Color Image Transcoding of Lossless Encoder and Standard Lossy Decoder based on JP2K

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ABSTRACT

In JPEG2000 (JP2K) color image system, lossless coding signal is not able to be reconstructed with lossy decoder directly. Then, this report proposes a new transcoding between lossless encoder and standard lossy decoder for color image signals base on JP2K. A proposed encoder is required reversible color transform (RCT) and reversible discrete wavelet transform (RDWT) with compatibility to standard lossy decoder based on JP2K (JP2K lossy decoder). To improve the compatibility, proposed encoder is designed by using Non-scaled RCT and Non-Scaled RDWT with embedding scaling parameter into quantization header. Then, this method can be practical use with JP2K lossy decoder without any change. It also reduces total rounding error and lifting steps. The results show that proposed method can keep lossless coding performance and improve transcoding functionality to JP2K lossy decoder. The quality of transcoding image was achieved to 50.05 dB (PSNR).

Keywords: Transcoding, JPEG2000, Lossless-Lossy

1. INTRODUCTION

Recently, various approaches of transcoding have been widely used [1-4]. Transcoding between video formats has reported [1-3]. Image transcoding between discrete cosine transform (DCT) and discrete wavelet transform (DWT) [5] also have been proposed. These reports indicates that there are many applications of transcoding, for example, transcoding of different bit rate of a compressed stream [1-2], different resolution of a compressed stream [3], lossless-lossy compatibility [5] and etc. However, this report focuses on transcoding between lossless encoder and lossy decoder based on JPEG2000 (JP2K).

The JP2K [6-7] is a standard compression which provides both lossless and lossy compression architecture. The transcoding between lossless and lossy coding in conventional JP2K is not applicable. The quality lossless-lossy transcoding image is not adequate. If the image signal by lossless encoder is reconstructed with lossy decoder in good quality, it has advantage in communication usage. For example, medical images which are stored without any loss in private domain. It is advantage if image lossless compression stored images can be sent directly to public domain by using standard lossy decoder based on JP2K (JP2K lossy decoder). Therefore, Transcoding between both is required to be improved.

So far, Lossless-Lossy discrete wavelet transform (DWT) have also reported. The factorization techniques have been proposed for reduction influence of rounding error of lossless-lossy [8-12]. In [8], [10], a reversible 2D 9/7 DWT (RDWT) based on non-separable 2D lifting structure compatible with irreversible DWT (IrDWT) also were proposed. These reports increase compatibility of transcoding between lossless (RDWT) and lossy (IrDWT) based on a 9/7 RDWT for monochrome images. Hence, a reversible color transform (RCT) compatible with an irreversible color transform (IrCT) is required. Then, this report applies it in color image.

Lately, a few works of RCT (lossless) designed by IrCT (lossy) have reported [13-15]. In [13-15] the RCT based on IrCT lifting steps was designed. Nonetheless, transcoding between RCT and IrCT has not existed. Therefore, a RCT with compatibility to an IrCT [16] is proposed by improving RCT lifting step [15]. In addition, it increased compatibility of color trasform by embedding scaling parameter into lossy encoder. However, JP2K system is composed of color transform, DWT and encoding part. In [16], the compatibility results were evaluated only the color transforms transcoding.

For this reason, RDWT part was excluded based on JP2K system. Then, we use RCT in previous report [16] and extend the experimental transcoding results with 3 types of RDWT [6], [8], [10]. Moreover, we also propose new structure lossless encoder for transcoding with lossy decoder. A proposed lossless encoder is designed by non-scaled RCT and non-scaled RDWT. Both are improved by removing scaling part from encoder (RCT part and RDWT part) and apply scaling parameter to lossy decoder in image signal. It is implemented by modifying quantization step size header in a bit-stream without changing any other part of the standard lossy decoder.

From previous studied of conventional and existing method, there is no lossless-lossy transcoding of color image based on JP2K. Therefore, the color

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image transcoding system is proposed in this paper. According to new transcoding structure, lifting steps and rounding error was reduced. Image signals bitrate (entropy) and the quality of reconstructed image signals (PSNR) were evaluated and compared with existing method. The performance of transcoding of this paper is confirmed by the quality of transcoding image as 50.05 dB (PSNR). It can confirm that proposed transcoding system keep lossless coding performance and also improves transcoding functionality to JP2K lossy decoder.

This paper is organized as following. The situation of transcoding between lossless encoder and lossy decoder based on JP2K is summarized in section 2. In section 3 and 4, we explain our purposed method, experimental results and discussion. Finally, conclusions are summarized in section 5.

2. TRANSCODING IN JP2K

Transcoding is a process of converting a media file or object from one format to another format. However, this research discusses about transcoding between lossless and lossy coding based on JP2K. We propose transcoding method between lossless encoder and JP2K lossy decoder.

