

A Simple Image Coding by Projection of Principal Component in Segmented Color Areas

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Abstract

This paper proposes a simple color image coding method using Principal Component Analysis (PCA) in the segmented color areas. A color image is segmented into different object areas with clustered color distributions. The chrominance a* and b* values in CIELAB space are observed to be strongly correlated with luminance L* value in the object areas. After the segmentation, each object area is characterized by PCA. The segmented object areas are indexed by the class number which is greatly com-pressed by the conventional loss-less coding. The coded class number is transmitted with L* image and the PCA parameters. PCA parameters are also compressed, because they are transmitted not by every pixel but by one set for each object area. The (a*, b*) values of each pixel are predicted by the projection of L* onto chromatic plane along to the first PC axis given by eigen vectors and are approximately restored from L* value. L* image can be compressed by the conventional lossive coding method such as JPEG or Wavelet. Finally, the full color image is reproduced by combining the luminance L* with (a*, b*). The paper discusses the coding efficiency and the image quality changing with the class number.

Introduction

The efficient image compression technology is being indispensable as the diffusion of image communication through the internet. Usually the image compression is performed independent of the image contents, while the color image is composed of strongly correlated colored objects where the redundancy should be removed for better color image coding. Each object has its own surface colors distinguished from others which are distributed with clustering in three dimensional color space. Here the color distance measures such as Euclid or Mabalanobis distances and Bayesian decision rule are introduced to segment the objects areas in CIELAB space. The segmented object areas labeled with class number and compressed by loss-less coding. The principal component analysis (PCA) is applied for extracting the color parameters from each segmented object's areas.

This paper proposes a simple image compression method by PCA of clustered color areas. The segmented PCA parameters are extracted depending on the objects' color distributions. The chrominance values in the object area are predicted from only the luminance values using the one set of PCA parameters.

System Concept

Fig.1 shows the conceptual model of the proposed system. First, the image is classified into different object areas with clustered color distributions. RGB color data are transformed to CIELAB data. In order to achieve full automatic image compression, the clustered L*a*b* values are automatically segmented into several key color areas dominant in the given image. After the segmentation, each object area is characterized by PCA. The principal components are composed of the eigen vectors for covariance matrix which represents the statistical correlations between the tri-color signals in each cluster, and the mean vectors which denotes the center of gravity in each cluster.

The class number greatly affects to the whole amount of information. It may occupy about the half of total information, if it is transmitted pixel by pixel as raw value. Because the segmented object area is labeled by the same class number, it is greatly compressed by the conventional coding technique. This is the key point of compression in the proposed method. The another key technology is in the use of strong correlations between the luminance and the chrominance in the segmented object's area.

Here the chrominance values, a* and b* are predicted by the projection of luminance value L* onto chromatic plane using the eigen vectors of covariance matrix and the mean vectors. Finally, the full color image is reproduced by combining the luminance L* with (a*, b*).

Image Segmentation

Clustering of Image Space

The first step is to segment the whole image into colored objects areas. The objects' colors are distributed with clustering in 3-D CIELAB color space. Here the three types of classifiers are tested to separate the key color areas, that is

