# Detailed Performance Assessment of Haar, Cosine, Slant and Hartley Transforms for Grayscale Image Colorization using Thepade's Transform Error Vector Rotation Algorithms of Vector Quantization

Padale Supriya
Masters of Computers Engineering,
Pimpri Chinchwad College of Engg,
SPPU, Pune

Sudeep D. Thepade
Ph.D. (Computer Engineering),
Pimpri Chinchwad College of Engg,
SSPU, Pune

Atul Pawar
Computers Engineering Department
Pimpri Chinchwad College of Engg,
SPPU,Pune

***Abstract*— The detailed performance comparison of four orthogonal transforms for grayscale image colorization using Thepade's Transform Error Vector Rotation(TTEVR) algorithm is done here with five different color pallet sizes. The Thepade's transform error vector rotation algorithms use binary numbers represented by four error vector sequences (Haar, Cosine, Slant & Hartley). The proposed technique uses vector quantization to generate a color pallet to color the grayscale image. The proposed technique has two stages. The first stage uses source (color) image from which color traits need to be taken is used to generate color pallet using Thepade's transform error vector rotation algorithms. In the second stage colors are transferred to a arget (grayscale) image using generated color pallet. There exist no objective criteria for qualitative analysis of performance evaluation of the colorization quality of proposed TTEVR for the orthogonal transforms alias Cosine, Haar, Slant and Hartley is done here to find better transform to be used in TTEVR based grayscale image colorization, hence the grayscale version of original color image is recolored using proposed technique and the mean squared error between original color image and recolored image is used as quality comparison criteria. Experimentation is done on 15 different images for five different color pallet sizes in RGB. The proposed techniques are compared with existing colorization technique KEVR. KEVR performs better than the proposed techniques in RGB color space.**

***Keywords*— TCEVR, THEVR, THtEVR, TSlEVR, color pallet**

## I. Introduction

Colorization of monochrome images enhances visual appearance and provides more information than monochrome images. Colorization has many applications like old photo restoration, vintage film colorization, medical imaging, recolorization, special effects.

A monochrome image is a one dimensional image which carries intensity information in one plane while color images consist of red, green and blue color planes. Grayscale version of the color image can be obtained by captivating pixel wise weighted average of individual color planes. It becomes very difficult finding the color component values for respective pixel wise grayscale values when only grayscale image is at hand. As there can be several combinations of color plane values resulting into their weighted average as the identical grayscale value. This 'many to one' mapping problem is converted into 'one to one probable' mapping by captivating group of pixels of color image along with their grayscale equivalent to generate color pallet. This color pallet based on grouping of grayscale pixels of target grayscale image can be used for colorization. The paper proposes use of Thepade's Transform Error Vector Rotation(TTEVR) algorithms for the color pallet generation with four assorted orthogonal transforms like Cosine, Haar, Slant and Hartley.

The process of colorization was invented by Wilson Markle in 1970[5]. Various methods have been proposed for grayscale image colorization from scribbling to segmentation. Few methods of grayscale image colorization are discussed in literature survey.

## II. Literature Survey

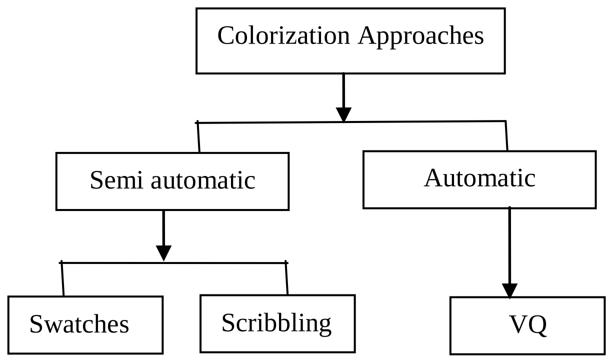


Figure 1 Tree diagram of colorization approaches

Grayscale image colorization methods can be classified into automatic and semi automatic approach. Semi automatic approach has two methods scribbling and swatches. Colorization using VQ falls under automatic approach[8][10]. Figure 1 shows classification of colorization approaches. A few methods of both the approaches are discussed here. We will start with semi-automatic approaches first.

