

Research Article

A Review of Image Contrast Enhancement Methods and Techniques

¹G. Maragatham and ²S. Md. Mansoor Roomi

¹Department of Electronics and Communication Engineering, Anna University, University College of Engineering, Ramanathapuram,

²Department of Electronics and Communication Engineering, Thiagarajar College of Engineering, Madurai, India

Abstract: In this study we aim to provide a survey of existing enhancement techniques with their descriptions and present a detailed analysis of them. Since most of the images while capturing are affected by weather, poor lighting and the acquiring device itself, they suffer from poor contrast. Sufficient Contrast in an image makes an object distinguishable from the other objects and the background. Contrast enhancement improves the quality of images for human observer by expanding the dynamic range of input gray level. A plethora enhancement techniques have though emerged, none of them deem to be a universal one, thus becoming selective in application. In such a scenario, it has become imperative to provide a comprehensive survey of these contrast enhancement techniques used in digital image processing.

Keywords: Automatic enhancement, histogram equalization, soft computing, spatial domain, stochastic resonance, transform domain

INTRODUCTION

Digital images are very important and have become integral part of everyday life. It finds numerous applications where digital images are pre-processed and used in such as surveillance, general identity verification, criminal justice systems, civilian or military video processing etc. Such applications require sufficient contrast that makes an object distinguishable from other objects and the background. In human visual perception, contrast is determined by the difference in the color and brightness of the object and other objects within the same field of view. It is also the difference between the darker and the lighter pixel of the image. Due to the poor quality of the imaging device, lack of expertise operator and the external adverse conditions, quality of the image or video will be in inadequate contrast.

Figure 1a shows the example of low contrast image taken at poor illumination and Fig. 1b is the histogram distribution of such a low contrast image where its Gray level spread is in limited low range. These problems occur due to the under-utilization of the accessible dynamic range. As a result, such images or videos may not reveal all the details in the captured scene, may have a washed-out and unnatural look. The question of increasing the visual appearance of these images looms large so that the image will be more interpretable and the aim of the contrast enhancement is to improve the

visual appearance of the image or to provide a better transformed representation for future processing such as analysis, detection, segmentation and recognition.

Image Contrast enhancement techniques can be broadly categorized into spatial domain methods and frequency domain methods or transform based methods. Spatial domain methods directly play on pixel intensity of the image, where as transform based methods manipulate image coefficients obtained by transforms such as Fourier Transform (FT), Discrete Cosine Transform (DCT), Wavelet Transform (WT), Curvelet Transform (CT) and etc for the enhancement of images. In the past decades, several contrast enhancement techniques based on gray level transformation techniques, such as sigmoidal (Naglaa and Norio, 2004), logarithmic and power law transformations (Snehal and Shandilya, 2012) have been suggested to improve the image contrast. Contrast enhancement using Retinex theory was first introduced by Land (2007). Jobson *et al.* (1997a) has explored contrast enhancement method for color images using single-scale retinex theory that also leads to good result. In recent years, many algorithms based on Retinex theory such as Multi Scale Retinex (MSR) (Rahman *et al.*, 1996), Multi Scale Retinex with modified Color Restoration (MSRCCR) (Jobson *et al.*, 1997b). The limitation of these approaches is that it requires more computation complexity. In some cases, object of interest in image may have less contrast compared to

Corresponding Author: G. Maragatham, Department of Electronics and Communication Engineering, Anna University, University College of Engineering, Ramanathapuram, India

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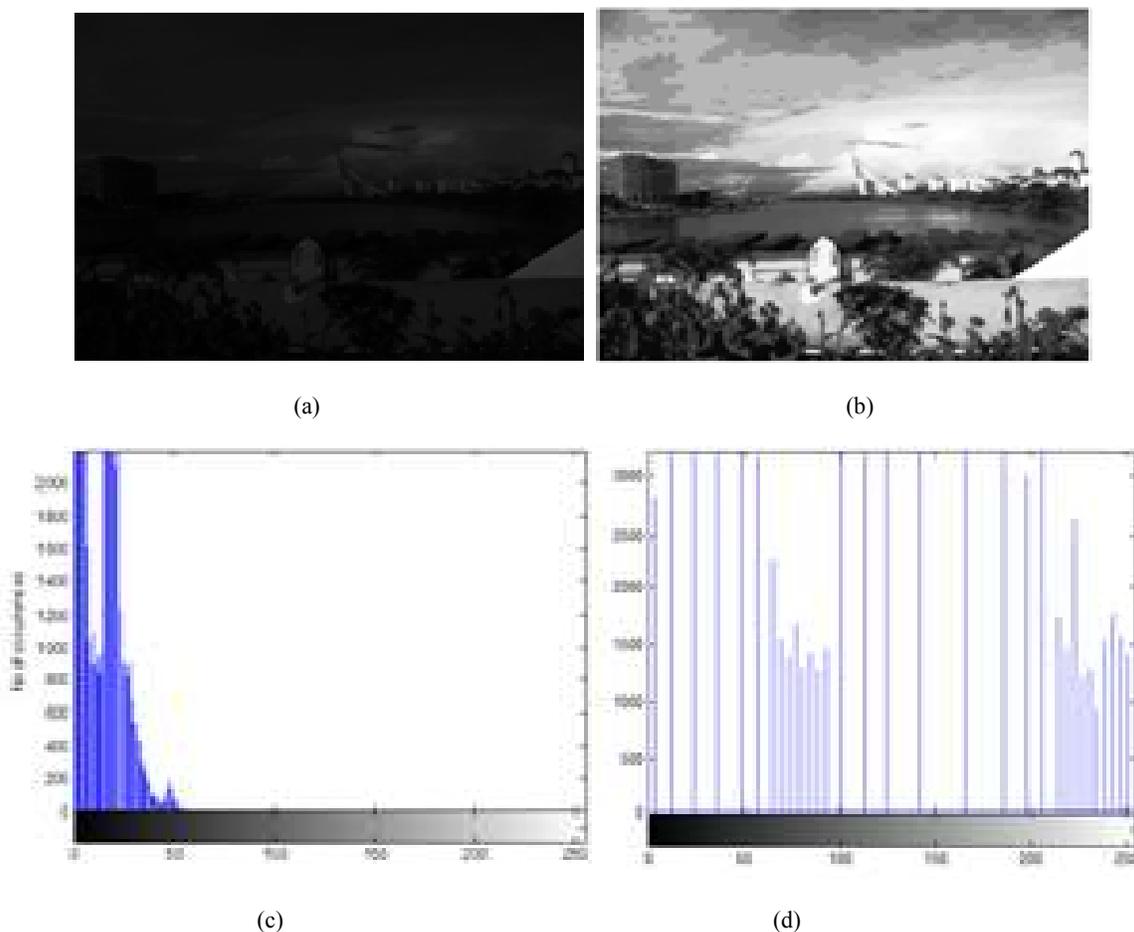


Fig. 1: Example image of low and high contrast image with their histogram distribution; (a): Low contrast city image; (b): Histogram distribution of low contrast image; (c): Enhanced city image; (d): Histogram distribution after enhancement

other regions in the image. A point operation is performed to enhance contrast of the image, so that these details become visibly appearance and natural look. Linear gray-level mapping and gamma correction are example for such a point wise contrast enhancement method. Contrast enhancement algorithms can also be divided into direct (Andrzej and Hong, 2009) and indirect method (In-Su *et al.*, 2010; Hanumantharaju *et al.*, 2011). Direct method defines a contrast measure and attempt to improve the image based on the measure computed for a given image. On the other hand, indirect method improves contrast of the image through stretching the dynamic range of the given without defining a specific contrast term. Up to now, many contrast enhancement algorithms have been proposed to improve the visual quality of poorly illuminated images. The main contribution of this study is of two-fold:

- Categorization of contrast enhancement algorithms into two groups as spatial domain based and transforms based contrast enhancement methods.
- Second, a comprehensive performance survey of all contrast enhancement algorithms.

SURVEY ON CONTRAST ENHANCEMENT

This section discusses about various techniques used for contrast enhancement of the images. Spatial domain enhancement includes histogram equalization and modification based, morphological based, evolutionary based and stochastic resonance based enhancement methods. Fourier Transform, Wavelet transform and curvelet transform based enhancement methods are grouped into the transform based image enhancement methods. Combinations of these two methods are presented as Hybrid methods and Automatic contrast enhancement methods.

Spatial domain based methods: Spatial domain methods favour many researchers attention because of its simplicity to understand and less computation complexity. Spatial domain process is denoted as:

$$g(x, y) = T[f(x, y)] \quad (1)$$

where,

$g(x, y)$ = The processed image
 T = The operator on f , the input image defined at the neighbourhood location of (x, y)

Several types of T functions have been proposed in the past decades which are based on histogram and its modification, stochastic resonance and morphology based operation and etc.

