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Gray Image Colorization using Thepade's Transform Error Vector Rotation With Cosine, Walsh, Haar Transforms and various Similarity Measures

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***Abstract*—** The paper presents various gray image colorization methods based on vector quantization for performing automatic colorization. To colorize gray target image by extracting color pixels from source color image, Thepade's Transform Error Vector Rotation vector quantization methods such as Thepade's Cosine Error Vector Rotation (TCEVR), Thepade's Walsh Error Vector Rotation (TWEVR) and Thepade's Haar Error Vector Rotation (THEVR) are used along with varied similarity measures. The quality of colorization of gray image is subjective to the source color image and target gray image (to be colored). Here the image test bed of 25 images is used to recolor the gray equivalent of the original color images for qualitative performance comparison of proposed colorization methods with help of PSNR between original color and recolored images. Colorization is performed using diverse similarity measures which belong to different families. These nine similarity measures are used for mapping gray image pixels with relatively corresponding multichorme image pixels. When these similarity measures are assessed for their comparison for colorizing the target gray image, it is observed that Chebychev outruns all other similarity measures and the worst performance is consistently given by Jaccard and Hamming distances. Among all the considered colorization methods Thepade's Haar Error Vector Rotation is much suitable algorithm for performing gray image colorization.

Keywords-*Vector Quantization (VQ);Codebook;TCEVR;THEVR; TWEVR; Similarity Measures, Colorization;*

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I. INTRODUCTION

The colorization is performed by adding colors to the gray target image which are to be extracted from a multichrome colored source image. Colorization helps in understand the image visualization perfectly. It improves the detailing of image by adding extra value for visual perception [1]. A multichrome colored image comprises of three planes (R, G and B) whose pixel values decide colors and contrast of it. The gray image is in one plane only. It is quite simple to convert from multichrome source image to a gray target image [5] [6]. For converting a colored image to gray image the mean of the pixels values from three planes is to be drawn. However it is difficult to get colors for the pixels in gray image from only gray image or from any reference color image. There are many fields where colorization is applied such as coloring classic movies, satellite image coloring, and many more. For performing colorization various techniques are followed such as manual colorization, semi- automatic colorization and automatic colorization [2].

In manual colorization, the gray target image is colored manually by adding colors in various sectors of image individually. This technique needs human intervention for deciding colors of parts and to add them separately [7] [8]. In semi-automatic colorization only the color mapping is to be done from colored image manually, remaining work is done automatically. This technique surpasses manual technique but still requires human intervention. In automatic colorization only the source and target images are need to be selected and all the processing is performed by the machine without any additional human interference [3]. The technique which used in the paper for coloring gray image is automatic colorization that is performed using vector quantization technique [4].

II. VECTOR QUANTIZATION CODEBOOK GENERATION METHODS

The paper compares Thepade's Cosine Error Vector Rotation (TCEVR), Thepade's Haar Error Vector Rotation (THEVR), and Thepade's Walsh Error Vector Rotation (TWEVR) for colorization using vector quantization. All vector quantization methods uses matrix that assists in generating various clusters which are then used for obtaining palettes of results.

The vector quantization methods are performed on various codebook sizes as 64, 128 and 256. Along with the vector quantization methods assorted similarity measures are used to map the color values with gray target image. The mapping is done on basis of PSNR values obtained between the pairs of recolored and original color image. Codebook size takes specific time as per system configuration and also on the size on image used. The color palette size is directly proportional with the time and result accuracy. Higher color palette (codebook) sizes have given better coloring.

A. Vector Quantization

The Vector Quantization (VQ) is one of the dominating strategies that are brought for performing the operation over gray target image. Vector Quantization (VQ) performs encoding and decoding of code vectors for obtaining clusters that are used for generation of codebook and color palette. The various vector quantization methods are here used for finding

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the closest match of the code vectors with that of gray target pixel values for bringing colors to the image [9].

