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Colour Image Enhancement Using Discrete Wavelet Transform-K Means Clustering Hybrid Design

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Abstract

In this study, an efficient approach to enhance the quality of colour in an image is proposed. Colour image enhancement plays a significant role in many areas such as remote sensing, biomedical image analysis and fault detection. The proposed system consists of series of stages; RGB to HSI colour transformation, DWT decomposition, clustering analysis and Histogram equalization. To effectively cluster the input image, the number of seed points for cluster analysis using K Means clustering is obtained automatically by Hill climbing algorithm. In order to assess the performance of the proposed system, Peak Signal to Noise Ratio (PSNR), Structural SIMilarity (SSIM) index, Universal Quality Index (UQI), and Entropy are computed. The results show that the proposed system enhances the given image with very good visual quality and achieves over 90% SSIM and UQI.

Index terms - Discrete Wavelet Transform, K-means clustering, Hill climbing, Histogram equalization, image enhancement.

1. INTRODUCTION

The goal of image enhancement system is to process an image in order to get the output more likely as the original image for any particular application. It is not only enhances the perception and acuity of the original image and also increases the finer details of an image and highlights the useful information. The generalization of enhancement techniques to colour images based on varies techniques are discussed in this section.

A new method for colour image enhancement is presented in [1] based on fast hue and range preserving histogram. It preserves the hue and ranges of red, green and blue channel. At first, the target intensity image is generated from the input image by matching the intensity channel of the RGB image into a specified histogram. Finally, enhanced RGB image is computed based on the target from the stretched image that satisfies the hue and gamut constraints.

Colour image contrast enhancement system is described in [2] using colour and depth histograms. The given RGB image and its corresponding depth images are initially transformed into HSI colour space. The intensity channel is only considered for histogram modification where Gaussian mixture model based histogram partitioning method is employed. Depth map based colour image enhancement technique is demonstrated in [3] using colour stereopsis. Initially, the depth perception between red and blue channel is analyzed and the intensity component of the given RGB image is weighted. The weights are computed from the colour image and the depth map.

Partial differential equation algorithm based on colour image enhancement is analyzed in [4]. A new filter of coupling a shock filter is designed based on single vectors of all components of the input image. It produces selective smoothing that reduces the noise efficiently and the edges are sharpened. Local processing based image enhancement is presented for colour images in [5]. The given RGB image is transformed into HSV colour space. Two types of enhancements; non linear transformation and local processing using neighborhood pixels are applied to the luminance channel only for image enhancement.

Space variant luminance map (SVLM) based colour image enhancement technique is presented in [6]. The RGB image is converted into intensity image. Then the intensity image is low pass filtered using a 2D discrete Gaussian filter to estimate its luminance.2D gamma correction combined with the SVLM is applied for luminance enhancement. The enhanced luminance information is applied to adaptive contrast enhancing process and the linear colour restoration. A new scheme for colour image enhancement based on directional transform using wavelet basis and Gaussian low pass filters is presented in [7]. To enhance the given image, wavelet decomposition is applied to obtain flat and edge regions and then adaptive shrinkage is applied.

Virtual histogram approach based colour image enhancement is presented in [8].The given RGB image is transformed into YCbCr colour space, where local and global processing takes place on luminance and chrominance components of the image. Brightness preserving dynamic histogram equalization based colour image enhancement technique is described in [9]. The RGB colour space is converted into HSI and only the intensity channel is processed. A new method for colour image enhancement technique in Discrete Cosine Transform (DCT) domain is discussed in [10]. The enhancement technique is performed by three steps; adjustment of background information, preservation of local contrast and preservation of colour. All the steps are performed in a block DCT space.

An automatic and parameter free contrast enhancement algorithm for colour images is presented based on piecewise linear transformation [11]. The luminance component is investigated by image content analysis algorithm to obtain the image illumination distributions. The parameters computed from the distributions are used in piecewise linear transformation function to enhance the images. Recursive rational filter (RRF) based colour image enhancement is presented in [12]. To control the dynamics effects in image, suitable nonlinear function is applied to the illumination component and the details can be enhanced by processing the reflectance.