Histogram based methods: Histogram Equalization (HE) is one of the typical enhancement techniques in spatial domain methods. This technique is commonly employed for image enhancement because of its simplicity and comparatively better performance on almost all types of images. The operation of HE is performed by remapping the gray levels of the image based on the probability distribution of the input gray levels. The probability density of each gray level in the image is given as in Eq. (2):

$$p_k = \frac{n_k}{N}, k = 0, 1, \dots, m-1 \quad (2)$$

where, m is the maximum gray level used in histogram equalization. The cumulative density function for the image is defined as:

$$c(k) = \sum_j^{k-1} p_j \quad (3)$$

Using this cumulative density function the transform function for the image is written as:

$$f(k) = X_0 + (X_t - X_0)c(k) \quad (4)$$

The enhanced image of HE is obtained using:

$$Y = f(X(i, j)), X(i, j) \in X \quad (5)$$

It flattens and stretches the dynamic range of the images histogram and resulting in overall contrast enhancement as in Eq. (5).

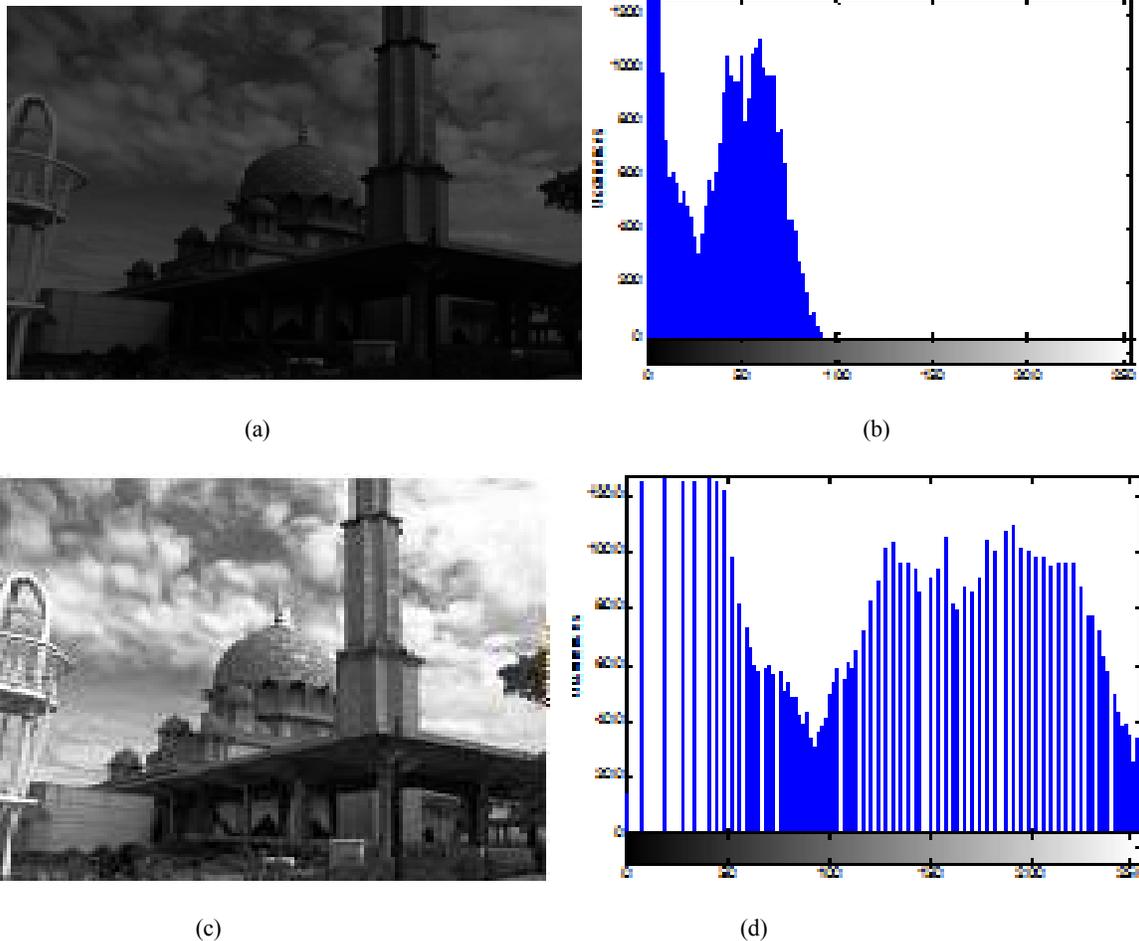


Fig. 2: (a): Original low contrast image; (b): histogram distribution of the original image; (c): Enhanced image using HE; (d): Histogram distribution of the HE enhanced image

Figure 2a shows original contrast image and its histogram distribution is shown in the Fig. 2b. Figure 2c and d show the enhanced image using HE method and its histogram spread. However, HE suffers from major drawbacks especially when implemented to process digital images and also this conventional HE fails with images having more homogeneous image regions. Figure 3a shows original low contrast girl image and its equalized image is shown in Fig. 3b. Figure 3c shows the result of HE enhanced image and Fig. 3d is histogram distribution after enhancement. From the Fig. 3c, it is shown that the HE method gives blocking artefact in the background which results in unnatural look. To overcome HE limitations, many advanced histogram-based contrast enhancement techniques have been explored, but most of them are modified version of conventional HE technique. Regional histograms are used to create locally varying gray scale transformations so that the image contrast can be improved in smaller regions. This procedure is generally referred to as Adaptive Histogram

Equalization (AHE) (Ketcham *et al.*, 1976). Figure 4 shows low contrast flower image and enhanced images using HE and AHE methods. A sliding window centered at each pixel is used, in which the local histogram is calculated and equalized, altering the value of that pixel. For an image of size $N \times N$ pixels, $2N$ local histograms need to be calculated. This time consuming procedure has been improved by Zimmerman *et al.* (1988).

The image is divided into blocks and the HE mapping is calculated only for each block and assigned to its central pixel. Then the mapping function for any other pixel is bi-linearly interpolated from the mapping functions of the pixel's four surrounding blocks. The only parameter to be determined in this method is the block size. It has been reported that this efficient AHE worked well for many images including chest radiographs and CT images.

The problem of excessive enhancement in ordinary histogram equalization is solved by a procedure called Contrast-Limited Adaptive Histogram Equalization