B. Thepade's Cosine Error Vector Rotation (TCEVR)

The TCEVR algorithm uses Discrete Cosine Transform matrix (DCT) which divides an image into various set of importance. The transformation on images is from spatial domain to frequency domain using DCT. The N x N transform matrix C={c (k, n)} which is DCT is given as [12]:

$$c(k,n) = \begin{cases} \frac{1}{\sqrt{N}}, & k = 0, 0 \le n \le N-1 \\ \sqrt{\frac{2}{N}} \cos\frac{\pi(2n+1)k}{2N}, & 1 \le k \le N-1, 0 \le n \le N-1 \end{cases} \quad (1)$$

.Error vector matrix of size 8 X 8 is shown in Figure 1 which is obtained from the cosine transform matrix.

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & -1 & 1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & 1 & -1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \end{bmatrix}$$

Figure 1. Cosine Error Matrix 8 x 8 Size

C. Thepade's Walsh Error Vector Rotation (TWEVR)

The TWEVR uses Walsh transform which have entries with +1 and -1 only. In Walsh matrix, every row is equivalent to Walsh Basis function [13]. The property of Walsh vector quantization method matrix is that the dot product of any two distinct rows or any two distinct columns is zero. The sequence ordering of the rows of the Walsh matrix can be derived from the ordering of the Hadamard matrix by first applying the bit reversal permutation and then the Gray code permutation [10]. The Walsh matrix (and Walsh functions) are used in computing the Walsh vector quantization method and have applications in the efficient implementation of certain signal processing operations [11]. The TWEVR error vector matrix for 4 x 4 is given in Figure 2, in generalized form it is given for $2 \le k \in N$:

$$H(2^k) = \begin{bmatrix} H(2^{k-1}) & H(2^{k-1}) \\ H(2^{k-1}) & -H(2^{k-1}) \end{bmatrix} \quad (2)$$

$$\begin{bmatrix} 1 & 1 & 1 & 1 \\ 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 \\ 1 & -1 & -1 & 1 \end{bmatrix}$$

Figure 2. Walsh Error Matrix 4 x 4 Size

D. Thepade's Haar Error Vector Rotation (THEVR)

The Haar transform matrix is used for generation of error vector matrix which is given as Figure 3.

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & -1 & -1 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix}$$

Figure 3. Haar Error Matrix 8 x 8 Size

III. SIMILARITY MEASURES

Here 9 assorted similarity measures are used here to search the color values from color palette for the target gray pixel groups. These similarity measures belong to different families.

1. *Euclidean distance:*
   It is nothing but an ordinary distance between two end points which can be simply measured by the scale. Euclidean distance formula can be given by Pythagorean Theorem.

2. *Chebychev Distance:*
   It can be defined as a metric defined on vector space where the distance between two vectors is the greatest of their differences along any coordinate dimension.

3. *Manhattan Distance:*
   It can be defined as the simple sum of the horizontal and vertical component and the diagonal distance is measured with the help of Pythagorean Theorem.

4. *Spearman Distance:*
   It can be defined as the square of the Euclidean distance between two rank vectors.

5. *Hamming distance:*
   It can be defined as it only measures the minimum numbers of substitution required to change one string to another.

6. *Jaccard Distance:*
   It measures the dissimilarities between the two sample sets, which is complementary to jaccard coefficient and is obtained by subtracting the jaccard coefficient by 1.

7. *Canberra Distance:*
   It can be defined as the measure of the distance between pair of point in a vector space. Canberra Distance is used for comparing ranking list and intrusion detection. Here P_i and Q_i are the set of two samples.
   The formulae of similarity measures are given in table 1 where P_i and Q_i to be two vector of size n and d be the value of dissimilarity between the value of P and Q.

