Comparative Analysis of Adaptive Color KLT and YCrCb for Representation of Color Images

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Abstract – **In this paper are represented the results of the experimental research on a new algorithm for Adaptive Color KLT and the comparison with the YCrCb color system for the representation of color images. The obtained results include several groups of color test images. The results of the made experiments are represented both in graphical and table form. They are showing the advantages of the new algorithm for Adaptive Color KLT in comparison with the YCrCb color system.**

Keywords – **color systems, adaptive color KLT, YCrCb color system, format for color images representation.**

I. Introduction

The transformation of the primary color space RGB is very important part of the image processing. In general the components of the RGB color system are correlated, the most important feature of the Adaptive Color KLT is that it permits the decorrelation of the components. There are many applications of the new algorithm– in the domain of image processing, image coding, color image recognition and many others.

There are two types of color spaces – deterministic and statistical. The deterministic transformations such as YCrCb, YUV, YIQ, CMYK [2, 3 ,6 ,7 ,8 ,9, 11, 12] are calculated using fixed coefficients and require less computations but the disadvantage of those color systems is that they are not adapted for each individual image that is being transformed. In the other type – the statistical transforms such as the Adaptive Color KLT [1] the generated color space is adapted to the statistical properties of each image or group of images that is being transformed but the disadvantage is that it requires more computations than the deterministic color systems. That gives better quality of the restored image, less correlation of the components, etc [4, 5].

The purpose of this paper is to introduce a new format for color image representation based on the color KLT (ACT) and the experimental results obtained by comparing it with the already existing format YCrCb on which are based many image formats like JPEG and JPEG2000 [3, 11]. The goal is to achieve better quality of the restored images based on the color transforms only. For the experiments we used different sets of images of various size and contents to prove that the new format works with all kind of images.

This paper is organized in the following manner – in part two we give the detailed algorithm description of the new format for representation of color images, in part three we give the experimental results and the conclusion is given in part four.

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II. Algorithm Description and Analysis

The proposed algorithm is a complete analytical solution to the problem of the color transform based on the KLT. It is based of the method presented in [1]. The algorithm is simplified so that to reduce the necessary computations of the color transform.

Transforming an RGB image into the new color format is made by the following steps following the proposed algorithm presented in Fig 2.1, blocks (1)-(9), which is the forward algorithm for the Adaptive Color KLT:

Step 1: Calculation of the primary color vectors $\vec{C}_s$ for each pixel from the original RGB image, where s is the current pixel and S the total number of the pixels in the image, therefore $S = M \times N$, where M and N are the image height and width.

Step 2: Calculation of mean values of the colors R,G and B- Fig 2.1, block (2). The mean values are necessary for the computation of the covariance matrix in the next step.

Step 3: Calculation of the image covariance matrix:

$$[K_C] = \left[\frac{1}{S}\sum_{s=1}^{S}\vec{C}_s\vec{C}_s^t\right] - \vec{m}_c\vec{m}_c^t = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{22} & k_{23} \\ k_{31} & k_{32} & k_{33} \end{bmatrix}$$

Where the coefficients $k_{i,j}$ are calculated using Fig 2.1, block (3). The covariance matrix is a diagonal matrix so therefore the eigenvalues are always real numbers.

Step 4: Calculating the coefficients of the characteristic equation of the covariance matrix

$$\det| k_{ij} - \lambda\delta_{ij} | = \lambda^3 + a\lambda^2 + b\lambda + c = 0$$

using equations Fig 2.1, blocks (4) and (5).

Step 5: Calculation of the eigenvalues of the characteristic equation defined in the previous step. Given that the covariance matrix $[K_C]$ is a diagonal matrix the eigenvalues can be defined by the “Cardano” relations or the so called trigonometric equations [10] Fig2.1, block (6). Where we have the condition

