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A new combined technique for automatic contrast enhancement of digital images

Ismail A. Humied *, Fatma E.Z. Abou-Chadi, Magdy Z. Rashad

Faculty of Computers and Information Sciences, Mansoura University, Mansoura, Egypt

Abstract   Some low contrast images have certain characteristics makes it difficult to use traditional methods to improve it. An example of these characteristics, that the amplitudes of images histogram components are very high at one location on the gray scale and very small in the rest of the gray scale. In the present paper, a new method is described. It can deal with such cases. The proposed method is a combination of Histogram Equalization (HE) and Fast Gray-Level Grouping (FGLG). The basic procedure of this method is segments the original histogram of a low contrast image into two sub-histograms according to the location of the highest amplitude of the histogram components, and achieving contrast enhancement by equalizing the left segment of the histogram components using (HE) technique and using (FGLG) technique to equalize the right segment of this histogram components. The results have shown that the proposed method does not only produce better results than each individual contrast enhancement technique, but it is also fully automated. Moreover, it is applicable to a broad variety of images that satisfy the properties mentioned above and suffer from low contrast.

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* Corresponding author.
E-mail addresses: Ismaiel555@yahoo.com (I.A. Humied), f-abochadi
@ieee.org (F.E.Z. Abou-Chadi), Magdi_z2011@yahoo.com (M.Z. Rashad).

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1. Introduction

Because some features are hardly detectable by eye in an image, we often transform images before display. Numerous contrast enhancement techniques exist in literature, such as gray-level transformation based techniques (e.g., logarithm transformation, power-law transformation, piecewise-linear transformation, etc.) and histogram processing techniques (e.g., Histogram Equalization (HE), histogram specification, etc.) [1–6]. Histogram Equalization (HE) is one the most well-known methods for contrast enhancement. Such an approach is generally useful for images with poor intensity distribution. Its basic idea lies on mapping the intensity levels based on the probability distribution of the input intensity levels. It

flattens and stretches the dynamics range of the image's histogram and resulting in overall contrast improvement [7]. However, it tends to change the brightness of an image and hence, often fail to produce satisfactory results for a broad variety of low-contrast images. Such as, the original image have the amplitudes of its histogram components are very high in the first component of the nonzero histogram components NZHC,

e.g., at the zero location on the gray scale and very small in the rest of the gray scale, which could cause a washed-out effect on the appearance of the output image [8].

Recently, a histogram-based optimized contrast enhancement technique called Gray-Level Grouping (GLG) was developed by Chen et al. [8]. The basic procedure of this technique is to first group the histogram components of a low-contrast im-
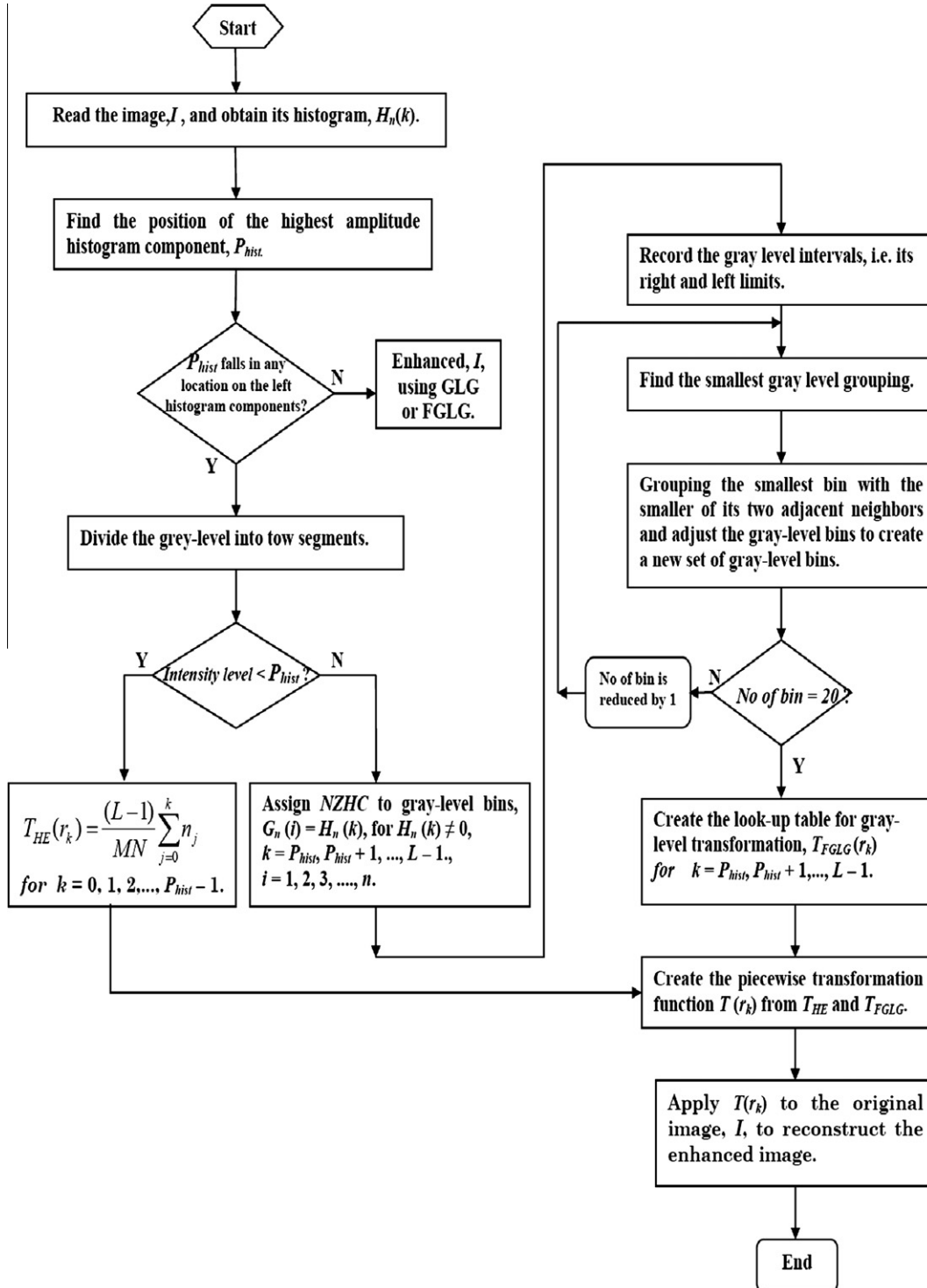

