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Image enhancement using Exposure based Sub Image Histogram Equalization

Kuldeep Singh [a,*], Rajiv Kapoor [b]

[a] Central Research Lab, Bharat Electronics Ltd., Ghaziabad 201010, India
[b] Department of Electronics & Communication, Delhi Technological University, Delhi 110042, India

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ABSTRACT

This paper presents a novel Exposure based Sub-Image Histogram Equalization (ESIHE) method for contrast enhancement for low exposure gray scale image. Exposure thresholds are computed to divide the original image into sub-images of different intensity levels. The histogram is also clipped using a threshold value as an average number of gray level occurrences to control enhancement rate. The individual histogram of sub images is equalized independently and finally all sub images are integrated into one complete image for analysis. The simulation results show that ESIHE outperforms other conventional Histogram Equalization (HE) methods in terms of image visual quality, entropy preservation and better contrast enhancement.

1. Introduction

Image enhancement techniques have gained attention of researchers from early years. Image enhancement improves the appearance of image and enhances the finer details of image having low luminance. These enhancement techniques can be broadly divided into two categories – transform domain and spatial domain (Gonzalez and Woods, 2002). The first category involves techniques operating on frequency transform of an image. Spatial domain techniques such as contrast enhancement operate directly on the pixel level of the image. Histogram Equalization (HE) is most extensively utilized contrast enhancement technique due to its simplicity and ease of implementation. Histogram equalization (Gonzalez and Woods, 2002) flattens the density distribution and stretches the dynamic range of gray levels to improve the overall contrast of the image. HE utilizes the cumulative density function (CDF) of image for transformation of the gray levels of original image to the levels of enhanced image. The main drawback of HE is that it tends to change the mean brightness of the image to the middle level of the dynamic range and results in annoying artifacts and intensity saturation effects. This drawback makes HE technique unsuitable for most of consumer electronics applications such as TV and Cameras.

Various methods have been suggested in the literature to overcome the above-mentioned shortcomings. Kim (1997) was the first one to propose Brightness preserving bi histogram equalization (BBHE) for preserving the mean brightness of image while improving the contrast. BBHE divides the histogram into two parts based on the input mean brightness and equalizes the two sub histograms independently. Dualistic sub image histogram equalization (DSIHE) (Wan et al., 1999) method claimed that it is better than BBHE in terms of preservation of brightness and average information content (entropy) of an image. DSIHE divides the histogram into two sub histograms containing equal number of bins and the division is based on median value instead of mean brightness.

Chen and Ramli (2003a,b) introduced minimum mean brightness error bi-histogram equalization (MMBEBHE) for preserving the mean brightness "optimally". This method is an improvement on BBHE, which calculates the absolute mean brightness error (AMBE) for gray levels 0 to $L-1$ and bisects the histogram based on the intensity value X_T, which yields minimum AMBE.

Chen and Ramli (2003a,b) proposed another approach named recursive mean-separate histogram equalization (RMSHE). This method recursively performs the BBHE in which the histogram is divided into two parts on the basis of average input brightness and BBHE is performed to each sub histogram independently. Sim et al. (2007) introduced a similar technique to RMSHE known as recursive sub-image histogram equalization (RSIHE). This algorithm performs the division of histogram based on median value of brightness instead of mean brightness. Finding the optimal value of iteration factor is a big challenge for producing significant enhancement results in RMSHE and RSIHE methods.

These above discussed techniques do not provide mechanism for adjusting the level of enhancement. New class of techniques based on clipping of histogram (Wang and Ward, 2007; Kim and Paik, 2008; Ooi et al., 2009) was proposed as a solution for

* Corresponding author. Tel.: +91 9910101592.
E-mail addresses: kuldeep.er@gmail.com (K. Singh), rajivkapoor@dce.ac.in (R. Kapoor).

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controlling the enhancement rate as well as preserving the original brightness. These methods control maximum value of histogram by clipping histograms higher than the pre specified threshold. These methods provide different approach for the determination of clipping threshold.

Although various techniques are available to cater specific problem of contrast enhancement, enhancement for low exposure images is still less explored area. We propose an algorithm named Exposure based Sub-Image Histogram Equalization (ESIHE), which is very effective for low exposure gray scale images and preserves entropy along with control on enhancement rate. The authors believe that the ESIHE technique that achieves the multiple objectives of entropy maximization and control on over enhancement is a better approach to image enhancement specifically for under exposed images.