$$\lambda_1 \ge \lambda_2 \ge \lambda_3 \ge 0 .$$

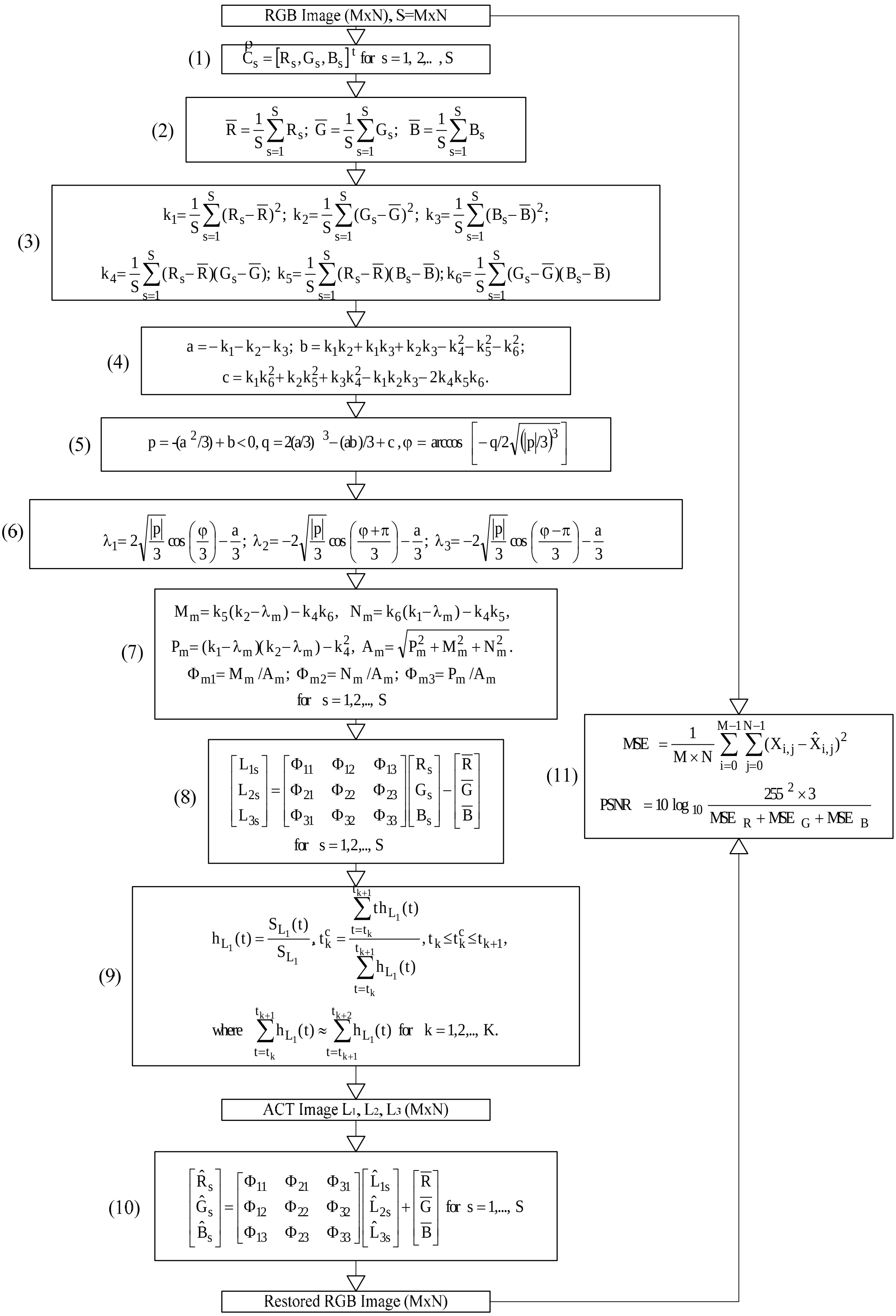


Fig 2.1 Block diagram of the algorithm for Adaptive Color KLT and the PSNR calculation

Step 6: Calculation of the eigenvectors of the covariance matrix $[K_C]$: Fig. 2.1, block (7). Here A_m, P_m, B_m, D_m are the coefficients used for the computations and $m = 1,2,3$. From the eigenvectors we form the transformation matrix $[\Phi]$:

$$[\Phi] = \begin{bmatrix} \vec{\Phi}_1^t \\ \vec{\Phi}_2^t \\ \vec{\Phi}_3^t \end{bmatrix} = \begin{bmatrix} \Phi_{11} & \Phi_{12} & \Phi_{13} \\ \Phi_{21} & \Phi_{22} & \Phi_{23} \\ \Phi_{31} & \Phi_{32} & \Phi_{33} \end{bmatrix}$$

Step 7: Performing the color transform using the already generated transformation matrix $[\Phi]$ to obtain the transformed color vectors $\vec{L}_s = [L_{1s}, L_{2s}, L_{3s}]^t$ using the equation Fig 2.1, block (8). Where again s is the current pixel that is being transformed and S is the total number of the pixels in the image.

