Performance Comparison of Various Pixel Window Sizes for Colorization of Grayscale Images using LBG, KPE, KFCG and KEVR in Kekre's LUV Color Space

H. B. Kekre, Tanuja Sarode, Sudeep D. Thepade, Supriya Kamoji

Abstract— Colorization is a computer aided process of adding colors to a grayscale image or videos. The paper presents the use of assorted window sizes and their impact on colorization of grayscale images using four different Vector Quantization (VQ) Codebook generation techniques used with Kekre's LUV color space. Also the paper analyses performance of Vector Quantization Algorithms Linde Buzo and Gray Algorithm (LBG) , Kekre's Proportionate Error (KPE) Algorithm, Kekre's Fast Codebook Generation Algorithm (KFCG) and Kekre's Error Vector Rotation (KEVR) Algorithm for colorization of grayscale images. Experimentation is conducted on Kekre's LUV color space for the different pixel windows of sizes 1x2, 2x1, 2x2, 2x3, 3x2, 3x3, 1x3, 3x1, 2x4, 4x2, 1x4 and 4x1 to compare results obtained across various grid sizes. The results shows that the KPE performs better for colorization with pixel window sizes 1x2 and 2x1 in Kekre's LUV color space.

Index Terms—— Colorization, Color spaces, Vector Quantization, LBG, KPE, KEVR, KFCG .

I. INTRODUCTION

There was a time when all images were solely grayscale due to limitation in technology. Color images always provide more clear information than grayscale images. Coloring of old Black and White movies and rare images of monuments, celebrities is one of the interesting applications of colorization of gray scale images. The color details in the images can be utilized for analysis and study of particular image in the applications like medical tomography, information security, image segmentation, etc.

Many techniques have been proposed to perform the task of coloring grayscale image as described in [1, 2, 3]. But all of these techniques have inherent drawback of needing certain amount of human interaction such as selecting a color from color palette, choosing a seed pixel and segmenting the regions of image for colorization. The main purpose of this paper is to reduce human interaction and achieve the effect of colorization of grayscale images. All that is needed is a source image of similar feature as of input grayscale image to be colorized [20]. Also the hindrance of needing source color image to be bigger than the target to be colored grayscale image [3,19, 20] is removed by use of Vector Quantization based on colorization process discussed here.

Colors perceived in an object are determined by nature of light reflected from the object. Due to the structure of human eye, all colors are seen as variable combinations of three basic colors Red, Green, Blue (RGB). The task of coloring a grayscale image involves assigning RGB values to an image which varies along only the luminance value [5]. Hence grayscale image colorization works on principle of mapping luminance values to color space values that can be used to reconstruct the original color. Since there exist one to many mapping between luminance values and color values, if pixel by pixel values is constructed then the probability of finding correct match for the given luminance value is extremely low. Thus to improve the probability of finding correct match (nearest match) , more than one pixels are grouped together to form pixel window (grid). Vector Quantization algorithms LBG and KFCG are applied on initial color palettes generated using different pixel window sizes 1x2, 2x1, 2x2, 2x3, 3x2, 3x3, 1x3, 3x1, 2x4, 4x2,1x4 and 4x1 to generate codebook of size 512. Depending on minimum Euclidean distance, color components of input source image are transferred to grayscale image pixel windows found and used for colorization of respective grayscale pixel windows from input grayscale image.

The effect of changing pixel window size on the vector quantization codebook as well as the colorization process using LBG, KPE, KFCG and KEVR codebook generation algorithms with various codebook sizes is analyzed and presented here with Kekre's LUV color space.

II. COLOR SPACE USED FOR EXPERIMENTATION

A. Kekre's L UV Color Space[15,19]

In the proposed technique Kekre's LUV color space is also used. Where L gives luminance and U and V give chromaticity values of color image. Positive values of U indicate prominence of red components in color image and negative value of V indicates prominence of green component.

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The RGB-to LUV and LUV-to-RGB conversion matrices are given in equations 1 and 2 respectively.

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

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

III. VECTOR QUANTIZATION CODEBOOK GENERATION ALGORITHMS

Vector Quantization (VQ) [7,8] is the lossy technique for compression of data and has been successfully used in various applications like a pattern recognition[11], speech data compression and face detection[12,13], Image segmentation[14] ,speech data compression [16],content based image retrieval CBIR[17,18] etc.