2.1 Situation of lossless and lossy Transcoding

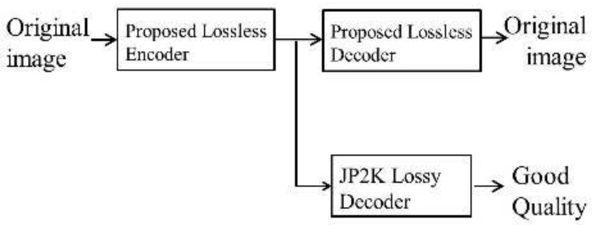

Fig.1: *Situation between lossless and lossy coding.*

From Fig. 1, transcoding between standard lossless encoder based on JP2K (JP2K lossless encoder) and JP2K lossy decoder is not compatible. When using JP2K lossy decoder to reconstructed image signal from JP2K lossless encoder, the quality lossless-lossy transcoding image is not adequate. Since, transformation matrix and numeric process between each lossless and lossy system are different. For examples, coefficient of filter in DWT and and coefficient of color transform matrix are different. Hence, problems are shown in Fig. 2. The problems consist of RCT-IrCT-1 compatibility (color transform(CT) problem) and 5/3 RDWT- 9/7 IrDWT-1 compatibility (DWT problem).

2.2 Transcoding of discrete wavelet transform

JP2K lossless encoder uses a 5/3 DWT structure form [6]. Despite, JP2K lossy decoder uses a 9/7

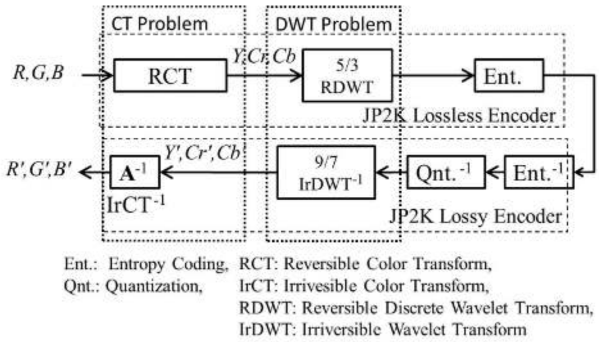

Fig.2: *Compatibility Problem of Lossless-Lossy coding.*

DWT as following in Fig. 2. The 5/3 RDWT encoder is not compatible with 9/7 IrDWT. Then for transcoding between them, reversible DWT has to originate to 9/7 structure form. There are a few researches discussing on 9/7 RDWT structure. In this part we will explain about a 9/7 RDWT structure in case of transcoding and compatibility with 9/7 IrDWT.

2.2.1 Irreversible 9/7 discrete wavelet transform

The forward 9/7 IrDWT utilized for JP2K lossy coding. It decomposes a 2D input signal X into low frequency component and high frequency component vertically, and then horizontally, where X is described as:

$$X = \sum_{p=0}^{N_1-1} \sum_{q=0}^{N_2-1} x_{p,q}\, z_1^{-p} z_2^{-q} \tag{1}$$

for an image signal with $N_1 \times N_2$ pixels. A pixel value at p-th row and q-th column is denoted as $x_{p,q}$. In the figure, H_{2n-1} and H_{2n}, $n\{1,2\}$ denote horizontal filters

$$\begin{bmatrix} H_{2n-1} \\ H_{2n} \end{bmatrix} = \begin{bmatrix} h_{2n-1} & 0 \\ 0 & h_{2n} \end{bmatrix} \begin{bmatrix} z_1^{+1/2} \\ z_1^{-1/2} \end{bmatrix} (z_1^{+1/2} + z_1^{-1/2}) \tag{2}$$

and ${H_m}^*$ are vertical ones in which z_1 is replaced by z_2. Values of the filter coefficients h_m and k are defined by JP2K [6]. It decomposes an input signal into four frequency bands $\{LL, LH, HL, HH\}$.

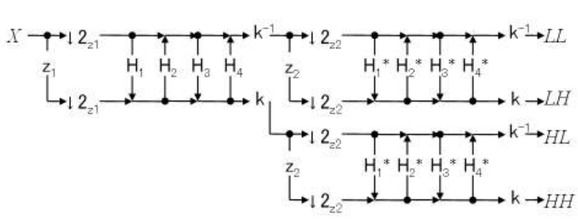

Fig.3: *9/7 IrDWT in JP2K [6].*

In this 9/7 structure of irreversible DWT

(IrDWT), it composes of lifting structure part and scaling part. Because of the scaling part, it is not able to apply in reversible DWT (RDWT) by only rounding process technique. Thus, all lifting 9/7 RDWT has been proposed.