Step 8: Perform an adaptive quantization of the obtained matrix $[L_1]$ to comply with the limits of 8 bits per pixel or 256 unique values in the matrix using the equations from Fig. 2.1, block (9). Here $h_{L_1}(t)$ is the histogram calculated for the first component of the Adaptive Color KLT, t_k^c is the center of gravity of the part of the histogram $h_{L_1}(t)$ between levels t_k and t_{k+1} of the component L_1 (k=1,2,..,K for K - number of quantization levels). After adaptive quantization we have three matrices $[\hat{L}_1],[\hat{L}_2],[\hat{L}_3]$ that comply with the limit of 8 bits per pixel or 24 bpp for each pixel in the image.

The restoration of an image already converted in the Adaptive Color KLT back into the primary format RGB is made with only one step using the equation from Fig. 2.1, block (10).

For the restoration of the original image in the primary color system RGB is needed the matrix $[\Phi]$, the quantization table and the mean values of the colors to be passed to the decoder. This information must be embedded to the file that contains the transformed color vectors. The new format explained in this part of the paper shows great results in terms of quality of the restored images. More detailed results are presented in the next section.

III. Experimental Results

As experimental dataset was used three different sets of images of different size – the "Kodak" image set plus the image "Lena" and "Barbara" 26 images in total, of size 512×768 or 768×512, Lena - 512×512 and Barbara - 640×512 pixels. The "cgraph" image set which comprises ten computer generated images of size 1024×768. The "natural" image set which is comprises 10 images of HD size, 1920×1024 pixels. All the images are in the format .bmp (primary format for the RGB color system) with 24 bits describing each pixel (bpp).

As an algorithm for YCrCb conversion was used the fix coefficients from the matrix equation [3]:

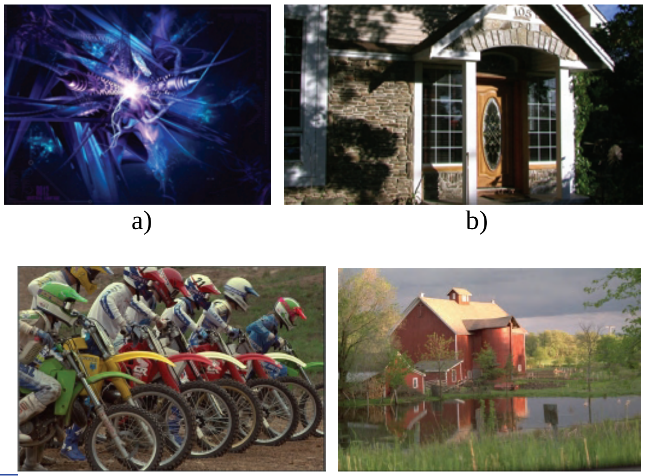
$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.2989 & 0.5866 & 0.1145 \\ -0.1688 & -0.3312 & 0.5000 \\ 0.5000 & -0.4184 & 0.0816 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

For quality measurement was used the Peak Signal to Noise Ratio (PSNR) equation given on Fig 2.1, block (11). The PSNR gives the objective representation of the restored image quality [3].

$$MSE = \frac{1}{M \times N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (X_{i,j} - \hat{X}_{i,j})^2$$

Where the MSE is the Mean Square Error of one component of the RGB image. The value $X_{i,j}$ is the original value from the original image and $\hat{X}_{i,j}$ is the restored value (from the restored image) in the point (i, j) of the image for the given component R, G or B. Therefore there are three different MSEs which represent the error in the image. So to find the total error we must add them $(MSE_R + MSE_G + MSE_B)$ [3].

$$PSNR = 10 \log_{10} \frac{255^2 \times 3}{MSE_R + MSE_G + MSE_B}$$



a) b) c) d)

Fig. 3.1

In Fig. 3.1 are shown some images from the test image sets: a) cgraph7 (1024×768, 24 bpp); b) natural4 (1920×1024, 24bpp); c) kodim05 (768×512, 24 bpp); d) kodim22 (768×512, 24 bpp).