Figure 1   Flow chart of the proposed method algorithm with combination of HE and FGLG.
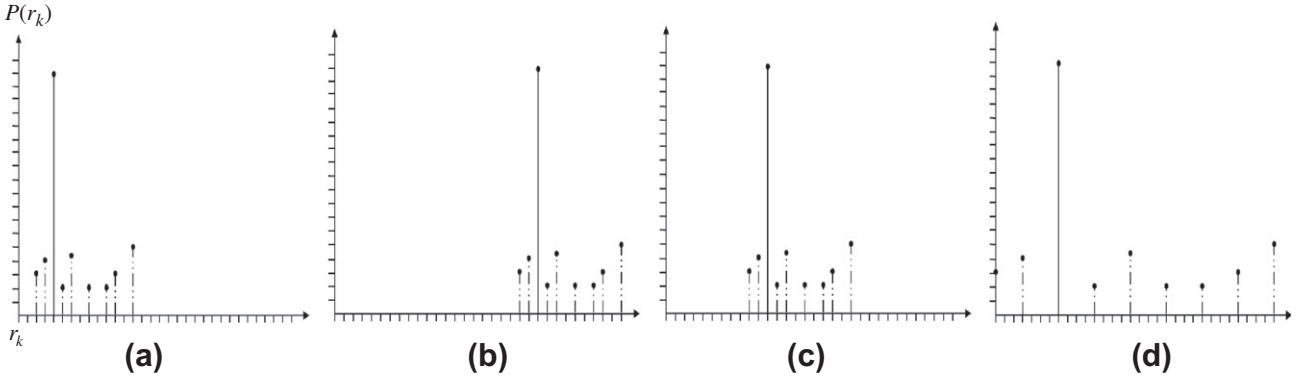
Figure 2 Histograms of a virtual image in four basic intensity characteristics. (a) Dark image. (b) Light image. (c) Low contrast image. (d) High contrast image.

age into a proper number of groups according to a certain criterion, then redistribute these groups of histogram components uniformly over the gray scale so that each group occupies a gray scale segment of the same size as the other groups, and finally ungroup the previously grouped gray-levels.

To reduce time in GLG technique as well as the number of iterations, a default value can be used for the total number of gray-level bins (as the right of Fig. 1), 20. In this method there is no need of constructing the transformation function and calculating the average distance between pixels on the gray scale for each set of gray-level bins. This method is called Fast Gray-Level Grouping (FGLG) since it is executed faster than basic GLG, as in [8]. It enhances the contrast of images that have the position of the highest amplitude histogram component, P_{hist}, in the first component of the nonzero histogram components $NZHC$. These techniques cannot enhance low contrast images that have P_{hist} lie in any location of the left region of $NZHC$ [9].

Fig. 2 shows the histograms of a virtual image in four basic intensity characteristics (dark, light, low contrast and high contrast) which the P_{hist}, solid line, lies in the left region of $NZHC$. The horizontal axis of each histogram plot corresponds to intensity values, r_k. The vertical axis corresponding to values of the probability of occurrence of intensity levels, $P(r_k)$.

In this paper, a new method is described to enhance low contrast images that have the amplitudes of its histogram components are very high at one location on the gray scale and very small in the rest of the gray scale.

This paper is organized as follows. Our proposed method is reported in the next section. In Section 3, the experimental results of our proposed method and other existing methods are presented and compared fairly. Section 4 contains our concluding remarks.

2. The proposed method

In this section, an automatic contrast enhancement technique is proposed that performs effectively with images that have the position of the highest amplitude histogram components lies in the left of $NZHC$ region. It is a combination of Histogram Equalization (HE) and Fast Gray-Level Grouping (FGLG). The proposed method is carried out via various stages. Fig. 1 illustrates a schematic diagram of the proposed method.

The histogram of an image with intensity levels in the range $[0, L - 1]$ is a discrete function $h(r_k) = n_k$, where r_k is the kth intensity level and n_k is the number of pixels in the image with intensity r_k. It is common practice to normalize a histogram by dividing each of its components by the total number of pixels in the image, denoted by product MN, where, as usual, M and N are the row and column dimensions of the image. Thus, a normalized histogram is given by $P(r_k) = n_k/MN$, for $k = 0$, $1, 2, \ldots, L - 1$. Loosely speaking, $P(r_k)$ is an estimate of the probability of occurrence of intensity level r_k in an image. Suppose that an input image I with intensity levels in the range $[0, L - 1]$ and its histogram was calculated, the basic procedure of the proposed method is as follows:

2.1. Histogram separation

Find the position of the highest amplitude histogram component, P_{hist}, on the gray scale. If P_{hist} lies inside the left segment of the $NZHC$ but not in the first component of the $NZHC$, the histogram can be separated into two sub-histograms, the first starting from 0 to $(P_{hist} - 1)$ intensity and the second starting from P_{hist} to maximum intensity level $(L - 1)$.

On the other hand, if P_{hist} lies inside the right segment of the $NZHC$ or in the first component of the $NZHC$ then we have to enhance low contrast image using FGLG.

2.2. Piecewise transformed function

Having performed the histogram separation based on the position of the highest amplitude histogram component, P_{hist}. We can directly apply the HE to first sub-histogram from 0 to $(P_{hist} - 1)$ and apply FGLG to second sub-histogram from P_{hist} to $L - 1$. The transformation function using HE can be expressed as followed [1,7]:

$$T_{HE}(r_k) = (L - 1) \sum_{j=0}^{k} p_r(r_j) = \frac{(L - 1)}{MN} \sum_{j=0}^{k} n_j \qquad (1)$$