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TABLE I. SIMILARITY MEASURES

Similarity Measures	Formulas
Manhattan Distance	$d = \sum_{i=1}^{n} \lvert Pi - Qi \rvert$
Euclidian Distance	$d = \sum_{i=1}^{n} (Pi - Qi)^2$
Chebychev Distance	$d = \max \lvert Pi - Qi \rvert$
Canberra Distance	$d = \sum_{i=1}^{n} \frac{\lvert Pi - Qi \rvert}{Pi + Qi}$
Spearman Distance	$d_s = 1 - r_s$
Square Chord Distance	$d = \sum_{i=0}^{n} (\sqrt{Pi} - \sqrt{Qi})$
Wave Hedges Distance	$d = \sum_{i=1}^{n} 1 - \frac{\min(Pi - Qi)}{\max(Pi - Qi)}$
Jaccard Distance	$1 - \frac{\sum_{i=1}^{n} (Pi \cap Qi)}{\sum_{i=1}^{n} (Pi \cup Qi)}$
Hamming Distance	$\sum_{i=1}^{n} [Pi \neq Qi]$

IV. EXPRIEMENT ENVIRONMENT

For performing comparisons variation of purposed colorization methods experimentation is carried on a set of 30 images. The experimentation is done with codebook sizes 64,128 and 256 used along with 9 similarity measures from different families .The test bed images are having various colors and different backgrounds. In all 3 algorithms of colorization the RGB values are extracted from source color image and mapped with the target gray image.

Figure 4. Test bed in purposed colorization techniques for qualitative comparison.

V. RESULT AND DISCUSSION

The quality of colorization method is subjective to the source color image and target gray scale image. There exist no objective criteria adjudge the qualitative performance. Here the gray scale equivalent of a source color test bed image is

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colorized using the source image itself and PSNR between original color image and colorized image is computed to decide quality of colorization. Higher the PSNR value indicates better colorization. Three colorization methods which are TCEVR, TWEVR, and THEVR, proposed methods are experimented to color the given target gray image. The below figure 5 shows the performance comparison of colorization methods with reference to various similarity measures in codebook size 64. In THEVR method the best performance is given by Wave Hedges, Canberra trailed by Spearman and the worse results are given by Jaccard and Euclidean. For TCEVR algorithm the superlative results are given by Manhattan, Chebychev and subsequently by Spearman. In TWEVR vector quantization method paramount results are given by Manhattan, Spearman and Canberra similarity measures. Substandard results are given by Jaccard and Hamming similarity measures. On an average or overall the preeminent results are given by Manhattan and the wickedest results are consistently given by Jaccard similarity measure.

In the given figure 6 shows the performance comparison of colorization methods with reference to various similarity measures in codebook size 128. It can be observed that the superlative performance from all similarity measure in THEVR method is given by Spearman followed by Chebychev similarity measure and when assessed for worse outcomes then Wave Hedge and Jaccard similarity measure gives least PSNR value thus the quality of colorization is low. When TCEVR and TWEVR is considered the prime performance is given by Chebychev and Manhattan similarity measures and substandard results are consistently given by Jaccard, Hamming headed by Square Chord.

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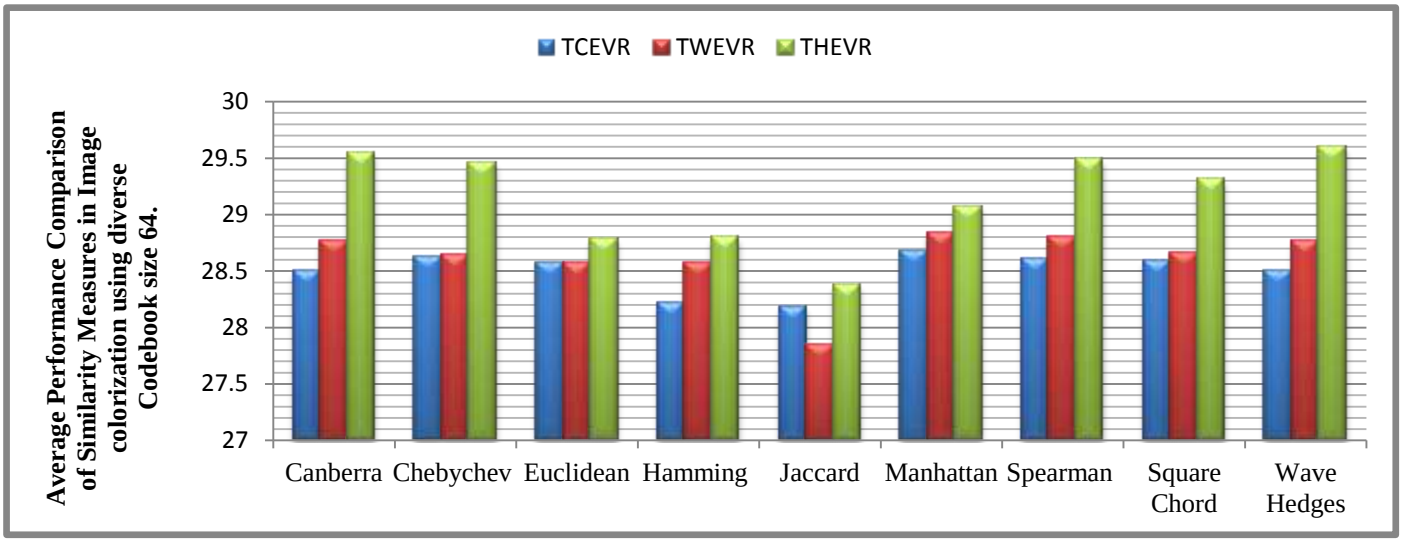