Image Set	ACT PSNR [dB]	YCrCb PSNR [dB]
Kodak + Lena +Barbara	48.44	46.57
Cgraph	48.97	46.12
Natural	48.59	46.01

Table 3.1. Mean PSNR values for all the image sets

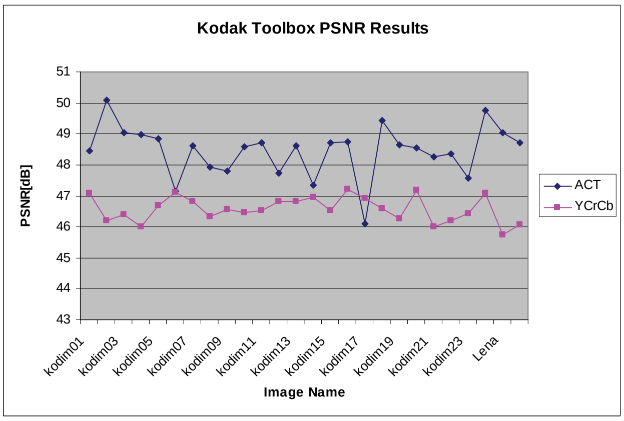


Fig 3.2 Kodak image set PSNR

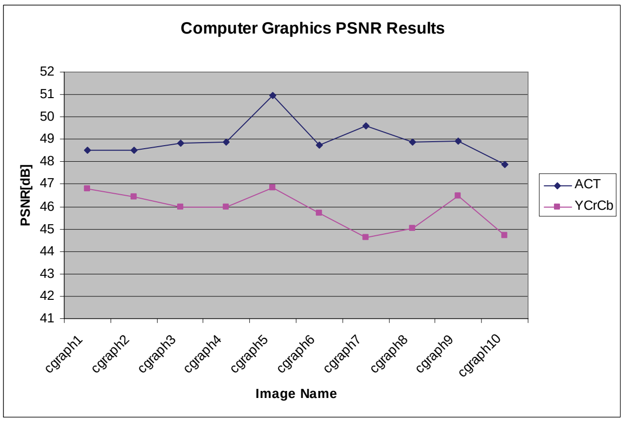


Fig 3.3 "Cgraph" image set PSNR

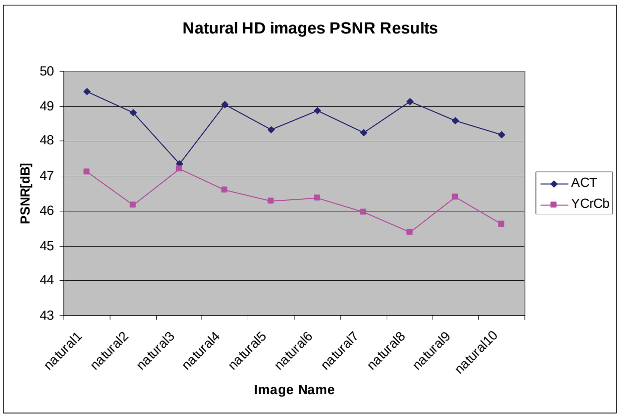


Fig 3.4 "Natural" image set PSNR.

From Table 3.1 we see that the average difference between the proposed format for representation of color images and the already existing YCrCb in no less than 2 [dB] for image set. This is something that can give many advantages in the domains of image processing and/or image coding.

From the charts Fig. 3.2, 3.3 and 3.4 we can see that the quality of the restored images is very high – plus 48 [dB] – without any visual loss in the image. The losses in the proposed algorithm result from the "casts" of the data types in the program. There are no losses from compression or any other kind of lossy actions on the image data.

IV. Conclusion

There are two types of color transforms – deterministic (RGB, YCrCb, YUV, YIQ, CMYK) [2, 3, 6, 7, 8, 9] and statistical (ACT – Adaptive Color KLT Transform) [4, 5]. The deterministic transforms are defined by fixed equations with fixed coefficients which are not changing for each image. The statistical transforms (ACT) the components are adaptive for each image that is being transformed. Therefore the transform matrix generated by the algorithm is adapted to the statistical information of the image that is being transformed. The algorithm gives very high quality of the restored image as we have seen in the previous part of the paper. The high quality of the output images can be carried with other algorithms such as image coding and compression. As a result of that we can say that the proposed algorithm has many applications – in the domain of image coding, compression, processing, etc.

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