In this study, DWT- K Means Clustering (DWT-KMC) hybrid approach for colour image enhancement technique is presented. This study is organized as follows: Section 2 gives the overall introduction to DWT, K-means clustering and Hill Climbing algorithms. The proposed colour image enhancement system is discussed in section 3. In section 4, the results obtained by the proposed system are discussed. The conclusion is made in the last section.

2. MATHEMATICAL PRELIMINARIES

The proposed colour image enhancement technique is built based on three concepts: DWT, Hill climbing algorithm and K-means clustering. In this section, the above techniques are briefly reviewed.

2.1 Discrete Wavelet Transform

The 2-D wavelet decomposition of an image is performed by applying 1-D DWT along the rows and then columns. At first, 1-D DWT is applied along the rows of the input image called row-wise decomposition. Then, 1-D DWT is applied again along the columns of the resultant image called column-wise decomposition. This operation produces four sub-band images referred as approximation (LL sub band), horizontal (HL sub band), vertical (LH sub band) and diagonal (HH sub band). For multi resolution analysis, the LL band of previous level is again decomposed by DWT. They have been used frequently in image processing and used for feature extraction, denoising, compression, face recognition, and image super resolution.

LL	LH
HL	HH

Fig 1. One level DWT decomposition

2.2 Hill climbing algorithm

Hill Climbing algorithm is an efficient and fast nonparametric algorithm that identifies the peaks of cluster in the histogram of an image automatically. In order to efficiently predict the peak value, where the histogram bins are exploited than the pixels themselves [13]. In order to find out the number of clusters (Peaks), the following steps are performed.

1. The DWT approximation coefficient is given as an input to the hill climbing algorithm. The histogram is computed from the input image.

2. The peak selection process is started at a non-zero bin of the histogram and makes uphill moves until reaching a peak as follows:
❖ The number of pixels of the current histogram bin is compared with the number of pixels of the neighboring (left and right) bins.
❖ If the neighboring bins have different numbers of pixels, the algorithm makes an uphill move towards the neighboring bin with larger number of pixels.
❖ If the immediate neighboring bins have the same numbers of pixels, the algorithm checks the next neighboring bins, and so on, until two neighboring bins with different numbers of pixels are found. Then, an uphill move is made towards the bin with larger number of pixels.
❖ The uphill climbing is continued (repeat steps 2.1-2.3) until reaching a bin from where there is no possible uphill movement. That is the case when the neighboring bins have smaller numbers of pixels than the current bin. Hence, the current bin is identified as a peak (local maximum).
3. Another unclimbed bin as a starting bin is selected and perform step 2 to find another peak. This step is continued until all non-zero bins of the histogram are climbed (associated with a peak).
4. The identified peaks represent the initial number of clusters of the input image; thus these peaks are saved and given as peak to the K-means clustering algorithm.

2.3 K means Clustering

The *K*-means algorithm is an iterative technique that is used to partition an image into *K* clusters. In statistics and machine learning, *k*-means clustering is a method of cluster analysis which aims to partition *n* observations into *k* clusters in which each observation belongs to the cluster with the nearest mean. The basic algorithm is:

- Pick *K* cluster centers, either randomly or based on some heuristic.
- Assign each pixel in the image to the cluster that minimizes the distance between the pixel and the cluster center.
- Re-compute the cluster centers by averaging all of the pixels in the cluster.
- Repeat last two steps until convergence is attained (e.g. no pixels change clusters).

