




# Image sub-division and quadruple clipped adaptive histogram equalization (ISQCAHE) for low exposure image enhancement

Upendra Kumar Acharya<sup>1,2,3</sup> · Sandeep Kumar<sup>1</sup> 

Received: 1 September 2021 / Revised: 12 September 2022 / Accepted: 18 September 2022 /  
Published online: 28 September 2022

© The Author(s), under exclusive licence to Springer Science+Business Media, LLC, part of Springer Nature 2022

## Abstract

In this paper, a novel image sub-division and quadruple clipped adaptive histogram equalization (ISQCAHE) technique is proposed for the enhancement of low exposure images. The proposed method involves, computation of the histogram which includes a new approach of image sub-division, enhancement controlling mechanism, modification of probability density function (PDF) and histogram equalization (HE). The original histogram is segmented into sub-histograms based on exposure threshold and mean, to preserve the brightness and entropy. Then, individual sub-histogram is clipped separately to control the enhancement rate. For enhancing the visual quality, HE is applied to individual sub-histogram using the modified PDF. The experimental results show that, the proposed ISQCAHE method avoids the unpleasant artifacts effectively and provide a natural appearance to the enhanced image. It is simple, adaptive and performs superior than other techniques in terms of visual quality, absolute mean brightness error, entropy, Natural image quality evaluation, brightness preservation, structure similarity index measure and feature similarity index measure.

**Keywords** Histogram equalization (HE) · Low exposure images · Image enhancement · Histogram sub-division · Histogram clipping

## 1 Introduction

In consumer imaging devices, image enhancement techniques take the crucial role for contrast boosting. The main purpose of contrast boosting is to improve the pictorial quality without any

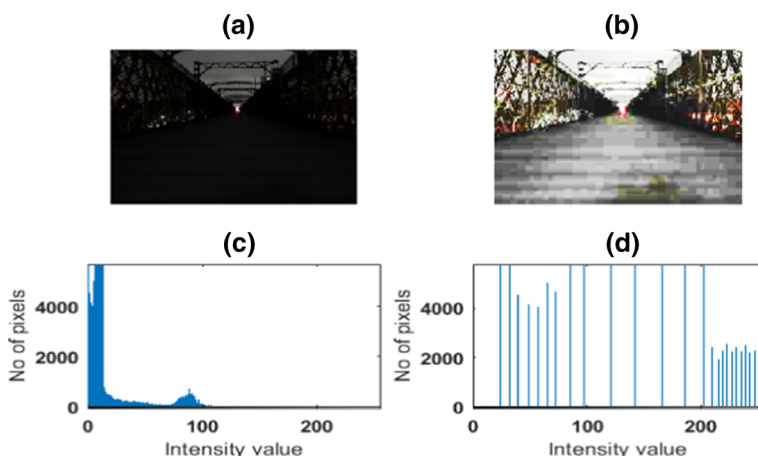
---

✉ Sandeep Kumar  
sandeep@nitdelhi.ac.in

<sup>1</sup> Department of Electronics and Communication Engineering, National Institute of Technology, Delhi, India

<sup>2</sup> Department of Electronics and Communication Engineering, Galgotias College of Engineering and Technology, Greater Noida, Uttar Pradesh, India

<sup>3</sup> Department of Electronics and Communication Engineering, KIET Group of Institutions, Ghaziabad, Uttar Pradesh, India



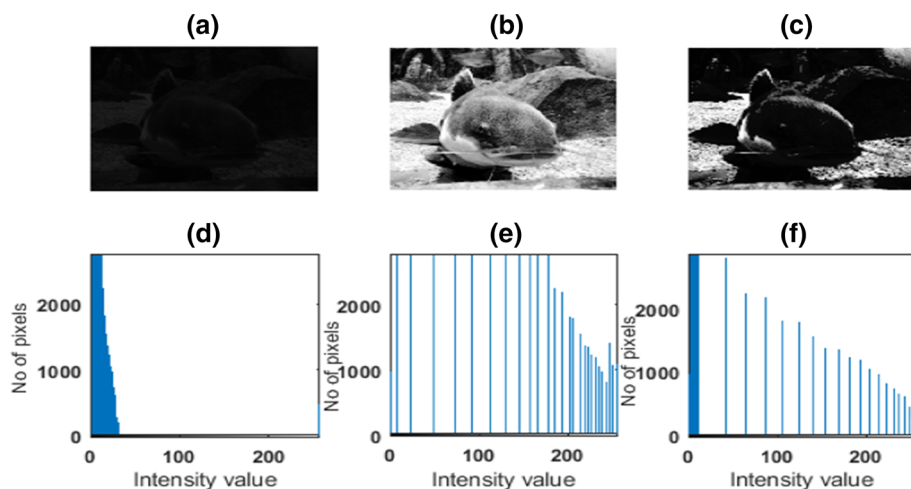
**Fig. 1** **a** Low exposure image, **b** HE, **c** Histogram of image-2, **d** Histogram of HE image

information loss. The method of image enhancement can be carried out by filtering the image, de-noising the image, modifying the histogram, stretching the histogram and equalizing the histogram. HE (Gonzalez & Woods, 2002) is widely used technique in medical imaging, surveillance imaging satellite imaging and low light image processing applications because of its simplicity. The method of HE can be performed by scaling the dynamic range and histogram distribution. In HE, a uniform transfer function is used for the entire image which flattens the gray scale distribution and enhancing the contrast as much as possible. But this method is not appropriate for consumer electronics and television as it results artifacts and noise amplification.

Here, Fig. 1a, b presents the input and HE enhanced image. Figure 1c, d represents the histogram of the input and enhanced image. From Fig. 1c, d, it is clearly observed that the HE technique flattens the gray level distribution, stretching the dynamic range and enhancing the contrast as much as possible. Because of the shifting of the gray level to a large extent, the enhanced image becomes brighter and results in artifacts and noise amplification in the enhanced image shown in Fig. 1b. From this figure, it has also been noticed that the histogram of the enhanced image doesn't follow the shape of the histogram of the original image. It indicates the change in structure and feature similarity with respect to the input image and there is a loss of information (entropy) after the equalization process. There is no specific parameter used to control the enhancement rate in HE. To avoid such limitations of HE, various methods (Kim, 1997; Wang et al., 1999; Chen & Ramli, 2003; Singh & Kapoor, 2014a; Singh et al., 2015; Singh & Kapoor, 2014b; Krayla et al., 2022) have been developed.

Young observed that the luminance of the image can be altered due to the flattening property of HE. So, he proposed a new technique to improve the contrast and preserve the luminance, known as brightness preserving bi-histogram equalization (BBHE) (Kim, 1997). In BBHE technique, the HE technique is applied to the individual sub-images, which are formed by dissolving the image depending on the mean value. The concept of image subdivision and HE methodology is used in this paper. The transfer function of the output image is formed by combining the transform function of both sub-images.

Figure 2a represents the low exposure image. The quality of this image is enhanced using HE and BBHE technique. From these images, it is observed that BBHE technique can be able to



**Fig. 2** **a** Low exposure image, **b** HE, **c** BBHE, **d** Histogram of image-4, **e** Histogram of HE image, **f** Histogram of BBHE image

preserve the mean brightness better than HE. But, the BBHE technique results some unnatural enhancement shown in the above figures. The observed gap between bins is less as compared to the HE technique. So, noise amplification is less as compared to HE but not noise free. The information loss in the BBHE based enhanced image is also less than the histogram equalized image. It indicates, the information content in the output image may be improved by modifying the HE technique. But this technique results artifacts. No mechanism is used to control the enhancement rate. Quality enhancement for low exposure image is not up to the level in BBHE. So this technique can be further improved for reducing the information loss, artifacts and controlling the enhancement rate.

