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Enhancement of Low Contrast Satellite Images using Discrete Cosine Transform and Singular Value Decomposition

A. K. Bhandari, A. Kumar and P. K. Padhy

Abstract**—**In this paper, a novel contrast enhancement technique for contrast enhancement of a low-contrast satellite image has been proposed based on the singular value decomposition (SVD) and discrete cosine transform (DCT). The singular value matrix represents the intensity information of the given image and any change on the singular values change the intensity of the input image. The proposed technique converts the image into the SVD-DCT domain and after normalizing the singular value matrix; the enhanced image is reconstructed by using inverse DCT. The visual and quantitative results suggest that the proposed SVD-DCT method clearly shows the increased efficiency and flexibility of the proposed method over the exiting methods such as Linear Contrast Stretching technique, GHE technique, DWT-SVD technique, DWT technique, Decorrelation Stretching technique, Gamma Correction method based techniques.

Keywords**—**Singular Value Decomposition (SVD), discrete cosine transforms (DCT), image equalization and satellite image contrast enhancement.

I. Introduction

IMAGE enhancement is the technique which is most widely required in the field of image processing to improve the visualization of the features [1]. Satellite images are useful in many applications for instance finding of the spectral signature of different objects such as the vegetation index, land cover classification, and crop pattern. The remote sensing image is vital in the areas of unfortunate natural disasters to provide humanitarian aid and damage assessment as well as to device new protection strategies [2]. One of the most common problem, occurs in satellite images while capturing image with a huge amount of distance, is the dark light and contrast of image. Contrast is determined by the difference in the color and brightness of the object with other objects in the same field of view [2]. Basically contrast is developed due to difference in luminance which is reflected from two surfaces.

If an image has been taken in very dark or a very bright situation, the information may be lost in those areas which are excessively and uniformly dark or bright [2]. The problem is how the contrast of an image can be improved from the input satellite image which has complete information but is not visible. There have been several technique reported in literature for the contrast analysis of satellite image such as General Histogram Equalization (GHE), Gamma correction and local histogram equalization (LHE) [2, 3]. These techniques are very simple and effective Indies for the contrast enhancement [4]. But these techniques are not efficient as the information laid on the histogram of the image which is totally lost.

During the last decade, the Wavelet Transform, more particularly Discrete Wavelet Transform has emerged as powerful and robust tool for analyzing and extracting information from non-stationary signal such as speech signals due to the time varying nature of these signals. Discrete wavelet transform is also widely useful in many fields like removing of noise, compression, enhancement and remote sensing [3]. Recently, many techniques [4] have been developed based on wavelet or wavelet packets for analysis of satellite images.

In this paper, a novel technique based on the singular value decomposition (SVD) and discrete cosine transform (DCT) has been proposed for enhancement of low-contrast satellite images. SVD technique is based on a theorem from linear algebra which says that a rectangular matrix A, that can be broken down into the product of three matrices, as follows: (i) an orthogonal matrix U_A, (ii) a diagonal matrix $\sum_A$ and (iii) the transpose of an orthogonal matrix V_A [4]. The singular-value-based image equalization (SVE) technique is based on equalizing the singular value matrix obtained by singular value decomposition (SVD) [1, 4, 5]. SVD of an image, which can be interpreted as a matrix, is written as follows:

$$A = U_A \Sigma_A V_A^T \quad (1)$$

where U_A and V_A are orthogonal square matrices known as hanger and aligner, respectively, and the Σ_A matrix contains the sorted singular values on its main diagonal and basic enhancement occurs due to scaling of singular values of the DCT coefficients [4, 5]. The singular value matrix represents the intensity information of image and any alteration on the singular values change the intensity of the input image. The main advantage of using SVD for image equalization comes from the fact that Σ_A contains the intensity information of the

A. K. Bhandari is with the Indian Institute of Information Technology Design and Manufacturing Jabalpur, Jabalpur-482005, MP, India (phone: 9479757406; e-mail: ashishb@iiitdmj.ac.in).
A. Kumar is with the Indian Institute of Information Technology Design and Manufacturing Jabalpur, Jabalpur-482005, MP, India (e-mail: anilkdee@gmail.com).
P. K. Padhy is with the Indian Institute of Information Technology Design and Manufacturing Jabalpur, Jabalpur-482005, MP, India (e-mail: prabin16@gmail.com).

image; here multiband satellite image has been taken for better the analysis [1, 5]. In the case of singular value decomposition the ratio of the highest singular value of the generated normalized matrix, with mean zero and variance of one, over a particular image can be calculated by the equation as given below:

$$\xi = \frac{\max(\Sigma_{N(\mu=0,\text{var}=1)})}{\max(\Sigma_A)} \tag{2}$$

where $\Sigma_{N(\mu=0,\text{var}=1)}$ is the singular value matrix of the synthetic intensity matrix. This coefficient can be used to regenerate an equalized image using

$$E_{equalized\ A} = U_A(\xi \Sigma_A)V_A^T \tag{3}$$

where $E_{equalized\ A}$ is used to denote the equalized image named A. The equalization of an image is used to remove the problem of the illumination, which is basically one cause of the low contrast image and blurring [1, 6].