In[11], the constraint of two neighboring pixels should have similar colors; if their intensities are similar the target image is followed. The grayscale image is scribbled manually. The difference between color at a pixel and the weighted average of colors at neighboring pixels is minimized here.

In[13], first the source(reference) image is converted to decorrelated lαβ color space where l represents luminance and αβ represent chromatic channels. After performing luminance remapping, for each pixel in the target image, best matching source pixel is found by comparing luminance and std. deviation of luminance values in neighborhood. Then colors are transferred to target pixel from source pixel. But this approach fails when corresponding colors don't have corresponding luminance values.

In[12], the above idea[13] is extended. In[12] user specifies corresponding swatches in source and target images. By performing luminance remapping between corresponding swatches, colors are transferred to target swatches from source swatches. Then best matching pixel in a colorized swatch for each grayscale pixel in the target image is searched. Colors are transferred from matching pixel to grayscale pixel.

[11] and [12] both has a drawback that the source image size is larger than the target image size that results into color pallet of varying sizes. The drawback of [11] and [12] is eliminated in [9]. This is an automatic approach of colorization. After searching the reference color image for coloring a grayscale image, the reference color image is converted to other color space. Then divide the image into distinct blocks forming a training set. Standard VQ algorithm LBG is used to get color pallet of required size. In LBG algorithm form a training set from a color(source) image. Centroid is represented by first codevector of this training set. Generate two vectors v1 and v2 by adding constant error to the codevector. Calculate Euclidean distances between all the training vectors and v1 and v2. Same process is repeated for every cluster. This process is repeated till we get color pallet of required size. Also divide the grayscale(target) image into distinct blocks. Using Mean Squared Error, the best match is searched from the color pallet for every row of grayscale intensity. Once we get the best match for each row of grayscale(target) image, the colors are transferred to grayscale pixel from best found pallet match. The idea is extended using Thepade's Transfrom Error Vector Rotation algorithms with Cosine, Haar, Slant and Hartley transforms here. the constraint of two neighboring pixels should have similar colors; if their intensities are similar the target image is followed. The grayscale image is scribbled manually. The difference between color at a pixel and the weighted average of colors at neighboring pixels is minimized here.

## III. Vector Quantization

Vector quantization is one of the lossy data compression techniques. A color pallet is generated using VQ. Here VQ acts a mapping function that maps k-dimensional vector space to finite set CB = {C1, C2, C3,…CN}. The set CB is recognized as codevectors and codevectors are Ci={ci1, ci2, ci3,…, cik}. A color pallet represents the whole image consists of a definite pixel pattern that represents color shades which is computed according to specific VQ algorithm. Here Thepade's error vector rotation (TCEVR, THEVR, TSlEVR, THtEVR) are used as specific VQ algorithms[17].

### A. Thepade's Cosine Error Vector Rotation(TCEVR)

In TCEVR, discrete Cosine transform developed by Ahmed, Natrajan, and Rao in 1974[6] is used. The discrete cosine transform belongs to a family of real –valued discrete sinusoidal unitary transforms. A discrete cosine transform includes a group of basis vectors that are sampled cosine functions. DCT is used to convert a signal into elementary frequency components. The discrete cosine transform is real and orthogonal. TCEVR was used for image compression[15]. The error vector matrix to be taken here is given in equation (1).

$$E_{TCt} = \begin{bmatrix} e_1 \\ e_2 \\ . \\ . \\ . \\ . \\ . \\ e_8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & -1 & 1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 \\ 1 & -1 & 1 & -1 & -1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 & 1 & 1 & -1 \end{bmatrix} \qquad (1)$$

### B. Thepade's Haar Error Vector Rotation (THEVR)

In THEVR Haar transform proposed by Alfred Haar[16] is used. Haar sequence is used to provide an instance of a countable orthonormal scheme for the space of square-integral functions on the real line. THEVR was used for image compression[14]. The error vector matrix to be taken here is given in equation (2).

$$E_{THt} = \begin{bmatrix} e_1 \\ e_2 \\ . \\ . \\ . \\ . \\ . \\ e_8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & -1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & -1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & -1 \end{bmatrix} \qquad (2)$$

