REVERSIBLE COLOR TRANSFORM WITH COMPATIBLITY TO IRREVERSIBLE TRANSFORM

Masahiro IWAHASHI and *Hitoshi KIYA*

Nagaoka University of Technology
Niigata, 980-2188, Japan

Tokyo Metropolitan University
Tokyo, 191-0065, Japan

ABSTRACT

This report proposes a new transcoding between a lossless encoder and a lossy decoder for color image signals. It requires a reversible color transform (Rev.CT) with compatibility to an irreversible color transform (Irrv.CT). An existing Rev.CT guarantees lossless reconstruction of signals. However its compatibility to an Irrv.CT is not high enough for practical use. This is because a scaling is excluded from the Rev.CT for lossless coding. In this report, we embed the scaling into quantization in lossy decoding to realize both lossless coding and transcoding with high compatibility. It is experimentally confirmed that image quality is improved by more than 37.6 [dB]. We also evaluate its performance based on various criteria including, bit-extension, word-length of signals and coefficients.

Index Terms— coding, transform, reversible, coding

1. INTRODUCTION

International standards such as JPEG and MPEG have been widely used as "lossly" coding in which reconstructed image is slightly distorted but data volume is highly compressed [1]. On the contrary, "lossless" coding such as JEPG-LS is necessary for storing original image signal without any loss of its quality. [2]. Recently, "lossless-lossy" unified coding have been also reported [3].

So far, various approaches of transcoding between MPEG-2 and H.264 [4], between discrete cosine transform (DCT) and discrete wavelet transform (DWT) [5] have been reported. A transcoding between "lossless" and "lossy" can be implemented based on a reversible DCT [6] or a reversible DWT [7] for monochrome images. When it is applied to color images, a reversible color transform (Rev.CT) compatible with an irreversible color transform (Irrv.CT) is required.

In [8,9], a Rev.CT based on four lifting steps is designed for a given Irrv.CT. It has high compatibility with an orthogonal and normalized CT. However, it is not high for non-orthonormal case such as in JPEG 2000 (JP2K).

In [10], a Rev.CT free from the orthonormality is proposed. It is designed based on three lifting steps and scalings. However, the scaling is excluded from the CT in implementation to guarantee lossless reconstruction of image signals. As a result, its compatibility is not high enough for practical use.

In this report, we propose a transcoding between a "lossless" encoder and a "lossy" decoder for color images. We increase its compatibility by embedding the scaling of the existing Rev.CT into inverse quantization procedure of lossy decoding. It is implemented by modifying quantization step size header in a bit-stream without changing any other part of the decoding.

We experimentally confirm that quality of reconstructed image signals is improved. We also evaluate performance of variations of the Rev.CT based on various criteria including, PSNR, entropy, bit-extension, word-length of signals and coefficients.

2. TRANSCODING BETWEEN LOSSLESS ENCODER AND LOSSY DECODER

Transcoding between lossless coding and lossy coding is summarized for JP2K based case as an example. Criteria on its performance are described.

2.1. Lossy Coding and Lossless Coding of JP2K

In "lossy" coding of JP2K, color signals R,G,B given as integers are transformed with a matrix $\mathbf{A}$ as:

$$\begin{bmatrix} Y & C_r & C_b \end{bmatrix}^T = \mathbf{A} \cdot \begin{bmatrix} R & G & B \end{bmatrix}^T \tag{1}$$

where

$$\mathbf{A} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.5 & -0.419 & -0.081 \\ -0.169 & -0.331 & 0.5 \end{bmatrix} \tag{2}$$

into Y,C_r,C_b. It is further transformed into some frequency band signals with 9-7 DWT. Since its output signals are expressed as real numbers, it is necessary to round them into integers before entropy coding. As a result, it is impossible to have reconstructed signals exactly same as their original waveforms. Therefore the transform in Eq.(1) is referred to as "irreversible" color transform (Irrv.CT).

On the other hand, in "lossless" coding of JP2K, "reversible" color transform (Rev.CT) defined as:

$$\begin{bmatrix} Y \\ C_r \\ C_b \end{bmatrix} = \begin{bmatrix} round[(R+2G+B)/4] \\ R-G \\ B-G \end{bmatrix} \qquad (3)$$

is applied where $round[x]$ denotes rounding x into an integer. In this case, in spite of the rounding, output signals of its inverse transform contains no error. Therefore combining with the reversible 5-3 discrete wavelet transform (DWT) of JP2K, "lossless" coding becomes possible.