Discrete cosine transform (DCT) is applied to extract texture features of an image. Texture segmentation is an important task in many applications [7]. It can be combined with other low-level features segmentation to improve the performance of the feature which is extracted from image [8, 9]. The DCT converts a spatial domain waveform into its constituent frequency components as represented by a set of coefficients. The process of reconstructing a set of spatial domain samples is called the Inverse Discrete Cosine Transform (IDCT) [10]. DCT is used to separate the lower and higher frequency coefficient in two parts. The DCT features are stored in the form of an array where the required features of the image can be calculated by DCT frequency coefficients [11]. Using the initial few values, it delivers reasonable performance for feature extraction of the satellite images [10, 11]. Hence, after inverse DCT (IDCT), the enhanced image will be more effective, sharper and having a good contrast [12].

In above context, therefore, in this paper a new technique is proposed based on combined effect of SVD and DCT.

II. Overview of DCT and SVD

A. DCT

DCT was first time used in 1974 [7]. The DCT coefficients can be quantized using visually-weighted quantization values. DCT is a fast algorithm similar to FFT [13, 14].

The discrete cosine transform is a technique for converting a signal into elementary frequency components. It is widely used for extracting the features [14]. The one-dimensional DCT is useful in processing of one-dimensional signals such as speech waveforms. For analysis of the two-dimensional (2-D) signals such as images, a 2-D version of the DCT is required. The DCT works by separating images into parts of differing frequencies [14, 15].

For an N x M matrix, the 2D-DCT is computed in a simple way. Initially, 1D-DCT is applied to each row of the matrix and then, to each column of the matrix'x'. Thus, the transform of x is given by:

$$y(u,v) = \sqrt{\frac{2}{M}}\sqrt{\frac{2}{N}}\alpha_u\alpha_v \sum_{u=0}^{M-1}\sum_{v=0}^{N-1} x(m,n)\cos\frac{(2m+1)u\pi}{2M}\cos\frac{(2n+1)v\pi}{2N} \tag{4}$$

where

$$\alpha_v = \begin{cases} \frac{1}{\sqrt{2}} & v = o \\ 1 & v = 1,2,.....N-1 \end{cases} \quad \& \quad \alpha_u = \begin{cases} \frac{1}{\sqrt{2}} & u = o \\ 1 & u = 1,2,.....N-1 \end{cases}$$

The image is reconstructed by applying inverse DCT operation according to Eq. 5:

$$x(m,n) = \sqrt{\frac{2}{M}}\sqrt{\frac{2}{N}} \sum_{u=0}^{M-1}\sum_{v=0}^{N-1} \alpha_u\alpha_v y(u,v)\cos\frac{(2m+1)u\pi}{2M}\cos\frac{(2n+1)v\pi}{2N} \tag{5}$$

Since, the 2D-DCT can be computed by applying 1D transforms separately to the rows and columns; it means that the 2D-DCT is separable in the two dimensions. As in the one-dimensional, each element *y(u,v)* of the transform is the inner product of the input and a basis function, but in this case, the basic functions are *M x N* matrices [16]. *x(m, n)* is the *x*, y^{th} element of the image represented by the matrix *y*, *M* is the size of the block of image on which the DCT is applied. Eqn. (5) calculates on entry (u, v^{th}) of the transformed image from the pixel values of the original image matrix [17, 18].

The DCT helps to separate the image into parts (or spectral sub-bands) of differing importance (with respect to the image's visual quality). The DCT is similar to the discrete Fourier transform: it transforms a signal or image from the spatial domain to the frequency domain as show in Fig.1. The popular block-based DCT transform segments an image non-overlapping block and applies DCT to each block. It gives result in three frequency sub-bands: low frequency sub-band, mid-frequency sub-band and high frequency sub-band. DCT-based enhancement is based on two facts. The first fact is that much of the signal energy lies at low-frequencies sub-band which contains the most important visual parts of the image. The second fact is that high frequency components of the image [17, 18]. The basic operation of the DCT is as follows: the input multiband satellite image is *M by N, f (i, j)* is the intensity of the pixel in rows i and column j, *s(x, y)* is the DCT coefficient in row k1 and column k2 of the DCT matrix. For most multiband satellite images, much of the signal energy lies at low frequencies; these appear in the upper left corner of the DCT.