Given a set of observations $(x_1, x_2, ... x_n)$, where each observation is a *d*-dimensional real vector, *k*-means clustering aims to partition the *n* observations into *k* sets $(k < n)$ $S = \{S_1, S_2 ..... S_k\}$ so as to minimize the within-cluster sum of squares (WCSS):

$$\arg\min_{S} \sum_{i=1}^{k} \sum_{x_j \in S_i} \left\| X_{i} - \mu_i \right\|^2 \tag{1}$$

where μ_i is the mean of points in S_i. The most common algorithm uses an iterative refinement technique. Due to its ubiquity it is often called the k-means algorithm; it is also referred to as Lloyd's algorithm, particularly in the computer science community. Given an initial set of *k* means $m_1^{(1)},....m_k^{(1)}$, which may be specified randomly or by some heuristic, the algorithm proceed by alternating between two steps. Assign each observation to the cluster with the closest mean by

$$S_i^{(t)} = \left\{ x_j : \left\| x_j - m_i^{(t)} \right\| \leq \left\| x_j - m_i^{(t)} \right\| \ \ for\ all \ \ i^* = 1, ..., k \right\} \tag{2}$$

Then, calculate the new means to be the centroid of the observations in the cluster.

$$m_i^{(t+1)} = \frac{1}{\left| S_i^{(t)} \right|} \sum_{x_j \in S_i^{(t)}} x_j \tag{3}$$

3. PROPOSED SYSTEM

The proposed colour image enhancement system is implemented by a series of stages; colour space transformation, DWT decomposition, clustering analysis and Histogram equalization. Figure 2 shows the complete block diagram of the proposed image enhancement system.