### C. Thepade's Slant Error Vector Rotation(TSLEVR)

In TSlEVR Slant transform proposed by Enomoto and Shibata[4] is used. The slant transform has a property that it is a non sinusoidal orthogonal transform which has sawtooth waveforms. It also has the sequence property which decreases monotonically in constant steps from maximum to minimum. TSlEVR was used for image compression[2]. The error vector matrix to be taken here is given in equation (3).

$$E_{TSL} = \begin{bmatrix} e_1 \\ e_2 \\ . \\ . \\ . \\ . \\ . \\ e_8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 \\ 1 & -1 & -1 & -1 & 1 & 1 & 1 & -1 \\ 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \end{bmatrix} \quad (3)$$

### A. THEPADE'S HARTLEY ERROR VECTOR ROTATION(THTEVR)

In THtEVR, Hartley transform proposed by Bracewell[3] is used. It is a real valued unitary transform. THtEVR was used for image compression[1]. The error vector matrix to be taken here is given in equation (4).

$$E_{THtt} = \begin{bmatrix} e_1 \\ e_2 \\ . \\ . \\ . \\ . \\ . \\ e_8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 \\ 1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\ 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\ 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 \\ 1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\ 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 \end{bmatrix} \quad (4)$$

## IV. PROPOSED COLORIZATION TECHNIQUE

The proposed colorization techniques using TCEVR, THEVR, TSlEVR & THtEVR[17] have two phases as color pallet generation and grayscale image colorization.

### *A. Generate color pallet using source image*

Step 1: Divide the image into non overlapping blocks. Each block will convert to vector and form training vector set.
Step 2: Calculate the centroid of this training vector by captivating column wise mean.
Step 3: Cosine / Haar / Hartley / Slant error vector e is generated.
Step 4: Error vector $e_i$ is added and subtracted from the code vector for generating two vector e1 and e2.
Step 5: Calculate Mean Squared error between all the training vectors belonging to this cluster. Clusters are divided into two vectors v1 and v2.
Step 6: The centroid is calculated for the clusters obtained in the above step 5.
Step 7: i is incremented by one and repeat step 4 to step 6 for each codevector.
Step 8: Step 3 to step 7 are repeated till codebook of desire size is obtained .i.e. our color pallet.

### *B. Target grayscale image colorization*

Step 1: Split the target grayscale image into distinct blocks.
Step 2: Steps 3 to 5 are repeated for all distinct blocks of step 1.
Step 3: A block is converted into a vector of grayscale values.
Step 4: Mean Squared error(MSE) is computed between the grayscale part of color pallet vectors and this grayscale vector.
Step 5: The colors are transferred from the best matching color pallet vector to the grayscale vector based on minimum MSE value.
Step 6: All grayscale vectors are converted to the blocks with found color values and target color image is obtained.

## V. RESULTS AND DISSCUSSION

The proposed methods are implemented using MATLAB on Pentium IV, 2.10 GHz, 4 GB RAM. For testing purpose test bed of 16 training images of size 512 × 512 as shown in figure 2 is used.

Figure 2 Training images for self recolorization

Figure 3 gives sample tested images in original and recolored forms using proposed grayscale image colorization technique using TCEVR, THEVR, TSlEVR and THtEVR with color pallet size 512. It is observed that proposed method gives better results with higher color pallet sizes. But THEVR performs better as indicated by lower MSE values. Figure 3 shows comparison between proposed colorization technique using TCEVR, THEVR, TSlEVR & THtEVR for varying color pallet sizes from 32 to 512 with respect to average MSE. From figure 3 it is seen that the proposed technique using THEVR performs better. It is also seen with higher color pallet sizes proposed technique gives better results.

