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# A STUDY OF SUBSET-PIXEL-BASED COLOR TRANSFORM FOR THE EFFICIENT COMPRESSION OF H&E STAINED WHOLE SLIDE IMAGES

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## ABSTRACT

Image compression with lossy codecs is being used to store and transfer extremely large pathological whole slide images even though this results in artifacts. We target efficient image compression with improved image quality; our approach uses color transform (CT) and the color features of H&E stained slide images. This paper adopts subset-pixel-based color transform (SP-CT) which is low computational color Karhunen-Loeve transform (KLT) using subset-pixels or a sub-region of the whole slide image. Experiments evaluate the PSNR of SP-CT components subjected to JPEG2000. The color KLT matrix calculated from the subset-pixels of the same slide image yields 1dB higher PSNR of compressed SP-CT components in any sub-region than that of compressed YCbCr components.

## 1. INTRODUCTION

The use of digital whole slide images (virtual slides) is rapidly being adopted for pathological applications such as education and conferences [1][2]. It is expected to be adopted for local and remote diagnosis in the future. As such images are very large, > 4Gbytes, compression is needed for their storage and transfer. JPEG [3] is used in several commercial systems in even though its lossy codec creates artifacts. Especially for remote diagnosis it is necessary to reduce the volume of whole slide images as much as possible. For this purpose, we need efficient image compression with improved image quality.

Hematoxylin-Eosin (H&E) stained whole slide images are generally used for morphological diagnosis of pathology. It is important that the images decoded from compressed H&E stained whole slide images exhibit accurate tissue colors and detailed morphological structures. The structures include nuclei, cytoplasm, interstitium, sinusoid and fat-cell etc. An efficient compression method with improved image quality suitable for digital pathology images is needed [4].

Color Karhunen-Loeve transform (KLT) is a well-known color transform (CT) that offers high decoded image quality [5]. The sub-sampling KLT method offers low computation complexity [6]. This study proposes a low complexity image compression method based on enhanced color KLT for whole slide images; it takes account of the unique color features of H&E stained tissue images. Experiments confirm its improved image quality across entire images.

## 2. COLOR SPACE FEATURES OF H&E STAINED TISSUE IMAGES

As H&E stained tissue images are a key part of morphological diagnosis, it is important that decoded image quality be as high as possible without large compression artifacts. From the viewpoint of the color space, H&E stained slide images have the following color features,

(1) Color localization

Their CbCr color space histograms show three color peaks on the CbCr plane shown as Fig.1(b). The violet peak N mainly comes from Hematoxylin-stained nuclei(see Fig 1 (c)). The red-pink peak C is generated

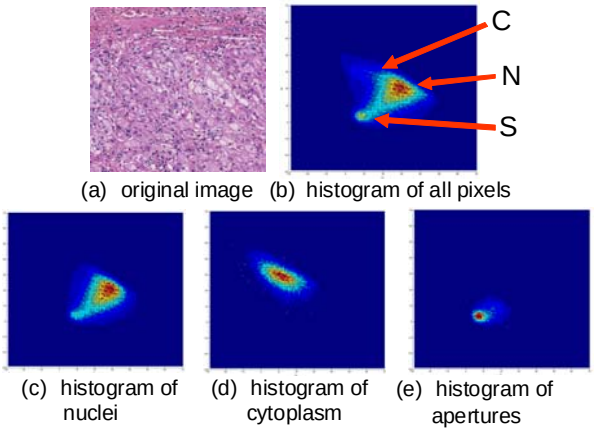



**Fig.1 CbCr color space histogram of H&E stained hepatocyte tissue image**

by Eosin-stained cytoplasm (see Fig.1 (d)). The white peak S comes from the color of glass slide area which shows area of sinusoid, blood vessels, and fat-cells etc. (see Fig.1 (e)). H&E stained slide images are strongly localized in the color space.

(2) Spatial Similarity

As H&E stained tissue images have almost the same spatial patterns and colors, all sub-regions in a whole slide have quite similar color histograms.

## 3. SUBSET-PIXEL-BASED COLOR TRANSFORM

### 3.1. Color KL Transform

Color KLT can be used for image compression since it offers high levels of decorrelation. However, it is not common in practice due to its high computational complexity and its relatively poor compression efficiency for general images.