This paper is organized as follows: Section 2 describes the proposed ESIHE method. Section 3 gives experimental results, and Section 4 concludes the paper.

2. Exposure based Sub Image Histogram Equalization

Poor contrast images do not occupy complete dynamic range. Images having histogram bins concentrated toward a lower part or the darker gray levels possess low intensity exposure whereas images having histogram bins concentrated toward a higher part or the brighter part possess high intensity exposure. Images can be broadly classified as under exposed and over exposed based on the intensity exposure.

In this section, the algorithm of ESIHE is presented. The algorithm consists of three steps, namely Exposure threshold calculation, histogram clipping and Histogram Sub Division and Equalization. The description of each step is presented in the following subsections.

2.1. Exposure threshold calculation

A parameter named as exposure threshold (Hanmandlu et al., 2009) is defined which denotes the measure of intensity exposure of the image. This parameter is being used to divide the image in under exposed and over exposed sub images .The normalized range of exposure value is 0–1. If the value of exposure for a particular image is more than 0.5 and tends toward 1, it means that the image has majority of overexposed region and if this value is less than 0.5 and tending toward 0 then image is containing majority of under exposed regions. In both cases image contains poor contrast and needs contrast enhancement. Image intensity exposure value can be calculated as

$$exposure = \frac{1}{L}\frac{\sum_{k=1}^{L} h(k)k}{\sum_{k=1}^{L} h(k)} \tag{1}$$

where $h(k)$ is histogram of image and L is total number of gray levels.

Another parameter X_a (as calculated in Eq. (2)) related to exposure is defined, which provides the value of gray level boundary that divides the image into under exposed and over exposed sub images.

$$X_a = L(1 - exposure) \tag{2}$$

This parameter attains a value of greater or lesser than $L/2$ (gray level) for exposure value lesser or greater than 0.5 respectively for an image having a dynamic range 0 to L.

2.2. Histogram clipping

The idea behind histogram clipping is to prevent over enhancement leading to natural appearance of image. For limiting the enhancement rate, we need to limit the first derivative of histogram or the histogram itself (Ooi et al., 2009).The histogram bins having the value greater than the clipping threshold are limited to the threshold (Fig. 1). The clipping threshold is calculated as an average number of gray level occurrences.

The formula for clipping threshold T_c is presented in (3) and (4) calculates the clipped histogram

$$T_c = \frac{1}{L}\sum_{k=1}^{L} h(k) \tag{3}$$

$$h_c(k) = T_c \quad \text{for } h(k) \geqslant T_c \tag{4}$$

where $h(k)$ and $h_c(k)$ are the original and clipped histogram respectively. This method of histogram clipping is computationally efficient and consumes lesser time.

2.3. Histogram Sub Division and Equalization

The original histogram is first bisected based on exposure threshold value X_a as calculated in (2). The Histogram Sub Division process results in two sub images I_L and I_U ranging from gray level 0 to X_a and $X_a + 1$ to $L - 1$ and can be termed as under exposed and over exposed sub images (Fig. 1). $P_L(k)$ and $P_U(k)$ are corresponding PDF of these sub images as defined in

$$P_L(k) = h_c(k)/N_L \quad \text{for } 0 \leqslant k \leqslant X_a \tag{5}$$

$$P_U(k) = h_c(k)/N_U \quad \text{for } X_a + 1 \leqslant k \leqslant L - 1 \tag{6}$$

where N_L and N_U are total number of pixels in sub images I_L and I_U respectively. $C_L(k)$ and $C_U(k)$ are corresponding CDF of individual sub images and CDFs can be defined as

$$C_L(k) = \sum_{k=0}^{X_a} P_L(k) \tag{7}$$

$$C_U(k) = \sum_{k=X_a+1}^{L-1} P_U(k) \tag{8}$$

The next step of ESIHE is to equalize all the four sub histograms individually. The transfer functions for histogram equalization based on Eqs. (7) and (8) can be defined as

$$F_L = X_a \times C_L \tag{9}$$

$$F_U = (X_a + 1) + (L - X_a + 1)C_U \tag{10}$$

F_L and F_U are the transfer functions used for equalizing the sub histograms individually. The final step involves the integration of both sub images into one complete image. The ESIHE-ed output image is

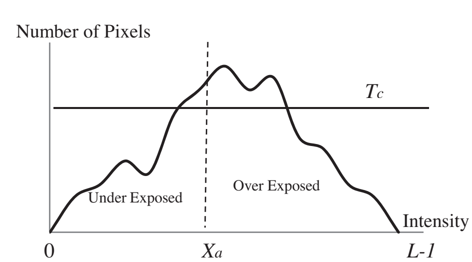

Fig. 1. Process of Histogram Sub Division and clipping.

produced by a combination of both transfer functions for further visual quality inspection and performance evaluation.