Figure 5. Average Performance Comparison of Similarity Measures in Image colorization using TCEVR,TWEVR and THEVR with Codebook size 64.

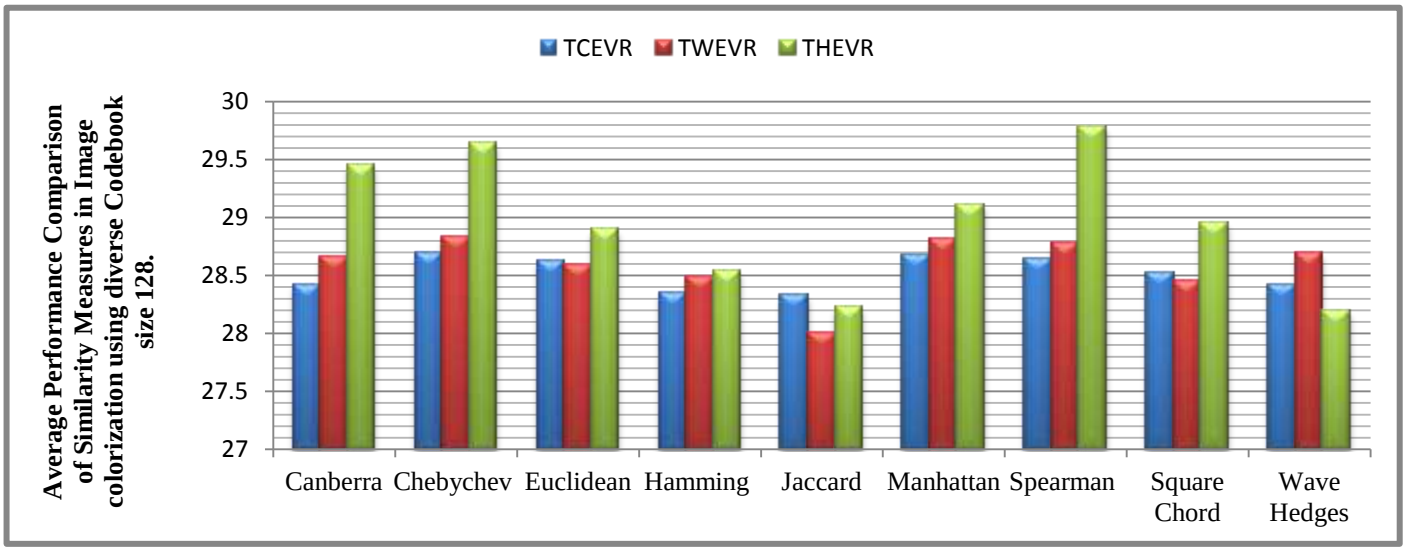

Figure 6. Average Performance Comparison of Similarity Measures in Image colorization using TCEVR,TWEVR and THEVR with Codebook size 128.

