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Colorization of Grayscale Images Using KPE and LBG Vector Quantization Techniques

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***Abstract*—**Colorization is a practice of adding colors to gray scale images and videos. This research aims at replacing each pixel value of grayscale image by the required color pixel value. Adding colors to grayscale images makes them more attractive and observable. It is easy for human visual system to recognize color information more proficiently as compared to gray information. Automation of this process is very important as manual colorization takes a lot of time and effort. In the proposed method, Kekre's Proportionate Error (KPE) codebook is used and five different vector quantization (VQ) codebook sized alias 32, 64, 128, 256 and 512 are considered. By using eight different color models: RGB, Kekre's LUV, YCbCr, YUV, YIQ, and Kekre's Biorthogonal color models and five VQ codebooks, total 40 versions of proposed colorization method are found. Testing is done on 30 images of different classes and results are compared with the existing method of LBG based image coloring. It is observed that the use of higher codebook sizes and YCbCr color model enhances the colorization.

***Keywords*—**Colorization; Codebook; VQ; LBG; KPE; Color Model

I. INTRODUCTION

Colorization is an interactive or automatic process of enhancing grayscale images and videos by adding colors to them which will help in observing the details in the colored image. It is very crucial in Medical, Entertainment, Crime Prevention, Military, Satellite imaging etc [1]. In this process, each pixel value is replaced by three components of the respective color model. The process of colorization can be categorized as semi-automatic and automatic. Semi automatic colorization process can be implemented using swatches or scribbling [2]. These methods allow more user interaction in the color transfer procedure and therefore it requires more time and effort. But the proposed system is implemented using automatic colorization process and hence there is no human intervention required. To implement automatic colorization, the concept of Vector Quantization is used. The process is divided into three steps: codebook generation using source image, search the respective matches for gray scale pixels in the color codebook and transfer colors from the best found codebook match to grayscale pixel [3].

Kekre's Proportionate Error (KPE) algorithm is used in color transfer to grayscale images. The performance of colorization method using KPE is proven to be better than the existing LBG based colorization. Section II introduces the concept of various color models; section III discusses the vector quantization algorithms: KPE and LBG. The proposed method is described in Section IV. Section V discusses the experimentation results and concluding remarks are given in section 6.

II. COLOR MODELS USED FOR EXPERIMENTATION

The various color models used in the proposed method are as follows [4,5]:

A. Kekre's LUV Color Model

In this color model, L represents luminance and U, V represent chromaticity. Positive value of U specifies the eminence of red component in color image and negative value of V specifies eminence of green component. RGB to LUV color model conversion is given in equation (1) which gives L, U, V components of color image for respective R, G, B components [6].

$$\begin{bmatrix} L \\ U \\ V \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 2 & 1 & 1 \\ 0 & 1 & 1 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \qquad (1)$$

R, G, B components can be obtained from L, U, V components using equation (2).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & -2 & 0 \\ 1 & 1 & -1 \\ 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} L/3 \\ U/6 \\ V/2 \end{bmatrix} \qquad (2)$$

B. YCbCr Color Model

In YCbCr color model, Y represents luminance and Cb, Cr represent chromaticity. RGB to YCbCr color model conversion is given in equation (3) which gives Y, Cb, Cr

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components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.2989 & 1 & 0.1145 \\ 0.1688 & 0.3312 & 0.5000 \\ 0.5000 & 0.4184 & 0.0816 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (3)$$

R, G, B components can be obtained from Y, Cb, Cr components using equation (4).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.0010 & 1.4020 \\ 1 & 0.3441 & 0.7140 \\ 1 & 1.7718 & 0.0010 \end{bmatrix} \begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} \quad (4)$$

C. YUV Color Model

In YUV color model, Y represents luminance (brightness) and U, V represents chrominance (color) components. RGB to YUV color model conversion is given in equation (5) which gives Y, U, V components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.14713 & 0.22472 & 0.436 \\ 0.614 & 0.51498 & 0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (5)$$