So, Yu Wang et al. introduced a new enhancement technique named as dualistic sub-image histogram equalization (DSIHE) (Wang et al., 1999) by partitioning the image into two sub-images of equal area. Again to maximize the brightness preservation, Soong-Der Chen et al. introduced another technique named as minimum mean brightness error bi-histogram equalization (MMBEBHE) (Chen & Ramli, 2003). As per MMBEBHE, the process of image division is carried out, depending on limiting parameter, which yield less AMBE. Another technique (Singh & Kapoor, 2014a, 2014b) for low exposure images has been developed by Singh et al. in which the process of division of images is based on exposure threshold. RS-ESIHE (Singh et al., 2015) is introduced for enhancement of low light images and performs the partition of image recursively based on exposure threshold. Again, he introduced another approach for image enhancement using mean and median, (Singh & Kapoor, 2014a, 2014b) to preserve the entropy, average luminance, background gray level and minimize the AMBE.

The author of the paper (Tan et al., 2012) proposed a background brightness preserving HE technique to preserve the background brightness. This method separates the input image based on background levels. Another technique for entropy restoration for dark images has been presented in the paper (Singh et al. 2018). The author utilizes the concept of gamma correction and swarm intelligence to achieve the objectives. Wang et al. (2019) introduced an ALS model for the enhancement of low light images (Wang et al., 2019). In this paper, the atmospheric light (AL) has been replaced by inverted AL to reduce the effect of atmospheric light. To enhance the target details, another algorithm is proposed by Thillainayagi et al. which

is based on bi-dimensional empirical mode decomposition (Thillainayagi & Senthil Kumar, 2019). Adaptive fuzzy HE technique (Subramani & Veluchamy, 2018) is introduced, for improving the low contrast images by preserving the brightness. In 2019, M. Zarie proposed a new algorithm named as triple clipped dynamic histogram equalization, which is based on standard deviation (TCDHE-SD) (Zarie et al., 2019). This method, utilize the concept of histogram partition which is based on standard deviation.

The paper (Choukali et al., 2020) presents a novel technique to improve the image quality automatically by employing the edge information. This technique first finds the edges content of an image and then allot a repulsive force to each. So that, gray levels are shifted to the new values as per the force of all edges As image enhancement problem is an optimization problem, so some of the optimization based enhancement techniques are presented in the paper (Acharya & Kumar, 2020; Acharya & Kumar, 2021a, 2021b, 2021c, 2021d; Bhandari et al., 2017; Rundo et al., 2019; and Jeong & Lee, 2021). These techniques optimize few parameters for maximizing the fitness value to obtain the best optimal results. An adaptive thresholding-based scheme is presented in (Kandhway & Bhandari, 2019) to improve the contrast, preserve the brightness and image features. This algorithm uses threshold values for image sub-division and the number of thresholds depends on the PSNR of the threshold image. To refine the brightness, a 2D HE technique is discussed in (Cao et al., 2020) utilizing two-level segmentation. The position of segmentation points has been determined using the modified 2D histogram and the author claim that it performs excellent brightness preservation and contrast. For satisfactory enhancement, a highly adaptive gamma value-set can be derived in (Singh et al., 2019). The robustness of this algorithm improved because of its adaptive behavior and it is more capable for covering different variety of images.

Including the above algorithms, many other techniques (Bhandari et al., 2015; Acharya & Kumar, 2021a, 2021b, 2021c, 2021d; Shoaib et al., 2020; Biswas et al., 2016; Hassan, 2019; Mittal et al., 2012; Ma et al., 2018; Li, 2018) have been introduced for the quality improvement of low exposure images which are based on HE technique. Zhang et al. proposed a smart detection technique (Zhang et al., 2016) for abnormal breasts using mammogram images, in which the preprocessing includes removal of noises, enhancing the images, and removal of background and pectoral muscles. For extracting global features, fractional Fourier entropy has been implemented. For selecting the important features, Welch's t-test was used. Classifiers like multi-layer perceptron was implemented in this paper and a novel chaotic adaptive real coded bio-geography based optimization is proposed for training such classifier. This technique results 92.52% accuracy and effective in abnormal detection. For the chest CT-based COVID-19 diagnosis, a five-layer deep CNN with stochastic pooling is presented in (Zhang et al., 2021). This technique results an accuracy of  $93.64\% \pm 1.42\%$ , for identifying COVID-19. Performance shows the proposed stochastic pooling yields better results than existing methods.

But some enhancement techniques produce artifacts, few techniques cause loss of information and affected the structural similarity. Few techniques improve the luminance of the image but cannot separate the object from back ground effectively. In some techniques, there is no control on enhancement rate. So in this paper, a novel image sub-division and HE based enhancement technique is presented to eliminate the above discussed drawback during low exposure image enhancement. The main contributions of this work, for achieving better visibility, for preserving the brightness and entropy, for controlling enhancement rate, and free it from artifacts, are discussed below.

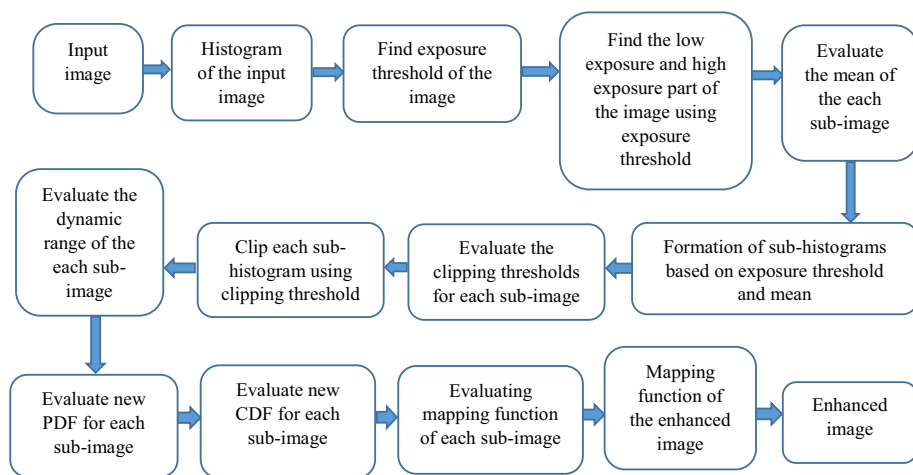
- (i) Modification of the PDF of the image using a novel way of image sub-division and clipping technique, to preserve the brightness and entropy.

- (ii) Controlling the enhancement rate by applying clipping technique to individual sub-histogram separately, in order to find the optimal result.
- (iii) Obtain the new mapping function of individual clipped histogram using modified cumulative density function (CDF).
- (iv) The Performance of the proposed method is measured by taking number of images from publicly available database (Sipi, 2016; Visual localization, 2020). Comparative analysis is also reported among proposed and some existing methods using image quality metrics such as visual quality, information contents (entropy), AMBE, FSIM, SSIM and NIQE.

This paper includes different sections which are distributed as follows. The details of proposed ISQCAHE method is presented in Sect. 2. The performance metrics and the comparison results among the proposed method and other published algorithms are discussed in Sect. 3. Section 4 concludes the proposed work.

## 2 Proposed ISQCAHE method

The Proposed ISQCAHE technique emphasizes to improve the image quality, minimize the information loss, preserve the brightness and optimize the over enhancement rate without affecting the structure and feature of the low exposure images. To achieve these requirements, the ISQCAHE technique includes following main steps. Initially the method of division of the input histogram is performed to eliminate the unnatural enhancement without loss of the information and preserve the brightness. To control the enhancement rate, individual sub-histogram is clipped using clipping threshold. After clipping the individual histogram, new mapping function for each partition has been formed using their respective dynamic range, modified PDF, and modified CDF. At last, the mapping function of the enhanced image is formed by combining individual sub-images. The flowchart of the ISQCAHE technique is presented in Fig. 3 and the details about this method is explained in Sects. 2.1, 2.2, 2.3 and 2.4.