2.2. Transcoding and Criteria on its Performance

Fig.1 illustrates "transcoding" between lossless coding and lossy coding. The former is composed of reversible transforms. The latter is composed of irreversible transforms and inverse quantization. When these are mutually connected as in the figure, there is a big difference between original R,G,B and reconstructed R',G',B' (compatibility is loq), even though inverse quantization is not applied (quantization step size is set to one).

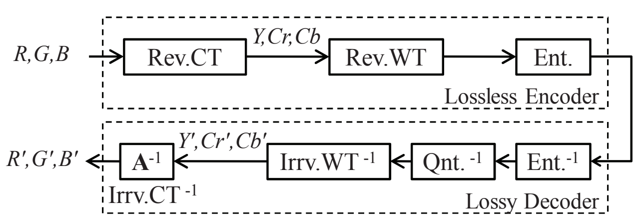
One of the reasons is difference between characteristics of the Rev. 5-3 DWT in encoding and inverse of Irrv. 9-7 DWT in decoding. This problem can be solved by replacing Rev. 5-3 DWT by Rev. 9-7 DWT in [7]. The other reason is difference between characteristics of color transforms. Denoting Eq.(3) as

$$[Y \quad C_r \quad C_b]^T = \mathbf{B} \cdot [R \quad G \quad B]^T + Error \qquad (4)$$

where

$$\mathbf{B} = \begin{bmatrix} 0.25 & 0.5 & 0.25 \\ 1 & -1 & 0 \\ 0 & -1 & 1 \end{bmatrix}, \qquad (5)$$

it is described as $\mathbf{AB}^{-1} \neq \mathbf{I}$.



Rev. : Reversible, CT: Color Transform,
Irrv.: Irreversible, WT: Wavelet Transform,
Ent.: Entropy Coding, Qnt.: Quantization

Fig.1 Transcoding between a lossless encoder and a lossy decoder. Difference between (R,G,B) and (R',G',B') is expected to be small. It is evaluated in PSNR [dB].

Table I summarizes difference between original color signals and reconstructed signals through Rev.CT in Eq.(3) and inverse of Irrv.CT in Eq.(2) denoted as $\mathbf{A}^{-1}$. It is measured in peak signal to noise ratio (PSNR). We can confirm that PSNR is 17.8 [dB] in average and the compatibility is not high enough for practical use.

The table indicates some other criteria for evaluation of Rev.CT. Decrease of the entropy averaged over color component signals is measured. It indicates how a Rev.CT contributes to data compression in bit per pixels [bpp]. The bit extension [10] indicates increase of integer part of signal values at maximum in [bit]. Larger is more likely to have longer bit length to avoid overflow inside the CT.

Table I Performance of Rev.CT in JP2K.

Image	Entropy Decrease [bpp]	Bit Extension [bit]	PSNR [dB]
Lenna	0.40	0.10	22.0
Mandrill	0.36	0.23	18.0
Pepper	-0.10	0.54	13.4
average	**0.22**	**0.29**	**17.8**

3. PROPOSED TRANSCODING

An existing Rev.CT is introduced. Its scaling part is embedded into lossy decoding of our proposed transcoding.

3.1. Non-scaled Reversible Color Transform

Fig.2 illustrates a non-scaled Rev.CT (NS-Rev.CT) reported in [10]. In the figure, F denotes word length of fraction part of signal values. Each of permutation matrices $\mathbf{E}_1$, $\mathbf{E}_2$ is one of following six matrices:

$$\mathbf{Q}_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \mathbf{Q}_2 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \mathbf{Q}_3 = \begin{bmatrix} 0 & 0 & 1 \\ 0 & 1 & 0 \\ 1 & 0 & 0 \end{bmatrix},$$
$$\mathbf{Q}_4 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}, \mathbf{Q}_5 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}, \mathbf{Q}_6 = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix}. \qquad (6)$$

