house" from University of Southern California Signal and Image Processing Institute (USC-SIPI) image database, "barbara", "boats", "goldhill" and "zelda" from JPEG test images. All images are 24bpp RGB color image; it has size of 512x512 pixels from "lenna" to "house" and 720x576 pixels from "barbara" to "zelda".

Table 2 and 3 list compression results. The results include side information such as code table for Huffman coding. The simulation results prove the following: 1) from Table 2, it is shown that the compression performance with the proposed lossless color coordinate transform is better than that without the color coordinate transform for PCM coding. The value of reduction of bit rate results in 1.97 [bits/pixel] for LsYUV transform and 2.17 [bits/pixel] for LsYIQ transform. And it is shown that there are two cases that the improvement of compression performance is high and poor depending on images. This results from the dynamics of the correlation between color components; the stronger the correlation between color components is, the higher the improvement of compression performance with color transform becomes. 2) From Table 3, it is shown that proposed lossless color coordinate transform is effective with respect to lossless JPEG. 3) From Table 2 and 3, it is shown that the bit rate with LsYIQ transform is lower than that with LsYUV transform in many cases. The value of reduction results in about 0.2 [bits/pixel] for PCM and 0.11 [bits/pixel] for lossless JPEG.



(a) Encoder.



(b) Decoder.

Figure 1: Coding system.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1).$$

In NTSC scheme, which is one of color television schemes, color images are transmitted to receiver after the color components have been transformed by using YIQ transform. YIQ transform is given by the following equation [5]:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & 0.322 \\ 0.211 & -0.523 & -0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (2).$$

In general, the bias value of the energy ratio between three color signals that have been transformed is greater than that between R, G, and B color signal. In the case of YIQ transform, it has been reported in [9] that the energy ratio is 93:5:2.

In this paper, instead of using KLT for RGB signal, we will apply color coordinate transform of equation (1) or (2) to lossless color image coding. By using these color coordinate transforms to remove the correlation and to bias the energy ratio between color signal components, we aim to improve the compression efficiency.

3. Lossless Color Coordinate Transform

In this section, we will introduce the ladder networks to form color coordinate transforms described in previous section as lossless transform.

3.1 A realization of losslessibility (reversibility)

If color coordinate transforms Eq.(1) and (2) described in previous section are directly implemented, the obtained color signals Y0, Y1 and Y2 will have real value. These signals must be quantized due to coding. To maintain losslessibility, then it has to fine the quantization step size at least less than 1. Because transformed signals are scaled up an integer value greater than 1, the amplitude range of signals increase as compared with that of input signal. Therefore the color signals obtained by this method have a redundancy [6]. Consequently, it seems that this method is not suited for lossless compression of color image.

Recently, as one of lossless coding schemes, lossless transform coding has been proposed in [7]. It is a method that transform matrices such as Discrete Cosine Transform (DCT) are implemented by using the ladder networks and rounding. Figure 2 demonstrates the case of 3x3 matrix. In this Figure, R denotes "rounder" (which converts from real value to nearest integer value). Hence, transformed sequences have an integer value. This method differs from the method described above in that rounder is used to convert from real value to integer value, and then increment of the amplitude range of signals can be suppressed as compared with that of input signal.

In this paper, therefore, we will implement color coordinate transform matrix as lossless transform by using the ladder networks in order to improve the compression efficiency.

3.2 Use of the ladder networks for lossless color transform

From Figure 2, it can be seen easily that transform matrix T implemented by the ladder networks can be written by triangular matrices with unity diagonal elements and diagonal matrix S, i.e.,

$$T = P_0 P_1 P_2 P_3 S \quad (3)$$

where

$$P_0 = \begin{bmatrix} 1 & c_6 & c_7 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, P_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ c_4 & c_5 & 1 \end{bmatrix},$$

5. Conclusion

We proposed lossless color coordinate transforms for lossless color image coding. The lossless color coordinate transforms were obtained by forming YUV transform and YIQ transform that are conventional lossy color transform as lossless transform by using the ladder networks. Since the proposed transform can be performed before lossless coding, it can be easily combined to conventional lossless codings for continuous tone images. Numerical simulation show that the compression performance with the proposed lossless color coordinate transform is better than that without the color coordinate transform.

Proposed lossless color coordinate transforms are restricted in three-dimensional color spaces such RGB. We now are attempting to apply to 4-dimensional color spaces such CMYK used in color printing system.

coef.	Color transform	
	LsYUV	LsYIQ
c_0	4.85580	0.38570
c_1	-4.85580	-0.38570
c_2	-0.34642	-1.18282
c_3	-0.65358	0.18282
c_4	-1.00000	-1.00000
c_5	-5.85580	-1.19946
c_6	4.99450	0.64331
c_7	1.00061	0.14309
s	1.00000	-1.00000

Table 1: The ladder networks coefficients.

Image	Color Transform		
	Without trans.	LsYUV	LsYIQ
lenna	21.982	20.929	20.594
baboon	23.087	22.646	22.300
airplane	19.871	17.441	17.451
house	22.219	21.101	20.627
barbara	22.972	20.405	20.092
boats	21.473	18.878	18.439
goldhill	22.842	19.435	19.571
zelda	22.336	20.161	20.355
average	**22.098**	**20.125**	**19.929**

Table 2: Coding results on PCM (in bits/pixel).

Image	Color Transform		
	Without trans.	LsYUV	LsYIQ
lenna	14.577	14.289	14.143
baboon	19.356	18.588	18.478
airplane	13.343	12.810	12.494
house	14.762	14.233	14.117
barbara	16.340	12.108	11.888
boats	14.038	10.593	10.496
goldhill	15.094	11.506	11.619
zelda	13.120	10.260	10.284
average	**15.079**	**13.048**	**12.940**

Table 3: Coding results on Lossless JPEG (in bits/pixel).

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