B. SVD

Singular value decomposition (SVD) can be calculated mainly by the three mutually compatible points of view [18]. On the one hand, we can view it as a method for transforming correlated variables into a set of uncorrelated ones that better expose the various relationships among the original data items [19]. At the same time, SVD is a method for identifying and ordering the dimensions along which data points exhibit the most variation. This ties in to the third way of viewing SVD, which is that once we have identified where the most variation is present, then it is possible to find the best approximation of the original data points using fewer dimensions [20]. Hence, SVD can be seen as a method for data reduction and mostly for feature extraction as well as for the enhancement of the low contrast images [20]. Following are the basic ideas behind SVD: taking a high dimensional, highly variable set of data points and reducing it to a lower dimensional space that exposes the substructure of the original data more clearly and orders it from most variation to the least [19, 20].

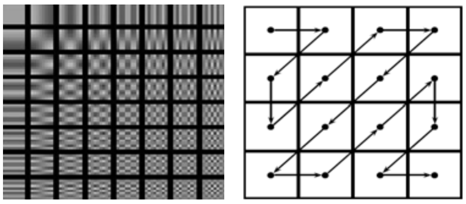

Fig. 1 (a) Lower and higher frequency distribution of an image (b) Zigzag (highest to lowest energy coefficients of DCT)

III. Proposed Methodology

In this paper basically two parts involve in the enhancement of the satellite image. The first one is SVD, as it is mentioned in Section 2 and the singular value matrix [19]. The SVD contains the illumination information in the image. So that, converting the singular values will directly change the illumination of the image, therefore the other information present in the image will be as same as before [20]. The second most significant aspect of this method is the application of DCT as it is discussed in previous section.

The DCT can be regarded as a discrete-time version of the Fourier-Cosine series [5-7]. It is a close relative of DFT, a technique for converting a signal into elementary frequency components [18, 19]. Thus DCT can be computed with a Fast Fourier Transform (FFT). Unlike DFT, DCT is real-valued and provides a better approximation of a signal with few coefficients [7-9]. This approach reduces the size of the normal equations by discarding higher frequency DCT coefficients, while avoiding the overhead of image resampling in the DCT domain [9-11]. In the DCT domain, each significance equation is dependent on the corresponding DCT frequency, and the frequency characteristics of the important structural information in the image. For the aerial images in our study, the important structural information is present in the low frequency DCT coefficients [12]. Hence, separating the high-frequency DCT coefficient and applying the illumination enhancement in the low–frequency DCT coefficient, it will collect and cover the edge information from possible degradation of the multiband remote sensing satellite images [13-15]. DCT output is followed by applying IDCT, and thereby reconstructing the final image by using IDCT, the consequence image will be enhanced with respect to illumination and it will be sharper with good contrast [20].

In the proposed technique, initially the input satellite image 'A' for processed by GHE to generate $A^{\wedge}$. After getting this, both of these images are transformed by DCT into the lower-frequency DCT coefficient, and higher–frequency DCT coefficient [15-18]. Then, the correction coefficient for the singular value matrix can be calculated by using:

$$\xi = \frac{\max\left(\Sigma_{D^{\wedge}}\right)}{\max\left(\Sigma_{D}\right)} \tag{6}$$

where $(\Sigma_{D^{\wedge}})$ is the lower-frequency coefficient singular matrix of the satellite input image, and (Σ_D) is the lower-frequency coefficient singular matrix of the satellite output image of the General Histogram Equalization (GHE). The new satellite image (D) is examined by:

$$\overline{\Sigma}_{D^{\wedge}} = \xi \Sigma_D \tag{7}$$

$$\overline{D} = U_D \overline{\Sigma}_{D^{\wedge}} V_D \tag{8}$$

Now, $\overline{D}$, is the lower DCT frequency component of the original image that is reorganized by applying the inverse operation (IDCT) to produce the consequence equalized image $\overline{A}$ as given by Eqn. (8):

$$\overline{A} = IDCT(\overline{D}) \tag{9}$$

Following steps are to be undertaken to discuss the main computational process of the proposed algorithm:

Step1: In the very first step, a low contrast input satellite image has been taken for the analysis.

Step2: Equalize the satellite image using general histogram equalization technique.

Step3: After equalization, compute the discrete cosine transform for the contrast enhancement.

Step4: In this step calculate the two variables $D^{\wedge}$ and D from the discrete cosine transform image.

Step5: After getting $D^{\wedge}$ and D, SVD is applied for the calculation of the U, Σ, V and find the max element in Σ.

Step6: Calculate Max $\sum_D$ & Max $\sum_{D^{\wedge}}$ with the help of singular value decomposition process.