for $k = 0, 1, 2, \ldots, P_{hist} - 1$. The transformation function using FGLG is $T_{FGLG}(r_k)$, for $k = P_{hist}$, $P_{hist} + 1$,
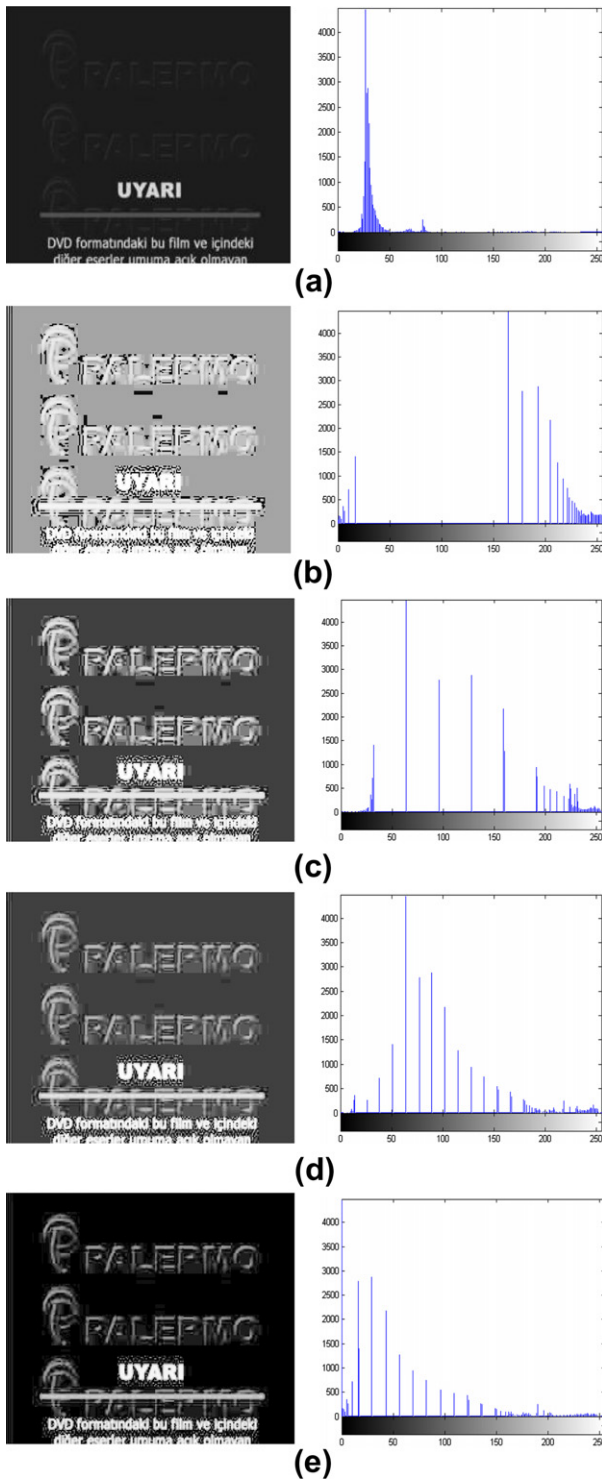
Figure 3 Images of sample text and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 27$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 8 found through the iterations process. (d) Result of FGLG. (e) Result of proposed method. (The highest amplitude in the histograms is the largest peak whose actual amplitude is 28089 Pixels. It is truncated so that the rest of the histograms can be displayed on a proper scale.)

$P_{hist} + 2, \ldots, L - 1$, as shown in Fig. 1. Therefore the piece-wise transformed function $T(r_k)$ can be expressed as followed:
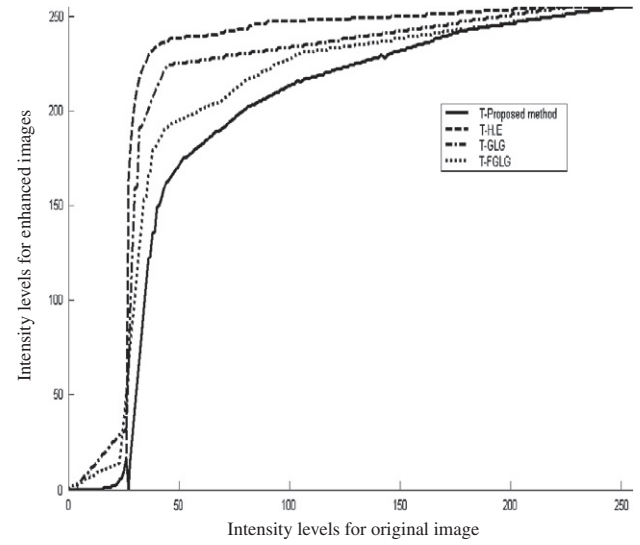

Figure 4 Transformation functions for the HE, GLG, FGLG and proposed method. Transformations where obtained from the histograms of the images in Fig. 3.

Table 1 The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 3.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	5.217	10.031	12.349	16.129
MSE	19561.882	6456.991	3786.424	1585.521
AMBE	0.536	0.259	0.211	0.009

$$T(r_k) = T_{HE}(r_k) + T_{FGLG}(r_k) \qquad (2)$$

for $k = 0, 1, 2, \ldots, L - 1$. Finally, the piecewise transformed function is applied to the original image to reconstruct the optimal enhanced image.

3. Experimental results

To demonstrate the effectiveness of the proposed algorithm, it was implemented and applied to a 46 of low contrast gray scale and colored images, such as text, faces and X-ray medical images.

As visual quality is extremely desirable for the contrast enhancement of the image, some specific properties are indicative of an effective contrast enhancement method. These are the probability of erroneous associations due to unsuitable illumination changes created by over-enhancement.

Fig. 3a shows the low contrast image of a sample text and histogram corresponding it, which show the position of the highest amplitude histogram component, $P_{hist} = 27$.

Fig. 3b is the equalized image using HE and histogram corresponding it. Histogram Equalization, on the other hand, substantially changes the original image. Many of the previously hidden letters are exposed. Unfortunately, at the same time, the enhancement over-saturates several areas of this image. Notice how the equalized image became washed out and not acceptable for many applications as mentioned earlier.
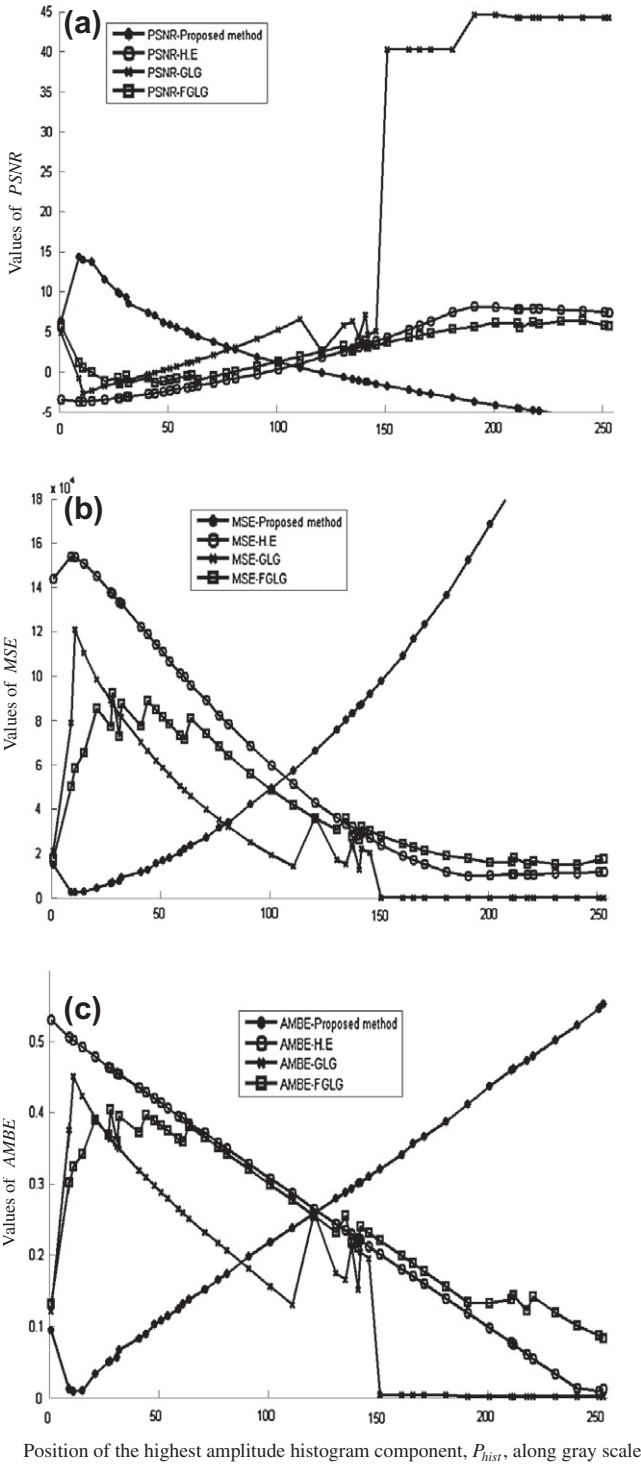
Figure 5 The values of: (a) *PSNR*. (b) *MSE*. (c) *AMBE*, for enhanced a set of low contrast images using HE, GLG, FGLG and proposed method. (The highest amplitude histogram component in these images has different position.)