2.2.2 All lifting Separable Reversible 9/7DWT [8]

Existing method [8] proposed a lifting factorization-based DWT architecture. The scaling part on DWT is factorized to four lifting steps. Hence, from 9/7 IrDWT scaling part (k^{-1}, k) as in Fig. 3, it applied factorization process for expanding scaling parameter as equation (3).

An IrDWT 9/7 has been factorized to be all lifting separable 9/7 RDWT. All lifting steps had been processed by integer to integer wavelet transform with rounding process as in Fig. 4.

$$\begin{bmatrix} k^{-1} & 0 \\ 0 & k \end{bmatrix} = \begin{bmatrix} 1 & G_4 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ G_3 & 1 \end{bmatrix} \begin{bmatrix} 1 & G_2 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 \\ G_1 & 0 \end{bmatrix} \quad (3)$$

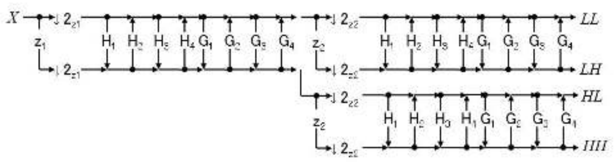

Fig.4: *All Lifting Reversible 9/7 DWT [8].*

2.2.3 All lifting Non-Separable Reversible 9/7 DWT [10]

Existing method [10] proposed a non-separable 9/7 RDWT for reduction of lifting steps and rounding error. Non-separable structure was derived from existing all lifting 9/7 DWT by processing horizontal and vertical term at the same time. Two dimension data accessing has implement as Fig. 5.

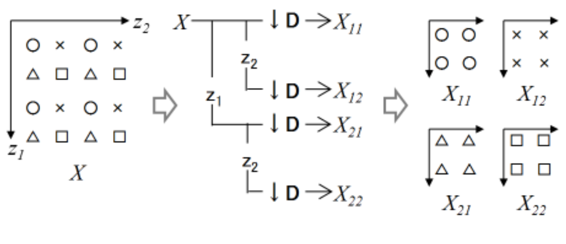

Fig.5: *2D Data Accessing for Non-Separable RDWT.*

All lifting separable 9/7 structure has been replaced by a non-separable structure as shown in Fig. 6. The total number of lifting step has been reduced. Then, rounding error with 9/7 IrDWT has been improved respectively.

In this reason, [8], [10] all lifting reversible 9/7 in separable and non-separable form are compatible with standard 9/7 DWT. By reversible and irre-

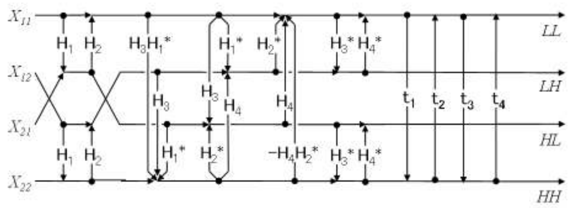

Fig.6: *Non- Separable All Lifting 9/7 RDWT [10].*

versible in 9/7 structure, they are different only the numeric process. RDWT uses integer, while IrDWT uses real number. For this reason, the number of rounding operation fluctuates to RDWT-IrDWT rounding error.

This research will apply transcoding between RDWT and IrDWT based on standard IrDWT 9/7 decoder. Then, we use various RDWT to convince the result of rounding error effect of transcoding. Table I shows the number of rounding operation and lifting step in 2D of first stage coding.

Table 1: *Comparison of 2D reversible 9/7 DWT.*

Type	Rounding operation	Lifting Steps
Separable	24(100%)	16(100%)
Non-Separable	16(66%)	11(69%)

2.3 Transcoding of color transform

As a color transform problem in Fig. 2, RCT (lossless) and IrCT (lossy) in JP2K is not compatible each other. This section will explain in detail of problem and solution for compatibility improvement.

2.3.1. Lossless and lossy color transform

A lossy coding equation of JP2K, color signals R,G,B given as matrix $\mathbf{A}$ as

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

where

$$\mathbf{A} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.5 & -0.419 & -0.081 \\ -0.169 & -0.331 & 0.5 \end{bmatrix} \quad (5)$$

In "lossless" coding of JP2K, "reversible" color transform (RCT) defined as:

$$\begin{bmatrix} Y \\ C_r \\ C_b \end{bmatrix} = \begin{bmatrix} round[(R+2G+B)/4] \\ R-G \\ B-G \end{bmatrix} \quad (6)$$

If we apply for transcoding, delight to simple equation.

$$[\ Y \quad C_r \quad C_b\ ]^T = \mathbf{B} \cdot [\ R \quad G \quad B\ ]^T + Error \quad (7)$$

where

$$\mathbf{B} = \begin{bmatrix} 0.25 & 0.5 & 0.25 \\ 1 & -1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \quad (8)$$

It is incompatible on account of $AB^{-1} \neq I$. Then, [16] proposes the way to improve by scaling method and permutation the parameter of exist method [15].