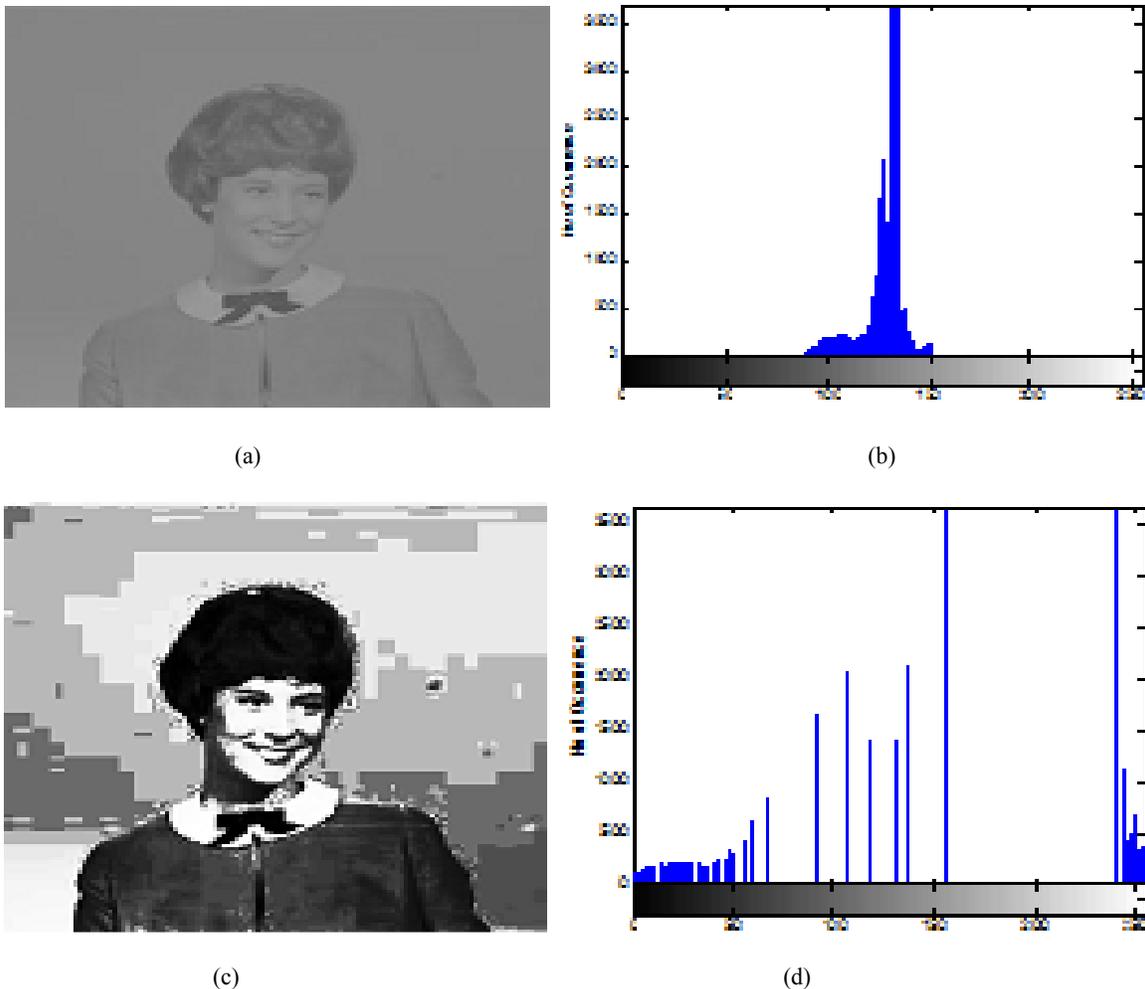


Fig. 3: (a): Original low contrast image; (b): Histogram distribution of the original image; (c): Enhanced image using HE; (d): Histogram distribution of the HE enhanced image

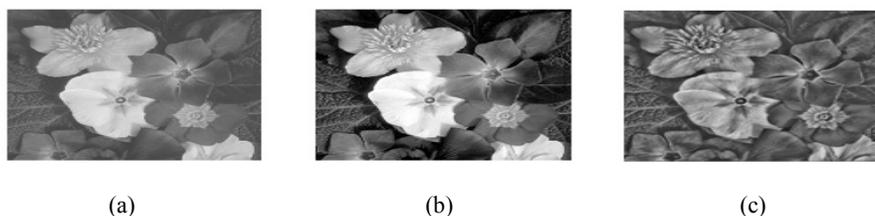


Fig. 4: (a): Original low contrast image; (b): Enhanced image using HE; (c): Enhanced image using AHE method

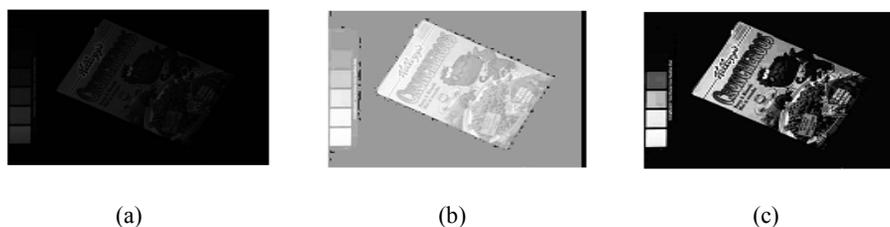


Fig. 5: (a): Original low contrast image; (b): Enhanced image using HE; (c): Enhanced image using BBHE method

(CLAHE) in which the local contrast gain is limited by restricting the height of local histograms (Pizer *et al.*, 1990). CLAHE is superior to AHE for its improved noise performance. Although it does not completely eliminate noise enhancement in smooth regions, the selection of contrast gain limit is image dependent. Histogram Specification (HS) is another method that takes a desired histogram by which the expected output can be controlled (Gonzalez and Woods, 2009). However specifying the output histogram is not a smooth task as it varies from image to image. A method called Dynamic Histogram Specification (DHS) generates the specified histogram dynamically from the input image (Sun *et al.*, 2005). This method can preserve the original input image histogram characteristics. However, the degree of enhancement is not that much significant.

Kim (1997a) proposed a contrast enhancement scheme using Brightness Preserving Bi-histogram Equalization (BBHE). BBHE that separates the input image histogram into two parts based on input mean. After separation, each part is equalized independently. After separation, each part is equalized independently. This technique tries to overcome the brightness preservation problem. Figure 5a shows low contrast Kellogg's image and Fig. 5b shows HE enhanced image and Fig. 5c is the enhanced result using BBHE method. From the Fig. 5b and c, it is evident that BBHE gives better visual appearance than HE. In Fig. 5b the background details of the Kellogg's image is appearing with over enhancement but BBHE gives sufficient overall brightness at the background behind the Kellogg's, leads image to have significant visual quality.

Mlsna *et al.* (1996) developed two novel image contrast enhancement approaches for color images which operate in 3-Dimensions and aim for full gamut

utilization. The first one is an extension of histogram explosion algorithm and other is the histogram decimation. Kim (1997b) later simplified his earlier work by quantizing discrete gray levels to have less hardware complexity. Caselles *et al.* (1997) developed a technique to equalize the image based on connected components. This technique requires very complex computation and hardware. Contrast Enhancement using Multi Peak Histogram Equalization (MPHE) is proposed by Wongsritong *et al.* (1997) where all histogram peaks are detected and independently equalized so that perceptibility is upgraded and mean brightness is preserved. Yu *et al.* (1998) presented an image enhancement based on Equal Area Dualistic Sub Image Histogram Equalization (DSIHE) which decomposes histogram into two equal area sub images based on its original probability density function and equalized independently. This technique enhances the image information effectively while maintaining original image luminance. Kim *et al.* (1998) proposed a contrast enhancement using spatially adaptive block overlapped HE with temporal filtering 1 for enhancing the contrast and suppressing the over- amplified noise. Stark (2000) proposed another adaptive contrast enhancement which uses generalization of HE. It provides a range of degrees of contrast enhancement through variation on cumulative density function. Kim *et al.* (2001) put forward an advanced contrast enhancement scheme using partially overlapped sub block HE. It uses low pass filter shaped mask to achieve quality improvement and is more effective and faster.

A global HE (GHE)-based enhancement technique that uses the Bin Underflow and Bin Overflow (BUBO) mechanism is proposed by Wang and Ward (2007), in which thresholds are set to the Probability Density Function (PDF) of the image using a lower (underflow)

threshold and an upper (overflow) threshold. HE is performed after thresholding. Both thresholds are obtained from one user controllable parameter, called ' α '. Minimum Mean Brightness Error Bi-Histogram Equalization (MMBEBHE) is the extension of BBHE technique that provides maximal brightness preservation (Chen and Ramli, 2003a). Recursive Mean Separate Histogram Equalization (RMSHE) is another improvement of BBHE which is based on multi-histogram decomposition (Chen and Ramli, 2003b). Figure 6 shows the low contrast couple image and its enhanced images using HE and modified HE methods. From the Fig. 6a to f, enhanced image using RMSHE gives better visual appearance compared to other existing HE based enhanced images. Figure 6f shows the poor performance of DSIHE method.

Though these techniques can perform good contrast enhancement, they also cause more annoying side effects depending on the variation of gray level distribution in the histogram. Cuizhu *et al.* (2004) presented a novel algorithm for color images that strikes a balance between histogram equalization and the maintenance of the pixel distribution of the image to produce realistic and good-looking HE pictures. Abdullah-Al-Wadud *et al.* (2007) projected a Dynamic Histogram Equalization [DHE] that enhances the image

without making any loss in image details. However, the extent of enhancement depends on a user defined parameter. Yafei *et al.* (2007) proposed new local HE by generalizing MMBEBHE and the partially overlapped sub-block HE to enhance the contrast details of images and preserve mean brightness. Menotti *et al.* (2007) suggested a Multi-HE, which decomposes the input image to sub images based on a cost function. This methodology performs a less intensive image contrast enhancement, in a way that the output image presents a more natural look but has a number of thresholds to control enhancement. However, the conventional HE and its modifications result over enhancement or under enhancement. A novel HE method called Weighted Mean Separated Histogram Equalization (WMSHE) using the piece histogram separation along with the piecewise transformed function was introduced (Pie-Chen *et al.*, 2010). In this method, first the histogram is divided into several sub-histograms precisely by using weighting mean function. Then, each piece of the sub-histograms is equalized with the piecewise transformed function to achieve better contrast enhancement.