[1] Euclidean distance
[2] Mahalanobis distance
[3] Bayesian decision rule

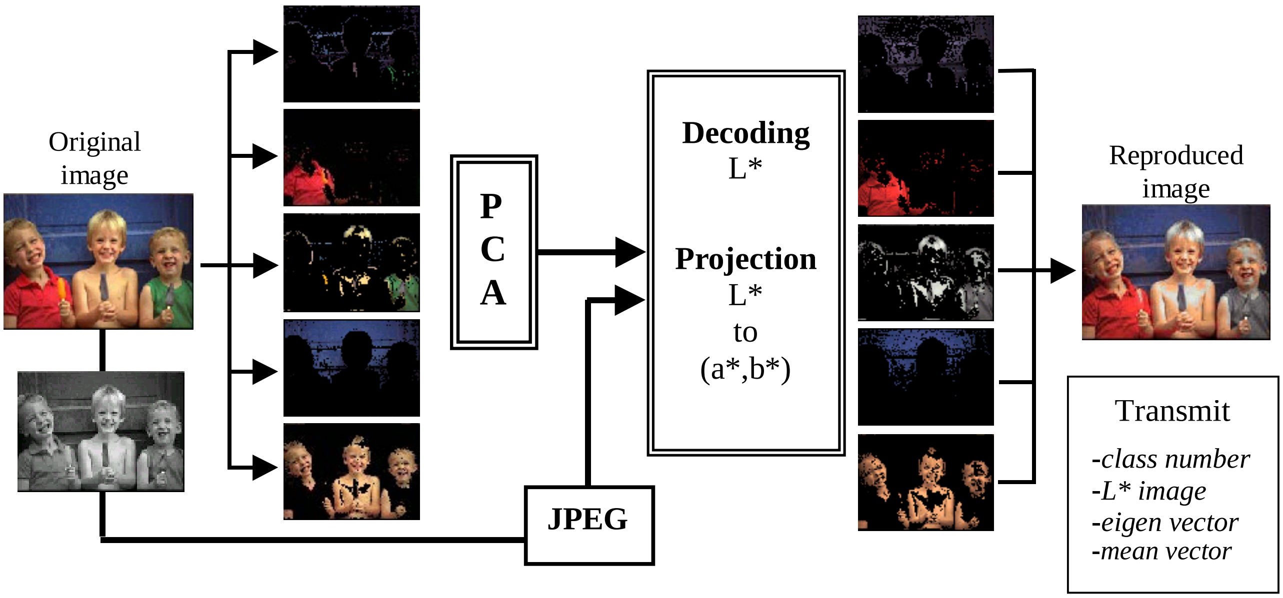


Figure 1. Overview of Color Coding System Model

The LAB components in each color cluster are assumed to be approximately distributed in an ellipsoid.

Letting a CIELAB color vector X and the mean vector μ be

$$X = [L^*, a^*, b^*]^t \tag{1}$$

$$\mu = E\{X\} = [\overline{L}^*, \overline{a}^*, \overline{b}^*]^t \tag{2}$$

where $E\{\arg\}$ is the expected value of the argument and t denotes the transpose.

Euclidian and Mahalanobis color distances between a color vector of pixel i and the mean vector ${}_k\mu$ in class k are defined by

$${}_k d(Euclid) = |X - {}_k\mu| \tag{3}$$

$$= \{(L^* - {}_k\overline{L}^*)^2 + (a^* - {}_k\overline{a}^*)^2 + (b^* - {}_k\overline{b}^*)^2\}^{1/2}$$

$${}_k d(Mahalanobis) = \{(X - {}_k\mu)^t \, {}_k\Sigma_X^{-1}(X - {}_k\mu)\}^{1/2} \tag{4}$$

where, ${}_k\Sigma_X$ denotes covariance matrix for class k given by

$${}_k\Sigma_X = E\{(X - {}_k\mu)(X - {}_k\mu)^t\} \tag{5}$$

Mahalanobis distance is a well-known statistical measure assuming the multi-dimensional normal Gaussian distribution. On the other hand, the maximum likelihood classifier is also used to minimize the classification errors in average. According to the Bayesian decision rule, the maximum likelihood is obtained when the following discrimination function is minimized for k.

$${}_k d(Bayes) = -\log\{p(k)\} + \frac{1}{2}\log(|{}_k\Sigma_X|)$$

$$+ \frac{1}{2}(X - {}_k\mu)^t \, {}_k\Sigma_X^{-1}(X - {}_k\mu) \tag{6}$$

where $p(k)$ means the prior occurrence probability of class k.

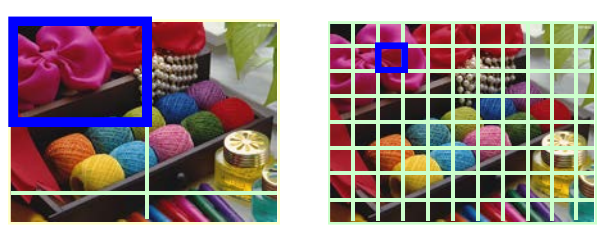
Thus a color vector X is classified into class $k = c$, if

$$\min\{{}_k d(method)\}_{k=1\cdots K} = {}_k d(method) \tag{7}$$

Image Segmentation Within Sub-Block

The proposed method approximates the full color image by the limited class number of key colors. To get the better reappearance image, the segmentation should be done not for whole image but for divided sub-block area, where a few key colors are included. The key colors in the sub-block area will be more precisely encoded by PCA.