2.3.2 Transcoding of lossless and lossy CT [16]

In [16], lifting and scaling RCT was proposed for transcoding with IrCT by using Non-scaled RCT as Fig. 7.

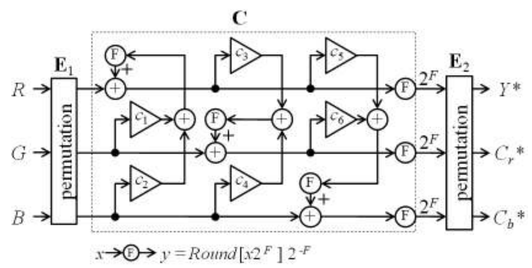

Fig. 7: *Non-scaled RCT with Permutation.*

In the figure, F denotes word length of fraction part of signal values. Each of permutation matrices E_1, E_2 is one of following six matrices:

$$\mathbf{Q}_1 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \mathbf{Q}_2 = \begin{bmatrix} 0 & 1 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & 1 \end{bmatrix}, \mathbf{Q}_3 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix},$$

$$\mathbf{Q}_4 = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & 1 \\ 0 & 1 & 0 \end{bmatrix}, \mathbf{Q}_5 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix}, \mathbf{Q}_6 = \begin{bmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \quad (9)$$

Permutation parts (row and column) were added to improve rounding error. It was effect the order of parameter of matrices $\boldsymbol{C}$. Since, combinations of permutation are 36 variations in total. From equation (7), this RCT is described as:

$$[\ Y^* \quad C_r^* \quad C_b^*\ ]^T = \mathbf{E_2 C E_1} [\ R \quad G \quad B\ ]^T + Error \quad (10)$$

where

$$\mathbf{C} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ c_5 & c_6 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ c_3 & 1 & c_4 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & c_1 & c_2 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad (11)$$

$$\mathbf{D} = diag[\ d_1 \quad d_2 \quad d_3\ ] \quad (12)$$

$$\mathbf{E_2 D C E_1} = \mathbf{A}. \quad (13)$$

According to RCT and IrCT transcoding, it was applied the $\boldsymbol{D}$ scaling and permutations for compatibility increasing [16]. Then, $\boldsymbol{C}$ and $\boldsymbol{D}$ parameters based on JP2K are calculated by defining $\boldsymbol{E_1}, \boldsymbol{E_2}$ and given matrix A.

Table 2: *Parameters of C and D by best PSNR result.*

c_1=0.5094	c_2=0.1942	c_3=-0.5870	c_4= 0.00002
c_5=-0.5870	c_6= 0.000095	d_1=0.587	d_2=0.7133
d_3=0.5643		$\boldsymbol{E_1 = Q_2}$	$\boldsymbol{E_2 = Q_1}$

The permutation $\boldsymbol{E_1}, \boldsymbol{E_2}$ is carefully selected in regard to [17-18]. The color system becomes robust to the rounding errors. Then, we apply scaling non separable lifting structure RCT [16] with those parameters in Table II as follows Fig. 7.

3. PROPOSED OF TRANSCODING

For proposed transcoding encoder, we design new proposed lossless encoder which is included RCT and RDWT with compatibility with JP2K lossy decoder. Proposed lossless encoder will be keep performance of lossless coding and extend transcoding function for lossy decoding as shown in Fig. 8.

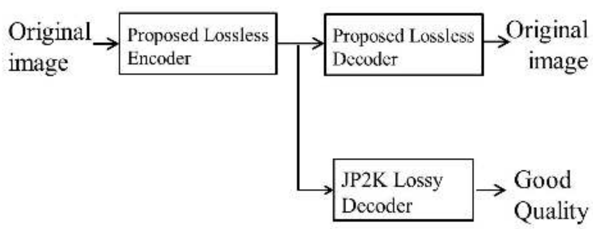

Fig. 8: *Proposed Transcoding system.*

3.1 Proposed Transcoding System I

As previous report for RCT [16], the experimental result has reported only RCT compatibility only. This research will extend the experiment by include DWT encoder part for transcoding with JP2K lossy decoder. We use non-scaled RCT for compatibility with IrCT by using embedding scaling parameter D on Table II in quantization header. From proposed lossless encoder in Fig. 8, we proposed transcoding system I as shown in Fig. 9. Proposed lossless encoder contains the non-scaled RCT and RDWT part. Non-Scaled RCT is chosen parameters as Table II. A proposed non-scaled RCT that is highlighted, are illustrated in Fig. 10. In Fig. 8, JP2K Lossy decoder is standard lossy decoder base on JP2K as shown in Fig. 9.