The cause for the washed-out appearance is that the middle of the gray scale on the histogram of the equalized image is simply empty.

Fig. 3c and d is the resulting images of GLG and FGLG respectively, which are better than the HE result and the histo-
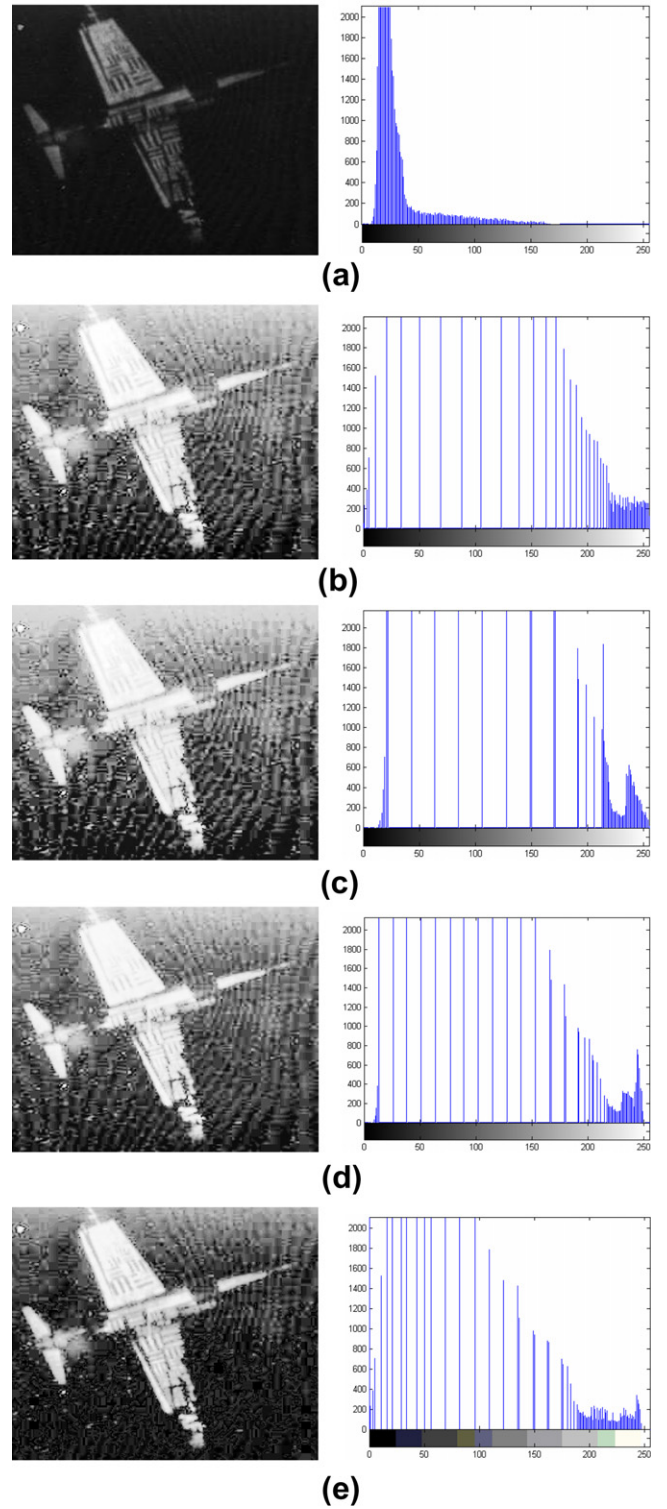

Figure 6 Images of airplane *U2*, and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 18$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 11. (d) Result of FGLG. (e) Result of proposed method.

grams for it results, are spread better than histogram for HE. Therefore the images result using GLG and FGLG are better
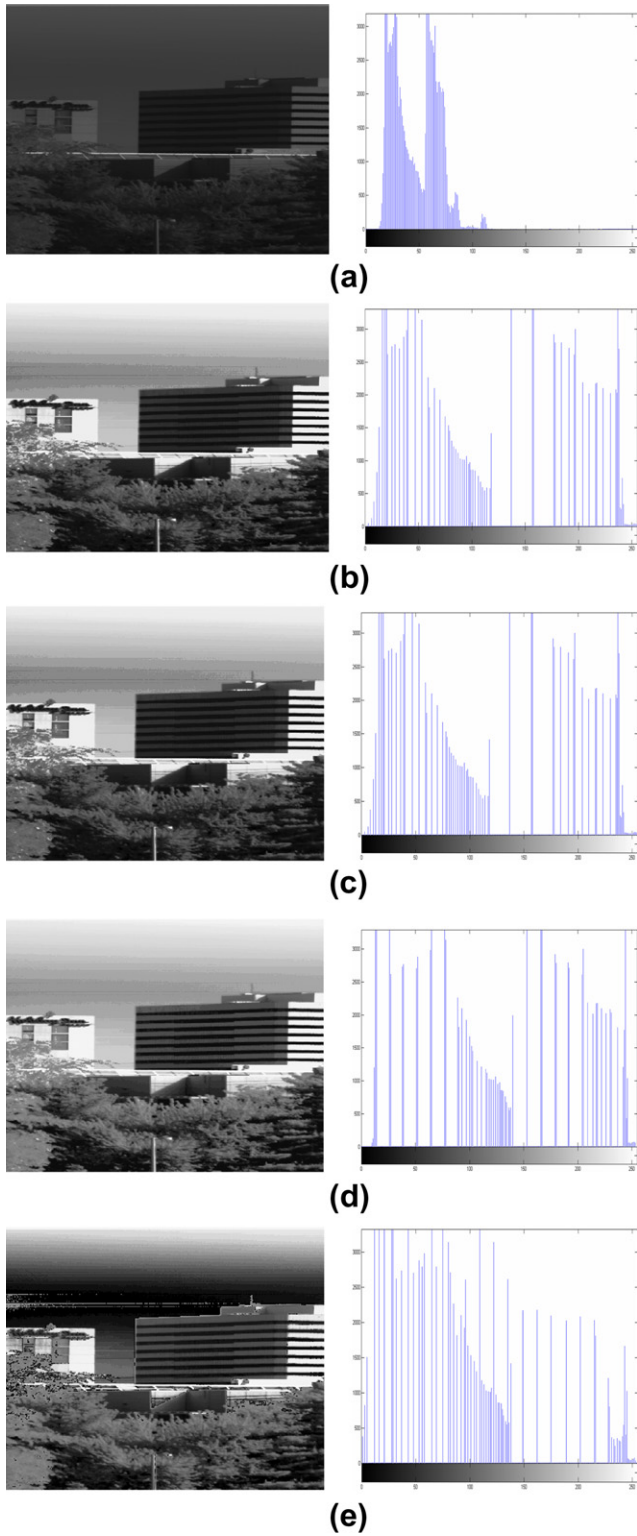
Figure 7 Images of house, and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 57$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 1. (d) Result of FGLG. (e) Result of proposed method.