VQ can be define as a mapping function that maps k-dimensional vector space to a finite set **CB = {C_1, C_2,C_3, ……, C_N}**. The set CB is called codebook consisting of N number of codevectors and each codevector C_i= {c_{i1}, c_{i2}, c_{i3}, ……, c_{ik}} 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 **X_i = (x_{i1}, x_{i2}, ……., x_{ik})**. The codebook is then searched for the nearest codevector C_{min} by computing squared Euclidian distance as presented in equation (3) with vector **X_i** with all the codevectors of the codebook **CB.** This method is called exhaustive search (ES).

$$d(X_i, C_{min}) = \min_{1 \le j \le N}\{d(X_i,C_j)\} \qquad (3)$$
$$\text{where} \quad d(X_i,C_j) = \sum(X_{ip} - C_{jp})^2$$

It is obvious that, if the codebook size is increased to reduce the distortion the searching time will also increase.
In the following sections A and B, the existing algorithms such as LBG , KPE , KFCG and KEVR are discussed briefly.

A. Linde Buzo and Gray Algorithm (LBG) [7,8]

In this algorithm centroid is first calculated by taking average as the first code vector for the training set. In figure1 two vectors are generated by using constant error addition to the codevector. Euclidean distances of all the training vectors are computed with vectors v1 & v2 and two clusters are formed based on closest of v1 or v2. This modus operandi is replaced for every cluster. The shortcoming of this algorithm is that the cluster elongation is $+135^{O}$ to horizontal axis in two dimensional cases resulting in inefficient clustering

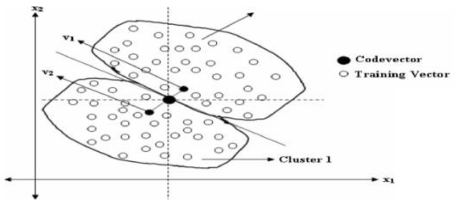


Fig1 LBG for Two Dimensional Case.

B. Kekre's Proportionate Error (KPE) Algorithm [10, 23]

Here to generate two vectors v1 & v2 proportionate error is added to the codevector. Magnitude of elements of the codevector decides the error ratio. Hereafter the procedure is same as that of LBG. While adding proportionate error a safe guard is also introduced so that neither v1 nor v2 go beyond the training vector space eliminating the disadvantage of the LBG. Fig. 2, shows the cluster elongation after adding proportionate error.

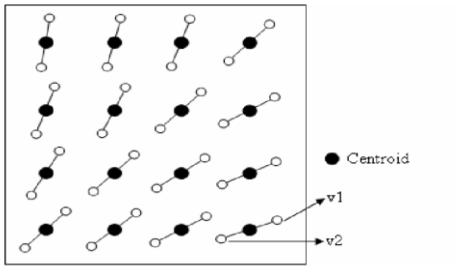
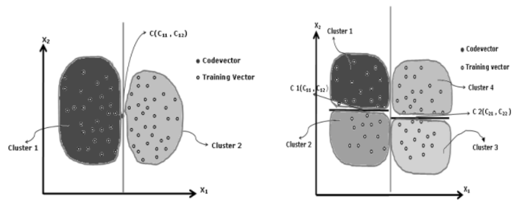


Figure 2 Orientation of line joining two vectors v1 and v2 after addition of proportionate error to the centroid.

C. Kekre's Fast Codebook Generation (KFCG) Algorithm [9, 24]

Here the Kekre's Fast Codebook Generation algorithm reduces the time of code book generation. Initially we have one cluster with the entire training vectors and the code vector C1 which is centroid. In the first iteration of the algorithm, the clusters are formed by comparing first element of training vector with first element of code vector C_1. The vector X_i is grouped into the cluster 1 if x_{i1}< c_{11} otherwise vector X_{i1} is grouped into cluster2 as shown in Figure 3a. where code vector dimension space is 2. In second iteration, the cluster 1 is split into two by comparing second element X_{i2} of vector X_i belonging to cluster 1 with that of the second element of the code vector. Cluster 2 is split into two by comparing the second element x_{i2} of vector X_i belonging to cluster 2 with that of the second element of the code vector as shown in Figure.3b.