**Fig. 3** Flowchart of ISQCAHE technique

## 2.1 Histogram division

If, HE technique is directly applied to low exposure images, then the image quality is improved but results information loss and over brighten images. So, the method of histogram division is used in this paper before applying HE technique to preserve the entropy and brightness. It can be performed using some of the standard parameters such as maxima, minima, mean, standard deviation, median and exposure threshold. But few techniques, while applied for poorly illuminated image enhancement, they may generate artifacts in the enhanced images which are shown in result section. In few cases unnatural enhancement has been observed. In some cases, histogram of the output image is completely changed as compare to input histogram by amplifying noise.

So, histogram of the input image is partitioned into four sub-histograms using exposure threshold of the image and mean of each sub-histogram. Then each sub-histogram is clipped separately to control the enhancement rate. The novel partitioning of the histogram has been used in this paper to preserve the brightness, entropy and minimizing the unnatural enhancement. Initially, exposure threshold of the image is computed to separate the image into two sub-images such as, over exposed and under exposed sub-image.

The exposure threshold  $X_a$  behave as the borderline between the sub-histograms  $I_l$  and  $I_u$ . The exposure value is evaluated using Eq. (1) to find the exposure threshold. Where, the variable  $Ex$  represents the exposure value,  $hi(k)$  is the histogram function and the maximum gray level is presented by the variable  $L$ . The main purpose of using exposure is only to find the types of the image. If the exposure value is more than 0.5 then it indicates that the image contains more over exposed region. If its value is less than 0.5 then the image contains more under exposed region.

$$Ex = \frac{1}{L} \frac{\sum_{k=1}^L hi(k)k}{\sum_{k=1}^L hi(k)} \quad (1)$$

Then the exposure threshold is measured using exposure value, shown in Eq. (2).

$$X_a = L \times (1 - Ex) \quad (2)$$

After that, the mean of individual sub-histogram is calculated using Eqs. (3, 4). Here  $X_{al}$  and  $X_{au}$  are the two means of the sub-histograms  $I_l$  and  $I_u$  respectively. The value of  $X_{al}$  and  $X_{au}$  are calculated before histogram clipping. The probability density functions of sub-histograms  $I_l$  and  $I_u$  are represented by  $P_{dl}(k)$  and  $P_{du}(k)$  in Eqs. (5, 6).  $N_l$  and  $N_u$  are the number of pixels of sub-histograms  $I_l$  and  $I_u$  respectively. Mean of the lower histogram is calculated as,

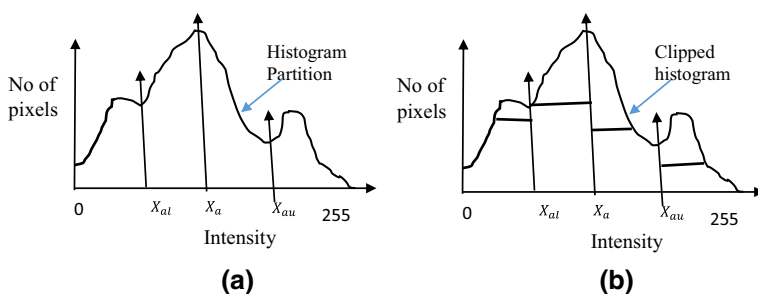
$$X_{al} = \sum_{k=0}^{X_a-1} P_{dl}(k) \times k \quad (3)$$

an of the upper histogram is calculated as,

$$X_{au} = \sum_{k=X_a}^{L-1} P_{du}(k) \times k \quad (4)$$

The PDF of sub-histograms  $I_l$  and  $I_u$  are evaluated as,

$$P_{dl}(k) = \frac{hi(k)}{N_l}, \text{ for } 0 \leq k \leq X_a - 1 \quad (5)$$



**Fig. 4** **a** Histogram division, **b** Histogram clipping

$$P_{du}(k) = \frac{hi(k)}{N_u}, \text{ for } X_a \leq k \leq L - 1 \quad (6)$$

Then each sub-histogram is partitioned into two sub-histograms, depending on corresponding mean  $X_{al}$  and  $X_{au}$ . The thresholds  $X_{al}, X_a, X_{au}$  are the three limit parameters, used to partition the histogram into four sub-histograms, shown in Fig. 4a. These four sub-histograms result four sub-images  $I_1, I_2, I_3, I_4$ . These four sub-images having gray level ranges from 0 to  $X_{al}$ ,  $X_{al} + 1$  to  $X_a$ ,  $X_a + 1$  to  $X_{au}$ ,  $X_{au} + 1$  to  $L - 1$ , respectively. Then, the PDF of each sub-histograms are calculated using Eqs. (7–10).

$$P_{dl1}(k) = \frac{hi(k)}{N_{l1}}, \text{ for } 0 \leq k \leq X_{al} \quad (7)$$

$$P_{dl2}(k) = \frac{hi(k)}{N_{l2}}, \text{ for } X_{al} + 1 \leq k \leq X_a \quad (8)$$

$$P_{du1}(k) = \frac{hi(k)}{N_{u1}}, \text{ for } X_a + 1 \leq k \leq X_{au} \quad (9)$$

$$P_{du2}(k) = \frac{hi(k)}{N_{u2}}, \text{ for } X_{au} + 1 \leq k \leq L - 1 \quad (10)$$

Here,  $N_{l1}, N_{l2}, N_{u1}, N_{u2}$  are the numbers of pixels of sub-images  $I_1, I_2, I_3, I_4$  respectively.

## 2.2 Quadruple histogram clipping technique

To well control the enhancement rate and visualize the image with natural look, it is required to limit the histogram. After clipping, the shape of the original histogram is altered depending on specific threshold. In this paper, median of individual sub-histogram is taken as the plateau limit for respective sub-image. The plateau limits for clipping the individual sub-histograms are represented in Eqs. (11–14).

$$cl1 = \text{median}(\text{histogram of subimage } I1) \quad (11)$$

$$cl2 = \text{median}(\text{histogram of subimage } I2) \quad (12)$$

$$cl3 = \text{median}(\text{histogram of subimage } I3) \quad (13)$$

$$cl4 = \text{median}(\text{histogram of subimage } I4) \quad (14)$$

Here the variables  $Cl1$ ,  $Cl2$ ,  $Cl3$  and  $Cl4$  represent the plateau limit or clipping threshold for individual histograms. Then the clipped sub-histograms are formed using the plateau limits  $Cl1$ ,  $Cl2$ ,  $Cl3$ ,  $Cl4$ , as per Eqs. (15–18) and shown in Fig. 4b. In this paper, the histogram bins are clipped to the plateau limit when their values are more than the plateau limit. If, value of bins are less than the clipping threshold then there is no change in the histogram.

$$hicl(k) = \begin{cases} cl1, & \text{if } hi(k) \geq cl1 \\ hi(k), & \text{if } hi(k) < cl1 \end{cases}, \text{ for } 0 \leq k \leq X_{al} \quad (15)$$

$$hicl(k) = \begin{cases} cl2, & \text{if } hi(k) \geq cl2 \\ hi(k), & \text{if } hi(k) < cl2 \end{cases}, \text{ for } X_{al} + 1 \leq k \leq X_a \quad (16)$$

$$hicl(k) = \begin{cases} cl3, & \text{if } hi(k) \geq cl3 \\ hi(k), & \text{if } hi(k) < cl3 \end{cases}, \text{ for } X_a + 1 \leq k \leq X_{au} \quad (17)$$

$$hicl(k) = \begin{cases} cl4, & \text{if } hi(k) \geq cl4 \\ hi(k), & \text{if } hi(k) < cl4 \end{cases}, \text{ for } X_{au} + 1 \leq k \leq L - 1 \quad (18)$$

### 2.3 Modified mapping function of individual sub-histogram

After clipping, each sub-histogram follows the method of equalization. It includes finding of the modified pdf, determination of CDF using modified pdf, and mapping function of individual sub-histogram. PDF of individual sub-image is determined using Eqs. (19–22) and represented by  $P_{dl1m}(k)$ ,  $P_{dl2m}(k)$ ,  $P_{du1m}(k)$ ,  $P_{du2m}(k)$  respectively.