Figure 8 Images of woman, and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 11$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 1. (d) Result of FGLG. (e) Result of proposed method.

than image result using HE, but the letters in these images still are not clear and appear slightly washed-out. Fig. 3e shows the
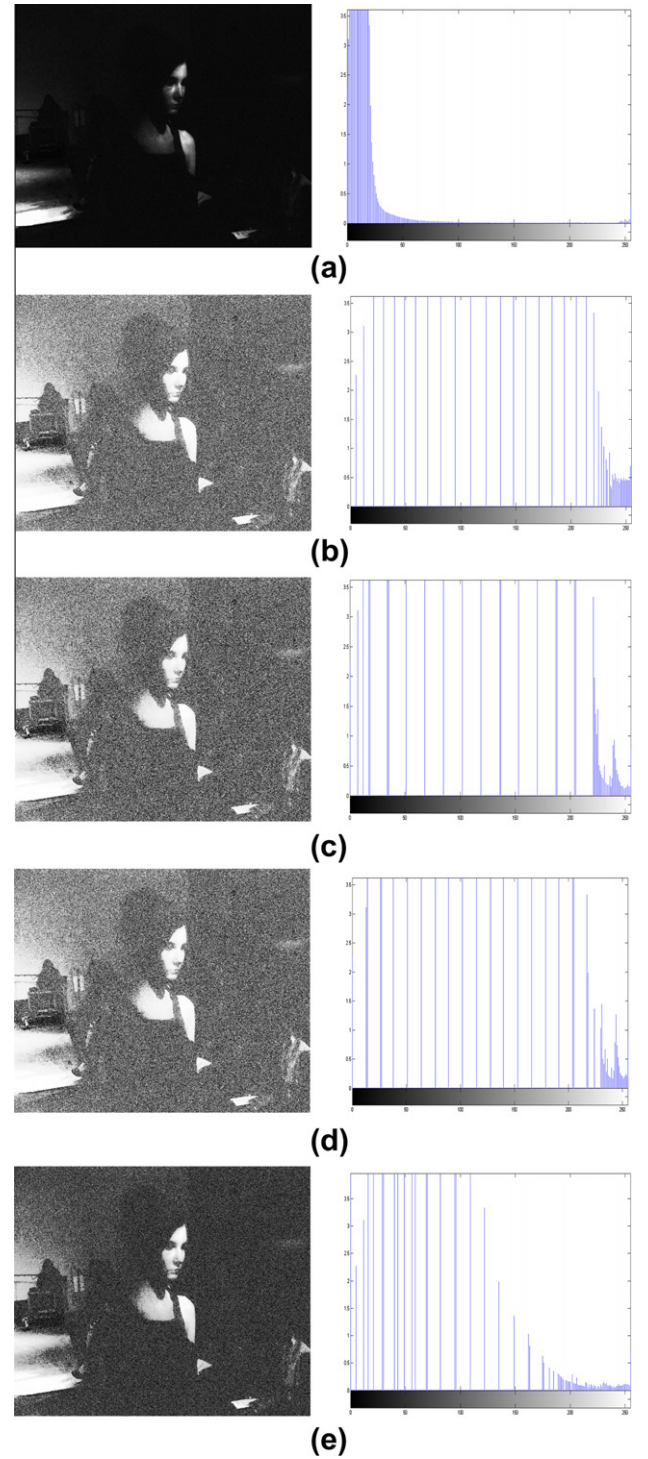
results of the proposed method and it is more effective than that obtained from techniques mentioned. The histogram corresponding it is more spread over the full range of gray scale, so there is no washed-out appearance in the output image and more natural looking effect.
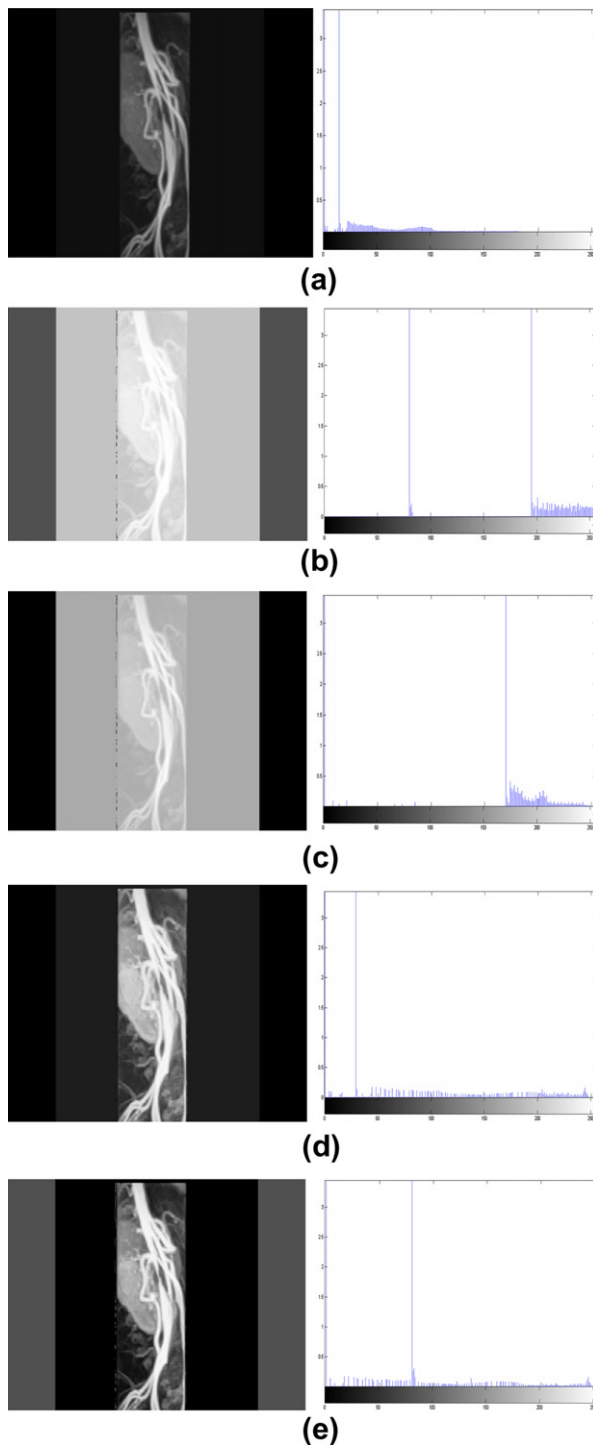
Figure 9 Images of stenosis of the abdominal Aorta in an infant, and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 14$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 3. (d) Result of FGLG. (e) Result of proposed method.