It has 36 variations in total. Similarly as Eq.(4), this Rev.CT is described as:

$$[Y^* \quad C_r^* \quad C_b^*]^T = \mathbf{E}_2\mathbf{C}\mathbf{E}_1[R \quad G \quad B]^T + Error \qquad (7)$$

where

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ c_5 & c_6 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ c_3 & 1 & c_4 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & c_1 & c_2 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \qquad (8)$$

$$\mathbf{D} = diag[d_1 \quad d_2 \quad d_3] \qquad (9)$$

$$\mathbf{E}_2\mathbf{D}\mathbf{C}\mathbf{E}_1 = \mathbf{A} \ . \qquad (10)$$

Table II indicates its parameters. Note that $|d_1|<1$ and $|d_2|<1$. These cases impede lossless coding since fraction part of signal values are discarded by rounding in Rev.DWT. Therefore, the scaling with **D** is excluded from the Rev.CT in **Fig.2**. It guarantees lossless coding however decreases compatibility. **Table III** summarizes performance of the existing Rev.CT. We can confirm that its compatibility is improved by 0.7 [dB] in average however it is still low for practical use.

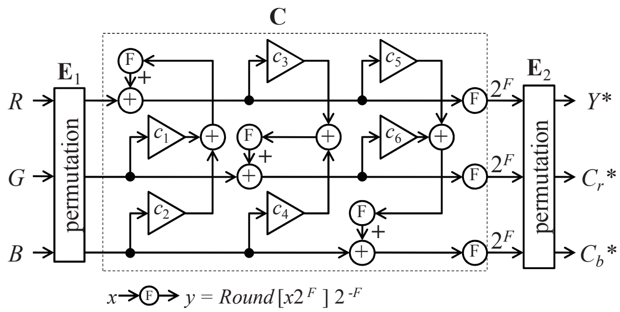


Fig.2 Non-scaled reversible color transform (NS-Rev.CT).

Table II Parameters of the existing NS-Rev.CT.

c_1=-0.337	c_2=-0.663	c_3=-0.172	c_4=-1.000
c_5=0.172	c_6=0.337	d_1=0.500	d_2=0.473
d_3=1.000	F=0	$\mathbf{E}_1$=$\mathbf{Q}_6$	$\mathbf{E}_2$=$\mathbf{Q}_3$

Table III Performance of the existing NS-Rev.CT.

Image	Entropy Decrease [bpp]	Bit Extension [bit]	PSNR [dB]
Lenna	0.35	0.09	22.6
Mandrill	0.17	0.40	16.7
Pepper	-0.07	0.43	16.2
average	**0.15**	**0.31**	**18.5**

3.2. Proposed Trancoding based on NS-Rev.CT

Fig.3 illustrates procedure of the proposed transcoding. It embeds the scaling with **D** excluded from the existing NS-Rev.CT into lossy decoding. Not that order of the scaling is modified to:

$$\mathbf{D}' = diag[d_1' \quad d_2' \quad d_3'] = \mathbf{E}_2\mathbf{D}\mathbf{E}_2^{-1}. \qquad (11)$$

We can confirm, from Eq.(7),(10),(11), that

$$\begin{aligned} &[Y' \quad C_r' \quad C_b']^T = \mathbf{D}'[Y^* \quad C_r^* \quad C_b^*]^T \\ &= (\mathbf{E}_2\mathbf{D}\mathbf{E}_2^{-1})(\mathbf{E}_2\mathbf{C}\mathbf{E}_1)[R \quad G \quad B]^T \qquad (12) \\ &= (\mathbf{E}_2\mathbf{D}\mathbf{C}\mathbf{E}_1)[R \quad G \quad B]^T = \mathbf{A}[R \quad G \quad B]^T \end{aligned}$$

and the original R,G,B is accurately reconstructed after applying $\mathbf{A}^{-1}$ (inverse of Irrv.CT) to Eq.(12).

Alternatively, the scaling with **D'** can be placed between inverse Irrv. DWT and entropy decoding. Furthermore, it can be embedded into inverse quantization. In this case, quantization step size is divided by **D'** so that the signals are scaled by **D'** as a result of inverse quantization. It is implemented by modifying quantization step size header in a bit-stream without changing any other part of the decoding as illustrated in **Fig.4**.