Step7: Calculate ξ using Eqn. (6) $\xi = \max(\Sigma_{D^{\wedge}}) / \max(\Sigma_D)$

Step8: Calculate the new $\sum_D^{\wedge}$ using equation (7) and (8) $\overline{\Sigma}_{D^{\wedge}} = \xi \Sigma_D$ & $\overline{D} = U_D \overline{\Sigma}_{D^{\wedge}} V_D$

Step9: Apply IDCT after getting new $\overline{\Sigma}_{D^{\wedge}}$

Step10: Equalized satellite image.

IV. Results and Discussion

In this section, the proposed method has been used for enhancement of the several satellite images. Different satellite images are included to demonstrate the usefulness of this algorithm. The performance of this method is measured in terms of following significant parameters:

$$\text{Mean } (\mu) = \frac{1}{MN}\sum_{x=1}^{M-1}\sum_{y=1}^{N-1} I(x-y) \qquad (10)$$

$$\text{Standard Deviation } (\sigma) = \sqrt{\frac{1}{MN}\sum_{x=1}^{M-1}\sum_{y=1}^{N-1}\{I(x,y)-\mu)\}^2} \qquad (11)$$

Mean (μ) is the average of all intensity value. It denotes average brightness of the image, where as standard deviation is the deviation of the intensity values about mean. It denotes average contrast of the image. Here I(x, y) is the intensity value of the pixel (x, y), and (M, N) are the dimension of the image.

A flowchart of the proposed methodology is illustrated in Fig. 2.

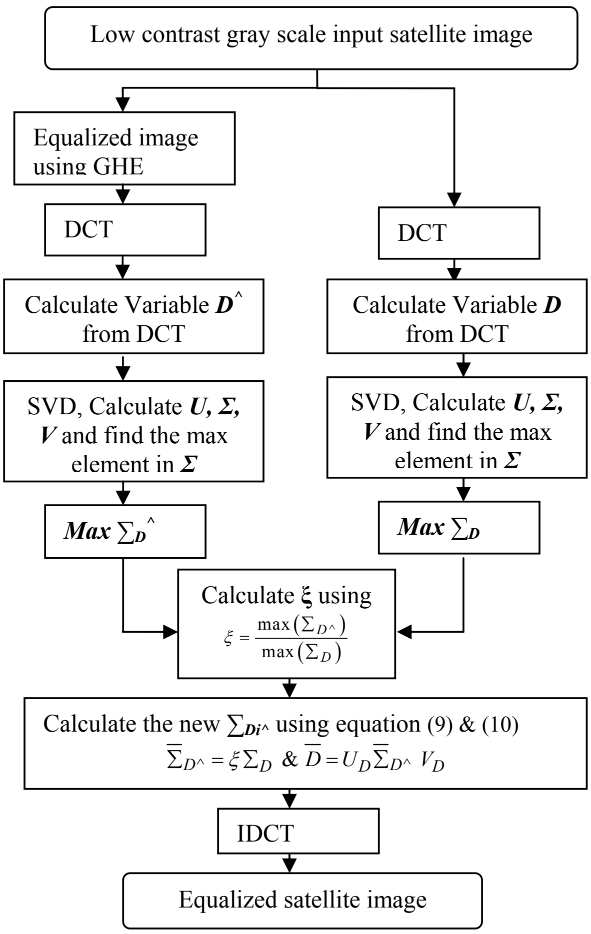

Fig. 2 Flow chart of the proposed mythology

First of all, the performance of the proposed algorithm is carried out in the different images sample. Thereafter, the comparison of proposed method is done with the following method: (1). Linear Contrast Stretching technique, (2). GHE technique, (3). DWT-SVD technique, (4). DWT technique, (5). Decorrelation Stretching technique, (6). Gamma correction method and (7). Proposed methodology DCT-SVD technique and it show the superiority of the proposed technique.

Here, four different satellite images of different region have been taken for enhancement. The simulation results obtained with the proposed methodology and other existing methods (Gamma Correction, General Histogram Equalizer and DWT) are included in Table 1 and graphically shown in the figures (3), (4), (5) and (6). [Fig.3, Fig.4 and Fig.6] shows the low-contrast image of Jabalpur region and the corresponding enhanced images whereas fig.5 indicates the gray scale low contrast satellite image of other region. The performance parameters in each method are:

DWT: μ=401.832, σ=401.832;
Decorrelation Stretch: μ=159.267, σ=139.7900;
Gamma Correction: μ=205.2559, σ=255.7578;
Linear Contrast Stretching: μ=136.503, σ=1.9981e+003;
GHE: μ=127.2831 σ=5.6340e+003
DWT-SVD: μ=141.6760, σ=4.9526e+003;
Proposed Methodology: μ=144.7128, σ=7.2827e+003;

The quality of the visual results indicates that the proposed technique is sharper and brighter than existing technique as compared. After obtaining mean and standard deviation, it is found that the proposed algorithm gives better results in comparison with the existing techniques. Mean (μ) represent the intensity of the image and the standard deviation represent (σ) the contrast present in the images. The proposed DCT method represents the better contrast as well as better brightness with appropriate contrast. However, the estimated mean (μ) and standard deviation (σ) in Figs. [3(e), 4(e), 5(e) and 6 (e)] of the proposed method covers a good range of gray level and this is the cause of the better illumination. Therefore the observation of the proposed DCT gives the better result.