Figure 10 Images of Chest X-ray and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 240$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 4. (d) Result of FGLG. (e) Result of proposed method.

The mapping curves are illustrated in Fig. 4. It can be seen, that the proposed method, solid line, has a smoother curve compared to other methods. The equalized image mapped using the proposed method is a smooth mapping curve and
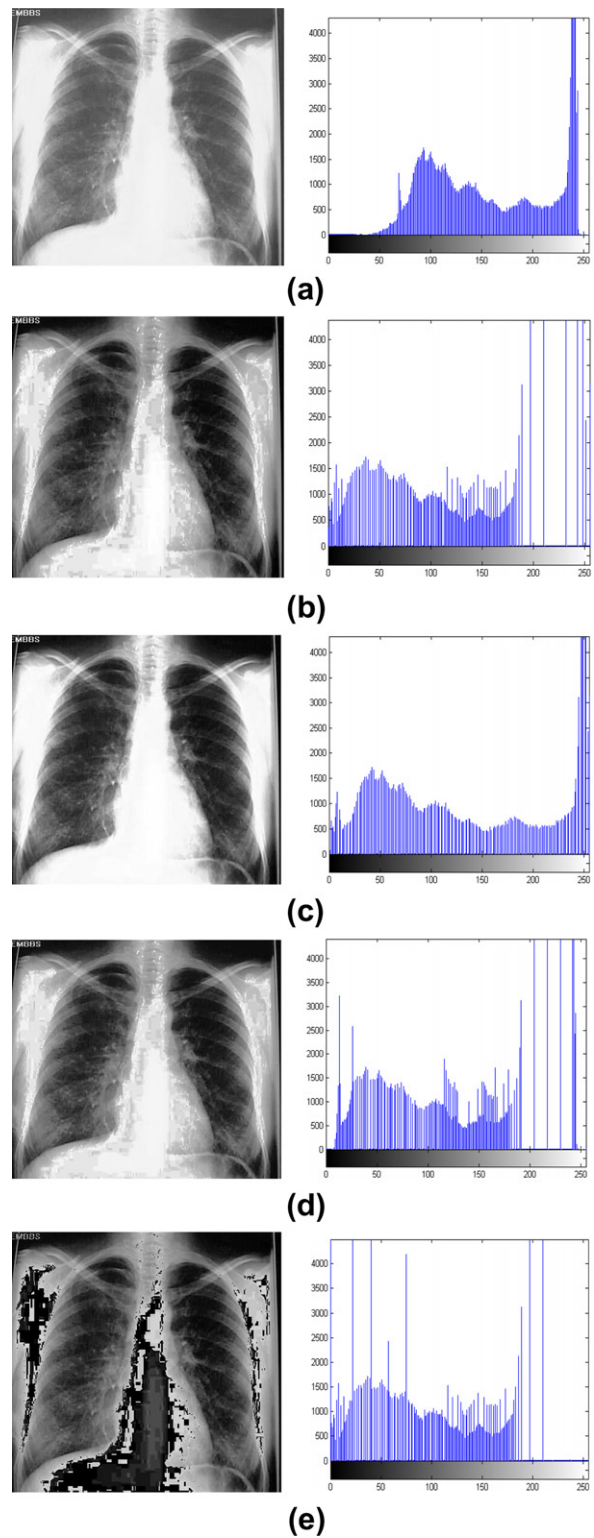
can produce a more natural looking enhancement of original image as shown in Fig. 3e.

Table 2   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 6.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	6.6762	6.4530	7.4718	10.4502
MSE	13979	14716	11639	5862.2
AMBE	0.4032	0.4099	0.3650	0.2093

Table 3   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 7.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	3.7663	4.5560	3.8208	6.9350
MSE	27318	22776	26978	13170
AMBE	0.3265	0.2748	0.3254	0.1591

Table 4   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 8.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	−8.2490	−7.9304	−7.9536	−3.1761
MSE	434490	403760	405920	135110
AMBE	0.4513	0.4204	0.4292	0.2297

Table 5   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 9.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	−4.9238	−3.0842	7.1777	8.9009
MSE	202050	132280	12454	11484
AMBE	0.5515	0.3826	0.0892	0.01210

Table 6   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 10.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	10.6806	13.0594	11.3682	2.9864
MSE	5559.3	3214.7	4745.2	3269.2
AMBE	0.1473	0.0793	0.1375	0.2997

Table 7   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 11.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	5.4167	5.9923	9.6832	4.8351
MSE	18681	16363	6994.6	21358
AMBE	0.2358	0.2092	0.1349	0.2511

Table 8   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 12.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	−0.5513	−0.1407	−1.1253	0.3483
MSE	73825	67166	84257	60014
AMBE	0.3997	0.3769	0.4207	0.3367

Table 9   The *PSNR*, *MSE* and *AMBE* values of the images of Fig. 13.

Criterion	Contrast enhancement technique			
	HE	GLG	FGLG	Proposed method
PSNR	−6.6627	−6.4426	−4.9739	-3.3682
MSE	301540	286640	204390	203820
AMBE	0.2364	0.2218	0.1721	0.1651

possible to compare their performance. The *PSNR* is defined as follows:

$$PSNR = 10\log_{10}\frac{255^2}{MSE} \tag{3}$$

where *MSE* is mean-square error, defined as

$$MSE = \frac{1}{MN}\sum_{x=1}^{M}\sum_{y=1}^{N}[I(x,y) - \bar{I}(x,y)]^2 \tag{4}$$

where I and $\bar{I}$ are the original and enhanced image, respectively, of size $M \times N$. Note that higher *PSNR* value and lower *MSE* represents greater image quality.

The performance of brightness preservation is rated by an objective measurement *AMBE*. It is defined as the absolute differential gray-level mean between the original image and enhanced image.

$$AMBE = |I_m - \bar{I}_m| \tag{5}$$

I_m and $\bar{I}_m$ denote the gray-level mean of the original and enhanced image, respectively. Note that lower *AMBE* value indicates that the brightness is better preserved and greater image quality.