R, G, B components can be obtained from Y, U, V components using equation (6).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 0.7492 & 0.50901 & 1.1398 \\ 1.0836 & 0.22472 & 0.5876 \\ 0.97086 & 1.9729 & 0.000015 \end{bmatrix} \begin{bmatrix} Y \\ U \\ V \end{bmatrix} \quad (6)$$

D. YIQ Color Model

In YIQ color model, Y represents luminance, I represents in-phase while Q represents quadrature. RGB to YIQ color model conversion is given in equation (7) which gives Y, I, Q components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.14713 & 0.22472 & 0.436 \\ 0.615 & 0.51498 & 0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (7)$$

R, G, B components can be obtained from Y, I, Q components using equation (8).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1 & 0.9563 & 0.6210 \\ 1 & -0.2721 & 0.6474 \\ 1 & 1.107 & 1.7046 \end{bmatrix} \begin{bmatrix} Y \\ I \\ Q \end{bmatrix} \quad (8)$$

E. Kekre's Biorthogonal Color Model

It includes three different color models: YCrgCrb (Kekre's Biorthogonal Red Color Model), YCgrCgb (Kekre's Biorthogonal Green Color Model) and YCbrCbg (Kekre's Biorthogonal Blue Color Model).

RGB to Kekre's Biorthogonal Red color model (YCrgCrb) conversion is given in equation (9) which gives Y, Crg, Crb components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ Crg \\ Crb \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & 1 & 0 \\ 1 & 0 & 1 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (9)$$

R, G, B components can be obtained from Y, Crg, Crb components using equation (10).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 1 & 1 \\ 1 & -2 & 1 \\ 1 & 1 & -2 \end{bmatrix} \begin{bmatrix} Y \\ Crg \\ Crb \end{bmatrix} \quad (10)$$

RGB to Kekre's Biorthogonal Green color model (YCgrCgb) conversion is given in equation (11) which gives Y, Cgr, Cgb components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ Cgr \\ Cgb \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -1 & 0 \\ 0 & 1 & -1 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (11)$$

R, G, B components can be obtained from Y, Cgr, Cgb components using equation (12).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 2 & 1 \\ 1 & -1 & 1 \\ 1 & -1 & -2 \end{bmatrix} \begin{bmatrix} Y \\ Cgr \\ Cgb \end{bmatrix} \quad (12)$$

RGB to Kekre's Biorthogonal Blue color model (YCbrCbg) conversion is given in equation (13) which gives Y, Cbr, Cbg components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ Cbr \\ Cbg \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\ 0 & 1 & -1 \\ 1 & -1 & 0 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (13)$$

R, G, B components can be obtained from Y, Cbr, Cbg components using equation (14).

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = 1/3 \begin{bmatrix} 1 & 1 & 2 \\ 1 & 1 & -1 \\ 1 & -2 & 1 \end{bmatrix} \begin{bmatrix} Y \\ Cbr \\ Cbg \end{bmatrix} \quad (14)$$

III. VECTOR QUANTIZATION (VQ)

VQ is used in various applications, such as colorization of gray images, face detection, data compression, pattern recognition, data compression, image segmentation, Content Based Image Retrieval etc. VQ function is used in image colorization to map n-dimensional vector space to a finite set CB = {C1, C2, C3,.., CK}. The set CB is called as codebook consisting of K number of codevectors and each code vector Ci = {ci1, ci2, ci3,…, cin} is of dimension n. A good color codebook design leads to better colorization. Codebook can be designed in spatial domain by clustering algorithms [7].

A. Linde-Buzo-Gray (LBG) Algorithm

LBG is a standard vector quantization algorithm for generating codebook [8]. In this, centroid of image is computed as a first codevector for the training set. Fig. 1 shows the generation of two vectors v1 & v2 as a result of addition of constant error to the code vector. Using vectors v1 and v2, Euclidean distances of all the training vectors are computed. Based on the nearest of v1 or v2 two clusters are formed. This procedure is repeated for every cluster. The disadvantage of this algorithm is that the cluster elongation is +135° to horizontal axis in two dimensional cases. This results in inefficient clustering. In encoding phase image is divided into non overlapping blocks.