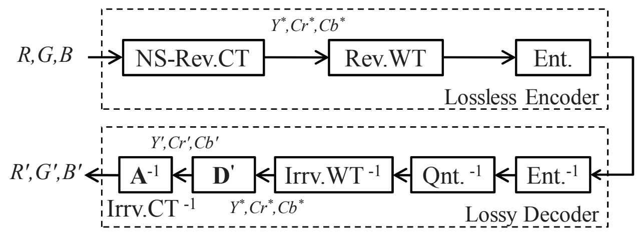


Fig.3 Basic procedure of the proposed transcoding.

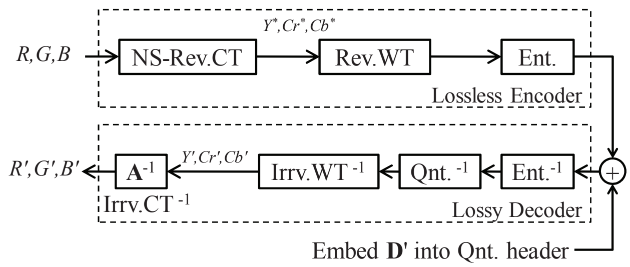


Fig.4 Implementation of the proposed transcoding.

4. EXPERIMENTAL RESULTS

We experimentally confirm that quality of reconstructed image signals is improved. We also evaluate performance of variations of the Rev.CT based on various criteria.

Table IV summarizes representative 7 of all the 36 variations of the NS-Rev.CT. Method #1 is the existing NS-Rev.CT reported in [10].

Fig.5 summarizes evaluation results of the compatibility. All the signal values are rounded into integers (F=0) inside the Rev.CT. When the coefficient values in Eq.(8), (9) have 64 [bit] word-length in their fraction part, method #5, 6 and 7 achieve 58.4 [dB]. Method #4 is the worst at 56.1 [dB]. It is confirmed that the compatibility is improved by more than 56.1-18.5=37.6 [dB] comparing to the conventional transcoding illustrated in Fig.1 and summarized in Table III.

In case of the word length of coefficients is set to 4 [bit], method #1 and 4 is the best. Even though the word length is so short, the proposed method can achieve high image quality at around 40 [dB] in PSNR.

Table IV Variations of the NS-Rev.CT.

#	permutation		Scaling Coefficients		
	$\mathbf{E}_1$	$\mathbf{E}_2$	d_1'	d_2'	d_3'
1	$\mathbf{Q}_6$	$\mathbf{Q}_3$	1	0.473	0.5
2	$\mathbf{Q}_4$	$\mathbf{Q}_6$	1	0.5	0.473
3	$\mathbf{Q}_3$	$\mathbf{Q}_3$	1	-0.473	0.5
4	$\mathbf{Q}_1$	$\mathbf{Q}_6$	1	0.5	-0.473
5	$\mathbf{Q}_2$	$\mathbf{Q}_2$	1	-0.419	0.564
6	$\mathbf{Q}_2$	$\mathbf{Q}_6$	1	-0.419	-0.564
7	$\mathbf{Q}_2$	$\mathbf{Q}_1$	0.587	0.713	0.564

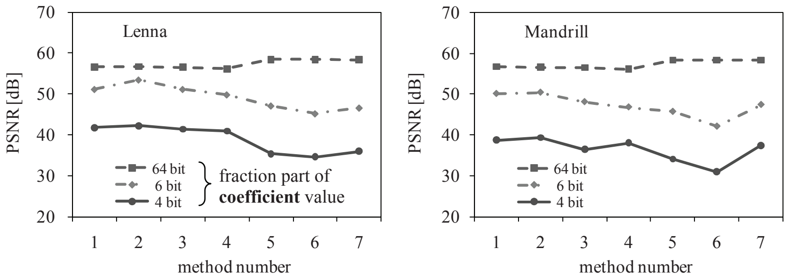


Fig.5 Errors caused by rounding of fraction part of "coefficient" value.

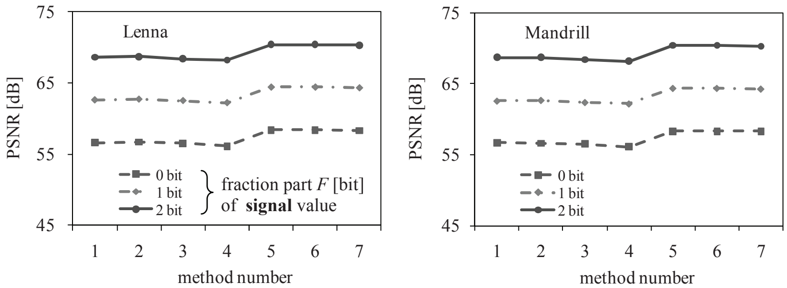


Fig.6 Errors caused by rounding of fraction part of "signal" value.