3(a). First Iteration 3(b) Second Iteration
Fig. 3. KFCG algorithm for 2-D case.

D. Kekre's Error Vector Rotation (KEVR) Algorithm [25]

In this algorithm two vectors v1 & v2 are generated by adding error vector to the codevector. Euclidean distances of all the training vectors are computed with vectors v1 & v2 and two clusters are formed based on closest of v1 or v2. The codevectors of the two clusters are computed and then both clusters are splitted by adding and subtracting error vector rotated in k-dimensional space at different angle to both the codevector. This modus operandi is repeated for every cluster and every time to split the clusters error ei is added and subtracted from the codevector and two vectors v1 and v2 is generated. Error vector ei is the ith row of the error matrix of dimension k. The error vectors matrix E is given in Equation 4.

$$E = \begin{bmatrix} e1 \\ e2 \\ e3 \\ e4 \\ e5 \\ . \\ . \\ . \\ e_l \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1\cdots\cdots\cdots 1 & 1 & 1 \\ 1 & 1 & 1 & 1\cdots\cdots\cdots 1 & 1 & -1 \\ 1 & 1 & 1 & 1\cdots\cdots\cdots 1 & -1 & 1 \\ 1 & 1 & 1 & 1\cdots\cdots\cdots 1 & -1 & -1 \\ 1 & 1 & 1 & 1\cdots\cdots\cdots -1 & 1 & 1 \\ . \\ . \\ . \\ \cdots\cdots\cdots\cdots\cdots\cdots \end{bmatrix} \quad (4)$$

Note that these error vector sequence have been obtained by taking binary representation of numbers starting from 0 to k-1 and replacing 0's by 1's and 1's by -1's.

IV. PROPOSED COLORING TECHNIQUE

Since the coloring problem always requires human interaction. So reference image of same class and of same feature is taken as of input source image. The color transfer algorithm is discussed for Kekre's LUV color space for different m x n pixel grid sizes. The main steps of algorithm for a color transfer are:

1) Convert RGB components of source color image into respective Kekre's LUV color components.

2) Divide the image in to non overlapping blocks of m x n pixels. Hence m x n x3 dimensional training vector set corresponding to LUV components of each pixel is obtained. On this set all the four VQ algorithms are applied and color palette is generated. (i.e. codebook of size 512.)

3) The input gray image is divided in to non overlapping blocks of mxn pixels. Each of these gray blocks is searched for nearest codevector of color palette using Mean Squared Error for color component values of the respective gray pixel in the block.

4) Once the nearest match is obtained gray block is replaced with Kekre's LUV code vector.

5) The final colored image in Kekre's LUV domain is then converted into RGB plane and MSE of original color image and recolored image are calculated.

V. RESULTS

The proposed algorithms are implemented using MATLAB 7.0 on Pentium IV, 1.66GHz, 1GB RAM. The quality of output of colorization algorithm is subjective to the type of source color image used to generate color palette and the target (to be colored) gray scale image. To test the performance of these algorithms color image is converted to grayscale image and this gray image is recolored back. Finally MSE of original color image and colored image is compared. Five color images belonging to different classes of size 128x128x3 are used.

Figure 3 to Figure 7 Shows the results of LBG, KPE, KFCG and KEVR algorithms on Book image considering same image as reference image for top five grids.

Figure 8 to Figure 9 Shows the results of LBG, KPE, KFCG and KEVR algorithms on scenery and dog images considering different image as reference image for 1x2 grid size.

