Colorization of Grayscale Images using LBG VQ Codebook for different Color Spaces

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ABSTRACT

The paper presents an innovative technique for colorization of grayscale images. Here the colors from some source color image are picked up and sprayed into the to be colored grayscale image. The color palette used in colorization technique discussed here is generated using the Linde Buzo and Gray (LBG) codebook. The technique is tested using various VQ codebook sizes like 32, 64, 128, 256 and 512. Also various color spaces like RGB, Kekre's LUV, YCbCr, YUV, YIQ, and Kekre's Biorthogonal color spaces are considered for colorization of grayscale images. In all 5 VQ codebook sizes and 8 color spaces give total 40 versions of proposed colorization method. All proposed versions are implemented and tested for colorization of grayscale images from different classes.

Keywords - **About five key words in alphabetical order, separated by comma**

I. INTRODUCTION

Colorization is a computer assisted process of adding color to a monochrome image or movie. The task of color traits transfer to the gray scale image is called as colorization of gray scale image. It is difficult because it involves three dimensional RGB pixel values to an image which varies along one dimension (luminance or intensity)[1,24,25]. Since different colors may have the same luminance value but vary in hue or saturation, the problem of colorizing grayscale images has no inherently unique solution [2]. Due to these ambiguities, human interaction usually plays a large role in the colorization process. Even in the case of pseudocoloring, [3, 4] where the mapping of luminance values to color values is automatic, the choice of the color-map is commonly determined by human decision. Pratt [4] describes this method as an image enhancement technique because it can be used to enhance the detect ability of detail within the image [1].

Grayscale image colorization can find its applications in black and white photo editing [1,5], classic movies colorization [3,6,7] and scientific illustrations [1,2]. Colorization can increase dramatically the visual appeal of grayscale images and perceptually enhance scientific illustrations. In medicine [1,4] , image modalities which only acquire grayscale images such Magnetic Resonance Imaging (MRI), X-ray and Computerized Tomography (CT) images can be enhanced with color for presentations and demonstrations. Pseudocoloring is a common technique for adding color to grayscale images such as X-ray, MRI, scanning electron microscopy (SEM) and other imaging modalities in which color information does not exist.

In this paper we present novel colorization method using LGB Vector Quantization codebook, five different codebook sizes varying from 32 to 512 are used to generate color pallet and eight different color spaces are used leading to 40 different colorization methods.

II. COLOUR SPACE USED FOR EXPERIMENTATION

This section presents various color spaces as Kekre's LUV, YCbCr, YUV, YIQ and Kekre's Biorthogonal color spaces.

2.1 Kekre's LUV Color Space [8, 9]

Here we have used Kekre's LUV color Space. Where L gives luminance and U and V gives chromaticity values of color image. Positive value of U indicates prominence of red component in color image and negative value of V indicates prominence of green component.
This needs the conversion of RGB to LUV components. The RGB to LUV conversion matrix given in equation 1 gives the L, U, V components of color image for respective R, G, B components.

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

The LUV to RGB conversion matrix given in equation 2 gives the R, G, B components of color image for respective L, U, V components.

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

2.2 YCbCr Color Space[10,21]

Here we have used YCbCr color Space. Where Y gives luminance and Cb and Cr gives chromaticity values of color image. To get YCbCr components we need the conversion of RGB to YCbCr components. The RGB to YCbCr conversion matrix given in equation 3 gives the Y, Cb, Cr components of color image for respective R, G, B components.

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

The YCbCr to RGB conversion matrix given in equation 4 gives the R, G, B components of color image for respective Y, Cb, Cr components.

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

2.3 YUV Color Space [11]

Here we have used YUV color Space. The YUV model defines a color space in terms of one luminance (brightness) and two chrominance (color) components. The YUV color model is used in the PAL, NTSC, and SECAM composite color video standards. Previous black-and-white systems used only luminance (Y) information and color information (U and V) was added so that a black-and-white receiver would still be able to display a color picture as a normal black and white pictures. YUV models human perception of color in a different way than the standard RGB model used in computer graphics hardware. The human eye has fairly little color sensitivity: the accuracy of the brightness information of the luminance channel has far more impact on the image discerned than that of the other two. The RGB to YUV conversion matrix given in equation 5 gives the Y, U, V components of color image for respective R, G, B components.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.144 \\ 0.14713 & 0.22472 & 0.436 \\ 0.615 & 0.51498 & 0.10001 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (5)$$

The YUV to RGB conversion matrix given in equation 6 gives the R, G, B components of color image for respective Y, U, V components.