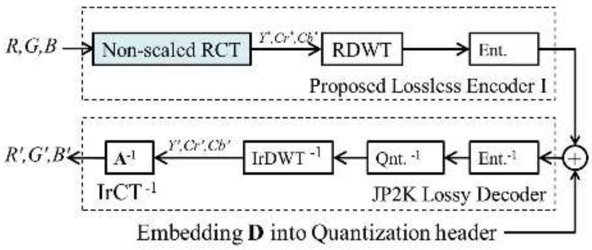

Fig.9: *Proposed Transcoding system I.*

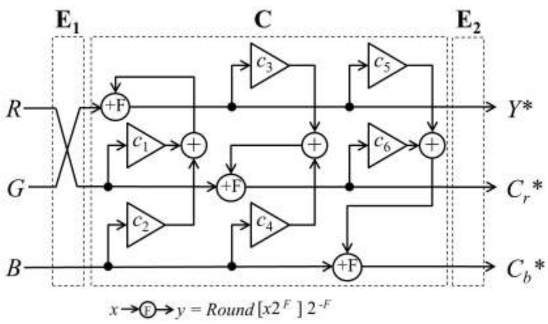

Fig.10: *A non-scaled RCT with parameter on Table II.*

As explanation in section 2.2, the difference of RDWT structure and rounding error affect transcoding compatibility to lossy decoder. Then, we investigate the effect of RDWT when using with non-scaled RCT by 3 type of existing RDWT. 3 RDWTs are as following:

1) Reversible 5/3 DWT (5/3 RDWT)[6].
2) All Lifting Separable Reversible 9/7 DWT (9/7 RDWT) [8].
3) All Lifting Non-Separable Reversible 9/7 DWT (NS 9/7 RDWT) [10].

For experimental result, transcoding system I is evaluated by comparing between original image and lossy reconstructed image using Peak Signal to noise ratio (PSNR). The result was implemented by lena image with 1st stage coding and 5th multi-stage DWT coding. Figure 11 and Fig. 12 are shown comparison transcoding result of 3 RDWT on proposed transcoding system I.

Figure 11 and Fig. 12 indicate that 5/3 RDWT is not compatible with JP2K lossy decoder. While 9/7 RDWT and NS 9/7 RDWT are compatible in JP2K

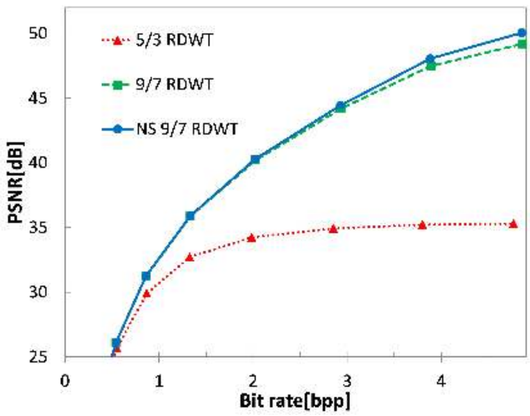

Fig.11: *1^{st} Stage comparison of 3 RDWT.*

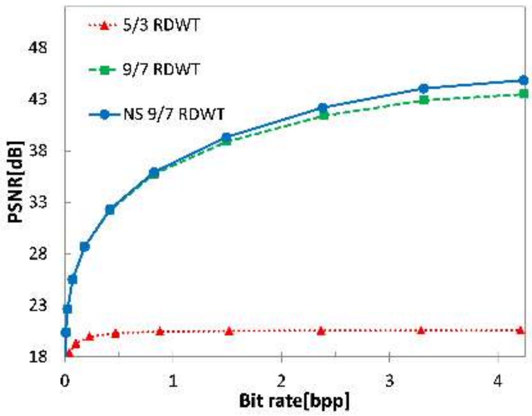

Fig.12: *5^{th} Stage comparison of 3 RDWT.*

lossy decoder. According to the number of rounding operation in Table I and comparison result of Fig. 11 and Fig. 12, NS 9/7 RDWT is the best candidate for proposed lossless encoder I. Then, NS 9/7 RDWT is proposed to use in proposed transcoding system I and II

3.2 Proposed Transcoding System II

Due to the number of rounding operation, transcoding has an effect in rounding error when reconstructing with lossy decoder. 9/7 RDWT and NS 9/7 RDWT have scaling lifting structure. If scaling lifting structure can be removed by embedding scaling parameter into quantization header, the number of rounding operation will be decreased. Proposed transcoding system II is designed to replace RDWT from Fig. 9 by Non-Scaled RDWT for rounding error reduction as highlighted block shown in Fig. 13.

However, all lifting separable reversible 9/7 DWT (9/7 RDWT) also have scaling lifting structure. In Fig. 3 shows that scaling parameter k and k-1 are complicate to apply in each stage coding. Since, every stage on DWT coding was scaling twice. While all lifting non-separable reversible 9/7 DWT (NS 9/7

RDWT) use once per stage. NS 9/7 RDWT is also the best candidate in proposed lossless encoder I.