In order to exhibit the superiority of the proposed methodology three different images have been taken for analysis. The singular values denote luminance of each image layer after decomposition using DCT methodology.

After analysis of all the technique, it has been found that the proposed technique indicates the better mean (μ) and standard deviation (σ) in comparison with LCS, GHE, DWT-SVD, DWT, Decorrelation Stretching and Gamma Correction method based techniques. The quality of the input image was poor but after applying the DCT, the result is optimized with reference to brightness and contrast. The histograms obtained from of the proposed technique are stretched in dynamic range, thereby signifying the improvement in contrast of the output image. The mechanism of contrast enhancement can be attributed to scaling of singular values of the DCT coefficients. Since singular values denote luminance of each image layer after decomposition, scaling of these values leads to variation (enhancement) of luminance of each layer and hence leads to overall contrast enhancement. Thus, it is evident that the proposed methodology based on DCT-SVD improves the image quality as well as contrast of the images.

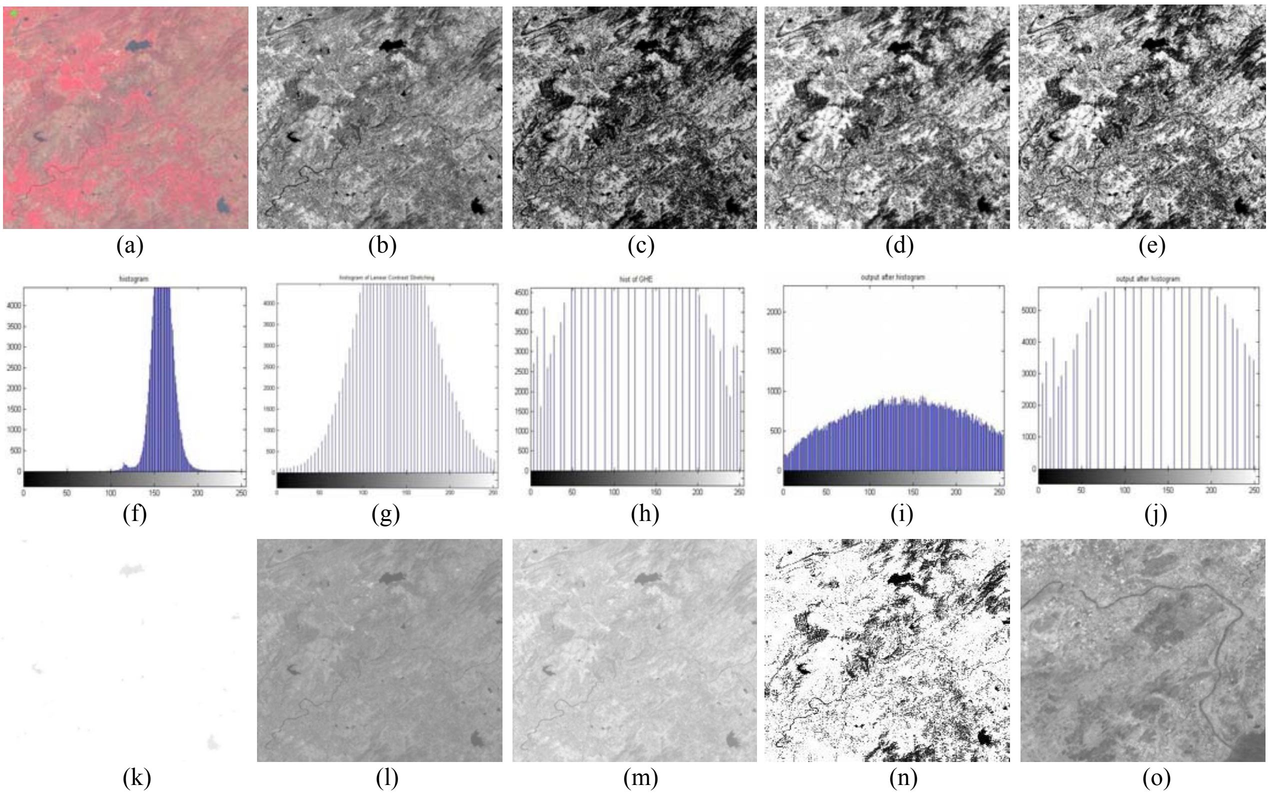

Fig. 3 Various resultant images using existing techniques and proposed technique.