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

2.4 YIQ Color Space [11]

The YIQ color space is derived from YUV color space and is optionally used by the NTSC composite color video standard. The "Y" stands for in phase and "Q" for quadrature, which is the modulation method used to transmit the color information. The inter-conversion equations for YIQ to RGB color space are given as per the equations 7 and 8.

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

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

2.5 Kekre's Biorthogonal Color Spaces:

Novel Kekre's Biorhogonal color spaces have been introduced in [11].

2.5.1 Kekre's Biorthogonal Red color space(YCrgCrb):

To get YCrgCrb components we need the conversion of RGB to YCrgCrb components. The RGB to YCrgCrb conversion matrix given in equation (9) gives the Y, Crg, Crb components of color image for respective R, G, B components.

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

The YCrgCrb to RGB conversion matrix given in equation (10) gives the R, G, B components of color image for respective Y, Crg, Crb components.

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

2.5.2 Kekre's Biorthogonal Green color space(YCgrCgb):
To get YCrgCrb components we need the conversion of RGB to YCgrCgb components. The RGB to YCgrCgb conversion matrix given in equation (11) gives the Y,Cgr,Cgb components of color image for respective R, G, B components.

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

The YCgrCgb to RGB conversion matrix given in equation (12) gives the R, G, B components of color image for respective Y,Cgr,Cgb components.

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

2.5.3 Kekre's Biorthogonal Blue color space(YCbgCbr):
To get YCbgCbr components we need the conversion of RGB to YCbgCbr components. The RGB to YCbgCbr conversion matrix given in equation (13) gives the Y,Cbg,Cbr components of color image for respective R, G, B components.

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

The YCbgCbr to RGB conversion matrix given in equation (14) gives the R, G, B components of color image for respective Y,Cbg,Cbr components.

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

3 VECTOR QUANTIZATION

Vector Quantization[12] is basically a clustering algorithm. Given image is divided into non overlapping group of pixels using appropriate window size. Then group is represented by a vector. Thus the image is converted into collection of vectors. Vectors of similar properties are grouped together to form a cluster. Each cluster will have a different textural property represented by the respective code vector representing the cluster. VQ [13, 14, 15, 16] can be defined as the mapping function that maps k-dimensional vector space to the finite set CB = { C1, C2, C3, ..., CN}. The set CB is called codebook consisting of N number of codevectors and each codevector Ci = {ci1, ci2, ci3, ……, cik} is of dimension k. The key to VQ is the good codebook. Codebook can be generated in spatial domain by clustering algorithms. In encoding phase image is divided into non overlapping blocks and each block then is converted to the training vector Xi = (xi1, xi2, ……., xik). The codebook is then searched for the nearest codevector Cmin by computing squared Euclidian distance between vector Xi or by calculating mean square error(MSE) and all the codevectors of the codebook CB. It is obvious that if the codebook size is decreased the search time will also decrease, at the cost of increased distortion and decreased accuracy. Vector quantization is used in many applications like gray image colorization, image segmentation[17], information hiding, face recognition[18], CBIR[19, 20] etc.

Linde-Buzo-Gray (LBG) Algorithm [22], [23]

LBG is standard VQ codebook generation algorithm. In this algorithm centroid is computed as the first codevector for the training set. In Fig. 1 two vectors v1 & v2 are generated by adding constant error to the codevector. Euclidean distances of all the training vectors are computed with vectors v1 & v2 and two clusters are formed based on nearest of v1 or v2. This procedure is repeated for every cluster. The drawback of this algorithm is that the cluster elongation is +135o to horizontal axis in two dimensional cases. This results in inefficient clustering.