Table 1 shows detailed performance analysis of proposed grayscale image colorization technique using TCEVR, THEVR, THtEVR and TSlEVR. In table 1 average MSE of original and recolored images using proposed technique on sixteen color images from different categories of sizes 512 x 512 x 3 for color pallet size 256 and 512 are given. From Table 1, it can be observed that the best colorization is given by proposed technique using THEVR for color pallet size 512. Also higher color pallet sizes perform better in RGB color space.

| Grayscale Image | Resultant image of TCEVR algorithm Color pallet size 512 | Resultant image of THEVR algorithm Color pallet size 512 | Resultant image of TSIEVR algorithm Color pallet size 512 | Resultant image of THtEVR algorithm Color pallet size 512 |
|---|---|---|---|---|
|  |  MSE = 587.05 |  MSE = 604.7 |  MSE = 564.38 |  MSE = 699.45 |
|  |  MSE = 48.15 |  MSE = 47.63 |  MSE = 46.72 |  MSE = 46.49 |

Figure 3 Few sample results of KEVR and proposed grayscale image colorization technique using TCEVR, THEVR, TSlEVR and THtEVR for recolorization

| Target Grayscale Image | Source Image | Proposed technique using TSlEVR | Proposed technique using THtEVR | Proposed technique using THEVR | Proposed technique using TCEVR |
|---|---|---|---|---|---|
|  |  |  CP size = 256 |  CP size = 256 |  CP size = 256 |  CP size = 256 |
| | |  CP size = 512 |  CP size = 512 |  CP size = 512 |  CP size = 512 |

Figure 4 Few sample results of proposed grayscale image colorization technique using TSlEVR, THtEVR, THEVR and TCEVR for colorization

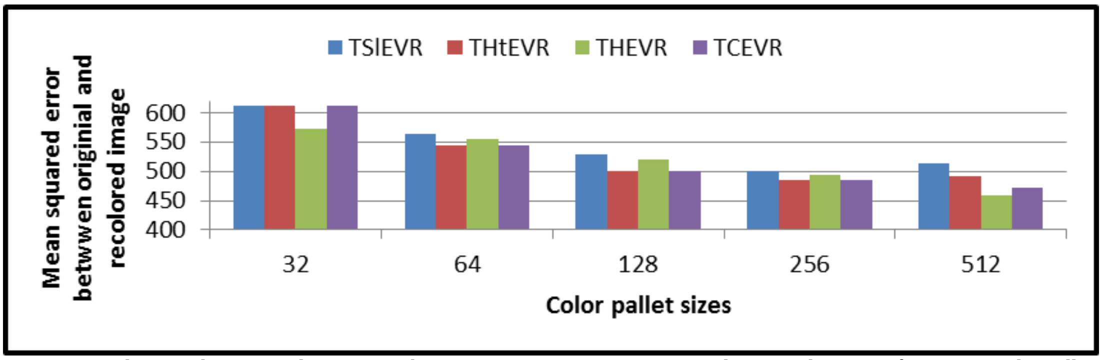


Figure 5 Comparison proposed grayscale image colorization technique using TCEVR, THEVR, TSlEVR and THtEVRfor varying color pallet sizes from 32 to 512 with respect to average MSE between original and recolored image.

Figure 4 shows sample results of proposed techniques for colorization for different source and different target image for color pallet size 256 and 512.

Figure 5 shows Comparison proposed grayscale image colorization technique using TCEVR, THEVR, TSlEVR and THtEVRfor varying color pallet sizes from 32 to 512 with respect to average MSE between original and recolored image.

TABLE I.
Average MSE of original and recolored images using proposed technique using TCEVR, THEVR, THtEVR and TSlEVR on fifteen color images from different categories of sizes 512 x 512 x3 in RGB color space.

| **Proposed Methods** | **Color pallet sizes** | | | | |
|---|---|---|---|---|---|
| | **32** | **64** | **128** | **256** | **512** |
| Proposed technique using TCEVR | 617.37 | 550.14 | 508.5 | 491.67 | 475.81 |
| Proposed technique using THEVR | 581.23 | 564.54 | 525.82 | 498.82 | 460.52 |
| Proposed technique using TSlEVR | 617.58 | 571.72 | 538.87 | 507.5 | 520.74 |
| Proposed technique using THtEVR | 617.37 | 550.14 | 508.5 | 491.69 | 497.49 |

## VI. CONCLUSION

The performance of proposed techniques using Thepade's transform error vector rotation algorithms are evaluated for four orthogonal transforms Cosine, Haar, Slant and Hartley. Better results are seen with higher color pallet sizes for the proposed techniques. But THEVR performs better indicated by lower MSE values. Second best performance is given by TCEVR. The proposed techniques are implemented in RGB color space.