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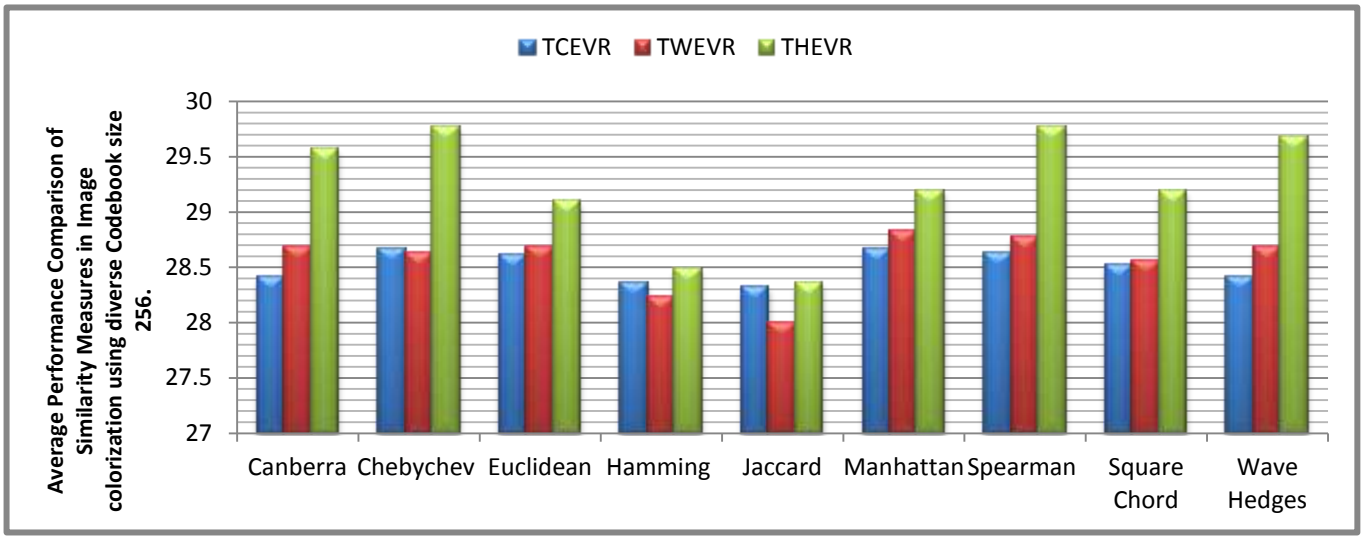

Figure 7. Average Performance Comparison of Similarity Measures in Image colorization using TCEVR,TWEVR and THEVR with Codebook size 256.

The Figure 7 displays the performance comparison of all similarity measure in codebook size 256 for all colorization algorithms. When it comes to THEVR the Chebychev preceded by Spearman gives prime results and the worst results compared to all similarity measures are given by Hamming followed by Jaccard. It can be observed that in TCEVR method Chebychev similarity measure gives the superlative results whereas the worst results are given by Jaccard. In TWEVR method the Manhattan preceded by Canberra and Euclidean similarity measure gives higher results from all other similarity measures and the worst performance is given by again Hamming preceded by Jaccard. One important thing to be observed from this graph is that the similarity measure Jaccard and Hamming are consistently giving worse performance in codebook size of 256. Hence found not suitable for colorization purpose. Overall it can be observed that in all algorithms Chebychev followed by Manhattan gives the superlative performance in codebook size 256

Figure 8 shows the results of colorization of the target gray image by the respective source image. The target gray image is colorized by mining the color values from the source image in codebook size 256. As it has been proven that as the codebook size increase the quality of image colorized also increase gradually. Thus this figure displays the performance of the vector quantization methods used for colorization in codebook size of 256 as the codebook size is superior to the 64 and 128, so the results obtained from this codebook size will eventually surpass the results obtained by the codebook size 64 and 128. From figure it can be perceived that the THEVR method outruns all the other colorization methods that are TCEVR and TWEVR. PSNR values acquired from colorized images of THEVR dominate other vector quantization methods consistently. The class obtained of colorized target gray image is of superior quality when compared to other colorization methods. Thus the THEVR is best in codebook size 256.