Morphological based image enhancement: Andrzej and Hong (2009) proposed a morphological based

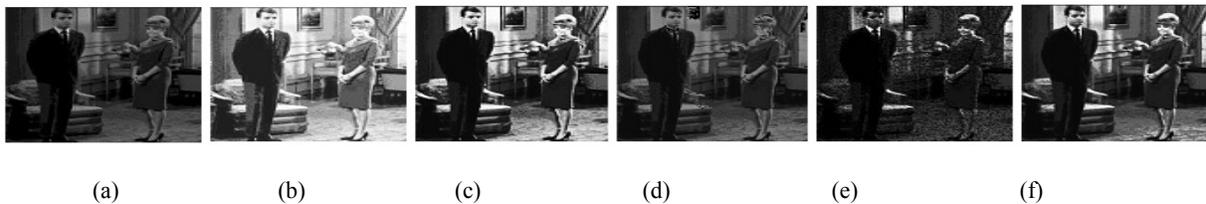


Fig. 6: (a): Original low contrast couple image; (b): Enhanced image using HE; (c): Enhanced image using BBHE; (d): Enhanced image using MPHE; (e): DSIHE enhanced image; (f): RMSHE enhanced image

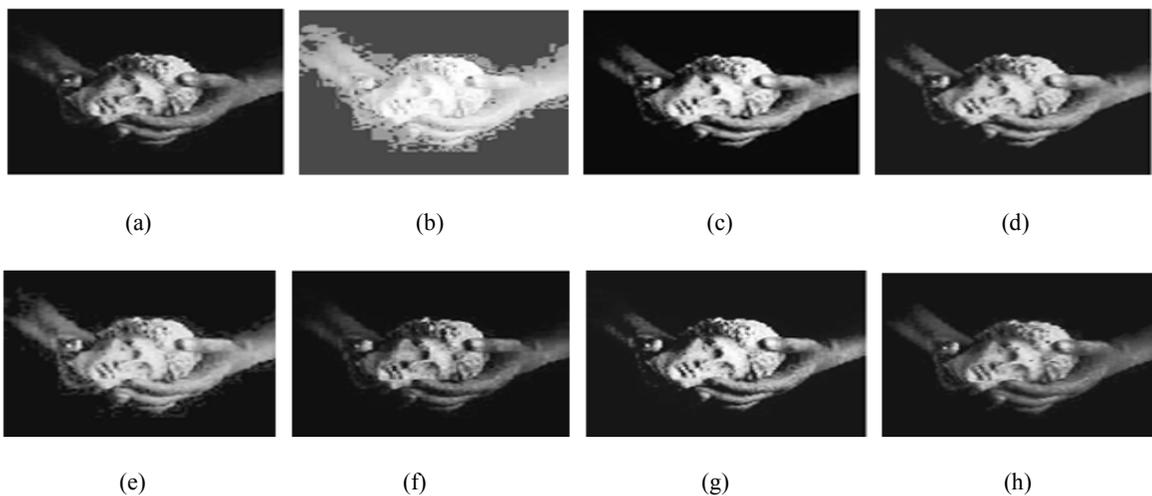


Fig. 7: (a): Original low contrast hand image; (b): Enhanced image using HE; (c): Enhanced image using GPHE; (d): Enhanced image using DSIHE; (e): MMBBHE enhanced image; (f): Enhanced image using MPHE; (g): Enhanced image using BBHE; (h): Object based enhancement method

enhancement method which is multi-scale, direct and adaptive for images with multiple objects of different sizes. But the result of this method significantly depends on the segmentation obtained from the morphological operation and local properties of the image.

An object based variant of HE method using morphological operation which tries to identify foreground and background pixels of an image has been proposed in Maragatham *et al.* (2011). Then bi-histogram equalization on the average mean of multi-objects present in the foreground and mean of background has been used as mean for BBHE enhancement. To segment foreground and background, morphology operation called opening by reconstruction is used which provides efficient segmentation. In this study, authors have observed that, this method gives better enhancement result for real time images as well as consumer electronic images (Television (TV) images). Figure 7a shows original low contrast hand image and its histogram equalized images using various HE methods are shown in Fig. 7b to g. Figure 7h shows enhanced image using object based image enhancement which gives natural look comparing to state of the art methods.

Similarly, Fig. 8a shows the original low contrast consumer electronics image and Fig. 8b to g show the enhanced images using HE modified methods Fig. 8h shows the enhanced image of object based enhancement method that gives better visual appearance but state of the art methods give more brightness with blocking artifacts. To test the performance of the object based enhancement method, author of the work as used quality measures such as Tenengrad, Peak Signal to Noise Ratio (PSNR) and contrast measure. The performance measures of the

images (hands and electronic image) using object based image enhancement result are shown in Table 1 and 2.

A method for enhancing ultrasound images based on multi-scale Morphology is explored by Bo *et al.* (2010). The main idea of this method is to preserve speckle region unchanged and enhance tissue boundaries. The speckle region is a similarity value obtained from histogram matching between the histogram in the processing window and a reference one derived from a speckle area. The intensity values of the scale-specific features of tissue boundaries area in the image extracted using multi-scale top hat transformation are modified to achieve local contrast enhancement. Locally enhanced features are combined to reconstruct the final enhanced image.

Table 1: Performance measure of object based enhancement method for hand image

Methods	PSNR	TENENG	Contrast measure
Original image	-----	181533	8.74
GPHE	18.04	105627	11.06
DSIHE	18.04	105627	11.06
MMBBHE	21.66	203126	9.39
MPHE	28.43	132225	8.72
HE	6.24	381296	11.48
RMSHE	30.05	196018	9.14
BBHE	20.45	321606	9.51
Object based	32.44	342229	13.44

Table 2: Performance measure of object based enhancement method for electronic image

Method	PSNR	TENENG	Contrast measure
Original image	-----	177388	12.92
GPHE	18.9433	489115	15.31
DSIHE	23.0926	660780	14.09
MMBBHE	22.7347	670353	14.14
MPHE	26.5946	504985	13.66
HE	20.3669	599525	14.95
RMSHE	25.9813	439082	14.8937
BBHE	23.8674	639524	13.9364
Object based	28.3523	1338859	17.6545

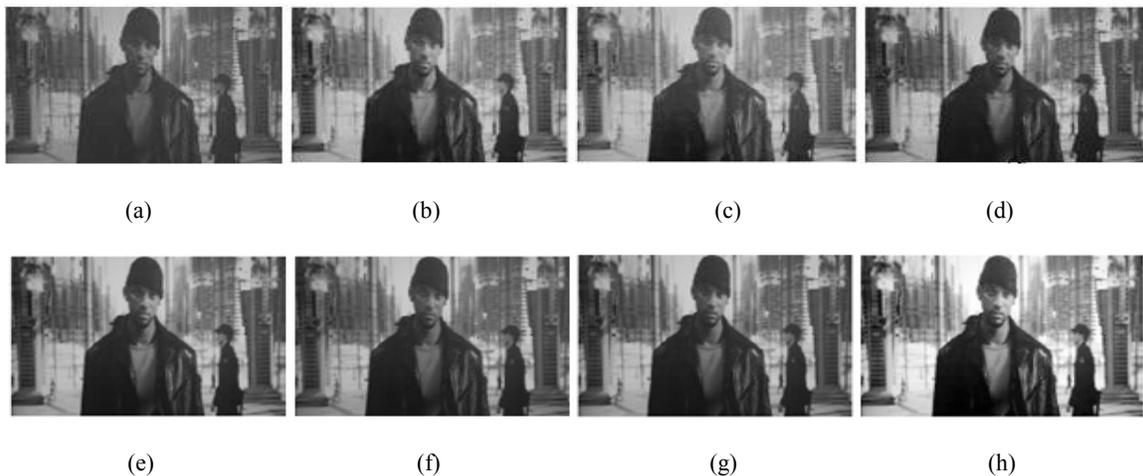


Fig. 8: (a): Original low contrast electronic image; (b): Enhanced image using HE; (c): Enhanced image using GPHE; (d): Enhanced image using DSIHE; (e): MMBBHE enhanced image; (f): Enhanced image using MPHE; (g): Enhanced image using BBHE; (h) Object based enhancement method

Soft computing based image enhancement: In recent years, a number of attempts have been made to treat contrast enhancement as an optimization problem. Due to flexibility in including desired properties for the enhanced images, optimization based contrast enhancement approaches have got attention. Contrast enhancement algorithm based on Genetic Algorithm (CEBGA) is presented to find a resultant histogram which maximizes a contrast measure based on edge information (Hashemi *et al.*, 2010). CEBGA suffers from the drawbacks, such as dependency on initialization and convergence to a local optimum. Hence, the resulting enhancement may not be reveal natural look. Furthermore, the convergence time of GA is proportional to the number of distinct grey levels of the input image. Unlike GA, Particle Swarm Optimization (PSO) has gained much interest towards contrast enhancement. PSO is tuned to obtain optimum solution such that the resultant image will be visually good. Malik *et al.* (2007) introduced enhancement method using PSO which maximizes fitness function in order to enhance the contrast and detail in the image. In this method, total number of pixels in the edge of the image serves as fitness function to PSO, such that image details will be more pleasing. Similarly, local and global contrast measures have been used as objective function to PSO for enhancing the low contrast image regions (Gorai and Ashish, 2009). Here, local entropy information and edge pixels of the image are used as objective function in PSO algorithm.