2.4. Algorithm of ESIHE

Step 1: Compute the histogram $h(k)$ of image.
Step 2: Compute the value of exposure and threshold parameter X_a.
Step 3: Compute the clipping threshold T_c and clip the histogram $h_c(k)$.
Step 4: Divide the clipped histogram into two sub histograms using the threshold parameter X_a.
Step 5: Apply the histogram equalization on individual sub histograms.
Step 6: Combine the sub images into one image for analysis.

3. Results and discussion

In this section, the simulation results of the proposed method ESIHE are compared with existing histogram equalization based methods i.e. BBHE, MMBEBHE, DSIHE, RMSHE and RSIHE. In order to analyze and compare the existing methods we use nine test images: Hands, Fish, Mosque, Tank, Cat, Butterfly, Aircraft, Couple and Field. Visual quality comparison of four images i.e. Hands, Fish, Tank and Cat is shown in Figs. 2–5.

To evaluate the performance of ESIHE, average information content is being used as image quality measure (Chen, 2012). Average information content (entropy) is a measure of richness of details of the image and usually measured in units as bits. The entropy here referred is the Shannon Entropy and it measures the uncertainty associated with gray levels in the image. Larger value of the entropy indicates that more information content is available in the image. Eq. (11) defines Entropy

$$ENT(p) = -\sum_{l=0}^{L-1} P(l) \log P(l) \tag{11}$$

where $P(l)$ is probability density function of a given image at intensity level l and L is total number of gray levels in the image. An image with a higher entropy value has richness of details and is perceived to have better quality.

3.1. Performance assessment based on average information content

The discrete entropy computed for the methods used in this work for all 9 images is tabulated in Table 1. ESIHE produces highest entropy for all the images thus becoming best suitable approach for bringing out information contents of the image. Specifically for Butterfly, aircraft, Mosque and fish image the entropy values are almost equal to original image. However for HE and MMBEBHE the entropy value for all the images is very less then the corresponding original image. The DSIHE method which claimed that it is better in terms of average information content of image is having entropy values lesser than the proposed method. The average of entropy produced by the ESIHE method for all images is 5.39 which is very close to average entropy (5.43) for original images, however average entropy of other methods is much smaller in comparison with the original image. The entropy closer to original image guarantees bringing out maximum information content of the image.

3.2. Assessment of visual quality

Qualitative assessment of contrast enhancement is necessary along with quantitative assessment. The enhancement results can only be appreciated if the resultant image gives pleasing effect in appearance. By Visual Quality inspection the judgment of annoying artifacts, over enhancement and unnatural enhancement can be done. The visual assessment results are effective quality measures to judge the performance of contrast enhancement algorithm.

Wide varieties of standard images ranging from under exposed to over exposed low contrast to high contrast, dark back ground to bright background, are chosen to test the robustness and versatility of the ESIHE method. The analysis of visual results from Figs. 2–5 shows the supremacy of ESIHE in all the images in terms of contrast enhancement and control on over enhancement. The concrete results in terms of contrast enhancement can be clearly observed in Fig. 2 of *Hands* image. HE, DSIHE and RSIHE results of *Hands* image are over enhanced, however ESIHE image provides control on over enhancement leading to good contrast enhancement results. The original *Fish* image in Fig. 3 is a low exposed image even though ESIHE has improved the quality of image in a big way.