$$P_{dl1m}(k) = \frac{hicl(k)}{N_{l1}}, \text{ for } 0 \leq k \leq X_{al} \quad (19)$$

$$P_{dl2m}(k) = \frac{hicl(k)}{N_{l2}}, \text{ for } X_{al} + 1 \leq k \leq X_a \quad (20)$$

$$P_{du1m}(k) = \frac{hicl(k)}{N_{u1}}, \text{ for } X_a + 1 \leq k \leq X_{au} \quad (21)$$

$$P_{du2m}(k) = \frac{hicl(k)}{N_{u2}}, \text{ for } X_{au} + 1 \leq k \leq L - 1 \quad (22)$$

Then CDF of each sub-histogram is evaluated in Eqs. (23–26) using respective determined modified PDF.

$$C_{dl1m}(k) = \sum_{k=0}^{k=X_{al}} P_{dl1m}(k) \quad (23)$$

$$C_{dl2m}(k) = \sum_{k=X_{al}+1}^{k=X_a} P_{dl2m}(k) \quad (24)$$

$$C_{du1m}(k) = \sum_{k=X_a+1}^{k=X_{au}} P_{du1m}(k) \quad (25)$$

$$C_{du2m}(k) = \sum_{k=X_{au}+1}^{k=L-1} P_{du2m}(k) \quad (26)$$

Finally, the mapping function of each sub-image is determined using the respective CDF and are shown in Eqs. (27–30).

$$M_{l1m} = (X_{al}) \times C_{dl1m} \quad (27)$$

$$M_{l2m} = (X_{al} + 1) + (X_a - (X_{al} + 1)) \times C_{dl2m} \quad (28)$$

$$M_{u1m} = (X_a + 1) + (X_{au} - (X_a + 1)) \times C_{du1m} \quad (29)$$

$$M_{u2m} = (X_{au} + 1) + (L - (X_{au} + 1)) \times C_{du2m} \quad (30)$$

## 2.4 Mapping function of the output image

Mapping function of the enhanced output image is obtained by combining the mapping function of each sub-image and represented by Eq. (31).

$$M = M_{l1m} \cup M_{l2m} \cup M_{u1m} \cup M_{u2m} \quad (31)$$

## 3 Results and analysis

In this paper, the low exposure images are taken from SIPI USC (Sipi, 2016), visual localization database (Visual localization, 2020) for simulation work. Then, the quality of these images have been improved using ISQCAHE method. The simulation works have been performed using Matlab-2018, Intel (R), Core (TM), i3-4005U CPU @1.70 GHz, 4.00 GB random access memory and 64 bit windows-7 operating system. The performance of the ISQCAHE technique is measured and compared with some of the existing methods like HE (Gonzalez & Woods, 2002), BBHE (Kim, 1997), DSIHE (Wang et al., 1999), MMBEBHE (Chen & Ramli, 2003), RSESIHE (Singh et al., 2015) and TCDHE-SD (Zarie et al., 2019) techniques in terms of visual quality, naturalness, AMBE, entropy, FSIM and SSIM which are discussed below.

### 3.1 Image quality assessment metrics

The quality of the enhanced image can be evaluated in the following aspects which are presented in Table 1. These parameters take the vital role for further processing of the images during computer vision applications. The supremacy of the proposed ISQCAHE technique is presented in Sect. 3.2 using following metrics.

### 3.2 Performance measurement based on Image quality assessment metrics

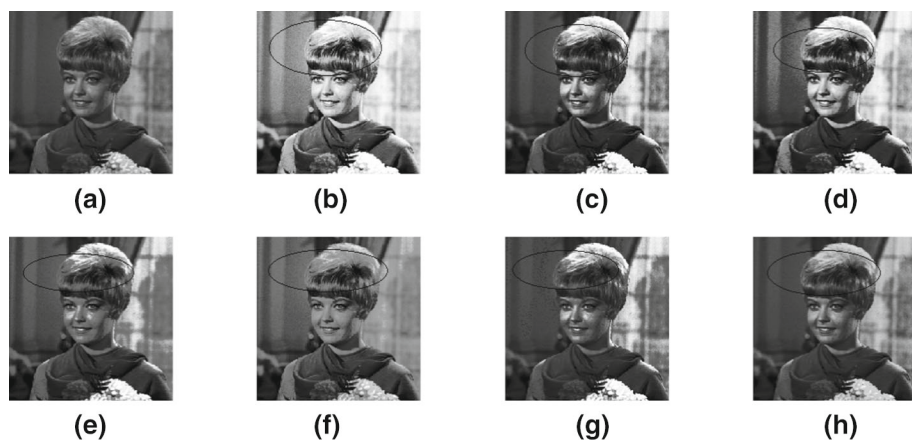
The simulation results of different enhancement techniques are shown in Figs. 5, 6, 7, 8, 9, 10, 11 and 12. Parameters like artifacts, unnatural enhancement, enhancement control rate, visually pleasantness are taken into consideration for visual quality analysis. Here, the low exposure input images are presented in Figs. 5a, 6, 7, 8, 9, 10, and 11a. After performing HE, it has been noticed that, HE technique results unnatural over enhanced images and artifacts, shown in the highlighted portion of Figs. 5b, 6, 7, 8, 9, 10, and 11b. This unnaturalness in

**Table 1** Quality assessment metrics

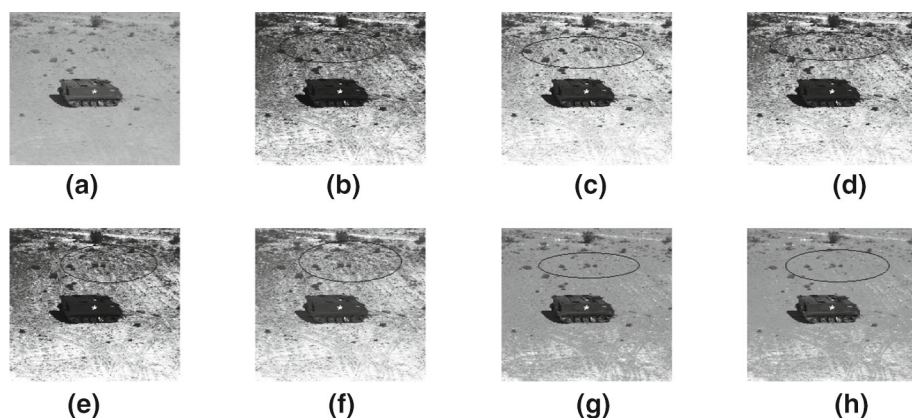
Parameters	Formula	Remarks
Entropy (Shokrollahi et al. 2020)	$H = -\sum_{i=0}^{l-1} pd(i) \log_2 pd(i)$	It indicates the average information contents within the image. Higher entropy represents more information contents in the image
AMBE (Kansal et al. 2018)	$AMBE(I, Y) =  mean(Y) - mean(I) $	This parameter measures the change of luminance in the output image. Lower AMBE indicates the higher brightness preservation
SSIM (Muniyappan & Rajendran, 2019)	$SSIM = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)(\sigma_x^2 + \sigma_y^2 + C_2)}$	This parameter compares the structure between output and original image. The enhanced image has better structure similarity, if its value is nearer to one
FSIM (Bhandari et al., 2018)	$FSIM = \frac{\sum_{x \in X} S_L(x) PC_m(x)}{\sum_{x \in X} PC_m(x)}$	It depicts the feature similarity among enhanced and input image. Its value should be close to one
NIQE (Mittal et al., 2012)	$D = \sqrt{\left( (v1 - v2)^T \left( \frac{(\sum_1 - \sum_2)}{2} \right)^{-1} (v1 - v2) \right)}$	It measures the distance between the multivariate Gaussian (MVG) fit to the features extracted from the distorted image and natural scene statistic (NSS) feature model. Smaller the NIQE better is the visualization effect

the HE based enhanced images is due to its flattening and intensity shifting property. The histogram of the histogram equalized image is shown in Fig. 12b. From this histogram, it has also been observed that, the bins of the histogram don't follow the histogram of the original image. More gaps have been found in between the bins of the HE images as compared to the original image. So, noise amplification is more in HE technique.