Kwok *et al.* (2006) have explored locally equalized contrast enhancement method using PSO technique. In this study, the image is initially partitioned randomly into several sectors and is equalized independently. Then PSO algorithm is tuned to obtain Gaussian weighting mask which helps to remove discontinuity along the sector boundary and determine the local regions where enhancement is needed. Kwok *et al.* (2009) explored image enhancement method using Multi-objective Particle Swarm Optimization (MPSO) technique. In this method, contrast enhancement is achieved by maximizing the information content carried in the image in continuous intensity transform function thereby enhancing the image using gamma correction method. Figure 9a shows the original low contrast image and Fig. 9b and c depict enhanced images using

GA and PSO technique. From these Fig. 9b and c, the enhanced image using PSO gives better visual appearance and sharpness in details compared to GA based enhancement.

Due to computational complexity of the optimization techniques, fuzzy based methods are widely used for contrast enhancement. Moreover, the definition of contrast of an image is fuzzy as well. Therefore, Cheng and Xu (2000) have applied fuzzy set theory to contrast enhancement. They introduced a novel adaptive direct fuzzy contrast enhancement method based on the fuzzy entropy principle and fuzzy set theory. This algorithm is very effective in contrast enhancement as well as in preventing over and under enhancement. Pal and King (1981) has used smoothing method with fuzzy sets to enhance images. They applied contrast intensification operations on pixels to modify their membership values. Li and Yang (1989) have used fuzzy relaxation technique for image enhancement.

Stochastic resonance based enhancement: Though, several contrast enhancement techniques have been exploited till now, stochastic resonance based enhancement method is of a greatest interest of many researchers. The Stochastic Resonance (SR) was first introduced by Benzi *et al.* (1981) for searching earth climatic change. In earlier years, it is demonstrated that noise plays important role in enhancing weak signals (Bulsara and Gammaitoni, 1996). The SR is defined by the nonlinear Langevin equation for one variable as:

$$x(t) = ax(t) - bx^2(t) + c \sin(\Phi(t)) + \zeta(t) \quad (6)$$

where,

a, b = Real parameters

c = The signal amplitude

Φ = The modulation frequency

$\zeta(t)$ = The zero mean white Gaussian noise function

For one dimensional signal, the stochastic version of Euler-Maruyamas iterative discretized equation in is written as:

$$x(n+1) = x(n) + \Delta t [ax(n) - bx^3(n) + Input(n)] \quad (7)$$



Fig. 9: (a): Original low contrast image; (b): GA based enhancement image; (c): Enhanced image using PSO technique

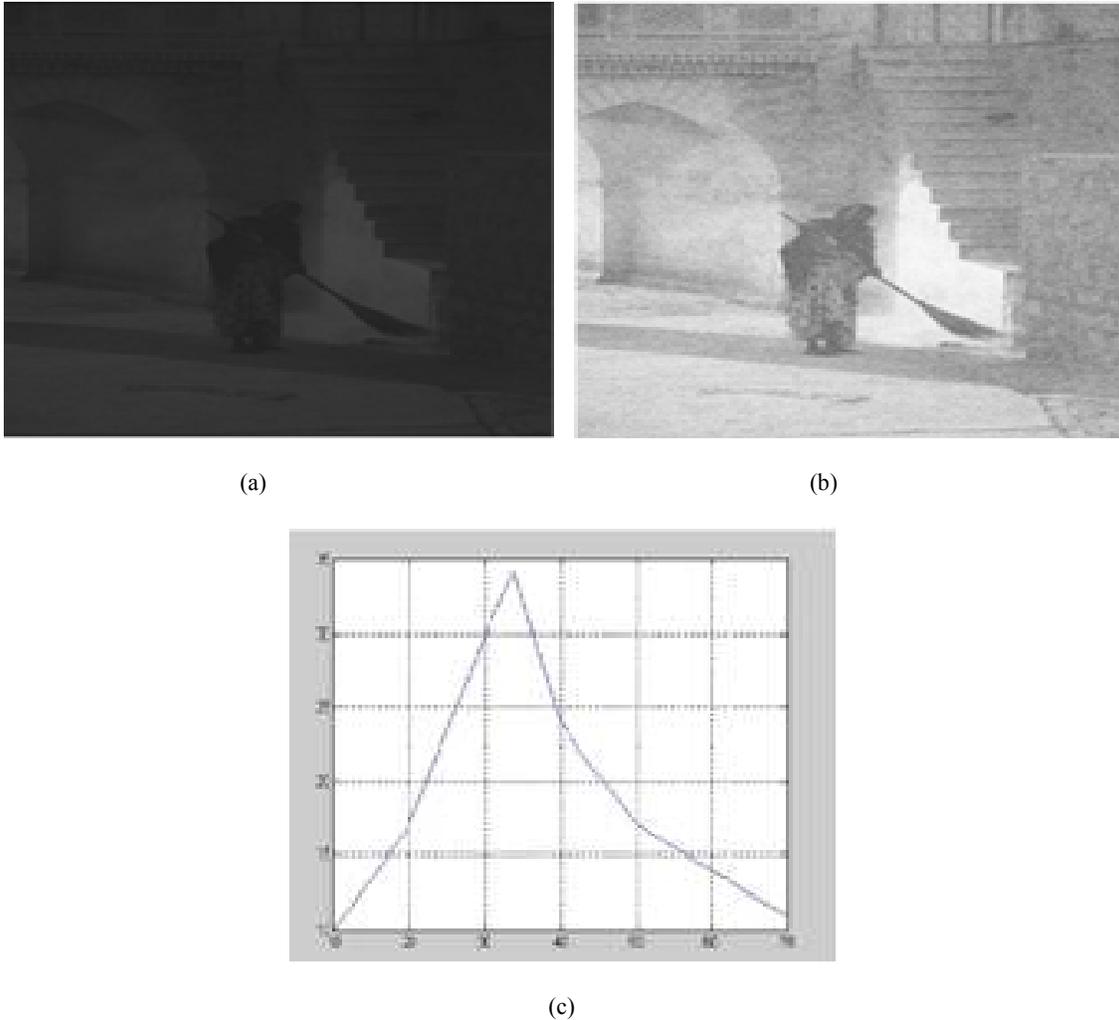


Fig. 10: (a): Original low contrast sweeper image; (b): Enhanced image using stochastic resonance technique; (c): PSNR vs. noise standard deviation for sweeper image

where, $Input(n) = B \sin(\Phi(t)) + \sqrt{D} \zeta(t)$ denotes the sequences of input signals with Gaussian noise signal with initial condition $x(0) = 0, a = 2\sigma_0^2, b = \frac{4a^3}{27}$, B is the amplitude, Φ is frequency of the periodic signal and Δt is the sampling time.

Earlier, SR has originated wide applications in 1-D signal processing such as controlling Schmitt trigger, Low power signal detection, transmission of aperiodic signal and etc. But, later this concept was extended to image processing applications such as contour detection in image, edge enhancement contrast enhancement and etc. At first, Qinghua *et al.* (2004) used stochastic resonance for enhancing the low contrast sonar image. Jha *et al.* (2005) have interestingly used this SR concept for contrast enhancement of real time images. The temporal noise of different standard deviation is added to the input low contrast image, to amplify the weak signal present in the image. After adding noise to the intensity of the image, thresholding is employed to find

the signal transition from one state to another state which helps to improve the contrast of the image. The transition state takes place when $I(x, y) + \zeta(t) \geq \Delta$ where Δ is the threshold. Finally, all the images are averaged to get enhanced stochastic image. Similar process is followed for various standard deviations of the Gaussian noise, to obtain the stochastic image with higher contrast. In this study, Peak Signal to Noise Ratio (PSNR) is used as measure to find the resonance of stochastic images, the image with maximum PSNR is the stochastic resonance image. Figure 10c shows PSNR versus noise standard deviation curve; from the Fig. 10c it is observed that it follows a resonant nature. Figure 10a is the original low contrast sweeper image and Fig. 10b is the stochastic resonance based enhanced image. Peng *et al.* (2007) have used this stochastic resonance concept to improve the low contrast medical images and found that it gives better enhancement result. Similarly, interesting approaches for the enhancement of MRI (Rallabandi and Roy, 2010) and

