

Comparative Study of Color Transforms for Image Coding and Derivation of Integer Reversible Color Transform*

Pengwei Hao and Qingyun Shi

Center for Information Science, Peking University, Beijing, 100871, China

phao@cis.pku.edu.cn, sqy@pku.edu.cn

Abstract

A color transform is necessary for better color image coding. In this paper, we concentrate on a comparative study of color transforms for color image coding in order to find the best one among 11 published color transforms: YCrCb, NTSC, PAL, HDTV, UVW, XYZ, DCT, DHT, two approximate K-L transforms (K1K2K3 and KLT) and the original reversible color transform (ORCT) adopted in JPEG-2000. Experiment results with JPEG-2000 verification model (VM5.1) are sorted by color transforms and counted up for all the test images and diverse bit rates. The sorting scoring table shows that the discrete cosine transform performs best among 11 tested color transforms at 6 lossy bit rates for all the 2 JPEG-2000 color test images and other 23 color images we used. Then we derive an integer reversible transform of DCT and an approximate implementation using additions and shifts only for both lossless and lossy color image coding. Experiments with the integer reversible color transforms show that the proposed transform scheme is better than ORCT for lossy image coding.

1. Introduction

JPEG-2000, the next generation image compression standard, is expected to be finalized early in the year 2000. The development of this standard involves work on improved compression algorithms, flexible compression system architectures, and extensible data formats. To satisfy the needs of many diverse applications, this new standard is required to provide numerous functionalities including both lossy and lossless compression. The lossy-to-lossless progressive image coding is expected generally. In the lossless case, a reversible subband transform is applied to the original image, and the transform coefficients are then bitplane coded. For color images, a reversible color transform is used to de-correlate the original tristimulus color components.

The use of an appropriate color transformation can provide significant increase in compression performance.

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Unfortunately, all standard color conversion systems except ORCT introduce small errors (when results are rounded to integer values). In a lossy system this is totally invisible because of other quantization. In a truly lossless system these errors are intolerable. The floating-point conversions are invertible, but loss happens because of the conversion from floating-point implementation or results to integer values.

In this paper, the primary objective is to find a linear color transform that maps integers to integers and reversible, yields good objective image quality in the case of lossy compression, performs well for lossless compression, and has low computational complexity. To achieve this goal, the color transforms under consideration were compared on three fronts: (1) objective lossy compression performance, (2) lossless compression performance, and (3) computational complexity.

For the problem of converting a reversible linear transform into integer mapping steps has been solved in [1], our main work is concentrated on the lossy (6 bit rates) compression performance of 11 linear color transforms we found in literature. Then an integer reversible color transform is derived based on the best one among the 11 tested transforms.

2. Linear color transforms

A commonly used transformation for image coding is from RGB to YCrCb color space, which was adopted by JPEG-2000 and can be found in [2]:

$$\begin{bmatrix} Y \\ Cr \\ Cb \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.500 & -0.419 & -0.081 \\ -0.169 & -0.331 & 0.500 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

One of the advantages of this transformation is that it reduces the psychovisual redundancy in an image. It has been shown that the human visual system is relatively insensitive to the high frequency content of the chrominance components. Thus, these components are commonly subsampled to remove redundancy as in the JPEG and MPEG standards.

An approximate reversible color transform accepted by

JPEG-2000, named ORCT in this paper, was given by [2]:

$$\begin{cases} Y = [(R + 2G + B)/4] \\ Cr = R - G \\ Cb = B - G \end{cases} \quad \text{and inverse:} \quad \begin{cases} G = Y - [(Cr + Cb)/4] \\ R = Cr + G \\ B = Cb + G \end{cases}$$

where [] is rounding operator (chopping here).

There are several major color TV systems all over the world, such as NTSC, PAL, SECAM. For the color TV systems, color transforms are devised with caution to transmit and reproduce human visual acceptable pictures. Generally, the transformed components carry the image luminance and the chrominance information.

NTSC system is currently in use in North America and Japan, and its color transform is defined as [3]:

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.311 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

PAL system is currently used in most of Western Europe, of which the color transform is defined as [3]:

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.437 \\ 0.615 & -0.515 & -0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

A standard for high definition television (HDTV) production has been established by the Society of Motion Pictures and television Engineers. It has the parameters shown as [3]:

$$\begin{bmatrix} Y \\ P_r \\ P_b \end{bmatrix} = \begin{bmatrix} 0.212 & 0.701 & 0.087 \\ 0.500 & -0.455 & -0.055 \\ -0.116 & -0.384 & 0.500 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The UVW space is a CIE uniform chromaticity scale, $V=Y$ =luminance [4]:

$$\begin{bmatrix} Y \\ U \\ W \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.405 & 0.116 & 0.133 \\ 0.145 & 0.827 & 0.627 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

XYZ space corresponds to the CIE X-Y-Z primary color coordinate system [4]:

$$\begin{bmatrix} Y \\ X \\ Z \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.618 & 0.177 & 0.205 \\ 0.000 & 0.056 & 0.944 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

To fully exploit color dependencies, an image dependent color transformation can be used. The Karhunen-Loeve Transform (KLT) has been used in decorrelating color components. It should be noted that the color transformation matrix used corresponds to the eigenvector of the correlation matrix which can be obtained from the image but of high computational complexity, and thus is image-dependent. However, an experimental example, K1K2K3, was given by Pratt [5]:

$$\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} = \begin{bmatrix} 0.575 & 0.615 & 0.540 \\ 0.608 & 0.120 & -0.785 \\ 0.548 & -0.779 & 0.305 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Another approximation of KLT for color transform was estimated from a large set of natural color images by [6], which was also confirmed experimentally by [7]:

$$\begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} = \begin{bmatrix} 0.3333 & 0.3333 & 0.3333 \\ 0.5000 & 0.0000 & -0.5000 \\ -0.2500 & 0.5000 & 0.2500 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Some of the orthogonal linear transforms can also be applied for color decorrelation, such as three channel discrete cosine transform (DCT) and discrete Hartley transform. (DHT).