Then, the entropy of the enhanced image is measured using entropy equation of Table 1. It has been observed that, the information contents in HE based image is very less as compared to the original image which is shown in Table 2. But the main purpose of the



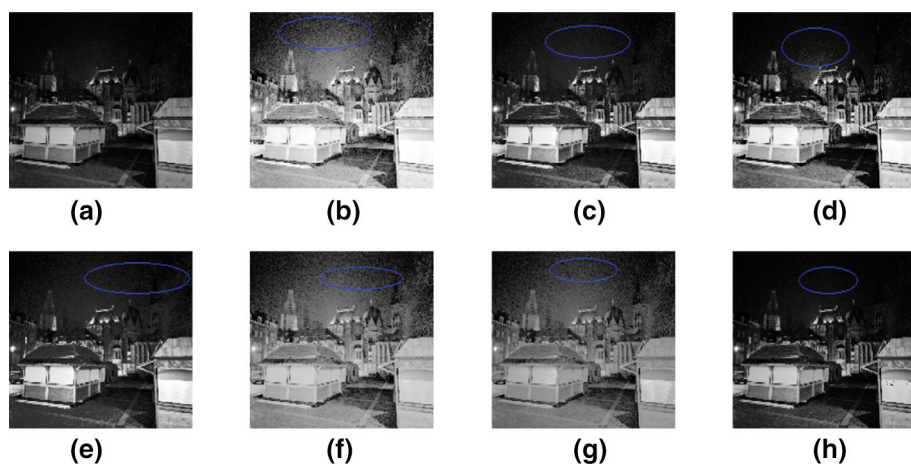
**Fig. 5** Enhanced image-1, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE



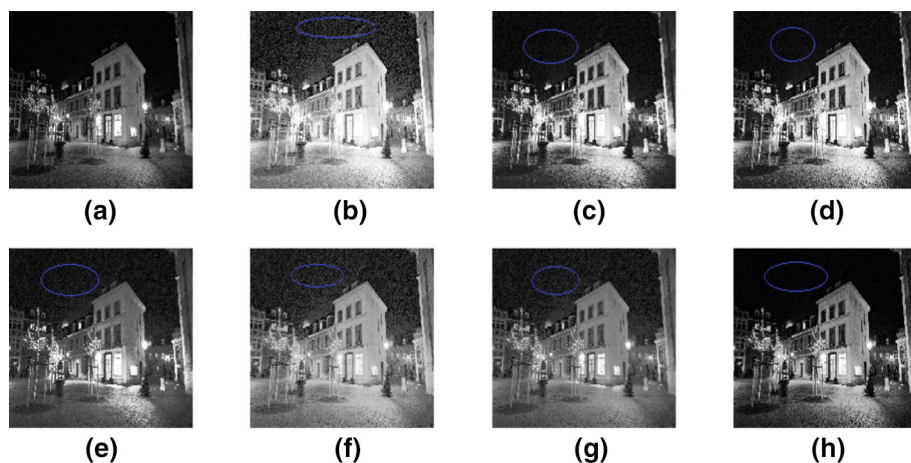
**Fig. 6** Enhanced image-2, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE

enhancement technique is to enhance the contrast without any information loss. So some other algorithms have been developed to enhance the image quality along with reducing the information loss. Information contents of the enhanced image obtained by existing methods like BBHE, DSIHE, MMBEBHE, RSESIHE, TCDHE-SD, and proposed ISQCAHE technique have been measured and presented in the same Table 2. From this table it has been noticed that the existing technique improves the information contents of the image as compared to HE technique, but not that much close to the information contents of the original image. But proposed ISQCAHE technique results better information contents compared to existing technique and close to the entropy of the original image.

After that, performance parameters like AMBE, SSIM, FSIM, NIQE are evaluated with respect to the original images. AMBE represents the mean brightness error between input and output image and it is measured to find out the brightness preservation capability of



**Fig. 7** Enhanced image-3, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE



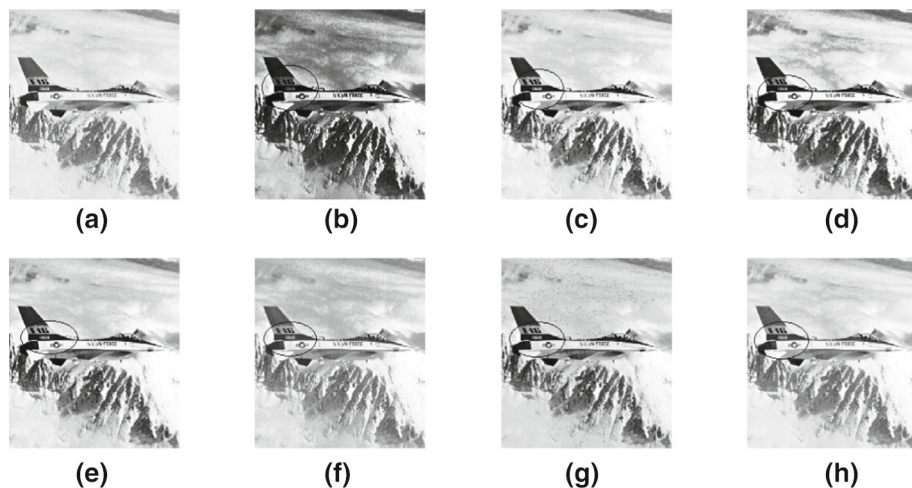
**Fig. 8** Enhanced image-4, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE

the respective enhancement technique. Its value is measured for different enhancement techniques and presented in Table 3. From this table, it has been observed that the AMBE value in HE technique is more as compared to other technique. It indicates that HE technique fails to preserve the brightness for low exposure images. So different histogram division-based techniques have been developed. The discussed existing techniques preserve the brightness better as compared to HE technique. But, the AMBE value obtained by proposed ISQCAHE technique is lower among all the discussed techniques. It indicates that, the brightness preservation by the proposed ISQCAHE technique is better than all the discussed technique.

From Tables 4, 5 and 6, it has been noticed that, the HE technique does not produce satisfactory result in terms of NIQE, structure and feature similarity as compared to other