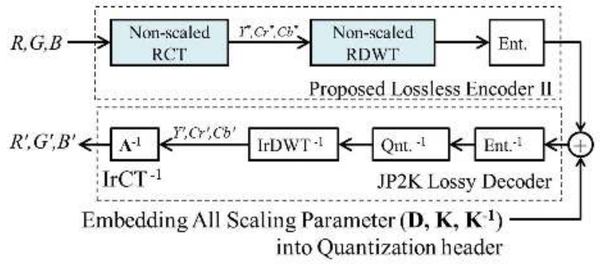

Fig.13: *Proposed Transcoding system II.*

Then, non-scaled NS 9/7 RDWT was selected in proposed lossless encoder II. It was designed by removing scaling k^2 and k^{-2} of NS 9/7RDWT [10] as shown in Fig. 14. Then, non-scaled NS 9/7 RDWT structure is designed as shown in Fig. 15.

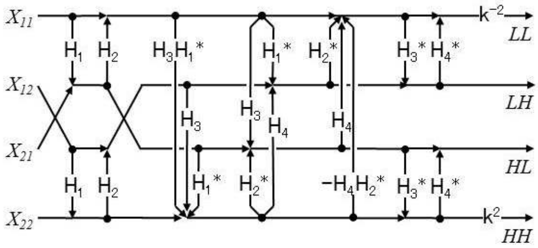

Fig.14: *NS 9/7 RDWT [10].*

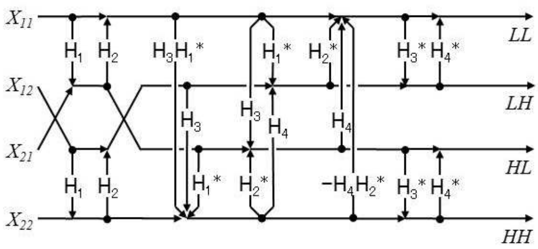

Fig.15: *Non-scaled NS 9/7 RDWT.*

On account of scaling parameter, those parameters are constant. We can apply by embedding to quantization of bit stream. When inverse quantization has been process, the scaling parameter will be multiplied as a step size. In this case, a scaling embedding is programed into lossless signal before transcoding has been sent.

Figure 16 illustrates a full implementation of Transcoding system II. In the next section, we will show experimentally result and discuss on (1) Evaluation of Transcoding, (2) Evaluation of Lossless Coding Performance and (3) Advantage and Disadvantage of each proposed encoder.

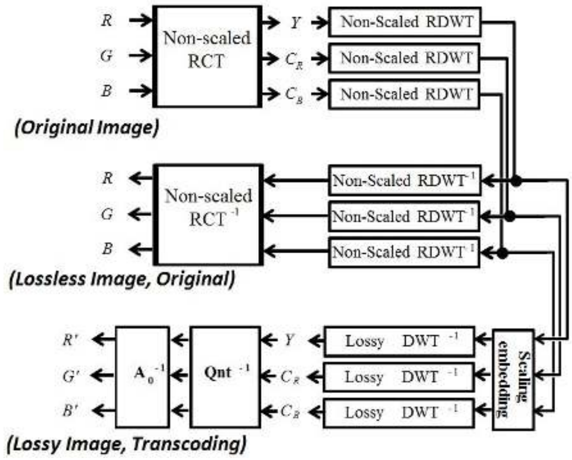

Fig.16: *Proposed Transcoding System II Implementation.*

4. DISCUSSION

According to section 3, we explained about proposed encoders. In this section, we will discuss on some other criteria. We investigate experimental result in the number of stages encoding and some test images. Then, this section is classified to evaluate performance of lossless coding and lossy transcoding. Moreover to compare with JP2K lossless encoder, we summarize an advantage and disadvantage.

4.1 Evaluation of Transcoding

Figure 17 shows that proposed encoders I and II in 1st RDWT coding, there is no significant difference in 1st stage transcoding.

Figure 18 summarized the number of rounding operators between Proposed Encoder I and Proposed Encoder II. When it applied more multi-stage coding, the numbers of rounding operators has increased. Then, the image quality of transcoding will be reduced depending on increasing of rounding error. Then, we evaluate the effect of image quality when transcoding on multi-stage coding. Even though lossy coding, the reconstructed image quality is affected by number of stages coding.

Figure 19 shows the comparison result of proposed lossless encoder I and II with the JP2K lossless encoder. The result was implemented by lena image with 5th multi-stage DWT coding. Then, we can confirm that the proposed transcoding system II improved the rounding error effect. Image quality is increased.