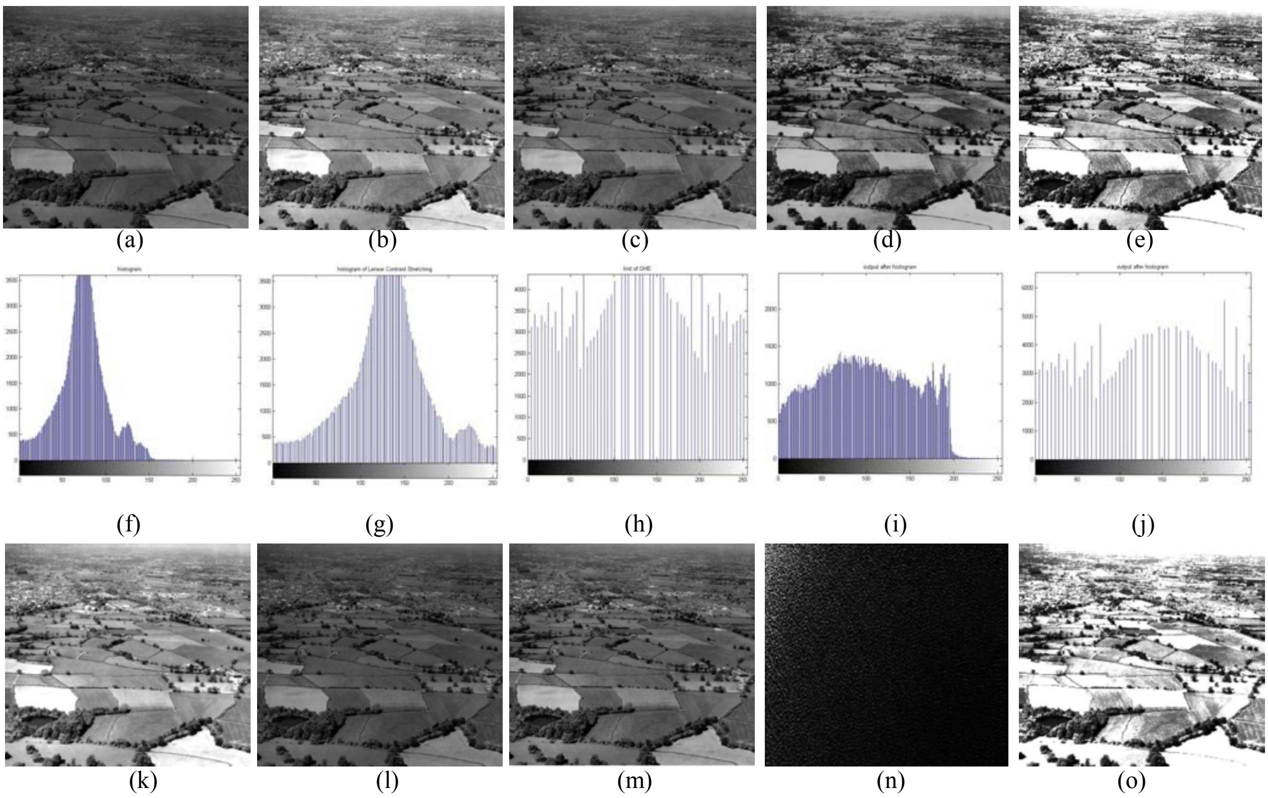

Fig. 4 Various resultant images using existing techniques and proposed technique.