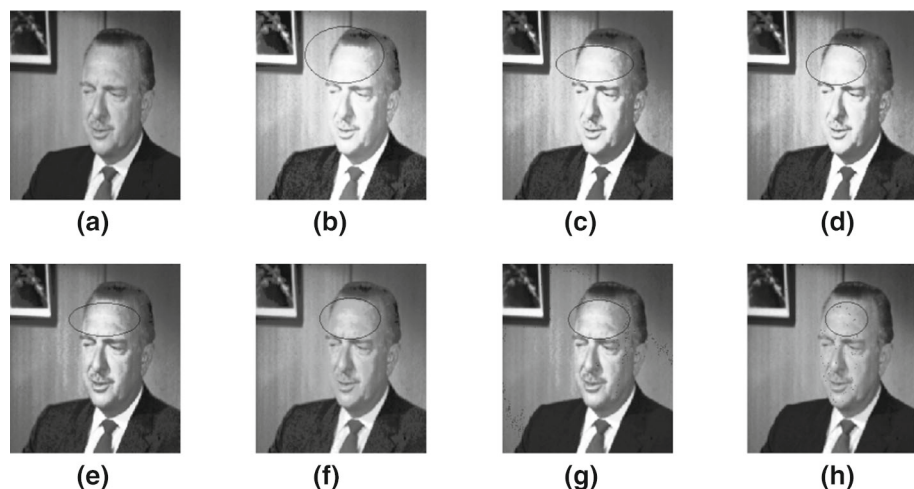


**Fig. 9** Enhanced image-5, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE

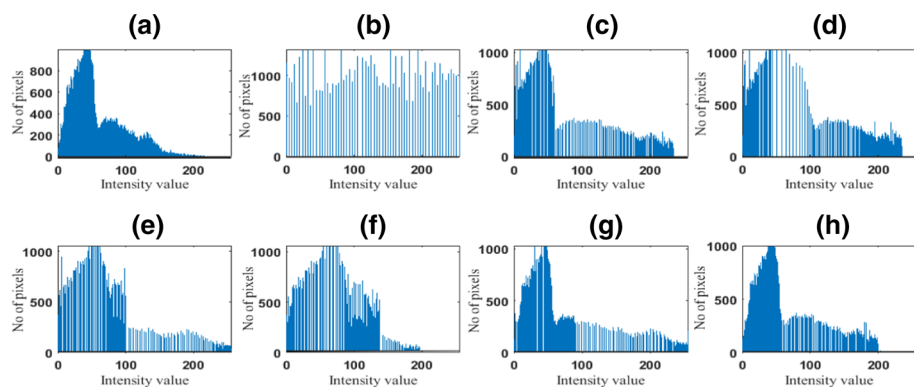


**Fig. 10** Enhanced image-6, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE

techniques. Here, NIQE parameter is used to measure the naturalness of the enhanced image with respect to original image. SSIM and FSIM parameters are used to measure the structural and feature similarity between enhanced image and original image and measured using equations of Table 1. From Table 4, 5 and 6, it has been noticed that, the HE technique results poor structural, feature similarity and naturalness as compared to discussed techniques. Other discussed existing techniques improve the structure, feature similarity and naturalness, but the proposed ISQCAHE technique generates better SSIM and FSIM which are closed to one. The measured NIQE is also very less in ISQCAHE technique over other existing techniques



**Fig. 11** Enhanced image-7, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE



**Fig. 12** Histogram of image-1, **a** Input image, **b** HE, **c** BBHE, **d** DSIHE, **e** MMBEBHE, **f** RSESIHE, **g** TCDHE-SD, **h** ISQCAHE

and presented in Table 6. It indicates the better naturalness in the enhanced image obtained by ISQCAHE over other existing techniques.

The variations in error, naturalness, structure and feature are clearly reflected in the histogram, shown in Fig. 12b. In HE, a single transfer function is used for both lower and higher exposure region of the image to enhance the image quality. That's why, such limitations have been observed in HE based technique. As, no parameters are used to restrict the enhancement rate, so the brightness content is more in HE image. So it is needed to improve the HE based enhancement techniques to enhance the visual quality without affecting the information contents, SSIM, FSIM and naturalness.

The enhanced image obtained by BBHE, DSIHE, MMBEBHE are shown in Figs. 5c–e, 6, 7, 8, 9, 10, and 11c–e. All these techniques are based on histogram division and HE technique. After histogram division, equalization is applied to individual histogram. As in

Table 2 Evaluation of entropy

Images/ techniques	Input image	HE	BBHE	DSIHE	MMBEBHE	RSESIHE	TCDHE-SD	ISQCAHE
1	7.052	5.945	6.896	6.888	6.791	6.749	6.970	6.994
2	5.053	4.565	4.954	4.888	4.892	4.936	5.028	5.035
3	6.751	5.610	6.502	6.573	6.482	6.417	6.670	6.721
4	6.945	5.638	6.621	6.656	6.581	6.616	6.805	6.880
5	7.524	5.951	7.271	7.294	7.336	7.313	7.460	7.500
6	6.702	5.710	6.544	6.579	6.588	6.527	6.584	6.644
7	7.217	5.777	6.796	6.773	6.910	7.004	7.013	7.177

**Table 3** Evaluation of AMBE

Images/ techniques	HE	BBHE	DSIHE	MMBEBHE	RSESIHE	TCDHE-SD	ISQCAHE
1	68.588	14.243	27.051	13.052	16.173	11.088	7.470
2	35.331	19.524	4.888	5.773	20.708	4.420	7.238
3	81.362	19.717	30.875	17.694	42.610	8.416	4.973
4	73.523	28.475	32.519	22.258	28.131	11.587	9.844
5	38.681	23.740	23.368	4.363	5.633	10.299	1.752
6	51.708	5.182	13.194	8.946	0.385	13.457	2.902
7	38.733	25.603	24.820	4.876	7.735	8.990	2.187

**Table 4** Evaluation of SSIM

Images/ techniques	HE	BBHE	DSIHE	MMBEBHE	RSESIHE	TCDHE-SD	ISQCAHE
1	0.591	0.891	0.785	0.892	0.879	0.887	0.969
2	0.322	0.567	0.463	0.331	0.473	0.659	0.788
3	0.356	0.821	0.812	0.796	0.484	0.860	0.979
4	0.442	0.656	0.667	0.637	0.616	0.917	0.956
5	0.804	0.834	0.832	0.896	0.903	0.918	0.950
6	0.553	0.957	0.866	0.885	0.878	0.782	0.958
7	0.780	0.840	0.840	0.904	0.907	0.915	0.931

**Table 5** Evaluation of FSIM

Images/ techniques	HE	BBHE	DSIHE	MMBEBHE	RSESIHE	TCDHE-SD	ISQCAHE
1	0.967	0.977	0.979	0.964	0.969	0.984	0.999
2	0.964	0.969	0.971	0.955	0.963	0.968	0.998
3	0.960	0.967	0.962	0.956	0.976	0.958	0.999
4	0.990	0.992	0.993	0.994	0.994	0.995	0.998
5	0.979	0.976	0.976	0.968	0.989	0.947	1.000
6	0.977	0.979	0.972	0.967	0.988	0.946	0.998
7	0.968	0.967	0.977	0.961	0.987	0.986	0.998

those techniques, separate equalization is applied to lower and upper part of the histogram, so they follow different dynamic range. That's why the brightness preservation and entropy value is better in such images as compared to HE based technique, which are presented in Tables 2 and 3. The structure, feature naturalness of such images are also better which are presented in Tables 4, 5 and 6. The gap between the bins is also reduced in such techniques. So the noise amplification and artifacts are also reduced. But the main drawback in such

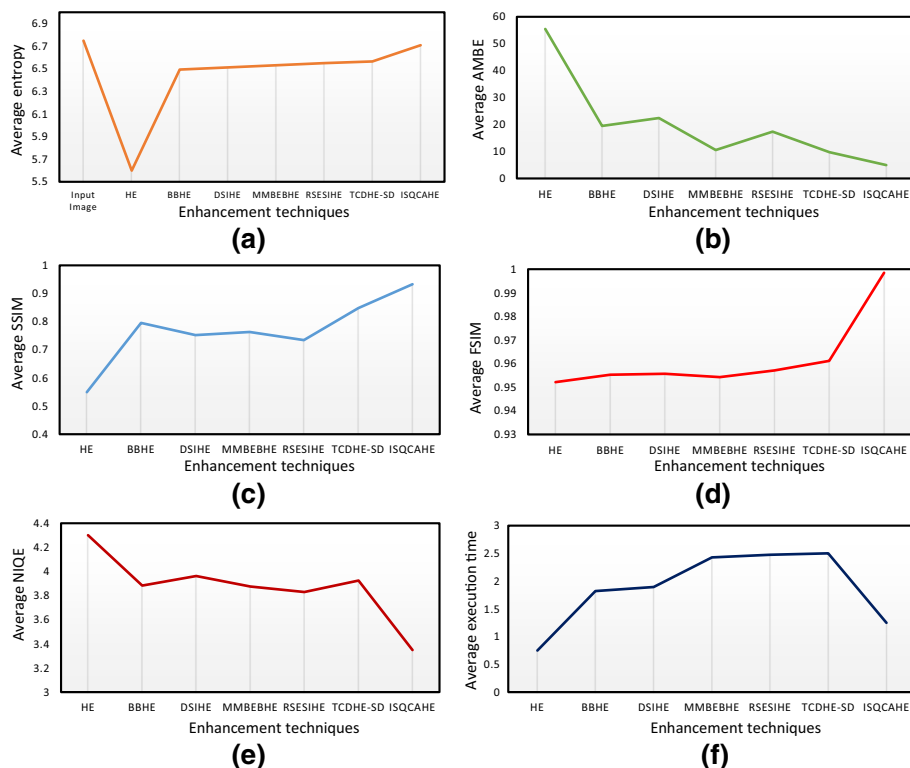
**Table 6** Evaluation of NIQE

Images/ techniques	HE	BBHE	DSIHE	MMBEBHE	RSESIHE	TCDHE-SD	ISQCAHE
1	4.881	4.197	4.889	4.337	4.080	4.073	3.476
2	8.023	7.279	7.525	7.342	6.907	8.729	5.597
3	2.411	1.666	1.496	1.686	2.017	1.598	1.318
4	3.740	3.551	3.517	3.648	3.522	3.324	3.052
5	4.116	3.901	3.895	3.841	3.897	4.037	3.750
6	3.151	2.608	2.584	2.668	2.801	3.476	2.756
7	3.792	3.977	3.828	3.600	3.589	4.468	3.500

technique is that, these techniques are not associated with any controlling mechanism to control the enhancement rate. So, this technique cannot produce satisfactory results in all kinds of images like low exposure and high exposure images.