The first feature of H&E stained tissue images suggests that color KLT can yield high quality compressed H&E stained tissue images.

### 3.2. Subset-Pixel-based Color Transform

The second feature suggests that we can apply virtually the same CT matrix to any sub-region of the whole slide.

Our proposal, subset-pixel-based color transform (SP-CT), is an enhancement of the sub-sampling color KLT method for H&E stained tissue image compression. SP-CT uses the color transform matrix calculated by KLT of any subset of the slide's pixels or a sub-region; the result is a new color space that offers effective image compression with high quality. Since SP-CT applies the same CT matrix to the whole slide, its computation complexity is low.

## 4. EXPERIMENTS AND RESULTS

We conducted three experiments. The first was to evaluate the impact of color KLT on H&E stained slide images. The second was to evaluate SP-CT. The third experiment identified the minimum number of subset pixels needed for SP-CT.

### 4.1 Test Images

5 test images were used in the experiments; LENA (512x512 pixels) as a general image, three H&E stained tissue region of interest (ROI) images named HE-A1, HE-A2, HE-A3, each with image size of 1024x1024, from a whole slide image of hepatocellular carcinoma and non-carcinoma area (see Fig.2 (a)), and one ROI image of H&E stained hepatocyte (HE-B1: 512x512 pixels) from another slide image captured by a different scanner (see Fig.2 (b)). Fig.3 shows these original images at the same size.

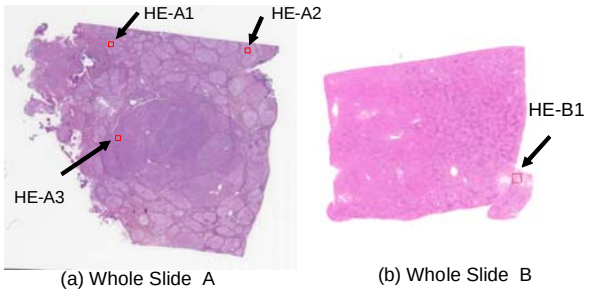



**Fig.2 Whole slide images**

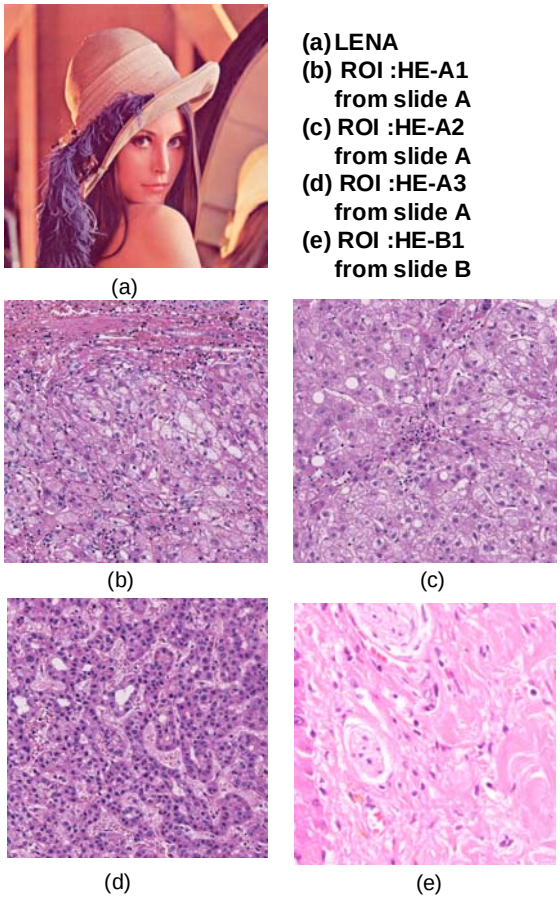



**Fig.3 Test images**

### 4.2. Experiment 1

To evaluate the impact of color KLT, we compared it to YCrCb, the common color transform of JPEG2000 [7]. Ensuring that the compressed image quality is comparable to original image quality is important for medical image diagnosis including pathological diagnosis. For specialized medical diagnosis application there are several useful and important criteria of image quality, such as image contrast, sharpness and color reproduction. PSNR is one such criteria that reflect total image quality. We choose PSNR (RGB components, see Fig.4) as the metric in this paper because we don't