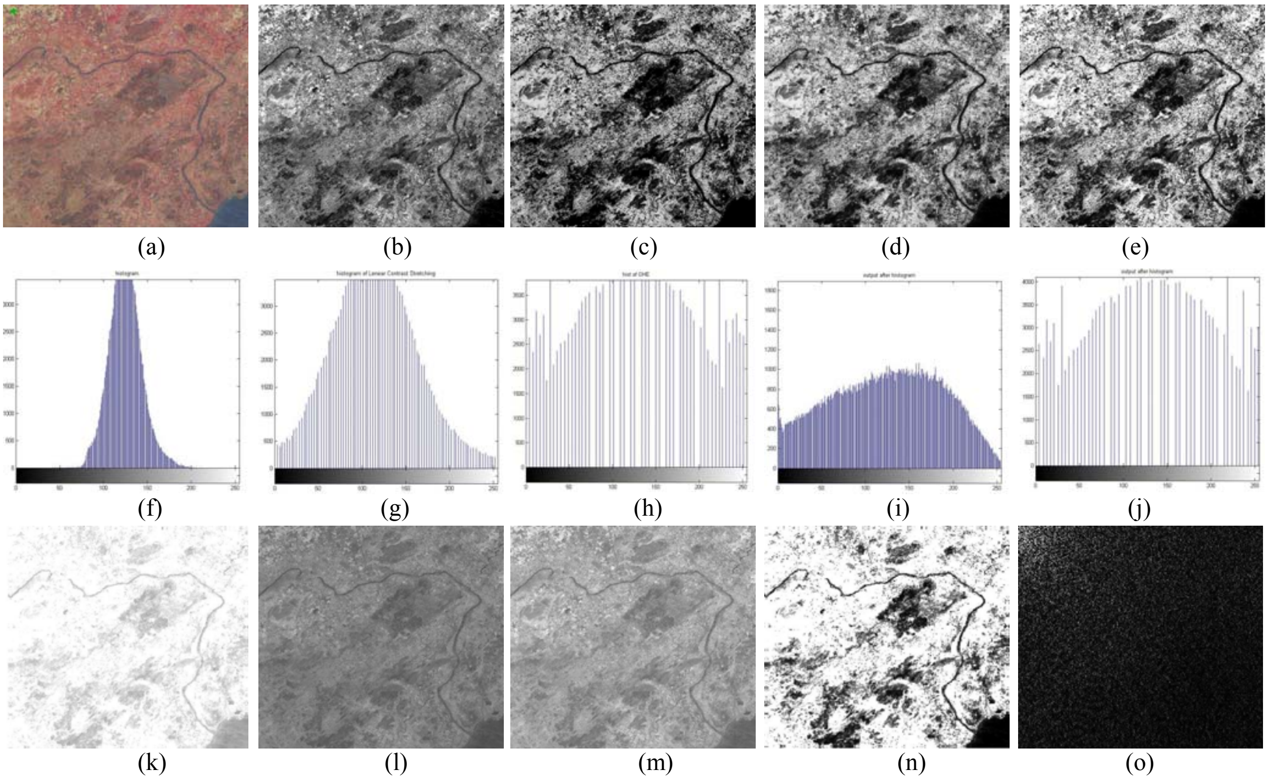

Fig. 5 Various resultant images using existing techniques and proposed technique.