TABLE II. COMPARISON OF COLOIZATION METHODS ACROSS ALL SIMILARITY MEASURES AND CODEBOOK SIZES

	TCEVR			TWEVR			THEVR		
Similarity Measures	**CB 64**	**CB 128**	**CB 256**	**CB 64**	**CB 128**	**CB 256**	**CB 64**	**CB 128**	**CB 256**
Canberra	28.49	28.42	28.41	28.76	28.66	28.69	29.54	29.44	29.57
Chebychev	28.62	28.68	28.67	28.64	28.83	28.63	29.45	29.63	29.77
Euclidean	28.57	28.62	28.61	28.56	28.59	28.69	28.78	28.89	29.09
Hamming	28.21	28.35	28.35	28.57	28.48	28.23	28.79	28.53	28.48
Jaccard	28.17	28.32	28.32	27.84	27.99	27.99	28.37	28.22	28.36
Manhattan	28.67	28.67	28.66	28.84	28.81	28.82	29.07	29.1	29.19
Spearman	28.6	28.63	28.62	28.79	28.77	28.78	29.48	29.78	29.76
Square Chord	28.59	28.52	28.52	28.66	28.44	28.56	29.31	28.95	29.19
Wave Hedges	28.49	28.42	28.416	28.76	28.69	28.69	29.59	28.19	29.68

TABLE III. AVERAGE PSNR VALUES FOR QUALITATIVE COMPARISON OF PROPOSED COLORIZATION METHODS(TAKEN FROM TABLE II)

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Target Image	TCEVR For codebook size 256	THEVR For codebook size 256	TWEVR For codebook size 256
			
Chocolate	PSNR 27.27	PSNR 28.49	PSNR 27.80
			
Statue of liberty	PSNR 34.25	PSNR 34.76	PSNR 33.69
			
Cars	PSNR 30.30	PSNR 30.73	PSNR 29.44
			
Barak Obama	PSNR 27.48	PSNR 29.11	PSNR 30.81

Figure 8. Colorization Of Target Gray Images with relatively similar

TABLE IV. PERFORMANCE COMPARSION ACROSS ALL COLORIZATION METHODS

source color images using color palette codebook of size 256.

Similarity Measures	Mean PSNR across all Colorization Methods
Spearman	29.02
Chebychev	28.99
Canberra	28.89
Manhattan	28.87
Wave Hedges	28.77
Square Chord	28.75
Euclidean	28.71
Hamming	28.44
Jaccard	28.18

The Table 2 shows the comparison of colorization methods across various similarity measures. Mean PSNR values are calculated across all colorization methods. The colorization methods are performed through color palette (codebook) sizes 64,128, and 256. The Table 3 depicts mean values of all similarity measures. From table 3 it can be observed that codebook size of 256 in THEVR gives best results. Table 4 is about performance comparison across all codebook size, here it represents that Spearman gives best results irrespective of colorization algorithms selected.

VI. CONCLUSION

To color the target gray image there are many Vector Quantization methods used, in this three vector quantization methods are used namely THEVR, TCEVR and TWEVR. These vector quantization methods are applied on codebook size 64,128, and 256, wherein 9 similarity measures are used which belongs to diverse family, which are ultimately used to map the color pixels value from RGB plane of source image to the single plane that is gray of the target gray image. The performance comparison in colorization of target image with codebook sizes 64, 128 and 256, and also the similarity measures are done for proposed variations of Thepade's Transform Error Vector Rotation. Results obtained have indicated that THEVR gives superlative results for all codebook sizes. The Spearman similarity measure gives prime outcomes than all other similarity measures in all codebook sizes and vector quantization colorization methods. When all similarity measures are assessed the worse outcomes are given by Jaccard and Hamming similarity measures regularly throughout all codebook sizes and vector quantization methods. Thus the outcomes of colorized image obtained from THEVR using Spearman similarity measure in codebook size 256 will always give unsurpassed outcome and also individually Spearman will always give good results for all colorization methods.

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