There are two methods to divide the target image: one is to fix the number of sub-blocks independent of image size (fig.2(a)). The other is to fix the area size of sub-block (fig.2(b)).



(a) Fixed number of sub-blocks (b) Fixed size of sub-blocks

Figure 2. Sub-block division methods

Compression and Decompression

Projection of L* onto chromatic plane

Fig. 3 illustrates the basic concept for the estimation of object colors by the projection of luminance axis to chrominance plane.

After the segmentation process, each object area is characterized by PCA. The principal components are composed of the eigen vectors of covariance matrix and mean vectors for each color cluster. The amount of PCA information is compressed by omitting the second and third principal components, where the PCA parameters are represented only by the mean vectors and the first principal component of covariance matrix in each segmented object area. Therefore, when an image is reproduced, the reduced PCA color information must be decompressed.

The color information is estimated based on the first principal component as follows.

$$\vec{\mathbf{X}} = \left(a^* b^* L^*\right) = \vec{\mathbf{m}} + t\vec{\mathbf{e}} \tag{8}$$

where $\vec{\mathbf{e}}$ denotes the eigen vector of the first principal component,

$$\vec{\mathbf{e}} = \left(e_{11}\, e_{12}\, e_{13}\right) \tag{9}$$

and $\vec{\mathbf{m}}$ denotes the mean vector

$$\vec{\mathbf{m}} = \left(m_1\, m_2\, m_3\right) \tag{10}$$

and, t means the following parameter,

$$t = \frac{L^* - m_1}{e_{11}} \tag{11}$$

Consequently, the a* and b* are predicted by the projection of L* onto chromatic plane using the eigen vector and the mean vector of first principal component. Thus, the full color image is reproduced by combining the luminance L* with (a*, b*). In short, all the image pixels are to be approximately reproduced only along the first principal component axis in each class characterized by PCA.

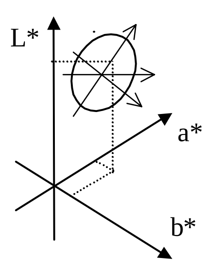


Figure 3. Restoration of Chrominance from Luminance by Projection

Compression of Luminance Information

The higher compression rate is possible by applying JPEG or Wavelet coding for the luminance L* image.

However, these lossive compression may cause double encoding error in the approximate reproduction of chrominance from luminance. Therefore, we must take care of trade-off between the reproducted image quality and the compression rate.

Compression of Class Numbers

The class number is a discrimination code for representing the segmented key color areas. If this code is confused with other area code and wrongly decoded, the objective color is not reproduced correctly. The decoding error in class number will bring the fatal mistakes, because the object colors are reproduced on the first principal component axis of the correct class which is actually segmented.

Therefore, it is necessary for the class number to be compressed by using the loss-less encoding that is restored perfectly. Here, Huffman encoding, arithmetic encoding, and LZW encoding have been examined.

Experimental Results

Comparison of Classifier Types

In the comparison of classifier types for the segmentation, the reproduced color appearances were much the same. Mahalanobis distance and Bayesian decision rule take the much calculation costs as compared with Euclidian. Hence, Euclidean distance is selected in practice from the economical point of view. The color difference in the reproduced image depends on the number of the seg-mented classes. An example of the experimental result for the color difference vs. class number is shown in Fig. 4.

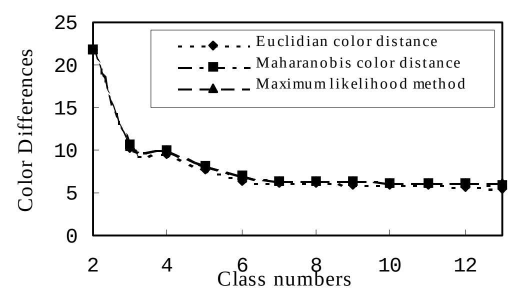


Figure 4. Color difference vs. class numbers

Compression of Class Numbers

While, as the number of the classes is increased, the amounts of transmitted information increase. So, we should set up an appropriate number of the classes within the tolerable color reproduction error.

Fig.5 shows an experimental result for the compression rate vs. class numbers.