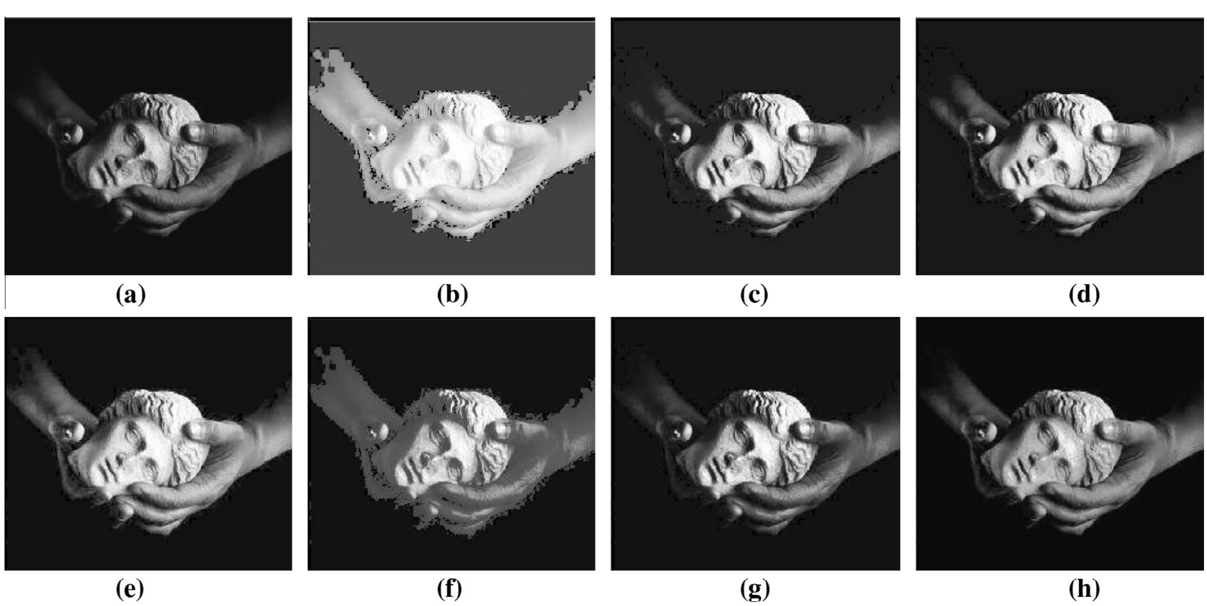

Fig. 2. Enhancement results of *Hands* image: (a) Original, (b) HE, (c) BBHE, (d) MMBEBHE, (e) DSIHE, (f) RSIHE, (g) RMSHE and (h) ESIHE.

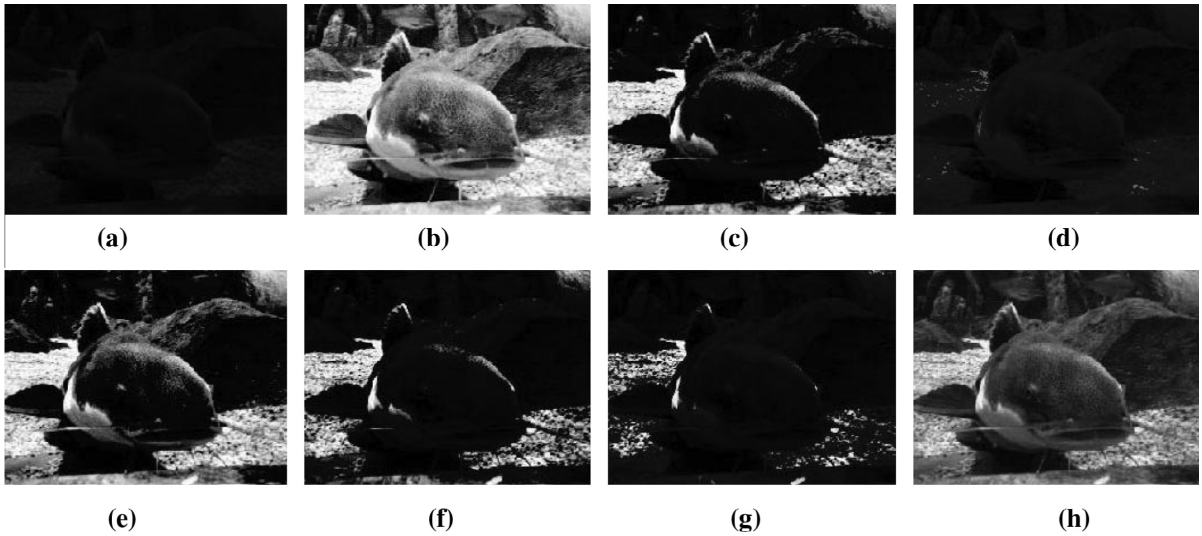

Fig. 3. Enhancement results of Fish image: (a) Original, (b) HE, (c) BBHE, (d) MMBEBHE, (e) DSIHE, (f) RSIHE, (g) RMSHE and (h) ESIHE.