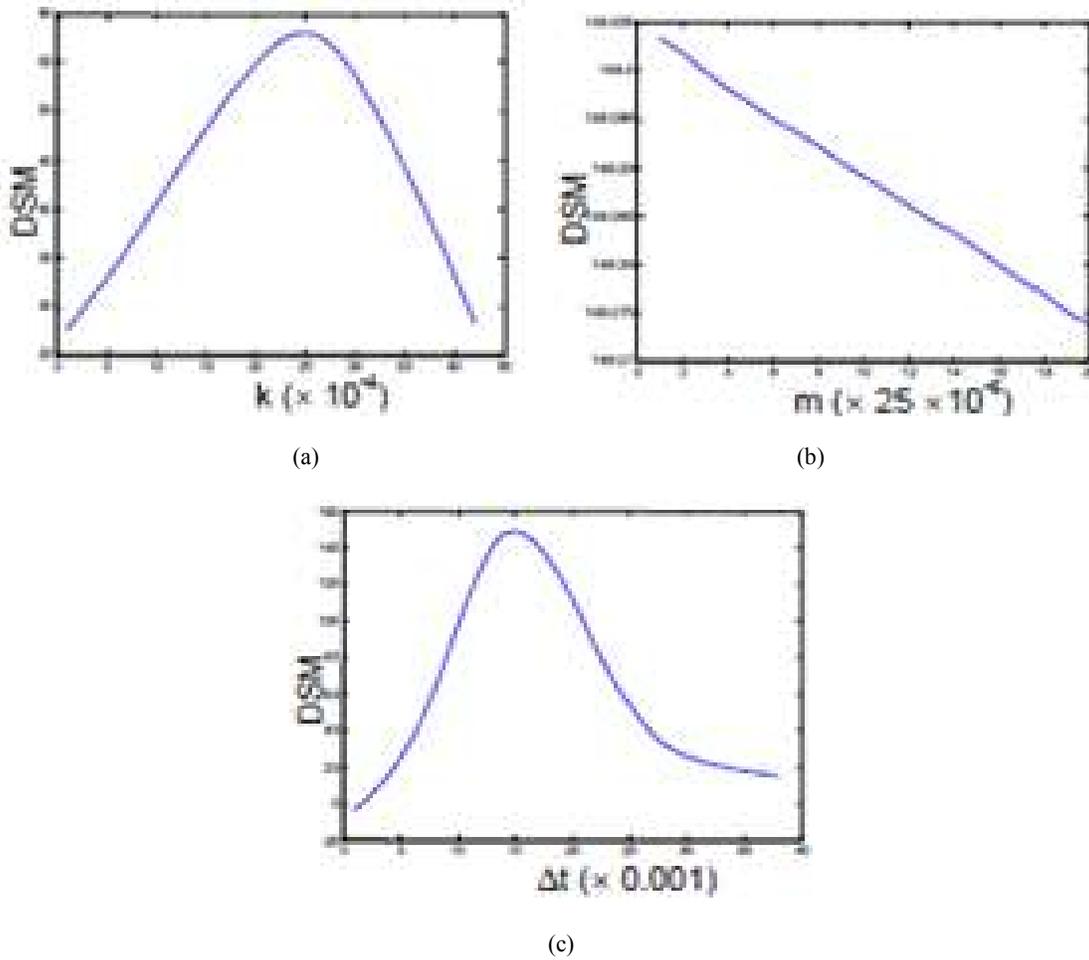


Fig. 11: Graph for low contrast Lena image; (a): DSM vs. k ; (b): DSM vs. m ; (c): DSM vs. Δt , DSM is observed to be maximum at $k = 25 \times 10^{-4}$, $m = 10^{-6}$ and $\Delta t = 0.015$ (Rallabandi and Roy, 2010)



Fig. 12: (a): Low contrast Lena image; (b): DSR-DWT based enhanced image; (c): Enhanced image using DSR-DFT; (d): HE equalized image

ultrasound images (Rallabandi, 2008) using stochastic resonance with Fourier and wavelet transform were developed. In these works, it is proved that stochastic resonance provides better enhancement for the medical images in detecting diagnosis compared to other conventional methods.

Chouhan *et al.* (2012) have proposed a novel method using Dynamic Stochastic Resonance (DSR)-based technique in Discrete Wavelet Transform (DWT) domain for enhancing very dark gray-scale and color images. The main idea is to obtain the resonance in the

performance measures such as Distribution Separation Measure (DSM), target to background enhancement measure based on standard deviation (TBEs) and target-to-background enhancement measure based on entropy (TBEe). During the experimentation, they have used 2000 iterations and observed the maximum resonance of DSM when $k = 25 \times 10^{-4}$, $\Delta t = 0.015$ and $m = 10^{-6}$ as in Fig. 11a to c.

The results of Lena image is shown in Fig. 12. Figure 12a shows original low contrast image and its enhanced images are shown in Fig. 12b to d.

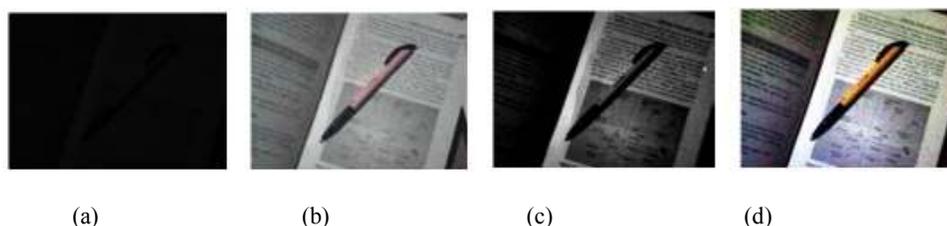


Fig. 13: (a): Original low contrast book image; (b): DSR-DWT based enhanced image; (c): Enhanced image using DSR-DFT; (d): HE equalized image

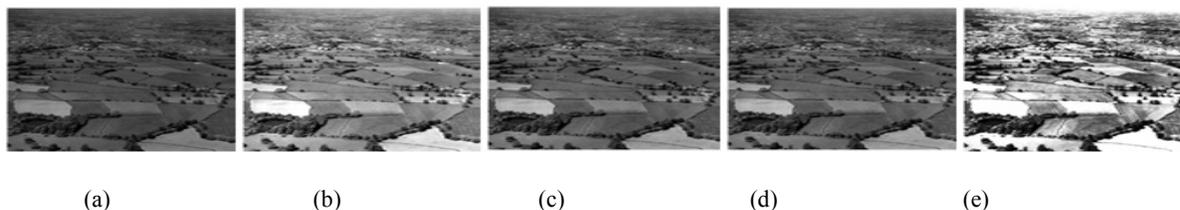


Fig. 14: (a): Original low contrast image; (b): Equalized image by the linear contrast stretching technique; (c): Equalized image by the GHE; (d): Equalized image by using Gamma correction technique; (e): Equalized image by the proposed methodology using SVD-DCT technique

Enhanced image using DSR-DWT shown in Fig. 12b shows better natural looking effect. Similarly, the low contrast book image and its enhanced images using DSR-DWT, DSR-DFT and HE are shown in Fig. 13.

Other methods for enhancement: Conventional methods, blindly applies enhancement algorithm without seeing the whole image discretely which results unnecessary details of the image to be enhanced. Hence, Mansoor Roomi *et al.* (1999) proposed a new method which identifies visually significant regions based on statistical measure and then enhances images using HE. Vinod and Tarun (2012) discussed two methods for image enhancement using fusion techniques which fuses enhanced image with gradient map image obtained from source and equalized edge map images. First method uses weights assigned by the user for enhancement whereas second method assigns weights automatically. Even though, this method preserves sharpness well, it fails if noise presents in the image.

Though, plenty of enhancement methods have been introduced for real images, only few methods are available for improving the quality of the radiometric images. Bhandari *et al.* (2011) proposed a novel contrast enhancement technique for low-contrast satellite image using Singular Value Decomposition (SVD) and Discrete Cosine Transform (DCT). Here the image is equalized using HE initially then SVD is applied after transforming the enhanced image using DCT. SVD represents the intensity information of the image; its values are more dependant on intensity change of the input image. Then DCT is applied to the

normalized SVD coefficients to get the SVD-DCT image. Finally, using the SVD coefficients the inverse DCT is applied to obtain the enhanced image result.

Figure 14a shows original low contrast remote sensing image and Fig. 14b to e show enhanced images using Linear contrast stretching, GHE, Comma Correction and SVD-DCT methods. The enhanced images shown in Fig. 14c to d have no improvement in enhancement. Even though GHE enhanced image shown in Fig. 14b gives better result compared to Fig. 14c and d some of the details are not revealed explicitly. But enhanced image in Fig. 14d contributes better brightness in details as well as visual appearance.

TRANSFORM BASED METHODS

Transform domain enhancement techniques make use of transforms like DCT, wavelets, curvelet and etc as basic functions. Due to the compatibility, processing in the DCT domain has attracted great attention. A contrast measure defined in the DCT compressed domain between successive bands of AC coefficients is scaled for enhancement (Tang *et al.*, 2003). Lee and Lertrattanapanich (2005) has proposed a similar approach for AC coefficients adjustment, but in an adaptive way for every image block. Recently, Gabor filters are widely used towards the image enhancement process. Yang and Baoxin (2005) proposed a non-linear selective contrast enhancement method which uses Gabor filter for enhancing the image in TV applications. This method uses contrast sensitivity function for selective contrast enhancement based on human visual system to improve the perceived visual quality of the television images.