To eliminate these problems, some more improved techniques like RSESIHE and TCDHE-SD have been developed whose simulation results are shown in Figs. 5f–g, 6, 7, 8, 9, 10, and 11f–g. Both techniques divide the histograms into sub-histograms. So, the level of enhancement for both low and high exposure image is different. Both techniques have used clipping mechanism to control the enhancement rate. So better enhancement rate is possible in such images over HE, BBHE, DSIHE techniques. From simulation results (Figs. 5f, 6, 7, 8, 9, 10, and 11f) and measured SSIM (Table 4), NIQE (Table 6), it has been detected that the RSESIHE results better in terms of SSIM, NIQE as compared to HE, BBHE, DSIHE and MMBEBHE techniques. But the main limitation of RSESIHE technique is that, a single enhancement rate controlling mechanism has been used for the entire image before applying HE. So it is not adaptive and does not produce better result for all types of images. The TCDHE-SD technique results more entropy and luminance preservation over HE, BBHE, DSIHE, MMBEBHE, RSESIHE technique which are shown in Figs. 5g, 6, 7, 8, 9, 10, and 11g. and Tables 2 and 3. The structure and feature similarity is also better over other techniques, shown in Tables 4 and 5. But this technique results some artifacts in the enhanced night time images.

This experiment has been performed using two hundred low exposure images and the resultant average value of the measured parameters are shown in Fig. 13. From this figure, it has been observed that, the proposed ISQCAHE technique results better in terms of entropy, AMBE, SSIM, FSIM, NIQE as compared to other discussed technique. The execution time (Kandhway et al., 2020) taken by ISQCAHE method is also less as compared to other techniques, but takes more time than HE technique which is shown in Table 7 and Fig. 13f. To reduce the information loss, to preserve more brightness and to reduce the artifacts contents in the enhanced output image, the proposed technique uses a novel approach of image sub-division which results four sub-histograms. After performing several experiment, it has been observed that the improvement of entropy is not significant for higher order histogram segmentation (more than four sub-histograms). The main advantages of this proposed technique is that, separate controlling mechanism has been used to individual sub-histogram to restrict the enhancement rate. As each sub-histogram has its own dynamic range, so the controlling mechanism is also different for different for each sub-histogram. So, the proposed method is more adaptive and results best enhanced images in terms of enhancement control, entropy,



**Fig. 13** **a** Average entropy **b** Average AMBE **c** Average SSIM **d** Average FSIM **e** Average NIQE **f** Average execution time (second)

**Table 7** Execution time (Second)

Images/ techniques	HE	BBHE	DSIHE	MMBEBHE	RSESIHE	TCDHE-SD	ISQCAHE
1	0.558	1.987	1.890	2.445	2.769	2.432	1.246
2	0.856	1.874	1.788	2.564	2.436	2.734	1.287
3	0.668	1.721	1.899	2.247	2.324	2.338	1.365
4	0.721	1.767	1.888	2.237	2.335	2.245	1.135
5	0.922	2.267	2.121	2.799	2.656	2.766	1.224
6	0.777	1.246	1.779	2.468	2.479	2.447	1.245
7	0.756	1.890	1.899	2.243	2.326	2.547	1.246

visual quality, brightness preservation without much affecting the structure, feature similarity and naturalness, shown in Fig. 13. The bins of the histogram generated by the proposed techniques are very close with each other and shown in Fig. 12h. So, noise amplification and artifacts are less in such images and image becomes more natural.

## 4 Conclusions

This paper presents a new image sub-division and quadruple clipped adaptive HE technique for the enhancement of the low exposure images. The novel way of partition of the histogram takes the important role to avoid unnatural artifacts, preserving brightness and entropy. In this paper, the controlling mechanism is used to clip each sub-histogram separately by taking the median of the each sub-histogram which helps to control the enhancement rate more effectively. So, the applied HE to each partition enhances the visual quality up to the mark. As a result, the proposed (ISQCAHE) method is more adaptive, produces visual pleasing enhanced images and make the images more natural. The proposed method is very simple and demonstrated results show the supremacy of the proposed method in terms of brightness preservation, AMBE, entropy, SSIM, FSIM, NIQE and execution time over other existing methods. Due to the simplicity and superior performance, the proposed method can be used in consumer electronics, process monitoring camera, medical imaging system and surveillance system.

## References

- Acharya, U. K., & Kumar, S. (2020). Particle swarm optimized texture based histogram equalization (PSOTHE) for MRI brain image enhancement. *Optik*, 224, 165760.
- Acharya, U. K., & Kumar, S. (2021a). Directed searching optimized mean-exposure based sub-image histogram equalization for grayscale image enhancement. *Multimedia Tools and Applications*. <https://doi.org/10.1007/s11042-021-10855-7>
- Acharya, U. K., & Kumar, S. (2021b). Genetic algorithm based adaptive histogram equalization (GAAHE) technique for medical image enhancement. *Optik*, 230, 166273.
- Acharya, U. K., & Kumar, S. (2021c). Image enhancement using exposure and standard deviation-based sub-image histogram equalization for night-time images. In *Proceedings of International Conference on Artificial Intelligence and Applications* (pp. 607–615). Springer.
- Acharya, U. K., & Kumar, S. (2021d). Swarm intelligence based adaptive gamma corrected (SIAGC) retinal image enhancement technique for early detection of diabetic retinopathy. *Optik*, 247, 167904.
- Bhandari, A. K., Kumar, A., & Singh, G. K. (2015). Improved knee transfer function and gamma correction based method for contrast and brightness enhancement of satellite image. *AEU-International Journal of Electronics and Communications*, 69(2), 579–589.
- Bhandari, A. K., Kumar, A., Chaudhary, S., & Singh, G. K. (2017). A new beta differential evolution algorithm for edge preserved colored satellite image enhancement. *Multidimensional Systems and Signal Processing*, 28(2), 495–527.
- Bhandari, A. K., Maurya, S., & Meena, A. K. (2018). Social spider optimization based optimally weighted Otsu thresholding for image enhancement. *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*. <https://doi.org/10.1109/JSTARS.2018.2870157>
- Biswas, S., Ghoshal, D., & Hazra, R. (2016). A new algorithm of image segmentation using curve fitting based higher order polynomial smoothing. *Optik*, 127(20), 8916–8925.
- Cao, Q., Shi, Z., Wang, R., Wang, P., & Yao, S. (2020). A brightness-preserving two-dimensional histogram equalization method based on two-level segmentation. *Multimedia Tools and Applications*, 79(37), 27091–27114.
- Chen, S. D., & Ramli, A. R. (2003). Minimum mean brightness error bi-histogram equalization in contrast enhancement. *IEEE Transactions on Consumer Electronics*, 49(4), 1310–1319.
- Choukali, M. A., Valizadeh, M., & Amirani, M. C. (2020). An efficient contrast enhancement method using repulsive force of edges. *Multidimensional Systems and Signal Processing*, 31(1), 299–315.
- Gonzalez, R. C., & Woods, R. E. (2002). *Digital image processing*. Pearson Prentice Hall.
- Hassan, M. F. (2019). Flexible color contrast enhancement method for red-green deficiency. *Multidimensional Systems and Signal Processing*, 30(4), 1975–1989.
- Jeong, I., & Lee, C. (2021). An optimization-based approach to gamma correction parameter estimation for low-light image enhancement. *Multimedia Tools and Applications*, 80(12), 18027–18042.