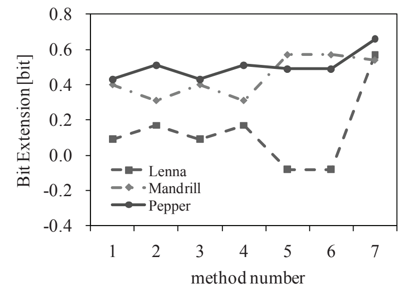


Fig.7 Bit extension by the NS-Rev.CT.

Fig.6 illustrates compatibility with different word length of signals. Word length of coefficients is set to 64 [bit]. Methods #5, 6, 7 are the best. It indicates that quality can be increased however entropy is increased by F [bit].

Fig.7 evaluates the bit extension for F=0. Method #7 is the most likely to have overflow. Performance of other methods depends on an input image signal.

Note that the entropy decrease of these methods is the same as that in table III. Data compression performance is slightly inferior to Rev.CT of JP2K in table I. It is only 0.07 [bpp] in average.

5. CONCLUSIONS

In this report, we proposed a transcoding between a "lossless" encoder and a "lossy" decoder for color images. It is based on designing a Rev.CT compatible to a given Irrv.CT. Embedding the scaling of the existing Rev.CT into inverse quantization procedure of lossy decoding, we confirmed that compatibility was increased by more than 37.6 [dB]. We also evaluate performance of variations of the Rev.CT according to various criteria such as PSNR, entropy, bit-extension, word-length of signals and coefficients. It was found that high quality can be achieved even though coefficients have only 4 [bit] in fraction part. It is implemented by modifying quantization step size header in a bit-stream without changing any other part .

Our discussion was carried out based on JP2K. It is not limited to that and it can be extended to other cases.

6. REFERENCES

[1] JTC1/ SC29, "Information technology -- Digital compression and coding of continuous-tone still images: Requirements and guidelines", ISO/ IEC 10918-1, 1994.

[2] M. Weinberger, G. Seroussi, G. Sapiro, "The LOCO-I Lossless Image Compression Algorithm: Principles and Standardization into JPEG-LS," IEEE Trans. Image Processing, vol. 9, no. 8, pp. 1309–1324, Aug. 2000.

[3] S. Chokchaitam, M. Iwahashi, S. Jitapunkul, "A New Unified Lossless/Lossy Image Compression based on A New Integer DCT," IEICE Trans. on Fundamentals, E88-D, no.7, pp.1598-1606, July 2005.

[4] S. Yeping, J. Xin, A. Vetro, S. Huifang, "Efficient MPEG-2 to H.264/AVC intra transcoding in transform-domain", IEEE ISCAS, vol.2, no.23-26, pp.1234-1237, May 2005.

[5] Po-Chin Hu, et.al., "A wavelet to DCT progressive image transcoder," IEEE ICIP, vol.1, no.10, pp.968-971, 2000.

[6] Vladimir Britanak, P. C. Yip, K. R. Rao, "Discrete Cosine and Sine Transforms: General Properties, Fast Algorithms and Integer Approximations," Academic, Oct.2006.

[7] M. Iwahashi, H. Kiya, "Non Separable 2D Factorization of Separable 2D DWT for Lossless Image Coding," IEEE International Conference on Image Processing (ICIP), no.SA.L1.L15, pp.17-20, Nov. 2009.

[8] Soo-Chang Pei, Jian-Jiun Ding, "Reversible Integer Color Transform," IEEE Trans. Image Processing, Vol.16, Issue 6, pp. 1686- 1691, June 2007.

[9] M.Iwahashi, K.Oguni, "Three Dimensional Integer Rotation Transform and Improvement of its Compatibility," IEEE International Symposium on Circuits and Systems (ISCAS), pp.2205 - 2208, May 2009.

[10] Soo-Chang Pei, Jian-Jiun Ding, "Improved Reversible Integer to Integer Color Transforms," IEEE International Conference on Image Processing (ICIP), pp.473-476, Nov. 2009.