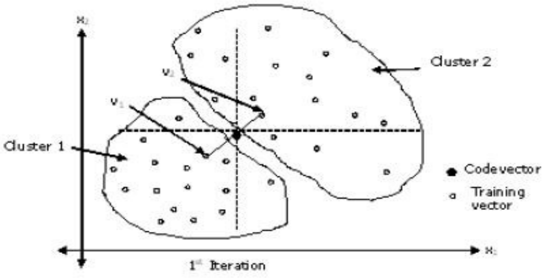

Fig. 1 LBG for 2-Dimensional space

B. Kekre's Proportionate Error (KPE) Algorithm

In this algorithm, two vectors v1 and v2 are generated by adding proportionate error to the centroid. Magnitude of elements of the centroid decides the error ratio. Hereafter the procedure is same as that of LBG. Addition of proportionate error removes the drawback of LBG as neither v1 nor v2 go outside the training vector space. If M is the total count of training vectors in every iteration to generate clusters, then for both LBG and KPE, 2*M number of Euclidean distance computations and 2*M number of comparisons are required [9].

IV. PROPOSED METHOD

For the colorization of grayscale image, reference source color images are required. The very first step is to transfer RGB source color image into respective color model image. Then the resulting color components are considered for color palette generation.

Let UVW be one of the color models specified in section 2. The component U is weighted average of R, G and B values, while V and W indicate the dominance of either of the color components from G and B. The colorization process mainly has three steps as given below:

1) Codebook generation using source image: The color source image is converted from RGB to UVW color model. The source image is then divided into the pixel windows of size 2x2. Every window is represented as array of GR, U, V and W values where GR is the gray value of each pixel taken in 2x2 window. This training set is called color palette. VQ codebook generation algorithm is applied to the color palette to generate codebook of required size. The generated codebook is used to color the target grayscale image.

2) Search the respective matches for grayscale pixels in the color codebook: The target grayscale image is also divided into the pixel windows of size 2x2. Every window is represented as array of grayscale intensity values of inclusive pixels. For every row of grayscale intensity values the best match is searched from the color palette using Mean Square Error (MSE). MSE is computed from grayscale target pixel window in color palette for all records. Wherever lowest MSE value is found that record is considered as the best match and is used to color the target 2x2 gray windows.

3) Transfer colors from the best found codebook match to grayscale pixel: U, V, W component values from the best match codebook are copied to the respective target image array. U, V and W intensity values of color codebook are then transferred back to U, V and W planes of target image at respective pixel window positions. Using UVW to RGB conversion matrix the Red, Green and Blue planes of colored target image are obtained and then the target color image is constructed using Red, Green and Blue planes.

V. RESULTS

The performance of color transfer algorithms cannot be compared using any objective criteria as the quality of color transfer algorithm is subjective to the grayscale image to be converted to color image. In this method, the grayscale image version of already colored images is recolored using the proposed algorithm. The Mean Square Error (MSE) between the original color and recolored images is considered as performance measure of the color transfer algorithm. In proposed method, thirty test images as shown in Fig. 2 are recolored using 8 color models and 5 codebook sizes (32, 64, 128, 256, 512).

Table 1 shows the average MSE between the original color and re-colored images using existing LBG based coloring algorithm for different color models and codebook sizes [10]. Table 2 shows the average MSE differences between the original color and re-colored images using KPE based coloring algorithm for different color models and codebook sizes. From Table 1 and Table 2, it is observed that KPE based colorization works better than LBG based colorization in YUV, YCbCr and Kekre's LUV color models.

The graphs plotted between average values of MSE and various color models for different codebook sizes using KPE algorithm are given in Fig. 3 and Fig. 4. From the graph it is observed that YCbCr color model gives better result than other color models when codebook of size 512 is used.

Fig. 5 shows the comparison between KPE and LBG based colorization for various color models and codebook sizes. It is observed that the performance of KPE is better in YUV, YCbCr and Kekre's LUV color models as compared to LBG algorithm.