The proposed techniques using TSlEVR and THtEVR give better results for color pallet size 256. The proposed techniques using TCEVR and THEVR give better results for color pallet size 512. The performance of the proposed technique can also be tested on grayscale video in future.

## REFERENCES


[1] Dr. Sudeep D. Thepade, Vandana Mhaske, Vedant Kurhade, "Thepade's Hartley Error Vector Rotation For Codebook Generation In Vector Quantization", in Advances in Computing, Communications and Informatics (ICACCI), IEEE, 22-25 Aug, 2013.

[2] Dr.Sudeep D. Thepade, Vandana Mhaske, Vedant Kurhade, "New Clustering Algorithm TSlEVR for Vector Quantization Using Slant Transform", in Emerging Trends and Applications in Computer Science (ICETACS), IEEE, 13-14 Sept, 2013

[3] William K. Pratt, "Digital Image Processing :PIKS scientific inside "Wiley-Interscience; 4 edition (February 9, 2007).

[4] H. Enomoto and K.R.Shibata, "Orthogonal System for television Signals", IEEE Trans, Electromagan, compact, Volume +3, PP, 11-17, 1971.

[5] K. N. Plataniotis, A. N. Venetsanopoulos, "Colour Image Processing and Applications", Monograph, 1st edition, Feb 18 2000.

[6] S. Jayaraman, S. Esakkirajan, T. Veerakumar, "Digital Image Processing", TMH, 10th edition, 2010.

[7] H. B. Kekre, Tanuja K. Sarode, "New Clustering algorithm for vector quantization using rotation of error vector", International Journal of computer and Information Security, Volume-7, Number-3, 2010.

[8] Dr. H. B. Kekre, Sudeep Thepade, "Colour Traits Transfer to Greyscale Images", Emerging Trends in Engineering and Technology, 16-18 July, 2008.

[9] Dr. H. B. Kekre, Sudeep Thepade, Nikita Bhandari, "Colorization of Grayscale images using LBG VQ Codebooks for Different Color Spaces", International Journal of Engineering Research and Applications( IJERA), Volume 1, Issue-4, Nov-Dec 2011.

[10] L. Qing, F. Wen, D. Cohsen-Or, L. Liang, Y.-Q. Xu, H. Shum, "Natural Image Colourization", Proceedings of the 18th Eurographics conference on Rendering Techniques (EGSR'07 ), in ACM, June 2007.

[11] A. Levin, D. Lischinski, Y. Weiss, "Colourization Using Optimization", ACM Transactions on Graphics (TOG) - Proceedings of ACM SIGGRAPH, Volume 23 Issue 3, August 2004.

[12] T. Welsh, M. Ashikhmin, and K. Mueller, "Transferring Colour to Greyscale Images", ACM Transactions on Graphics (TOG) - Proceedings of ACM SIGGRAPH, Volume 21 Issue 3, July 2002.

[13] E. Reinhard, M.ashikhmin, B. Gooch and P. Shirley, "Colour Transfer between Images", Computer Graphics and Applications, IEEE, Volume: 21, Issue: 5, IEEE, Sept/Oct 2001.

[14] Dr. Sudeep D. Thepade, Vandana Mhaske, Vedant Kurhade, "Thepade's Haar Error Vector Rotation For Codebook Generation In Vector Quantization", in Information & Communication Technologies (ICT), 2013 IEEE, 11-12 April, 2013.

[15] Dr.Sudeep D. Thepade, Vandana Mhaske, Vedant Kurhade, "New Clustering Algorithm TCEVR for Vector Quantization Using Cosine Transform",,in Elsevier, June 2013.

[16] Haar, Alfred ,"Zur Theorie der orthogonalen Funktionensysteme", Mathematische Annalen **69** (3): 331–371. doi:10.1007/BF01456326, 1910.

[17] Dr. Sudeep D. Thepade, Supriya Padale, "Performance Comparison of Thepade's Transform Error Vector Rotation algorithms of Vector Quantization for Grayscale Image Colorization with Slant and Hartley Transforms", IEEE International Conference on Futuristic Trends in Computational Analysis and Knowledge Management (A-BLAZE), Amity University, Delhi, 25-27 Feb 2015.