Wavelet based enhancement technique: Wavelet-based image analysis offers the opportunity to enhance images using features extracted at different scales and sub-bands. In a two-part wavelet domain image enhancement method, a locally adaptive filter is applied to the wavelet transform detail coefficients to simultaneously suppress noise and enhance edge contrast (Xu *et al.*, 1994). Approaches based on wavelet transform, Tenengrad operator and human visual properties using multi scale information to improve the unsharp masking image enhancement is proposed in (Mao-Yu *et al.*, 2002). Image contrast enhancement via multi scale gradient transformation achieves contrast by modifying the modulus of the gradient image at multiple scales. Yet another wavelet based approach, the approximation coefficients are histogram equalized and detailed coefficients are high boost filtered to achieve robust contrast and edge enhancement (Lu and Healy Jr, 1994). Enhancements on wavelet coded images were proposed to avoid blocking artifacts in DCT coded images and ringing artifacts in wavelet coded images. Here an edge direction in a image block is detected and an appropriate window is applied to the decoded block of nonlinear filtering (Jinhui and El-Sakka, 2003). Recently, Cheng *et al.* (2010) has introduced wavelet based enhancement method which decomposes image using wavelet transform then making use of wavelet coefficients it performs the contrast enhancement.

Curvelet based enhancement technique: Curvelet transform based contrast enhancement was probed by Starck *et al.* (2003). The curvelet transform represents edges better than wavelets and is therefore well suited for multi-scale edge enhancement. In a range of examples, authors used edge detection and segmentation among other processing applications, to provide quantitative comparative evaluation. It is found that curvelet based enhancement outperforms other enhancement methods on noisy images. But on noiseless images curvelet based enhancement is not better than wavelet based enhancement. Brightness preserving contrast enhancement using curvelet and Histogram matching is addressed in Rajavel (2010). In this study bright regions of the original image are identified by the curvelet transform and modified with

respect to their respective histogram. Enhanced output images with no artifacts, better improved visual quality and brightness preservation are generated by this technique.

ENHANCEMENT USING HYBRID METHODS

There exists methods that use spatial and frequency information as hybrid function to enhance images. An approach to enhance the image using semi HE based on cosine function computed for low contrast image have been discussed (Celik and Tjahjadi, 2012). This method works well even if the image is darker in nature. Chaofu *et al.* (2012) have explored a hybrid technique to enhance the image. This method uses the Gauss filter to enhance image details in the frequency domain and smooth the contours of the image by the morphological operations (top-hat and bot-hat) in spatial domain. This method is more suitable to enhance the details of the infrared images, but the limitation of this method is that the contour of the image is also smoothed. Recently, a hybrid technique by combining Non Subsampled Contourlet Transform (NSCT) with CLAHE to give better enhancement for the low contrast image has been explored (Najafi and Zargari, 2011). Here, initially NSCT is applied to the given image, then according to the NSCT coefficients fuzzy membership function is modified using the frequency transform. Finally inverse NSCT is applied to reconstruct the image and CLAHE is applied to get the enhanced image.

Even though, several enhancement methods have been made to enhance real time image, only few methods have concentrated to improve the image quality of medical images. A hybrid method using region based CLAHE with additive gradient for the enhancement of medical images such as MRI and CT images has proposed (Sonia Goyal, 2011). In this approach, region growing method is used to segment image into background and foreground region, then CLAHE is applied to enhance the foreground and background regions separately. Then the enhanced background and foreground images are combined to get resultant enhanced image. In order to improve the visual quality of the image the resultant enhanced image is fused with gradient map image which is computed from the original.

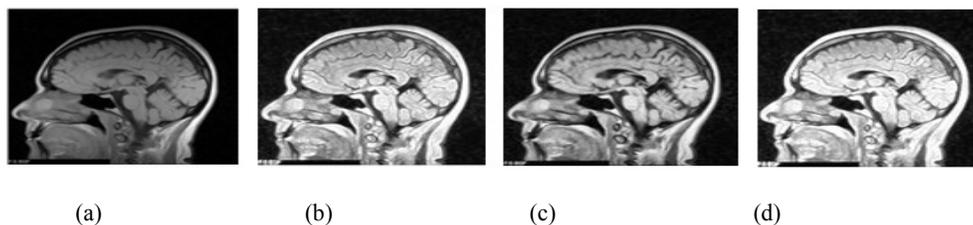


Fig. 15: (a): Original MRI brain image; (b): Enhanced using CLAHE; (c): Enhanced image using RBACE; (d): Enhanced image using RBCLAHEG

Figure 15a shows original MRI brain image and Fig. 15b to d are the results of enhanced images using CLAHE, Region Based Adaptive Contrast Enhancement (RBACE) and Region Based Contrast Limited Adaptive HE with Additive Gradient (RBCLAHEG), respectively. From the Fig. 15d, it is shown that the enhanced image using RGCLAHEG gives better visual appearance and the details in the brain region are visually more agreeable.

AUTOMATIC CONTRAST ENHANCEMENT TECHNIQUE

Importantly, most of the existing techniques discussed above require interactive procedures, to obtain satisfactory results and therefore are not suitable for automated enhancement applications. Besides requiring the user interaction, many such techniques require specification of external parameter like contrast gain, which sometimes are difficult to fine tune. By employing a multiple regression technique, a partial automation is attempted based on subjective evaluations done by human interpreter for enhancement of a given

image (Munteanu and Rosa, 2004). Two techniques for performing a fully automated contrast enhancement of radiological images were proposed in Digalakis *et al.* (1993). In the first technique, a regionally adaptive filtering algorithm takes into account the nonlinear relationship between film exposure and image quality. The second technique facilitates the display of 16-bit digital x-rays on 8-bit displays. Battiato *et al.* (2004) have developed a method for automated exposure correction using feature extraction technique. The effect of contrast improvement on noisy images is studied and a novel technique for automated enhancement of noisy images by combining sharpening and smoothing is proposed (Fabrizio, 2005). An automated contrast enhancement system for video, which selects suitable mapping functions for luminance contrast mapping based on histogram analysis, is presented (Goh *et al.*, 2004). Cuizhu *et al.* (2004) presents an automated image quality improvement in video conferencing system, by correcting the exposure and enhancing the contrast. This technique works for typical applications such as face segmentation and fail for natural images since the work is based on exclusive skin color model.

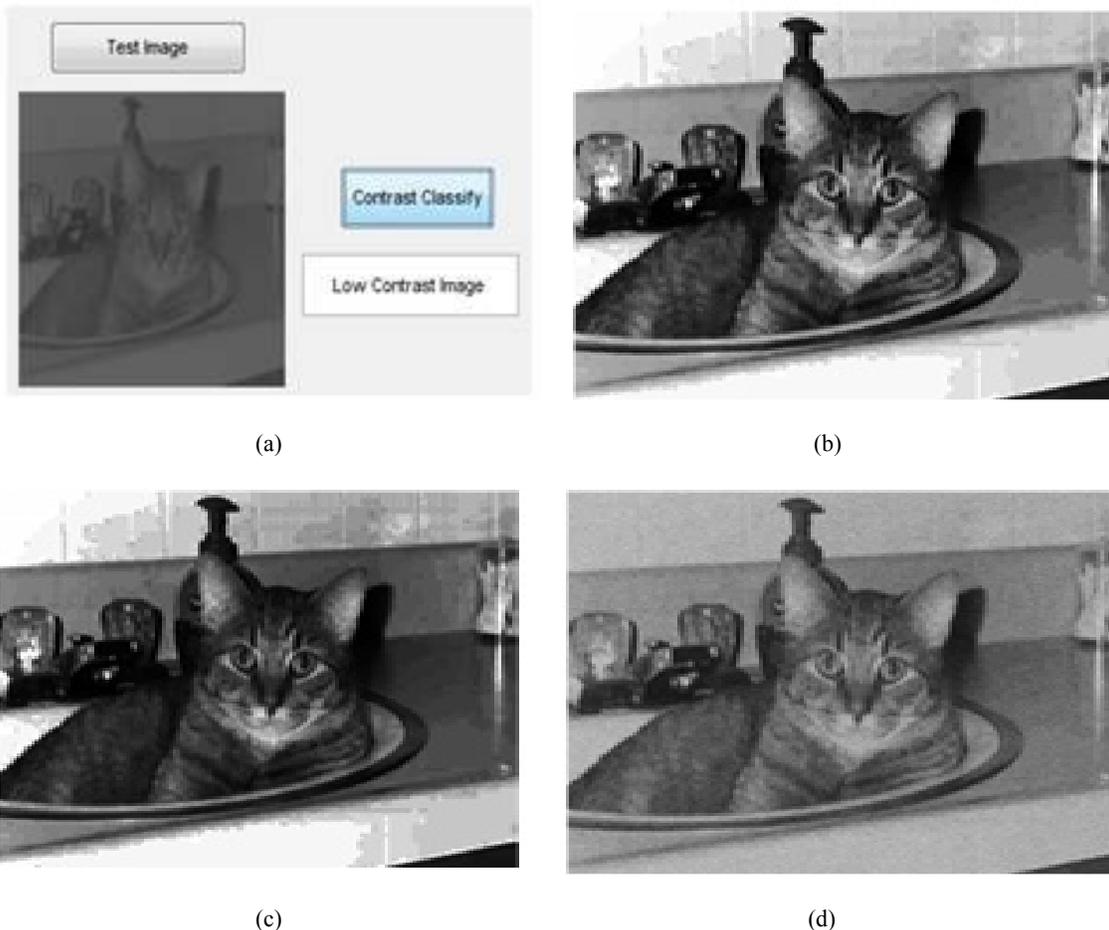


Fig. 16: (a): Original low contrast cat image and its contrast classified result; (b): Enhanced image using HE; (c): Enhanced image using DSiHE; (d): Proposed method