The three channel DCT is:

$$\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} = \begin{bmatrix} 0.5774 & 0.5774 & 0.5774 \\ 0.7071 & 0.0000 & -0.7071 \\ 0.4082 & -0.8165 & 0.4082 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

The three channel DHT can be expressed as [8]:

$$\begin{bmatrix} C_1 \\ C_2 \\ C_3 \end{bmatrix} = \begin{bmatrix} 0.5774 & 0.5774 & 0.5774 \\ 0.5774 & 0.2113 & -0.7887 \\ 0.5774 & -0.7887 & 0.2113 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Some other color space representations that have been proposed for color imagery exploit specific properties that are useful in areas such as image printing and human system modeling. In this paper, we will study the above mentioned 11 color transforms to test for lossy image coding. The transforms are referred to as YCrCb, ORCT, NTSC, PAL, HDTV, UVW, XYZ, K1K2K3, KLT, DCT, and DHT, respectively.

3. Evaluation methodology

For evaluation purposes, version 5.1 of the JPEG-2000 verification model (VM) software developed jointly by SAIC and the University of Arizona was employed. Before this software was used, however, a minor change was made to the color transform calculation code in order to test compression performance. The two modified files are `component_mix.c` for forward color transform and `component_demix.c` for reverse respectively. The wavelet filters employed in the experiments are Cohen-Daubechies-Feauveau bi-orthogonal 5/3 filter for both lossy and lossless compression.

The test data used in our study consisted of 25 images. They are Bike, Woman, Airplane, Baboon, Barb, Boats, Couple, Fruits, Frymire, Girl, Girl2, Girl3, Goldhill, House, Lena, Monarch, Peppers, Sail, Sailboat, Serrano, Splash, Tiffany, Tree, Tulips, and Zelda, of which Bike and Woman are taken from the JPEG-2000 test set and most of the others can be found at:

It can be implemented by integer mapping algorithms as described in Algorithm 2:

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Algorithm 2: Proposed SHIRCT
SHIRCT forward:
T = r - ((g+b+1)>>1);
C1 = b + g + ((T+1)>>1);
C3 = -g + ((C1+(T>>3)+1)>>1);
C2 = T + ((C3+C3+C3+2)>>2);
The inverse:
T = C2 - ((C3+C3+C3+2)>>2);
g = -C3 + ((C1+(T>>3)+1)>>1);
b = C1 - g + ((T+1)>>1);
r = T + ((g+b+1)>>1);

```

6. Experiments for the integer reversible color transforms

We applied the integer reversible color transforms to all the 25 test images mentioned above, for both lossless and lossy image coding. For lossless compression, the final bit rate was used to measure performance. For lossy tests, PSNR metric was used. In order to compare the performance, the resultant bit rates, bits per pixel (bpp), for lossless tests and the final PSNR for lossy compression tests were sorted and counted up respectively. The counting results are listed in ascending order by transforms in Table 2.

Table 2: Sorting and scoring of bite rate (lossless) and PSNR (lossy) for tests by color transforms

Order	Lossless			Lossy		
	1(best)	2	3	1	2	3(best)
ORCT	17	2	6	147	1	2
RDCT	7	13	5	1	32	117
SHIRCT	1	10	14	2	117	31

ORCT hits 17 times for the lowest bit rates of lossless tests while RDCT hits 117 times for the highest PSNR of lossy image coding with all of the 25 color images at 6 bit rates. The proposed scheme, SHIRCT, performed better than ORCT for most of the lossy coding cases although it is not better than the best, floating-point calculated RDCT.

Of all 25 test images, the average bit rate for lossless experiments are 11.82, 11.93, 11.98 bpp for ORCT, RDCT and SHIRCT, and the average PSNR for lossy tests are 29.28, 29.95, 29.87 dB, respectively. The proposed SHIRCT is about 0.6 dB averagely better than ORCT for lossy image coding. It is satisfying.

7. Comparison of computational complexity

Computational complexity of SHIRCT is 9 integer additions (the triple operation can be implemented by 2 additions), 5 bit shifts and 4 rounding arithmetic operations, while the integer arithmetic numbers of

ORCT are 4, 1, 1, respectively. Both of the reversible transforms are calculated using only integer arithmetic. ORCT requires the less computation, and SHIRCT has moderate computational complexity.

8. Conclusions

11 published color transforms were studied for lossy image coding comparatively, a reversible DCT and an integer reversible color transform, SHIRCT, were derived from the best performed transform, DCT. The proposed transform was evaluated using 25 images in our experiments and yielded comparable objective image quality when used for lossy compression. If a lossy-to-lossless progressive image coding is needed, SHIRCT is likely the best choice due to its multiplier-free nature, low operation count, and the better performance for lossy compression. Although there is a computational cost in going from ORCT to SHIRCT, SHIRCT does provide a reasonable improvement in lossy compression performance.

9. References

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