(a) Original image | (b) Gray image | (c) 1x2 mse | (d) 2x1 mse | (e) 1x3 mse | (f) 3x1 mse

Fig 4 Colorization of Book grayscale image using LBG

(a) Original image | (b) Gray image | (c) 1x2 Mse | (d) 2x1 mse | (e) 1x3 mse | (f) 3x1 mse

Fig 5 Colorization of Book grayscale image using KPE

(a) Original image | (b) Gray image | (c) 1x2 mse | (d) 2x1 mse | (e) 1x3 mse | (f) 3x1 Mse

Fig 6 Colorization of Book grayscale image using KFCG

(a) Original image | (b) Gray image | (c) 1x2 mse | (d) 2x1 mse | (e) 1x3 mse | (f) 3x1 mse

Fig 7 Colorization of Book grayscale image using KEVR

Gray Image | Reference Image | (a) 1x2 LBG | (b) 1x2 KPE | (c) 1x2 KFCG | (d) 1x2 KEVR

Fig 8 Colorization of Scenery grayscale image using different source image

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Gray Image | Reference Image | (a) 1x2 LBG | (b) 1x2 KPE | (c) 1x2 KFCG | (d) 1x2 KEVR

Fig 9 Colorization of Dog grayscale image using different source image

Algorithm	Grid Sizes											
	1x2	2x1	2x2	2x3	3x2	3x3	2x4	4x2	1x3	3x1	1x4	4x1
LBG	561.5	55 9.7	591	772.26	745.9	730.6	734.3	726.21	613	594	731	673
KPE	481.9	506.6	587.8	660.5	636.3	636.7	591.8	596.76	553.4	521.8	532.1	538.8
KFCG	526.4	571.6	536	695.4	684.4	666.4	647.1	645.5	586.1	527.1	581.2	580.2
KEVR	567.46	518.24	557.88	667.46	663.07	644.8	655	642	595.11	603.21	593.8	587.69

Table I. Average MSE between original color and colorized image for proposed colorization methods.

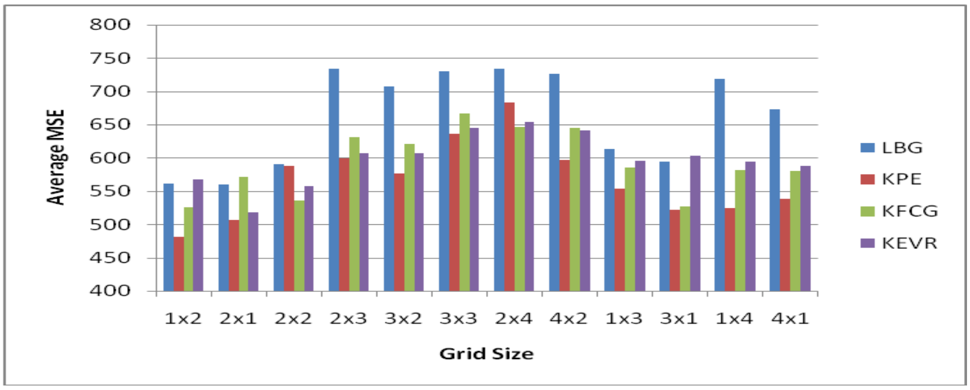

Fig 10 Average MSE across various Grid sizes

The considered five sample images are used for performance comparison of proposed colorization techniques using LBG KPE, KFCG and KEVR for Kekre's LUV color spaces on various pixel window sizes. From the data given in Table I, it is seen that the performance gradually decreases as the pixel window size increases. Further MSE for unidirectional pixel window is less indicating better performance compared to bidirectional Pixel window sizes 1x2 and 2x1 are showing better results as compared to larger pixel window sizes. Figure 10 shows the comparison of average mean squared error obtained across all images on Kekre's LUV color space. It can be seen from the chart , KPE performs well with respect to other VQ algorithms. Also performance deteriorates as pixel window size increases from unidirectional (1x2, 2x1, 1x3, 3x1, 1x4 and 4x1) to become bidirectinal(2x3, 3x2, 2x4, 4x2 and 3x3).

IV. CONCLUSION

The paper presents the performance analysis of pixel windows of various sizes using vector quantization codebook generation algorithms. These codebooks generated using four different VQ algorithms such as LBG, KPE, KFCG and KEVR are used as color palettes for colorization of grayscale images with help of Kekre's LUV color space. The experimentation results show that the colorization using single dimensional pixel window give better results than those of two directional pixel windows for all the codebook generation methods. The KPE codebook generation method surpasses all other three VQ algorithms by giving better colorization. Thus in conclusion it can be stated that KPE algorithm with grid size 1x2 shows best performance in Kekre's LUV color space.

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