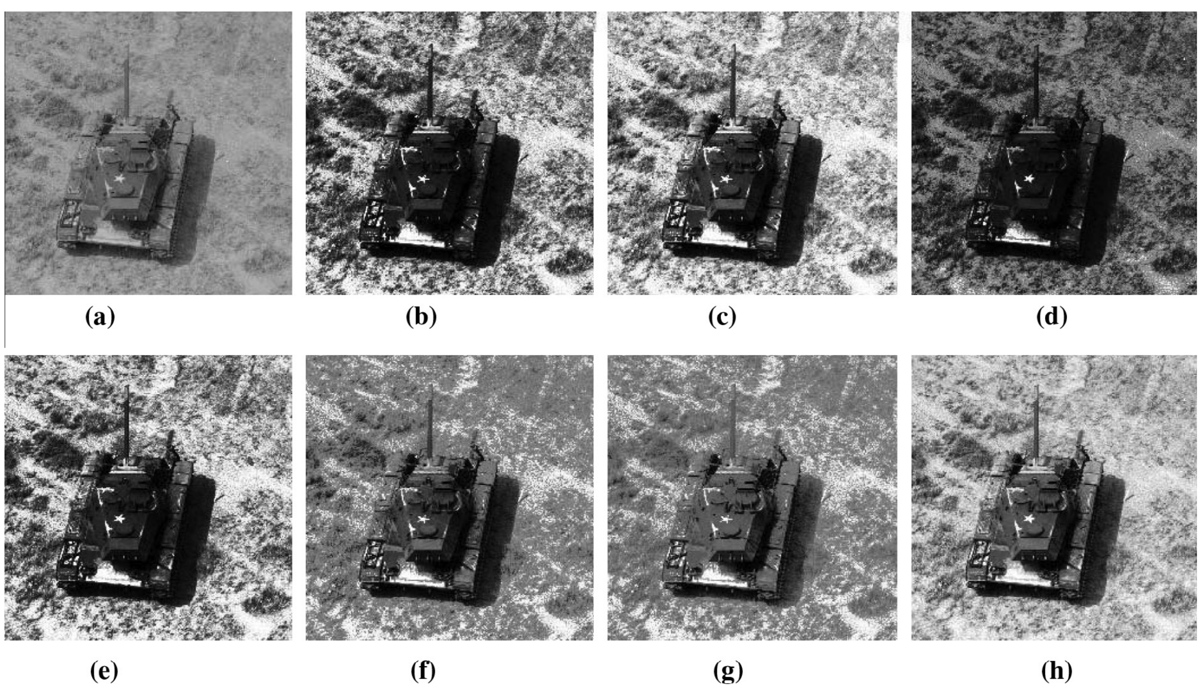

Fig. 4. Enhancement results of Tank image: (a) Original, (b) HE, (c) BBHE, (d) MMBEBHE, (e) DSIHE, (f) RSIHE, (g) RMSHE and (h) ESIHE.

The objects in ESIHE-ed *Fish* image are clearly visible however except HE, other methods are not able to enhance the image and object as well as background is not clearly visible in enhanced images.

The *Tank* image in Fig. 4 is a low contrast image and ESIHE yields contrast enhanced image along with natural appearance. The HE, BBHE, DSIHE and MMBEBHE outputs do not provide a clear vision of the object in case of *Tank* image. From Fig. 5 of *Cat* image it is clearly noticeable that the ESIHE-ed image enhances the low exposed part of image i.e. the left ear of the cat effectively. Although the ESIHE results in Fig. 5 for *Cat* image and Fig. 4 for *Tank* image are visually comparable to other methods the proposed method yields the highest entropy value for these images. This shows that the ESIHE method produces images with richness of details.

3.3. Summary of assessment and discussion

After visual inspection and assessment of entropy measures it can be concluded that:

(i) ESIHE method is well suited for under exposed images in comparison to other methods.
(ii) ESIHE technique is the best among other methods in terms of richness of details i.e. provides highest entropy.
(iii) ESIHE produces images with good contrast enhancement and control on over enhancement.