Fig. 6 shows the Original color Onion Slice image and recolored Onion Slice images using KPE for various color models and codebook sizes. YCbCr color model gives better colorization with higher codebook sizes, YCbCr-512 being the most proximate to original color image.

Fig. 2 Images used for qualitative analysis of color transfer to grayscale images

Table 1. Average MSE Differences of Original Color Image And
Re-Colored Images for Various Color Models (CM) And Codebook (CB) Sizes Using LBG

CB **CM**	**32**	**64**	**128**	**256**	**512**
KB_red	542.3477	504.9072	498.1245	490.1095	450.1883
KB_green	435.9561	470.4851	432.9810	426.9645	393.2851
KB_blue	603.6014	643.0342	603.1575	603.1395	579.6903
YIQ	3723.609	3724.186	3715.295	3705.072	3691.753
YUV	423.4982	404.8641	369.8877	353.1164	331.2695
K'LUV	691.0091	687.4744	670.4924	665.6909	643.7042
YCbCr	**287.4696**	**299.351**	**246.2984**	**236.3423**	**214.2033**
RGB	1038.338	981.1666	978.1088	939.8247	923.4526

Table 2. Average MSE Differences of Original Color Image And
Re-Colored Images for Various Color Models (CM) And Codebook (CB) Sizes Using KPE

CB **CM**	**32**	**64**	**128**	**256**	**512**
KB_red	598.276	660.064	597.3	568.813	578.615
KB_green	655.936	577.84	617.604	601.557	576.756
KB_blue	815.016	753.84	789.433	775.109	754.339
YIQ	3764.55	3768.68	3759.72	3729.05	3709.63
YUV	355.436	341.524	317.175	295.886	274.306
K'LUV	583.325	539.181	610.803	593.026	577.714
YCbCr	241.016	214.331	195.906	174.59	160.368
RGB	1029.8	1021.69	1011.05	971.188	1012.91

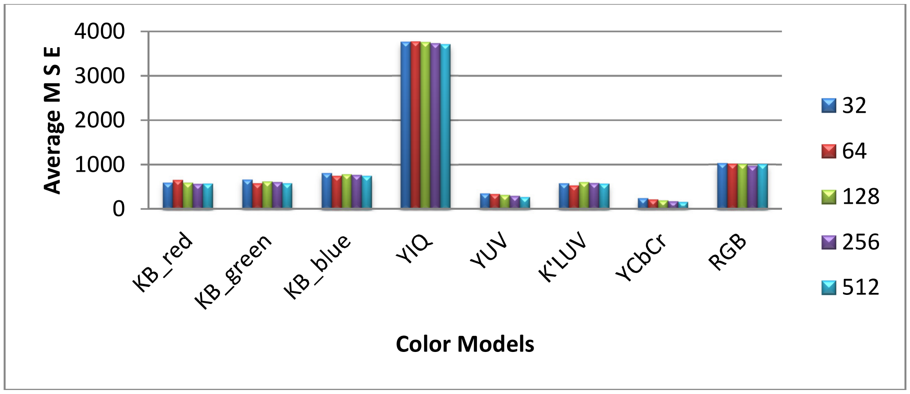

Fig. 3 Average MSE differences of original color image and recolored images for various color models and codebook sizes using KPE (Observation : In all color spaces/ models higher codebook sizes have given better colorization as indicated by lower MSE values)