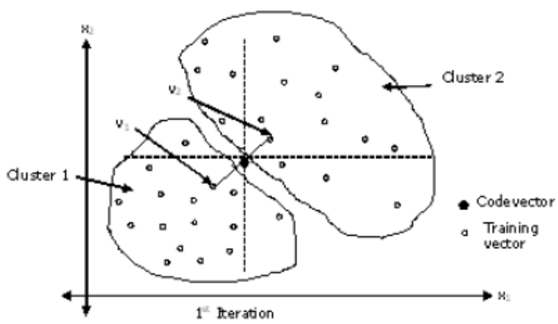

Figure 1: LBG for 2-dimentional case

4 PROPOSED COLORIZATION

For the colorization of grayscale image initially user needs to find the reference source color image. Then one can follow the steps given below to color the target grayscale image. Here the very first step is to transfer RGB components of source color image into respective color components of the color space considered. Then the resulting color components are considered for color palette generation.

Let "DEF" be the one of the color space out of the eight color discussed in the previous section considered for color traits transfer.

Here component D will be weighted average of R, G and B values, while E and F will be indicating the dominance of either of the color components from G and B. The color traits transfer algorithm mainly has three steps as given below.

a. Generate Codebook using source image

The colored source image is converted from RGB to DEF color space. The source image is then divided into the pixel windows of size 2x2. Every window is represented as array of GR, D, E and F values of inclusive pixels where GR is the gray value of the each pixel taken in 2x2 window. This training set is called color palette. After applying the VQ codebook generation algorithm to this color palette we get codebook of required size. The generated codebook is used to squirt colors in target grayscale image.

b. Search the respective matches for gray scale pixels in the color palette

The target grayscale image is also divided into the pixel windows of same 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 Squared Error (MSE). Here the MSE value is computed of grayscale target pixel window in color palette from first record to last record. Wherever the MSE value is lowest that is considered to be best match and is chosen to squirt colors in target 2x2 gray window.

c. Transfer the colors from best found palette match to grayscale pixel

The D, E, F component values from best match palette entry are copied to the target image array as respective pixels D, E, F component values. All these D, E and F intensity values are then transferred back to D, E and F planes of target image at respective pixel window positions. Using DEF to RGB transformation matrix the Red, Green and Blue planes of colored target image are obtained and thus the target image is constructed using these pixel windows as a color image with Red, Green and Blue planes.

5 RESULTS

Quality of grayscale image colorization technique is subjective to the source color image selected for coloring and also to the grayscale image to be colored. There are no objective criteria to check the performance of colorization method. At most one may take a source grayscale of source color image and try to recolor it using the colors from source color image. The mean squared error (MSE) difference between the original color and recolored images may serve as performance measure to see the quality of colorization method. So to compare the proposed colorization techniques here 30 color test images as shown in Figure 2 are recolored and depending on 8 color spaces and 5 codebook sizes (32, 64, 128, 256, 512) the average MSE differences are computed. Table-1 shows the average MSE differences between the original color and re-colored images using LBG algorithm for different color spaces and codebook sizes. Figure 3 and Figure 4 shows the graph plotted between average values of MSE and the color spaces and different codebook sizes using LBG algorithm. From the graph it is observed that YCbCr color space gives better result than other color spaces when the codebook of size 512 is used. Figure 5 shows original color of MickyMouse image and recolored chair images by proposed colorization method using LBG algorithm. The perceptibility of YCbCr color space is better in all the results shown in Figure 5.