When applying more multi-stage RDWT coding, Fig. 20 shows that proposed lossless encoder II can keep the transcoding image quality in higher stage. In the other hand, image quality of JP2K lossless encoder and proposed lossless encoder are respectively decreased when applying more multi-stage.

Figure 21 shows examples of reconstructed

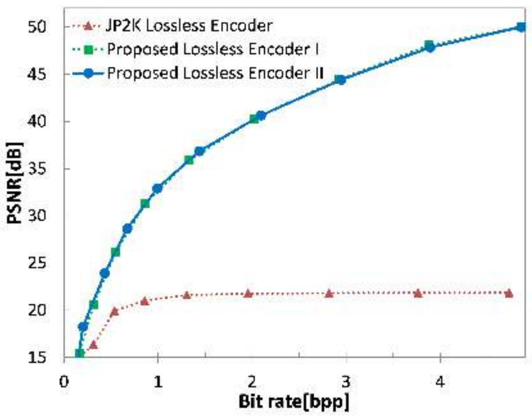

Fig.17: *1st Stage RDWT on Proposed Lossless Encoder.*

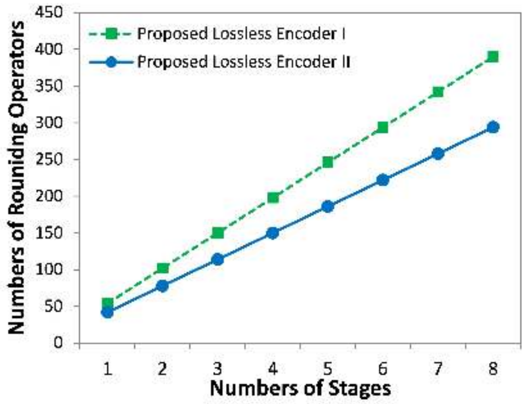

Fig.18: *Number of rounding operators in each stage.*

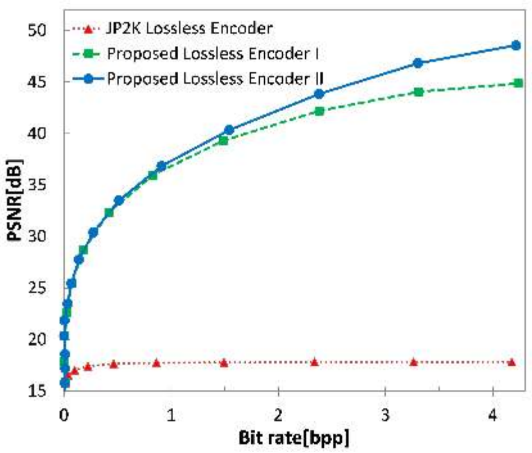

Fig.19: *Comparison of Proposed Lossless Encoder.*

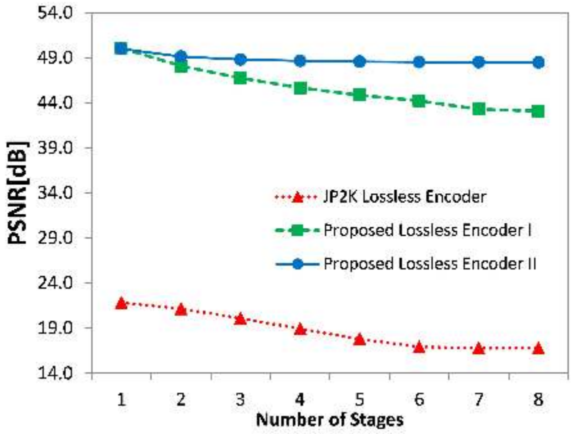

Fig.20: *Transcoding Result in Multi-stage.*

transcoding image of proposed transcoding system II. The examples are 1^{st} and 5^{th} stage reconstructed images of Lena and Mandrill image.

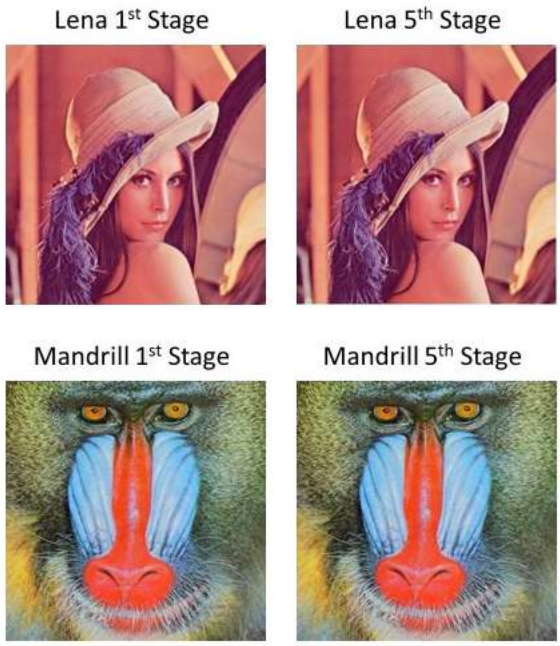

Fig.21: *Reconstructed Transcoding Image Samples.*

Figure 21 illustrates that there is no significant difference between reconstructed transcoding image of proposed transcoding system II in 1^{st} stage and 5^{th}stage. It can keep performance of transcoding in multi-stage.