- Kandhway, P., & Bhandari, A. K. (2019). An optimal adaptive thresholding based sub-histogram equalization for brightness preserving image contrast enhancement. *Multidimensional Systems and Signal Processing*, 30(4), 1859–1894.
- Kandhway, P., Bhandari, A. K., & Singh, A. (2020). A novel reformed histogram equalization based medical image contrast enhancement using krill herd optimization. *Biomedical Signal Processing and Control*, 56, 101677.
- Kansal, S., Purwar, S., & Tripathi, R. K. (2018). Image contrast enhancement using unsharp masking and histogram equalization. *Multimedia Tools and Applications*, 77(20), 26919–26938.
- Kim, Y. T. (1997). Contrast enhancement using brightness preserving bi-histogram equalization. *IEEE Transactions on Consumer Electronics*, 43(1), 1–8.
- Krayla, J., Kumar, S., Acharya, U. K., Sahani, A. K., Kumar, P., & Sengupta, A. (2022). Comparative analysis of fuzzy logic-based image enhancement techniques for MRI brain images. In R. Asokan, D. P. Ruiz, Z. A. Baig, & S. Piramuthu (Eds.), *Smart data intelligence* (pp. 447–458). Springer.
- Li, G. (2018). Image contrast enhancement algorithm based on gm (1, 1) and power exponential dynamic decision. *International Journal of Pattern Recognition and Artificial Intelligence*, 32(02), 1854002.
- Ma, J., Fan, X., Yang, S. X., Zhang, X., & Zhu, X. (2018). Contrast limited adaptive histogram equalization-based fusion in YIQ and HSI color spaces for underwater image enhancement. *International Journal of Pattern Recognition and Artificial Intelligence*, 32(07), 1854018.
- Mittal, A., Soundararajan, R., & Bovik, A. C. (2012). Making a completely blind image quality analyzer. *IEEE Signal Processing Letters*, 20(3), 209–212.
- Muniyappan, S., & Rajendran, P. (2019). Contrast enhancement of medical images through adaptive genetic algorithm (AGA) over genetic algorithm (GA) and particle swarm optimization (PSO). *Multimedia Tools and Applications*, 78(6), 6487–6511.
- Rundo, L., Tangherloni, A., Nobile, M. S., Militello, C., Besozzi, D., Mauri, G., & Cazzaniga, P. (2019). MedGA: A novel evolutionary method for image enhancement in medical imaging systems. *Expert Systems with Applications*, 119, 387–399.
- Shoaib, M., Mohsin, M., Ansari, I. K., Maddhesiya, H., & Acharya, U. K. (2020). Single image haze removal using variable fog-weight. *Journal of Physics: Conference Series*, 1706(1), 012091.
- Shokrollahi, A., Mazloom-Nezhad Maybodi, B., & Mahmoudi-Aznaveh, A. (2020). Histogram modification based enhancement along with contrast-changed image quality assessment. *Multimedia Tools & Applications*, 79, 19193–19201.
- Singh, K., & Kapoor, R. (2014a). Image enhancement using exposure based sub image histogram equalization. *Pattern Recognition Letters*, 36, 10–14.
- Singh, K., & Kapoor, R. (2014b). Image enhancement via median-mean based sub-image-clipped histogram equalization. *Optik*, 125(17), 4646–4651.
- Singh, K., Kapoor, R., & Sinha, S. K. (2015). Enhancement of low exposure images via recursive histogram equalization algorithms. *Optik*, 126(20), 2619–2625.
- Singh, H., Kumar, A., Balyan, L. K., & Singh, G. K. (2018). Swarm intelligence optimized piecewise gamma corrected histogram equalization for dark image enhancement. *Computers & Electrical Engineering*, 70, 462–475.
- Singh, H., Kumar, A., Balyan, L. K., & Lee, H. N. (2019). Optimally sectioned and successively reconstructed histogram sub-equalization based gamma correction for satellite image enhancement. *Multimedia Tools and Applications*, 78(14), 20431–20463.
- Sipi, U. (2016). The USC-SIPI image database. 2005-07-12 [2009-08-05]. <http://sipi.usc.edu/services/database/data-base.html>.
- Subramani, B., & Veluchamy, M. (2018). MRI brain image enhancement using brightness preserving adaptive fuzzy histogram equalization. *International Journal of Imaging Systems and Technology*, 28(3), 217–222.
- Tan, T. L., Sim, K. S., & Tso, C. P. (2012). Image enhancement using background brightness preserving histogram equalisation. *Electronics Letters*, 48(3), 155–157.
- Thillainayagi, R., & Senthil Kumar, K. (2019). Bi-dimensional empirical mode decomposition based contrast enhancement technique for UAV thermal images. *IETE Journal of Research*, 1–8.
- Visual localization, image database. (2020). [www.visuallocalization.net](http://www.visuallocalization.net).
- Wang, Y., Chen, Q., & Zhang, B. (1999). Image enhancement based on equal area dualistic sub-image histogram equalization method. *IEEE Transactions on Consumer Electronics*, 45(1), 68–75.
- Wang, Y. F., Liu, H. M., & Fu, Z. W. (2019). Low-light image enhancement via the absorption light scattering model. *IEEE Transactions on Image Processing*, 28(11), 5679–5690.
- Zarie, M., Pourmohammad, A., & Hajghassem, H. (2019). Image contrast enhancement using triple clipped dynamic histogram equalization based on standard deviation. *IET Image Processing*, 13(7), 1081–1089.

- Zhang, Y., Wu, X., Lu, S., Wang, H., Phillips, P., & Wang, S. (2016). Smart detection on abnormal breasts in digital mammography based on contrast-limited adaptive histogram equalization and chaotic adaptive real-coded biogeography-based optimization. *SIMULATION*, 92(9), 873–885.
- Zhang, Y. D., Satapathy, S. C., Liu, S., & Li, G. R. (2021). A five-layer deep convolutional neural network with stochastic pooling for chest CT-based COVID-19 diagnosis. *Machine Vision and Applications*, 32(1), 1–13.

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Springer Nature or its licensor holds exclusive rights to this article under a publishing agreement with the author(s) or other rightsholder(s); author self-archiving of the accepted manuscript version of this article is solely governed by the terms of such publishing agreement and applicable law.



**Upendra Kumar Acharya** has completed his Ph.D. from National Institute of Technology, Delhi, India. He received his M.Tech degree in Electronics and Communication Engineering and B.Tech degree in Electronics Tele-communication Engineering. He is working as an Assistant Professor in the Department of Electronics and Communication Engineering in KIET group of institutions, Ghaziabad, Uttar Pradesh, India. He has nine years of experience in teaching and one year experience in industry. His research interests include image processing and soft computing techniques.



**Sandeep Kumar** received his B.Tech degree in Electronics & Instrumentation Engineering from the Institute of Engineering & Technology, MJP Rohilkhand University, Bareilly, India, in 2006 and his M.Tech and PhD degrees in Electronics & Communication Engineering from the Indian Institute of Technology (ISM), Dhanbad, India, in 2008 and 2015, respectively. He has more than 12 years of teaching and research experience. Currently, he is working as Assistant Professor in the Department of Electronics & Communication Engineering, National Institute of Technology, Delhi. His research interests include digital signal processing and its application in speech, audio, image, optical and bio-signal processing. He has been published more than 50 research articles in reputed International Journals and conferences. He is an Indian adapting author for Signals and Systems by Simon Haykin and Barry Van Veen, book published by Wiley. He is an active reviewer of many reputed journals published by IEEE, Elsevier, Springer, Wiley etc.