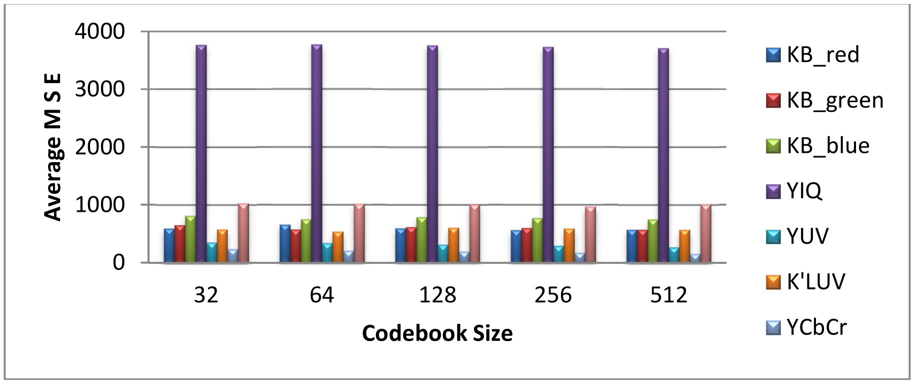

Fig. 4 Average MSE differences of original color image and recolored images for various color models and codebook sizes using KPE Algorithm (Observation: In all codebook sizes, YCbCr color model has given better colorization as indicated by lower MSE values)

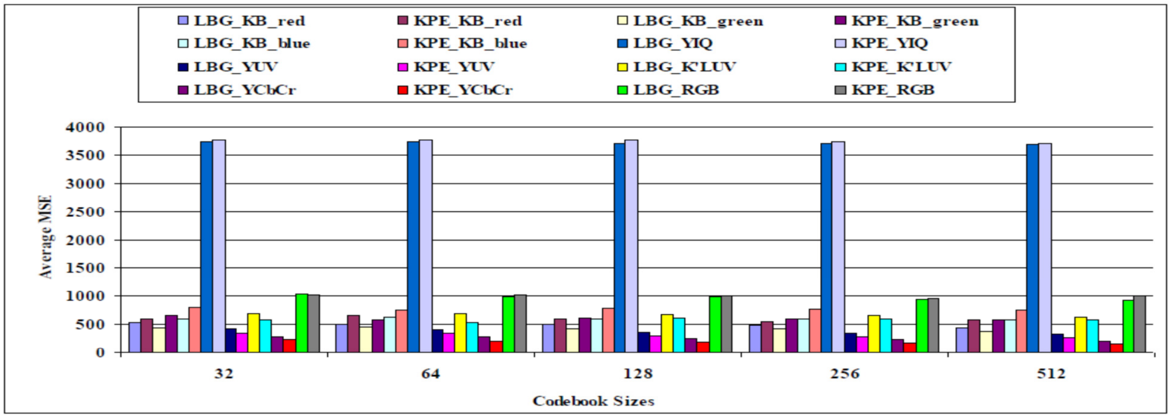

Fig. 5 Comparison of KPE based colorization with LBG based colorization


Original Image Gray Image

Recolored Images Using Original Color Image


RGB-32 RGB-64 RGB-128 RGB-256 RGB-512

YCrgCrb-32 YCrgCrb-64 YCrgCrb-128 YCrgCrb-256 YCrgCrb-512

YCgrCgb-32 YCgrCgb-64 YCgrCgb-128 YCgrCgb-256 YCgrCgb-512

YCbrCbg-32 YCbrCbg-64 YCbrCbg-128 YCbrCbg-256 YCbrCbg-512

YIQ-32 YIQ-64 YIQ-128 YIQ-256 YIQ-512

YUV-32 YUV-64 YUV-128 YUV-256 YUV-512

K'LUV-32 K'LUV-64 K'LUV-128 K'LUV-256 K'LUV-512

YCbCr-32 YCbCr-64 YCbCr-128 YCbCr-256 YCbCr-512

Fig. 6 Colorization of Onion Slice image using KPE with various color models and codebook sizes
(Observation: YCbCr color model gives better colorization with higher codebook sizes,
YCbCr-512 being the most proximate to original color image)

VI. CONCLUSION

Color transfer to grayscale images is gaining momentum because of its interesting range of applications. In this paper, VQ codebook based colorization approach is presented using Kekre's Proportionate Error algorithm. This method helps to overcome the assumption of using bigger source color image than the target grayscale image and gives better performance than LBG colorization algorithm. Eight color models with five codebook sizes are used to get 40 variations of KPE based Colorization algorithm. The experimental results have shown that KPE based color transfer method outperforms LBG based colorization in YUV, YCbCr and Kekre's LUV color models. It is observed that the use of higher codebook sizes and YCbCr color model enhances the colorization. Even at the lowest codebook size KPE gives better result when YCbCr color model is used.

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