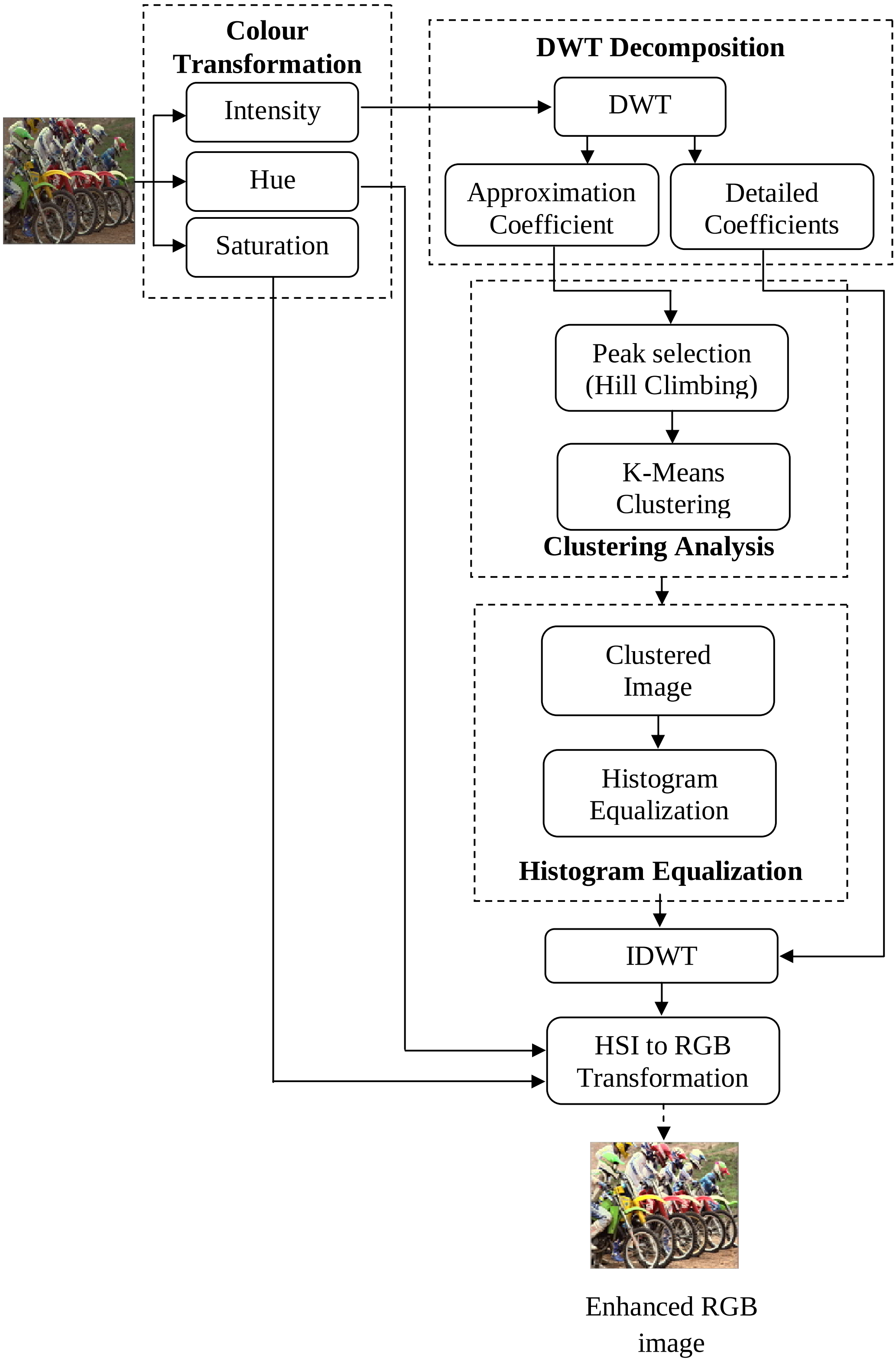

Fig.2 Proposed colour image enhancement system

3.1 RGB to HSI colour space conversion

The *HSI* colour model represents a colour in terms of Hue (*H*), Saturation (*S*), and Intensity (*I*). The *I* component is the gray level of the pixels in a monochrome image, where 0's represents black colour and 1's represents white colour. The *H* component illustrates the colour itself in the form of an angle between [0,360] a degree, where 0 degree represents the red colour, 120 represents the green colour, 240 signifies the blue colour, 60 degrees meant the yellow colour and finally magenta is represented by 300 degrees. The *S* component describes the amount colour polluted with white. Hence the range of the *S* component is between 0 and 1.The *HSI* colour transformation is processed by the following equations [14].

$$H = \cos^{-1}\frac{0.5[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}} \qquad H \in [0,\pi] \text{ for } B \le G \tag{4}$$

$$H = 2\pi - \cos^{-1}\frac{0.5[(R-G)+(R-B)]}{\sqrt{(R-G)^2+(R-B)(G-B)}} \qquad H \in [\pi,2\pi] \text{ for } B \succ G \tag{5}$$

$$S = 1 - \frac{3}{R+G+B}\min(R,G,B) \tag{6}$$

$$I = \frac{R+G+B}{3} \tag{7}$$

If $S = 0$, then H is meaningless. If $(B/I) > (G/I)$ then H=360-H, since H is an angle in degree, H is normalized to $(0,1)$ with $H=H/360$. Among the three components, the proposed image enhancement system uses only I component for DWT decomposition due to its complementary informative nature.

3.2 DWT decomposition

The *I* component of the given input image is represented by DWT which is a multi resolution analysis at one level decomposition which produces one low and three high frequency sub bands. The low frequency sub-band has approximate coefficients, which hold almost the original image whereas high frequency sub-bands have detail coefficients that hold additional information about the image. To enhance the image, the low frequency sub-band is subjected to cluster analysis and then inverse DWT is applied along with high frequency sub-bands in order to preserve the fine details in the image.

3.3 Clustering analysis

In order to achieve better enhancement result, the proposed system segments the low frequency sub-band image using *K* means clustering and contrast of each segment is improved by using Histogram equalization. The main difficulty is the selection of number of seed points for *K* means clustering. To avoid random selection of *K* seed points, hill climbing algorithm is employed as automated *K* selection algorithm [15]. After the prediction of appropriate number of peak point by hill climbing, *K* value is set as the number of predicted peak points and the segmented image is obtained by *K* means clustering algorithm.

3.4 Histogram equalization

Histogram equalization (HE) technique is applied to each segment of the clustered image independently. Hence the image contrast is enhanced by adjusting each cluster intensity value. The conversion formula for i^{th} cluster is as follows:

$$\text{hist} = \min_i + \left(\max_i - \min_i\right) \sum_{k=\min_i}^{\max_i} \frac{\text{number of pixels with gray value } k}{\text{total pixels in the cluster } i} \tag{8}$$

After contrast enhancement in the wavelet domain, inverse DWT is applied to bring the given input image in spatial domain using the unaltered high frequency sub-bands. Finally, HSI to RGB conversion is applied to get the enhanced image in the RGB mode by using the following three conditions.