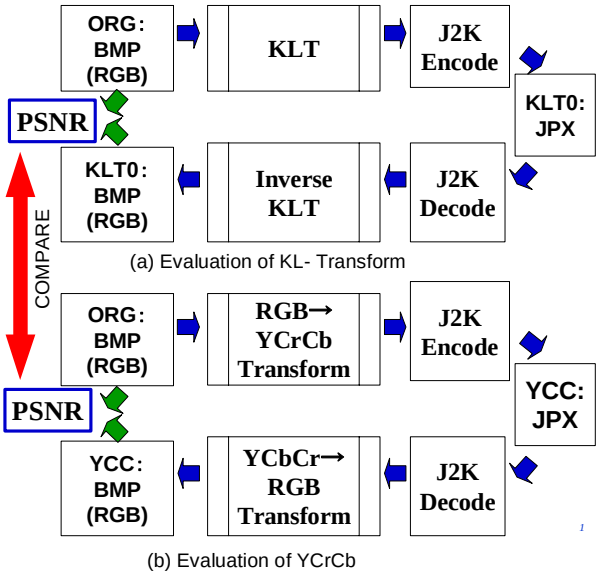
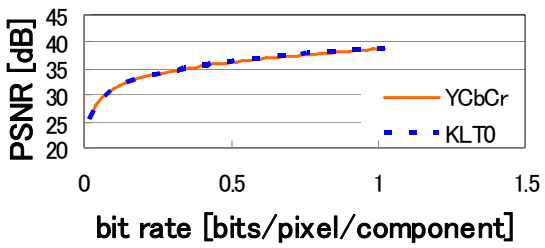
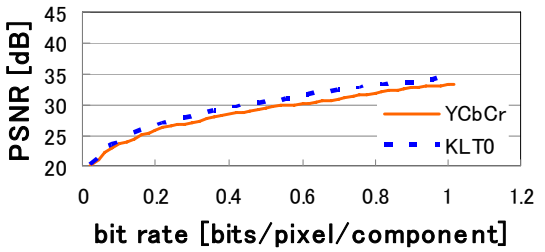


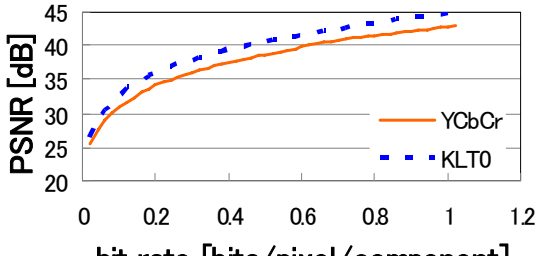

**Fig.4 Procedure of Experiment 1**




(a) LENA




(b) HE-A1




(c) HE-B1

**Fig.5 PSNR with color KLT and YCbCr**

specify any specific pathological diagnosis approach, and pay attention to the total image quality reduction caused by compression artifacts as a first step.

The color KLT matrix of each image was calculated from all image pixels of the original image (ORG) by themselves. The encoded components using the KLT matrix of ORG pixels are named KLT0 in this paper. PSNR was calculated from the original image and decoded KLT0 in this experiment.

Results are shown in Fig.5 (a) - (c). These figures show just the relationships between PSNR and the bit rate of LENA, HE-A1 and HE-B1, as original images. In case of the general image LENA, PSNR of KLT0 was almost same as that of YCbCr (see Fig. 5(a)). On the other hand in case of HE-A1 and HE-B1, which are H&E stained tissue images, the PSNR of KLT0 is 1-2dB higher than that of YCbCr. (see Fig.5 (b) (c)) The results of HE-A2 and HE-A3 are almost the same as that of HE-A1.

### 4.2. Experiment 2

Fig.6 shows how Experiment 2 examined the image quality of SP-CT. To get the CT matrix, color KLT was calculated from a sub-region of the whole slide image. This experiment used images HE-A1 and HE-B1 as the reference sub-region images for matrix calculation. Original image components were transformed by the CT matrix, and encoded by JPEG2000 (KLT-A1 or KLT-B1). PSNR was calculated from the original image and decoded KLT-A1 or KLT-B2 in RGB space.