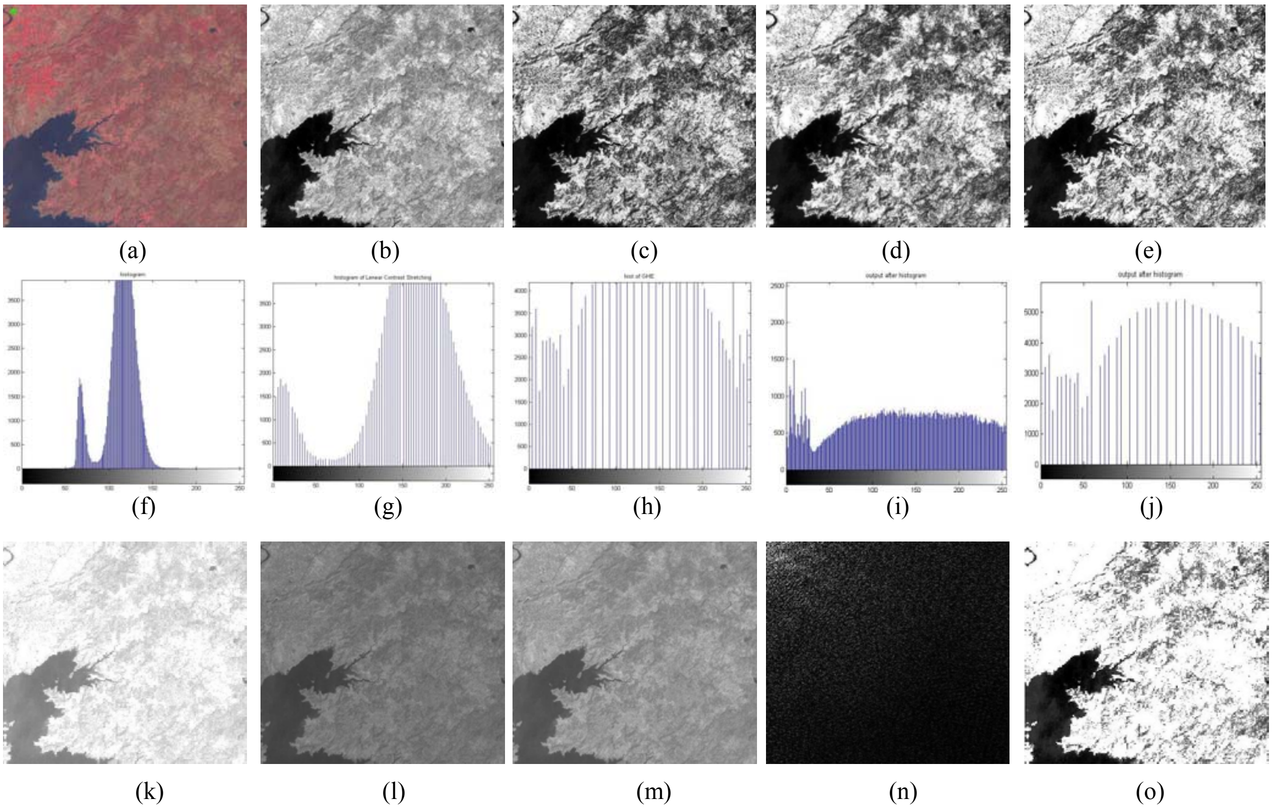

Fig. 6 Various resultant images using existing techniques and proposed technique.

[Fig.3, Fig.4, Fig.5 and Fig.6]: (a) Low contrast original image for analysis, (b) Equalized image by the Linear Contrast Stretching technique, (c) Equalized image by the GHE, (d) Equalized image by using DWT-SVD technique, (e) Equalized image by the proposed methodology using SVD-DCT technique, (f) Histogram of the input satellite image, (g) Histogram of the Linear Contrast Stretching output image, (h) Histogram of the GHE output image, (i) Histogram of the DWT-SVD technique, (j) Histogram of the proposed methodology using DCT-SVD technique, (k) Equalized image by using DWT technique (l) Equalized image by the Decorrelation Stretch technique, (m) Equalized image by using Gamma Correction technique, (n) Lower and higher frequency coefficient after applying DCT and (o) LL frequency component using DWT technique.

TABLE I
COMPARISON OF THE RESULTS BETWEEN DIFFERENT PROPOSED METHODOLOGY AND ALREADY EXISTING TECHNIQUE

Sr. No.	**Input Image Mean (μ) & Standard Deviation (σ)**	**DWT image Mean (μ) & Standard Deviation (σ)**	**Decorrelation Stretch Tech. Mean (μ) & Standard Deviation (σ)**	**Gamma Correction Mean (μ) & Standard Deviation (σ)**	**LCS Image Mean (μ) & Standard Deviation (σ)**	**GHE Image Mean (μ) & Standard Deviation (σ)**	**DWT-SVD image Mean (μ) & Standard Deviation (σ)**	**Proposed DCT-SVD Image Mean (μ) & Standard Deviation (σ)**
1	μ=162.018 σ=1.0767e+003	μ=401.832 σ=401.8321	μ=159.2671 σ=139.7900	μ=205.2559 σ=255.7578	μ=136.5033 σ=1.9981e+003	μ=127.2831 σ=5.6340e+003	μ=141.6760 σ=4.9526e+003	**μ=144.7128 σ=7.2827e+003**
2	μ=72.7006 σ=787.3876	μ=145.780 σ=2.8814e+003	μ=72.7006 σ=787.3901	μ=90.4819 σ=1.3150e+003	μ=129.5507 σ=2.4796e+003	μ=127.5886 σ=5.6067e+003	μ=97.8396 σ=2.9958e+003	**μ=150.2097 σ=7.7711e+003**
3	μ=123.906 σ=807.6552	μ=249.941 σ=1.0645e+003	μ=124.8362 σ=340.9537	μ=159.0034 σ=609.7450	μ=114.3337 σ=2.5902e+003	μ= 127.5320 σ=5.5745e+003	μ=123.5106 σ=4.0413e+003	**μ=135.7598 σ=6.3169e+003**
4	μ=114.854 σ=937.7782	μ=225.020 σ=1.3280e+003	μ=112.6464 σ=358.4536	μ=142.7744 σ=626.8973	μ=152.3935 σ=3.3372e+003	μ=127.6460 σ=5.5899e+003	μ=141.0827 σ=5.8780e+003	**μ=154.1794 σ=8.1553e+003**

V. CONCLUSION

In this paper, a novel technique based on SVD-DCT domain for enhancement of low-contrast satellite images has been proposed. The basic enhancement occurs due to scaling of singular values of the DCT coefficients. Performance of this technique has been compared with existing contrast enhancement techniques like histogram equalization, gamma correction and SVD-DWT based techniques. The experimental results show that the proposed technique gives better performance in terms of contrast (variance) as well as brightness (mean) of the enhanced image as compared to the other existing techniques. Thus, this technique can be considered suitable for enhancement of low contrast satellite image.

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