Table 1, lists the *PSNR*, *MSE*, *AMBE* values of the HE, GLG, FGLG and proposed method. We can conclude from the results tabulated in this table that the proposed method achieves the highest *PSNR* and the lowest *MSE* and *AMBE* values. It should be noted these results agree with the visual inspection by the human eye.

In addition to qualitative evaluation, quantitative accuracy is also utilized to evaluate the proposed method and compare its performance with other methods. Using the Peak Signal-to-Noise Ratio (*PSNR*), Mean Square Error (*MSE*) and Absolute Mean Brightness Error (*AMBE*), are the most common measures of picture quality in image processing [10,11], it is
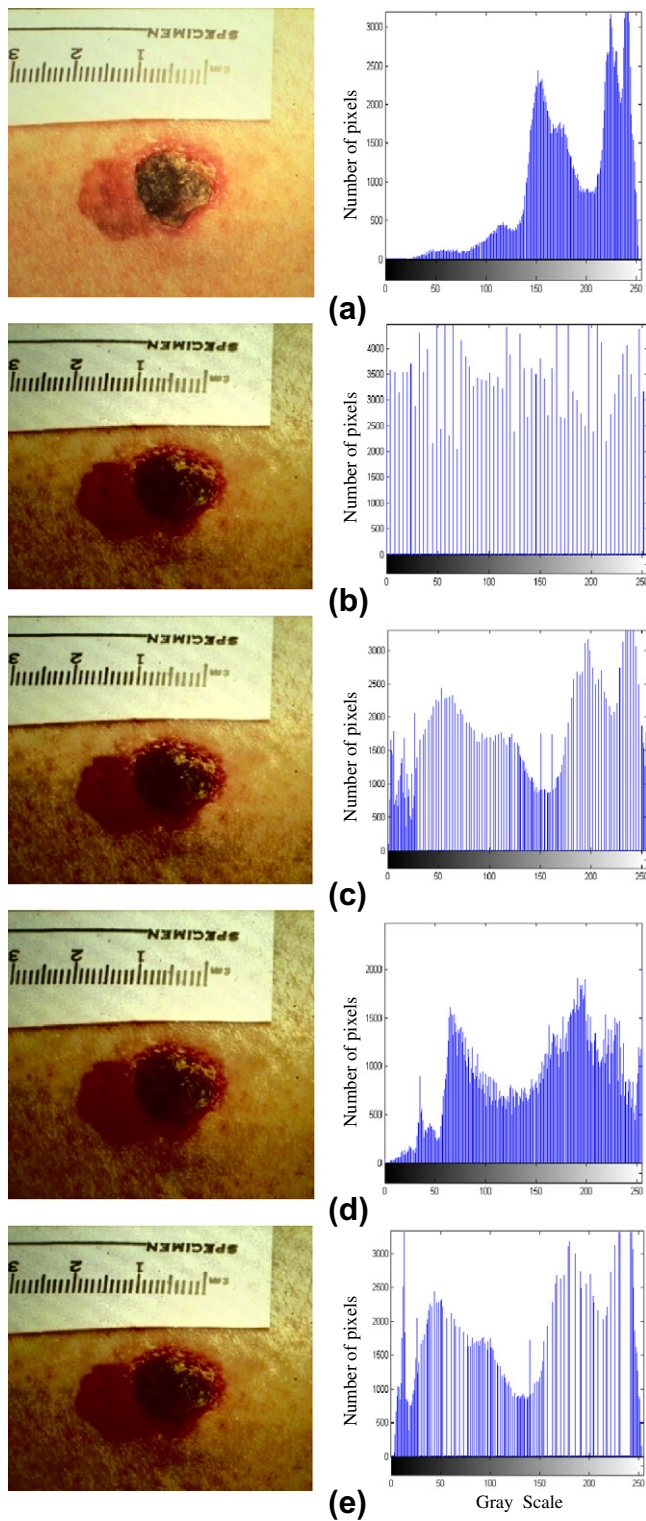
Figure 11   Medical examination images and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 241$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 2. (d) Result of FGLG. (e) Result of proposed method.

Figure 12   Images of fruits and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 15$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 30. (d) Result of FGLG. (e) Result of proposed method.