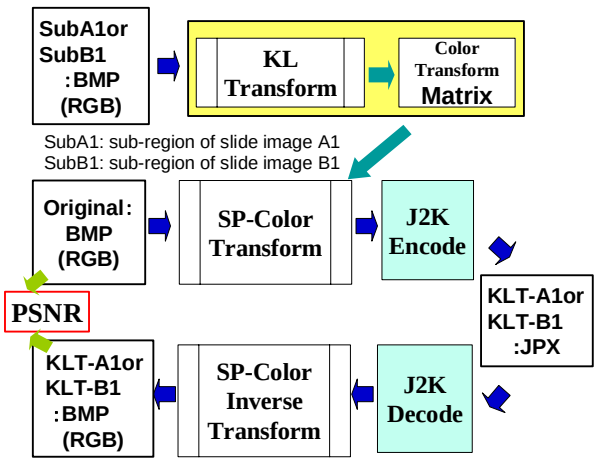



**Fig.6 Procedure of Experiment 2**

Fig.7 shows the results for original images HE-A2 and HE-A3. This figure plots the PSNR of KLT0, KLT-A1, KLT-B1 and YCbCr. In this figure, PSNR of KLT0 is also 1dB higher than YCbCr, see experiment 1.

In the case of KLT-A1, PSNR gain was more than 1dB higher than that of YCbCr and - its quality matched that of KLT0. The result is applied for both image HE-A2 (Fig.7 (a)) and HE-A3 (Fig.7 (b)). From the viewpoint of image quality, SP-CT using other images' KLT matrix of same slide achieved the same quality as using the matrix of itself. The KLT matrix calculated by the sub-region is effective for any region within the whole slide.

On the other hand, PSNR of KLT-B1 was almost the same as that of YCC and was 1dB less than that of KLT0. This means SP-CT in not effective as the matrix used by other slide images.

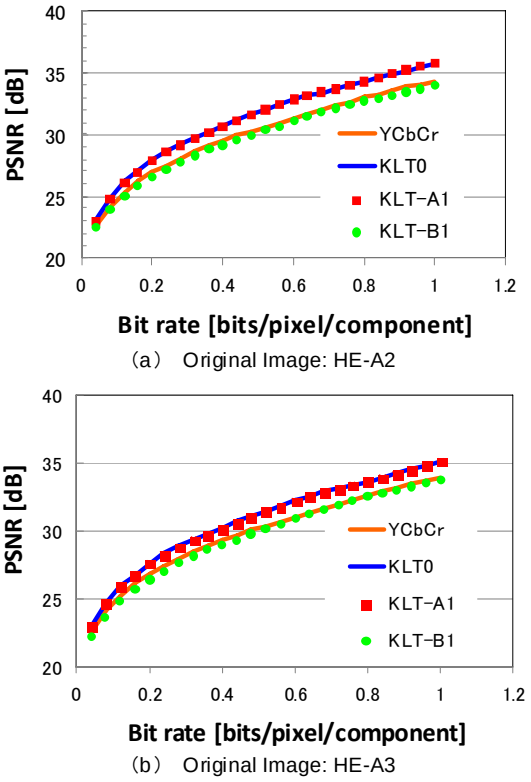



**Fig.7 PSNR with SP-CT, color-KLT and YCbCr**

### 4.2. Experiment 3

In experiment 3, color KLT was calculated just using subset-pixels of a sub-region instead of all pixels of that region to get the CT matrix. Subset-pixels were obtained by down sampling the image of the region (see Fig.8). After getting CT matrix, PSNR was calculated by the same procedure as experiment 2. Subset-pixels were examined for sub-region HE-A1 and the sizes selected were 256x256, 64x64, 16x16, 4x4 and 2x2. Examples of subset-pixels are shown in Fig.9.

PSNR of HE-A1 image using the subset-pixels' KLT matrix is shown in Fig. 10. This result shows that the gain of PSNR using SP-CT retained its 1dB superiority even when the sub-pixel size was 4x4.