Sangeun (2007) presented a content based contrast enhancement method using retinex theory. Though this algorithm enhances the details in dark and bright areas, it works only in compressed domain and blurs images. An automatic contrast enhancement method based on basic Gray Level Grouping (GLG) has been developed by ZhiYu *et al.* (2006a). GLG is a general technique, still has limitations and cannot enhance low contrast images superbly. To overcome this, the same authors have proposed Selective Gray Level Grouping (SGLG) (ZhiYu *et al.*, 2006b). Though SGLG is automated, it still requires user intervention in order to yield the best results for desired applications.

Recently, an automatic contrast enhancement method using stochastic resonance has been introduced for low contrast images (Maragatham and Mansoor Roomi, 2013). In this approach, based on experimentation of more number of low contrast as well as high contrast images, contrast measures computed have been modelled as Gaussian. For a given test image, contrast measure is calculated and modelled as Gaussian, then similarity function is calculated between training and testing Gaussian model. The test image is

then categorized into either low contrast or high contrast based on similarity measure value.

Figure 16a shows original low contrast ‘Cat’ image, used to analyze the proposed technique. Figure 16b and c show the traditional histogram equalized images of low contrast ‘Cat’ image. From the Fig. 16b and c, it is shown that the methods HE and DSIHE fail to reduce over enhancement in background regions and also enhanced images look unnatural. Figure 16d shows the enhanced result obtained using proposed method. The proposed method offers sufficient overall brightness at the background and the objects behind the ‘Cat’ is also having significant visual quality.

Apart from the gray scale images, color images have also been tested. Figure 17a shows original low contrast colour plate image and enhanced version of the image using HE are shown in Fig. 17b and c. It is evident from the results (Fig. 17b and c) that the HE and its modified version do not contribute pleasing appearance. Moreover, the details of the images are over enhanced. On the other hand, proposed method gives better enhancement in the structural details

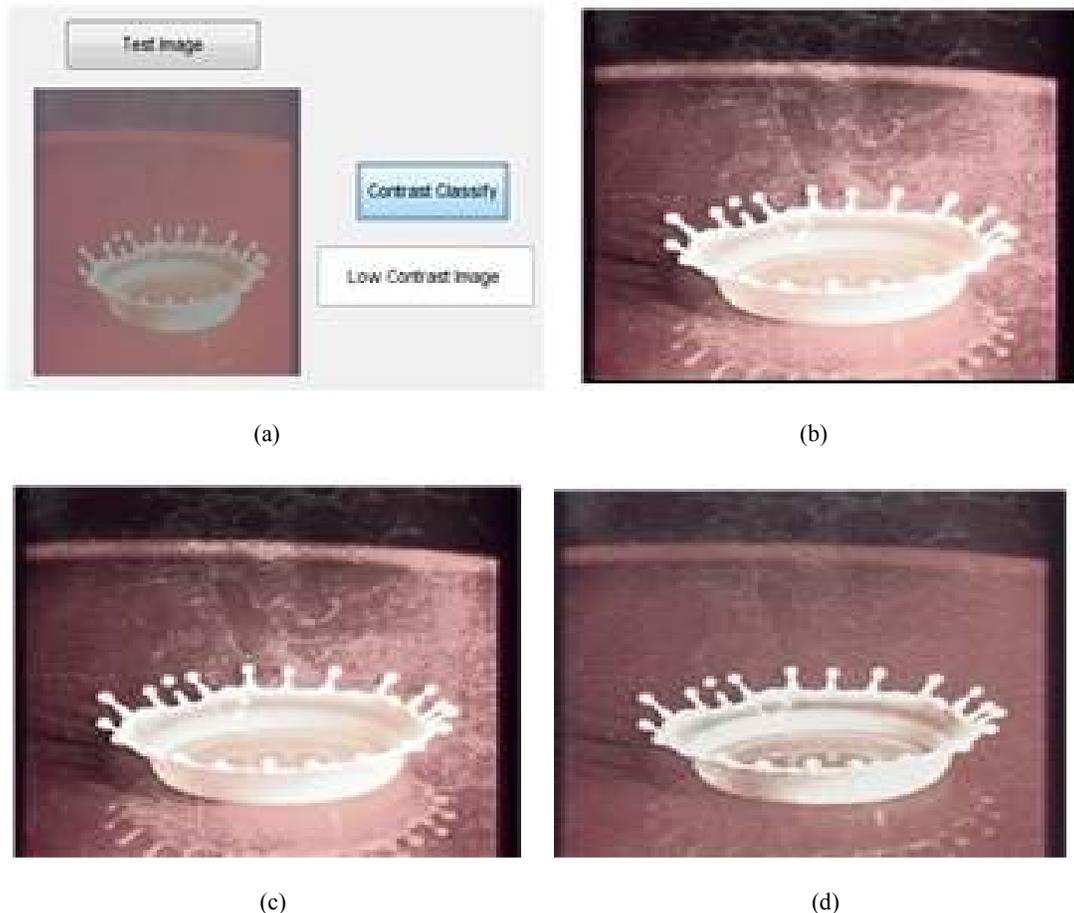


Fig. 17: (a): Original low contrast color plate image and its contrast classified result; (b): Enhanced image using HE; (c): Enhanced image DSIHE; (d): Proposed method

Table 3: Performance measure using TENENG

Images	Original image	HE	DSIHE	Proposed method
Cat	367521	1990194	1504577	10547820
City	0	1121090	2173933	7975890
Car	801777	2832151	2749295	13670805
Hand	744013	828464	571908	6099855
Girl	787160	2295403	1588626	3894105

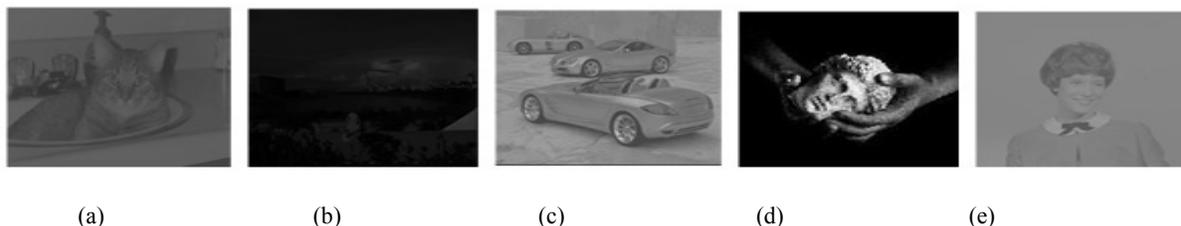


Fig. 18: Low contrast images; (a): Cat image; (b): City image; (c): Car image; (d): Hand image; (e): Girl image

of the object compared to other existing methods (Fig. 17d). To confirm the efficiency of the proposed method in enhancement, TENENG is measured and is compared with existing HE and DSIHE techniques.

Table 3 shows the TENENG measure before and after enhancement for various test images such as cat, city, car, hand and girl shown in Fig. 18. From the Table 3, it is shown that the proposed method achieves better visual quality as well as larger TENEG value compared to state of the art algorithms.

CONCLUSION

A survey on various contrast enhancement methods and techniques is presented. Image enhancement techniques, comprise a wide variety of approaches to attain visually acceptable images. The choice of such techniques is a function of the specific task, image content, observer characteristics and viewing conditions. In this survey, the review is focused on various contrast enhancement methods such as spatial domain methods and frequency domain methods, hybrid methods and automatic enhancement algorithms. The advantages and disadvantages of the respective algorithms and the applicability of these techniques in various application domains are also discussed.

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