Fig. 5 shows the values of *PSNR*, *MSE* and *AMBE* for a 46 of low contrast images enhanced using HE, GLG, FGLG and
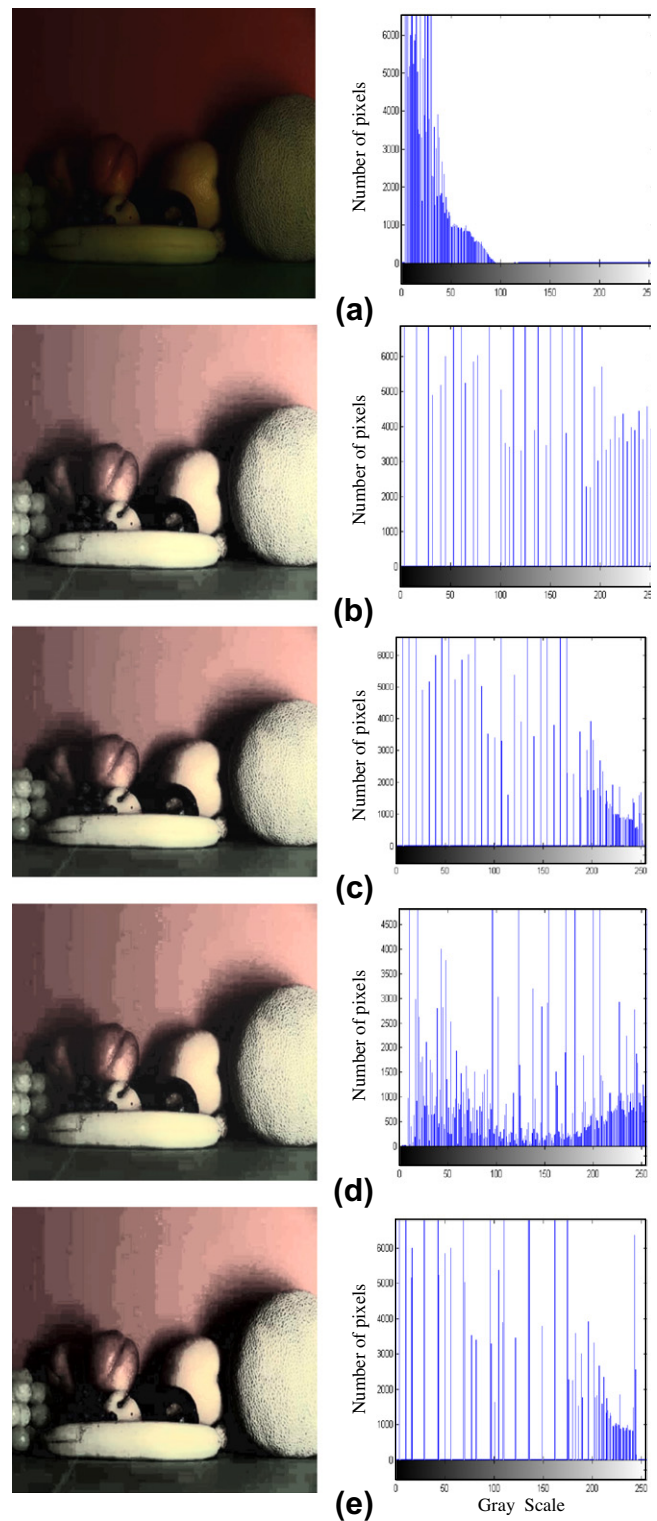
proposed method versus the position of the highest amplitude histogram component, P_{hist}, on these images along gray scale. The highest amplitude histogram component in these images
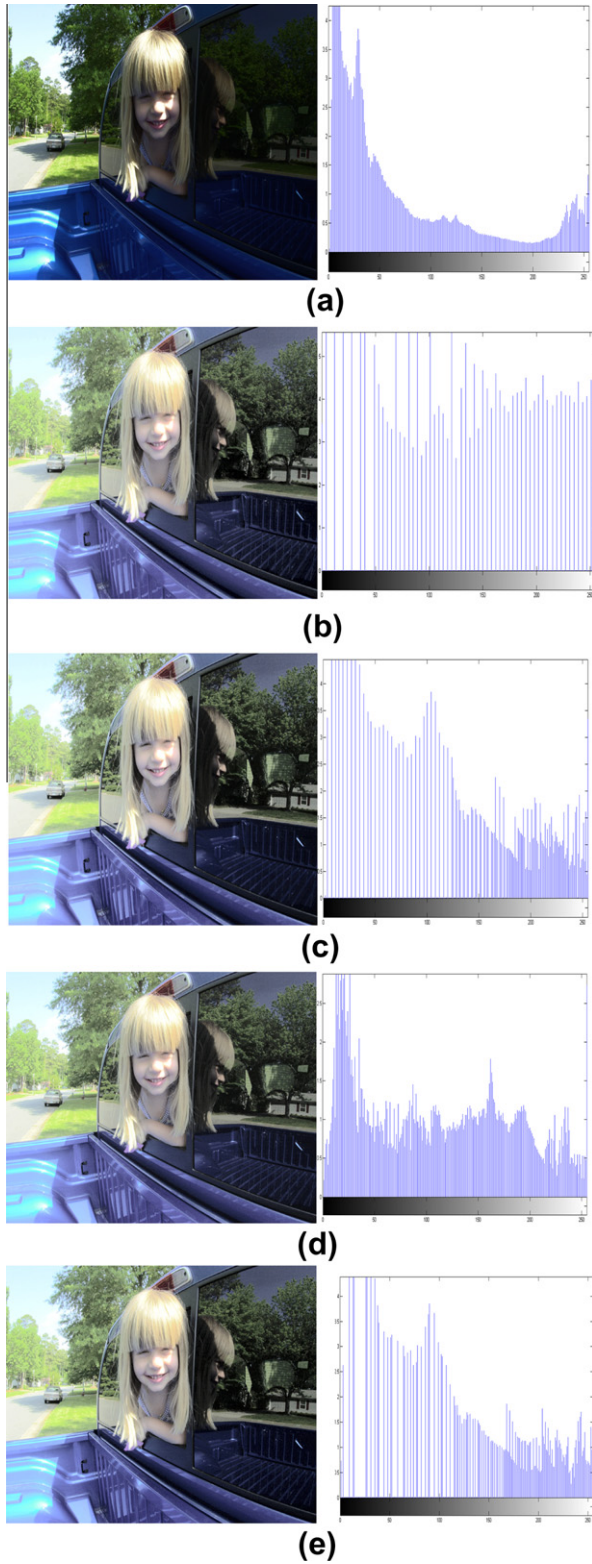
Figure 13 Images of girl and their corresponding histograms. (a) Original low-contrast image, with $P_{hist} = 6$ intensity level. (b) Result of HE. (c) Result of GLG, with the optimal bin numbers of 53. (d) Result of FGLG. (e) Result of proposed method.

has different position. In the left segment of gray scale shows that the proposed method has a highest *PSNR* values and lowest *MSE*, *AMBE* values. Moreover, it can be seen that the *PSNR* values decrease when we move away from the left of gray scale and there is an increase in the *MSE* and *AMBE* values.

Figs. 6–9 show examples of low contrast gray scale images to demonstrate the effectiveness of the proposed method when P_{hist} lies in the left segment of the histogram component. These figures illustrate the results obtained from applying HE, GLG, FGLG and proposed algorithm. It can be seen from these figures that visual quality of original image has been greatly enhanced in the resultant images.

Fig. 10, on the other hand, shows the Chest X-ray images, where the resultant image has not been enhanced by applying the proposed method. However, these images have been enhanced using GLG and FGLG method because P_{hist} lies in the right segment of the histogram components.

The quantitative analyses of the images in Figs. 6–10 are calculated and listed in Tables 2–6. It is noted that the images in Figs. 6–9 have significantly larger *PSNR* values and smaller *MSE* and *AMBE* values comparison with the other techniques. These results indicate that the proposed method performed better than other techniques. The interpretation of these results is that low-contrast images have noisy backgrounds representing a fairly large percentage of the image area.

The high amplitudes of the histogram components corresponding to the noisy image background often prevent the use of conventional Histogram Equalization techniques and the new basic GLG technique, because they would significantly amplify the background noise, rather than enhance the image foreground [9].

On the other hand, the images which have P_{hist} lies in right segment of the histogram component can be processed using the GLG or FGLG method as shown in the flowchart in Fig. 1. These characteristics often prevent the use of proposed method because of nature algorithm of the FGLG, the transformation function, T_{FGLG}, shows the P_{hist} mapping into zero location in gray scale. So the sudden change in result image in visual is occurrence in this case. As a result in Fig. 10e, the image is not desirable in visual.

The following Tables 7–9 show the quantitative analysis of HE, GLG, FGLG and the proposed method when applied to colored images as shown in Figs. 11–13. It can be seen from these figures that visual quality of original image has been greatly enhanced in the resultant image.

4. Conclusion

In this paper, a new method for automatic contrast enhancement images is described, which is a combination of the Histogram Equalization (HE) technique and the Fast Gray-Level Grouping (FGLG) technique. Experimental results show that the proposed method produces is effective and robust enhancement and better enhancement for various images than using each technique separately. The results show that the proposed method achieves the best quality through qualitative visual inspection and the image quantitative analysis of Peak Signal-to-Noise Ratio (*PSNR*), Mean square error (*MSE*) and Absolute Mean Brightness Error (*AMBE*) for the used images. The proposed method can be conducted in a fully-automated manner to contrast enhancement.

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