Figure 2. Images used for colorization (total 30)

Table 1: Average MSE differences of original color image and re-colored images using LBG algo

CB \ CS	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

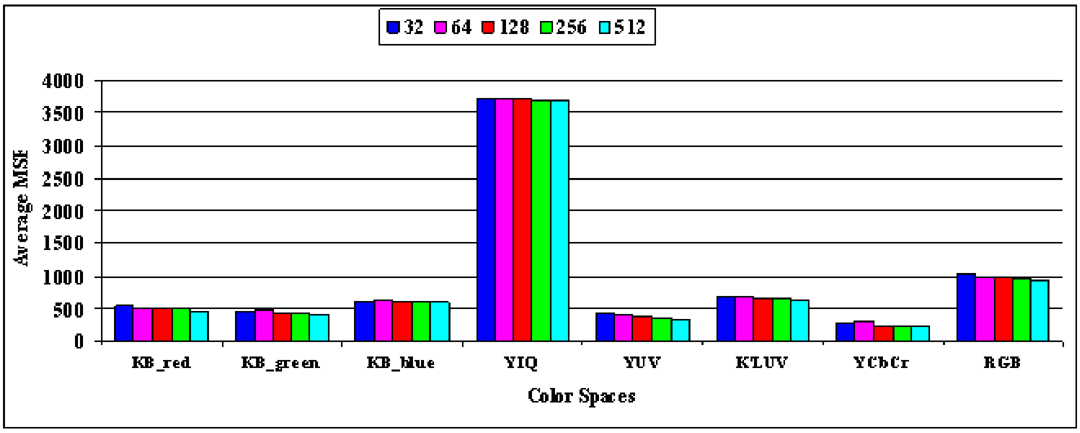

Figure 3: Average MSEs differences of images for different color spaces using LBG Algorithm

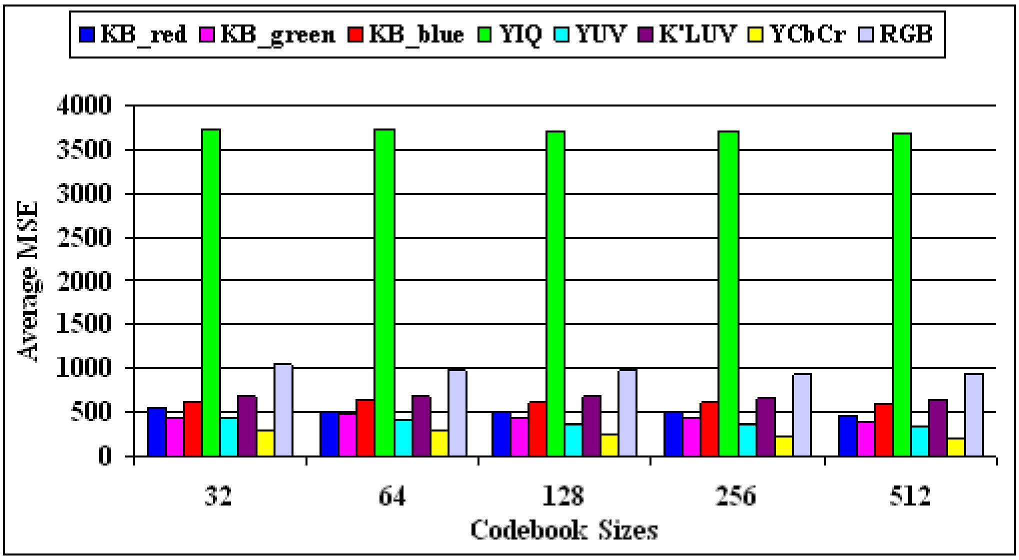

Figure 4: Average MSE differences of images for different codebook sizes using LBG Algorithm

				
a. Original Image		b. Gray Image		
Recolored Images using the original color image				
				