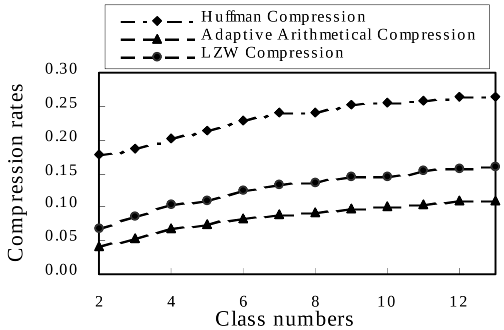


Figure 5. Compression rate vs. class numbers

Compression of Luminance with JPEG

The smaller the number of classes is, the larger the reproduction error is and the reproduced colors tend to be de-saturated due to the mixture of various colors. Fig.6 is shows the compressed image with JPEC for L*. When the compression rate of JPEG is increased, there are a little change in the reproducted color difference.

However, PSNR drops remarkably because of the influence which is characteristic of JPEG of the block noises in JPEG, and the reproducted image quality is much decreased.

Image Segmentation Within Sub-Block

The image segmentation in the sub-block is very useful to improve the reappearance color differences, because the local image areas include small number of key colors. Furthermore, as the number of sub-blocks increased, it was found out that the noisy artifacts on the block boundaries are reproduced. This means the division number or area size of sub-blocks are closely related to the number of key colors contained in on sub-block and the segmented number of classes is better to be adaptively changed dependent of key color numbers in individual sub-blocks. The color difference $\Delta E^*_{ab} = 6.16$ could be obtained when the most suitable number of the classified classes can be chosen. However, great calculation becomes necessary to choose automa-tically the different number of the classified classes in each sub-block.

Fig.8 shows examples of reproduced images by our coding method: (a) original image; (b) normal coding in 12 classes; (c) with JPEG cording in 12 classes; (d) best selected variable numbers of the classified classes in each sub-blocks.

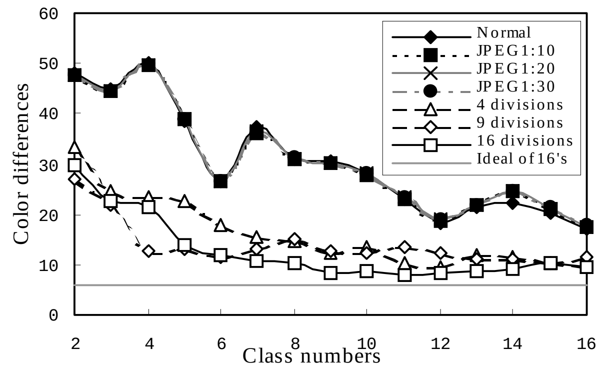


Figure 6. Color difference vs. class numbers

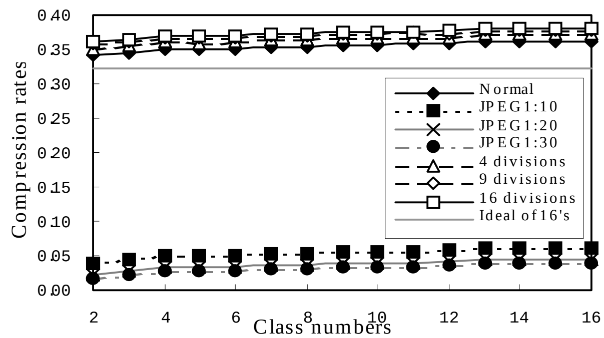


Figure 7. Compression rates vs. class numbers

(a) original

(b) normal; class No = 12

(c) with JPEG 1:20; class No=12

(d) valiable class numbers in sub-block division

Figure 8. Examples of reproducted image

Conclusion

A simple and novel color image coding method is discussed. The major concept of the proposal lies in the approximation of segmented object areas based on the color correlations in the local area. In principle, the proposed method doesn't reproduce the correct colors, because it uses only the first principal component to estimate the chrominance. However, our fundamental experiment brought an unexpected good approximation for object colors in spite of very few number of segmentation. Of course, this method is not suitable for the application where the exact color reproduction is required, but available for coding the images composed of clear key colors or multi-color graphical images.

The utilization of second principal component for the better approximation is remained to the future work.

References

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Biography

Yoshie Imai received the B.S. degree in Image Science from Chiba University in 1999. She is a student at Graduate School of Science and Technology, Chiba University. Her current interests include color image compression, image segmentation, and image processing.