In case of more sample test images, we add more test images for studying transcoding performance.

Fig. 22 and Fig. 23 confirmed that the result of other image is similar result to Lena image.

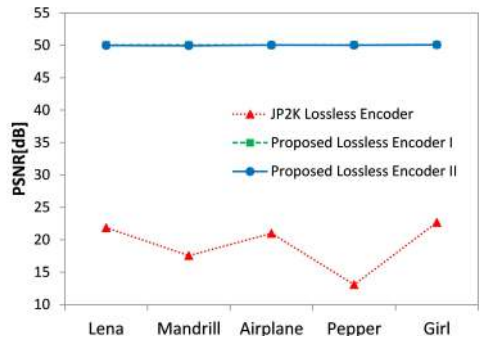

Fig.22: *1^{st} Stage RDWT on Proposed Lossless Encoder.*

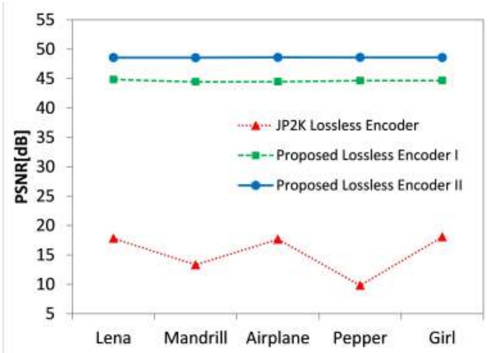

Fig.23: *5^{th} Stage RDWT on Proposed Lossless Encoder.*

4.2 Evaluation of Lossless Coding Performance

Next, we evaluate lossless coding performance by using multi-stage criteria. The results were evaluated in average bit rate [bpp] of three color component.

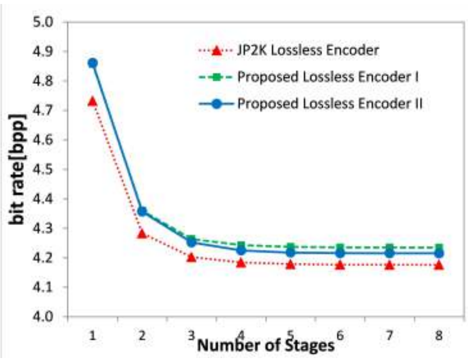

Fig.24: *Average bit rate in Lena image.*

Figure 24 and Fig. 25 show the bitrate when applying more multi-stage RDWT coding. It indicates that JP2K lossless encoder bit rate is the best. However, there is no significant difference in lossless performance. Since, average difference maximum and minimum bitrate of all stage is only 0.09 bit. Therefore, proposed transcoding system can keep lossless performance when improve transcoding functionality.

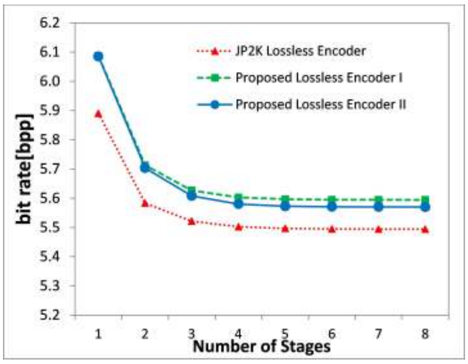

Fig.25: *Average bit rate in Mandrill image.*

4.3 Advantage and Disadvantage

Consistent with the evaluation, we can confirm that proposed encoders have improved the compatibility with JP2K lossy decoder. However, bit rate of proposed encoders was expanded from JP2K lossless encoder. There is no significant difference in average bit rate lossless performance.

Proposed lossless encoder II is the best candidate for transcoding, since it can keep image quality of reconstructed image signal in higher stage of IrDWT. Though, its embedding scaling parameter technique is more complexity than proposed lossless encoder I in term of more parameters.

5. CONCLUSION

In this paper, we proposed new lossless encoder which has more functionality for transcoding with standard lossy decoder based on JP2K. We designed by modified existing RCT and RWT to Non-scaled lifting mode and modifying quantization step size header in a bit-stream without changing any other part of the lossy decoder.

As the result we can achieve transcoding signal image to 50.05 dB without any change of standard lossy decoder based on JP2K. Proposed lossless encoder also can keep lossless performance if compare with JP2K lossless encoder.

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