RGB-32	RGB-64	RGB-128	RGB-256	RGB-512

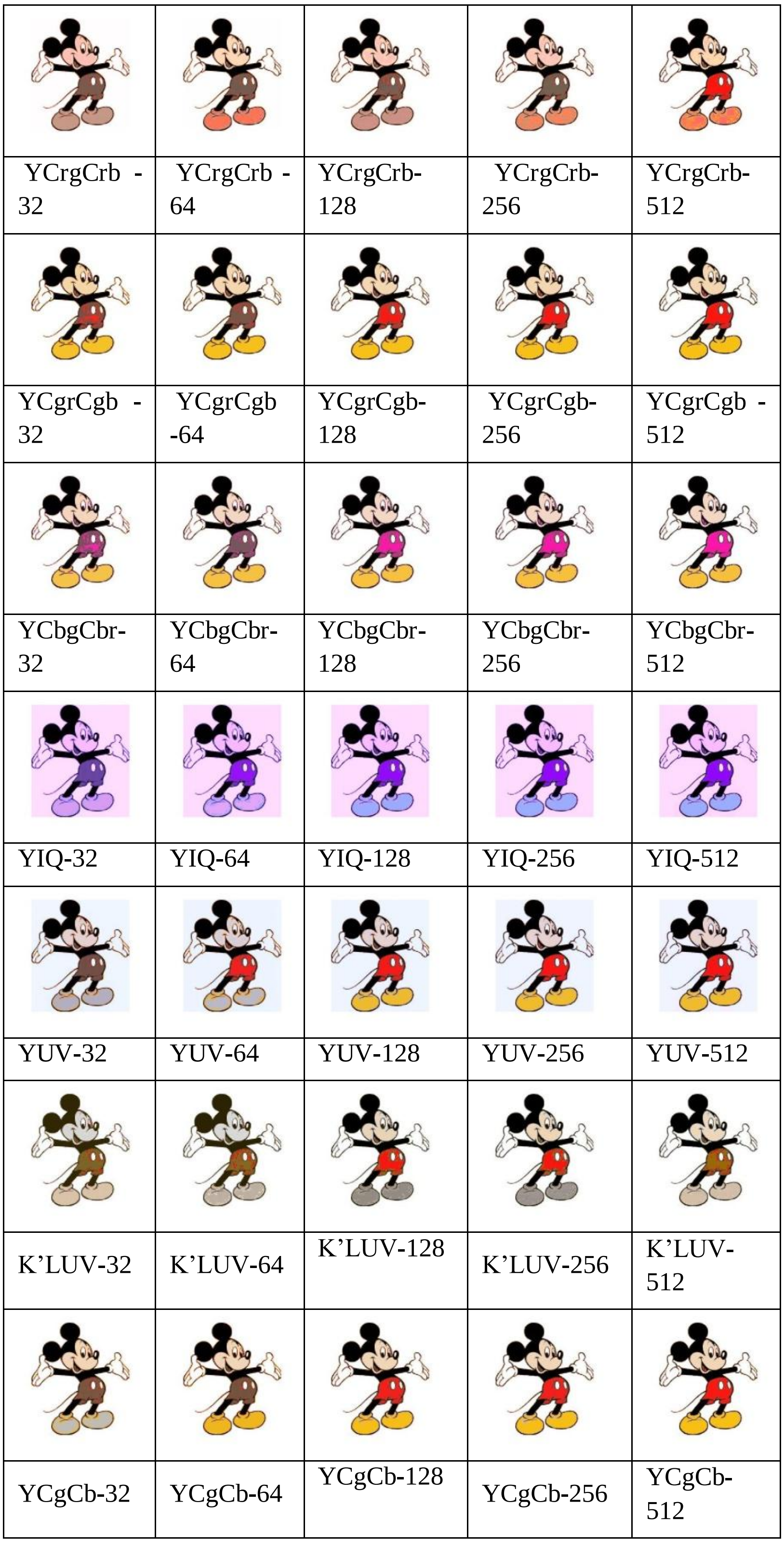

Figure 5: Original color MickeyMouse image and recolored MickeyMouse images by proposed method using LBG algorithm

6 Conclusion

Colorization improves the perceptibility of grayscale image to great extent. The method of grayscale image colorization is proposed here with help LBG VQ codebbook generation algorithm and 8 color spaces with five different codebook sizes resulting into in all 40 assorted solutions for colorization of gray scale images. The technique helps to overcome the assumption of having source color image size bigger than the target grayscale for colorization algorithms given in earlier approaches. Newly introduced Kekre's Biorhogonal Red, Green and Blue color spaces are compared in the paper. This method works good on human faces also. From the results one can conclude that, increasing codebook size (up to128/256) improves the quality of coloring when YCbCr color spaces is used. In all YCbCr color space gives better colorization even at minimum codebook size.

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