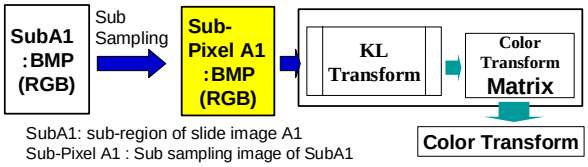



**Fig.8 Calculation of CT matrix in Experiment 3**

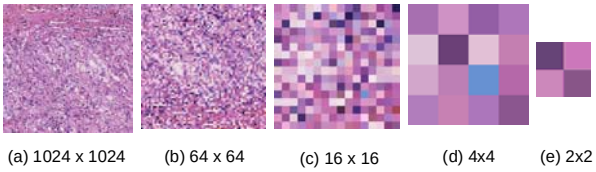



**Fig.9 Subset-pixels for color KLT**

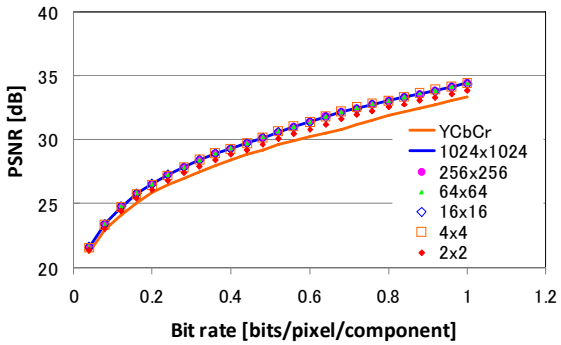



**Fig.10 PSNR with SP-CT using subset-pixels**

## 5. DISCUSSION

Experiment 1 showed that the color KLT components yielded a PSNR gain of more than 1dB (for a JPEG 2000 compressed sub-region image) over the use of YCbCr.

From the result of HE-A1 (see Fig.5 (b)), PSNR was 31.9 dB with YCrCb at the bit rate of 0.80 bits/pixel/component. The encoded image in this bit rate yields 1/10 volume of original images and is normally used for digital slides. At the same PSNR with color KLT, the bit rate was 0.66 bits/pixel/component. This means the 1dB PSNR gain in decoded image quality with KLT makes the encoded volume size 17.5% less than YCbCr encoded volume at the same image quality. The results gained with other images indicate basically the same rate of reduction. For image transfer in remote

pathological diagnosis, this volume reduction or image improvement is very useful, because the volumes of whole slides are extremely large.

This means that the sub-region approach using color KLT components is effective in improving the quality of JPEG 2000 compressed H&E stained slide images; it is not so effective for general images like LENA.

Experiment 2 showed that SP-CT improved PSNR by at least 1dB over that of YCbCr when the SP-CT matrix is calculated from a sub-region of the whole slide. Using other sub-regions of the same slide yielded almost the same results. On the other hand, the PSNR gain was eliminated when a sub-region of a different slide was used, even though the image was an H&E stained tissue image.

Experiment 3 showed that very small numbers of subset-pixels, such as 16 pixels, can be effective for compression using KLT in the case of H&E stained tissue images. This result shows that 16x16 pixel KLT is good enough; its computation overhead is very low even though this method uses KL transform.

These experiments showed that the SP-CT matrix calculated from just a few subset-pixels of the whole slide achieves effective image compression with improved quality for extremely large whole slides with low computation cost.

Another merit of this proposal is that the method just use color transform and is independent of the compression algorithm. Therefore, it is easy to adapt to existing virtual slide techniques such as JPEG and JPEG2000. It is also expected that further quality improvement or more efficient compression of pathological images will be realized by combining the proposed methods with a specific compression algorithm.

## 6. CONCLUSION

We introduced an efficient image compression method that uses our subset-pixel-based color transform (SP-CT). Experiments showed that JPEG 2000 with SP-CT where the subset-pixels of the sub-region came from the same slide, yielded 1dB higher PSNR for digital images of H&E stained tissue with very low computation overhead. The results confirmed that the proposed method can enhance the compression efficiency of remote pathological diagnosis system images.

## 7. ACKNOWLEDGMENTS

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