Initially *H is* restored to degrees with $H = 360H$

If $0 < H \leq 120$ then

$$B = I(1 - S) \tag{9}$$

$$R = I\left[1 + \frac{S\cos H}{\cos(60^0 - H)}\right] \tag{10}$$

$$G = 3I - (B + R) \tag{11}$$

If $120 < H \leq 240$ then $H = H - 120$

$$R = I(1 - S) \tag{12}$$

$$G = I\left[1 + \frac{S\cos H}{\cos(60^0 - H)}\right] \tag{13}$$

$$B = 3I - (G + R) \tag{14}$$

If 240< $H \leq$ 360 then $H = H - 240$

$$G = I(1 - S) \quad (15)$$

$$B = I\left[1 + \frac{S\cos H}{\cos(60^0 - H)}\right] \quad (16)$$

$$R = 3I - (B + G) \quad (17)$$

4. RESULTS AND DISCUSSIONS

4.1 Database Description

In order to assess the performance of the proposed DWT-KMC+HE algorithm for colour image enhancement system, Media Information and Communication Technology Laboratory (MICT) database [16] images are used. It is developed by university of Toyama, Japan and it composed of 14 reference images. All images in the database are in BMP format at 768x512 pixels resolution. All the images are enhanced by the proposed algorithm and their performance metrics are tabulated.

4.2 Performance Metrics

The following image quality assessment parameters; PSNR, SSIM, UQI and Entropy are used to evaluate the proposed DWT-KMC algorithm for colour image enhancement. The metrics are briefly discussed in this section.

4.2.1 PSNR

The PSNR metric is used to evaluate the image quality. Commonly, PSNR is the assessment standard of the reconstructed image quality, and it is considered as an important measurement feature for viable image assessment analysis [17]. High value of the PSNR indicates that the better enhanced image and it is measured in decibels (dB).The formula of the PSNR measurement as follows.

$$PSNR = 20 * \log_{10} \frac{255}{RMSE} \quad (18)$$

where $RMSE = \sqrt{MSE}$ and 255 is the maximum possible gray value that can be attained by the image signal. Mean square error (MSE) is defined as

$$MSE = \frac{1}{mn} \sum_{i=0}^{m-1} \sum_{j=0}^{n-1} [I(i, j) - K(i, j)]^2 \quad (19)$$

where *I* and *K* corresponds to input and enhanced image and *m*, *n* is the size of the input image.

4.2.2 SSIM

In order to assess the similarity between two images, structural similarity index is taken into account, in a manner that is more consistent with human perception. Generally, SSIM is a full reference metric, which measures the image quality based on original image as reference image [17].

$$SSIM = \frac{(2\mu_x \mu_y + c_1)(2\sigma_{xy} + c_2)}{(\mu_x^2 + \mu_y^2 + c_1)(\sigma_x^2 + \sigma_y^2 + c_2)} \tag{20}$$

where μ_x and μ_y is the average of *x* and *y*. σ_x^2 and σ_y^2 is the variance of *x* and *y*. σ_{xy} is the covariance of *x* and *y*. $c_1 = (k_1 L)^2$ and $c_2 = (k_2 L)^2$ are used to stabilize the division with weak denominator, where L is the dynamic range of the pixel values, k_1 and k_2 are 0.01 and 0.03.

4.2.3 UQI

Universal image quality index (*Q*) is commonly known as one of the efficient image quality assessment parameter. It is calculated by product of three distortions named as loss of correlation, luminance distortion and contrast distortion [18]. The range of the *Q* value varies from 0 to 1.The UQI is computed as follows:

$$Q = \frac{4\sigma_{xy}\,\bar{x}\,\bar{y}}{\left(\sigma_x^2 + \sigma_y^2\right)\left[(x)^2 + (y)^2\right]} \tag{21}$$

$$\text{Correlation Coefficient} = \frac{\sigma_{xy}}{\sigma_x \sigma_y} \tag{22}$$

$$\text{Lu min ance Distortion} = \frac{2xy}{(x)^2 + (y)^2} \tag{23}$$

$$\text{ContrastDi stortion} = \frac{2\sigma_x \sigma_y}{\sigma_x^2 + \sigma_y^2} \tag{24}$$

If *Q* achieves 1, it signifies that $x = y$.