The objective of this paper is to maximize entropy, enhance under exposed images and control the over enhancement. Bisecting the image on the basis of a parameter related to exposure value

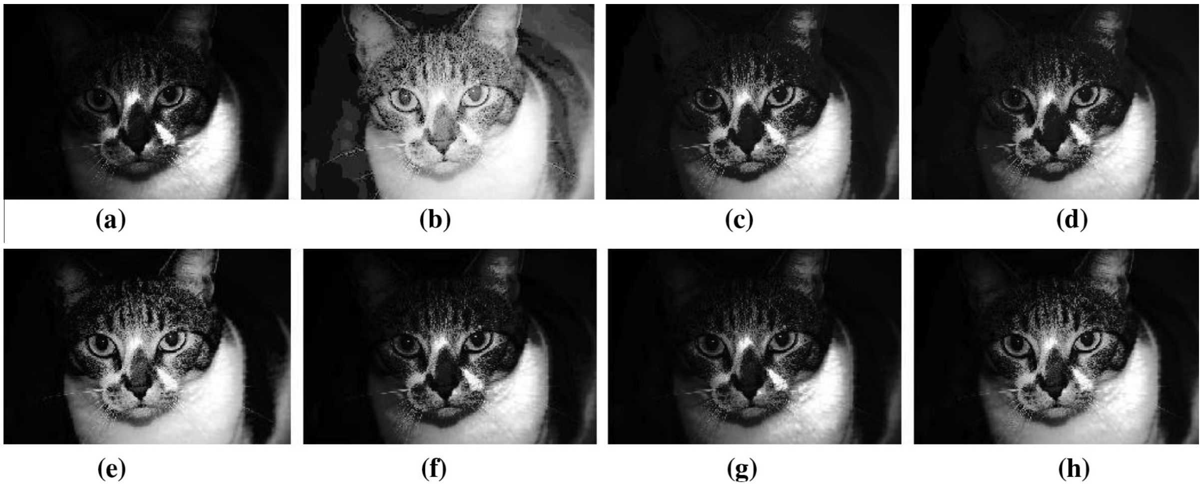

Fig. 5. Enhancement results of Cat image: (a) Original, (b) HE, (c) BBHE, (d) MMBEBHE, (e) DSIHE, (f) RSIHE, (g) RMSHE and (h) ESIHE.

Table 1
Entropy results of different methods.

Images	Original	HE	BBHE	MMBEBHE	DSIHE	RSIHE($r = 2$)	RMSHE($r = 2$)	ESIHE
Butterfly	4.89	4.70	4.83	4.78	4.83	4.81	4.86	4.89
Aircraft	4.00	3.75	3.90	3.86	3.87	3.95	3.94	3.99
Tank	5.49	4.97	5.42	5.31	5.38	5.45	5.46	5.47
Field	6.56	5.96	6.46	6.41	6.46	6.52	6.49	6.52
Fish	4.49	4.43	4.38	4.22	4.48	4.43	4.48	4.49
Cat	6.01	4.85	5.62	5.64	5.69	5.85	5.68	5.88
Hands	3.99	2.89	3.73	3.79	3.86	3.55	3.80	3.92
Mosque	6.26	5.83	6.11	6.06	6.09	6.08	6.10	6.26
Couple	7.20	5.96	7.01	7.01	7.01	7.06	7.04	7.12
Average	5.43	4.82	5.27	5.23	5.30	5.30	5.32	5.39

plays the role for enhancement of low exposure part and maximizing entropy.

The deciding factor for division of image depends on exposure value and it possess values greater then $L/2$ gray level for under exposed images (exposure value less than 0.5) and compensates for low exposure by introducing higher gray levels in sub image so that after individual histogram equalization process the over all exposure value increases. The inverse is true for the over exposed images where the sub division of images is done on the gray level lesser than $L/2$ gray level. Over enhancement can be controlled by histogram clipping approach by restricting the enhancement rate. The combination of all above mentioned process termed as ESIHE meets the objective of the paper and produces images which are not only quantitatively better but also better in terms of quality in comparison to other conventional HE methods.

4. Conclusion

This paper presents a new method for sub division of image based on exposure related parameter. Exposure based division of image and histogram equalization of sub images proved very effective technique for enhancing under exposed images. The histogram clipping technique is also combined with histogram equalization to provide control on over enhancement that leads to natural enhancement. The entropy measures of the ESIHE method clearly show that it outperforms other HE based methods. The Visual quality of ESIHE-ed images shows the robustness of the method and supremacy on other methods for a wide variety of images.

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