4.2.4 Entropy

The entropy measure is used to evaluate the information content of an image. It represents the information carried out by enhanced colour image [19]. High value of entropy indicates the high information in the enhanced image. It is computed by using eqn.24.

$$\text{Entropy} = -\sum_{i=0}^{255} P(i)\log_2 P(i) \quad (24)$$

where $P(i)$ is the ratio of the number of the pixels with gray value equal to i over the total number of the pixels.

4.3 Discussions

Figure 2 shows the enhancement results of the proposed system for test images in MICT database images.

Fig.3 First row: original images - Middle row images: DWT+HE

Last row images: DWT-KMC+HE enhancement images

It is clearly observed that the proposed system enhances the dark regions with superior colour preservation. Also the enhanced images have good quality with fine local and global details and balanced contrast. To support this subject evaluation, statistical performance metrics such as PSNR, SSIM, UQI and Entropy are computed by using equations in section 4.2. The obtained performance metrics of all images in

MICT database is given in table 1.

Table 1 Results of the proposed DWT-KMC+HE method for MICT database

Image	Performance metrics							
	PSNR		SSIM		UQI		Entropy	
	DWT+ HE	DWT-KMC+HE	DWT+ HE	DWT-KMC+HE	DWT+ HE	DWT-KMC+HE	DWT+ HE	DWT-KMC+HE
1	24.7811	34.26	0.6932	0.8643	0.6675	0.9503	7.0615	7.685
2	24.5866	33.4732	0.7536	0.8777	0.6897	0.9159	7.1100	7.625
3	26.3715	42.8531	0.8769	0.7463	0.8078	0.8168	7.2311	7.8249
4	24.3775	31.2355	0.6828	0.944	0.6183	0.96	6.7430	7.7089
5	24.8027	35.1869	0.6857	0.8626	0.663	0.9391	6.7154	7.7619
6	24.4157	30.6007	0.6887	0.9573	0.6393	0.9577	7.3175	7.7924
7	24.1519	41.2818	0.7417	0.9103	0.7678	0.9842	5.4427	7.3358
8	24.2646	29.5045	0.7643	0.9055	0.7005	0.9425	7.2581	7.6509
9	24.4505	40.1271	0.7276	0.8901	0.6838	0.9402	7.0182	7.7095
10	24.1414	26.6345	0.6924	0.9542	0.5497	0.9612	5.7068	7.0982
11	25.2579	28.9758	0.7007	0.9637	0.6765	0.9761	6.6377	7.3173
12	24.2424	35.9698	0.7332	0.9425	0.6726	0.9763	7.0048	7.5147
13	24.3948	28.5791	0.715	0.8993	0.6892	0.9296	7.2304	7.4545
14	24.2981	34.0039	0.7503	0.9649	0.6826	0.9875	7.1653	7.4076
Average	24.6098	33.7633	0.7290	0.9060	0.6792	0.9455	6.8316	7.5633

It is noted that the performance of the proposed approach gives better performance than classical histogram approach on DWT decomposed image. The maximum value of SSIM represents the high similarity between the given image and enhanced image. The SSIM of the proposed system is approximately 17.7% higher than classical histogram on DWT image. Also, the other image quality parameters like UQI, entropy and PSNR also achieves better results with high resolution than classical method.

5. CONCLUSION

In this study, DWT based efficient colour image enhancement technique is presented. The proposed method uses K-means clustering approach in the wavelet domain and histogram equalization for contrast enhancement of each cluster. The number of seed points is automatically chosen by using hill climbing algorithm which ensures the appropriate number of clusters to be segmented out. Experimental results show that the proposed approach could be potentially used for various applications to enhance the specific categories of images such as surveillance images, biomedical images and satellite images with better perception.

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