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A General Framework for 1-D Histogram-baesd Image Contrast Enhancement

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ABSTRACT

In this paper, a general framework for image contrast enhancement algorithm based on an optimization problem is presented. Through this optimization, the intensities can be better distributed. The algorithm is based on the facts that the histogram of the enhanced image is close to the input image histogram and uniform distribution, simultaneously. Based on this fact, we obtain a closed form optimal solution for the histogram of the enhanced image. Experimental results in a wide range of images demonstrate the high-performance of the proposed method.

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1. INTRODUCTION

Image contrast enhancement is one of the most important requirement in image processing and machine vision applications.

The contrast of an image is affected by lighting, inaccuracy of imaging process and device quality. As a result, the captured images lose some details and look too washed out and unnatural [1].

Contrast enhancement techniques are categorized generally into two main groups: direct methods [2, 3] and indirect methods [4, 5]. In direct methods, we determine a contrast enhancement measure and try to make it better. In indirect methods, the dynamic range of gray-level is expanded by utilizing the no-used area of the input range.

The second methods can be grouped into two following subgroups: i) algorithms based on modifying the histogram [6] and ii) algorithms based on transformation [7]. Algorithms in the first subgroup such as Histogram Equalization (HE) gets a lot of attention from researcher due to its simplicity and low computational time. HE is the most popular technique for image contrast enhancement which expands the dynamic range of image by mapping the input image, using the Cumulative Density Function (CDF) as input-output mapping function [8]. However, HE -without any modification- often leads to over enhancement and produces unrealistic effects. Because due to large smooth areas in the image, a large number of pixels having exactly the same gray-levels as their neighbors, so histogram spikes occur. Therefore, at that value of pixels, the resulted CDF maps a narrow range of gray values to a much wider range of gray values. Hence, it causes contouring and grainy noise type artifacts in uniform regions. From this point of view, a mapping function is better if it has not excessive slope at the spike bin gray-level and is closer to the no-change curve.

To modify the HE, Bi-Histogram Equalization (BHE) [6] and Dualistic Sub-image Histogram Equalization [9] were presented. They separate the histogram in two parts based on mean and median intensity of gray levels, respectively and then equalize them individually. These two methods produce spikes in the histogram of the enhanced image. Oppenheim et al. [10] histogram low-pass filtering to eliminate the histogram spikes.

These aforementioned methods cannot control the level of enhancement. To adjust the level of enhancement, Arici et al. [11] formulated the controllable contrast enhancement as a weighted sum of mixed norm problemand proposed a smoothed histogram which is closed to the original histogram and uniformly distributed histogram. Celik et al. [12]

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proposed Two Dimensional Histogram Equalization (2DHE) to avoid losing the contextual information. Although, 2DHE is the generalized form of HE, its creating is computationally demanding which exponentially increases with the size of considered neighborhood [12].

Hassanpour et al. [13] presented an image quality enhancement algorithm based on pixel-wise gamma correction using support vector machine. The feature vector was constructed from intensity histogram, gray level co-occurrence matrix and DCT coefficents.

Celik et al. [14] proposed a spatial entropy-based method which employs spatial location information of gray-levels of an input image to perform non-linear mapping function.

Gu et al. [15] enhanced the image contrast based on a reduced-reference image quality metric using combination of phase congruency and statistical information of the image histogram. Wu et al. [16] formulated contrast enhancement as an optimization function based on new definition of contrast and tone distortion. Then, solved the optimization problem with linear programming.

Gu et al. [17] proposed a saliency preserving contrast enhancement method which combines the original image, its histogram equalized product, and its visually pleasing version created by a sigmoid transfer function. the parameters were selected automatically based on the concept of saliency preservation.

Stochastic resonance-based methods in spatial domain have been proposed for the enhancement of dark- and low-contrast images [18, 19].

Hashemi et al. [20] presented a genetic algorithm based image contrast enhancement method in spatial domain. Using a suitable chromosome structure, fitness function and selection algorithm, a natural looking image with better contrast is produced. Raju et al. [21] proposed an algorithm based on the fuzzy logic and histogram under the control of the mean intensity and the contrast intensification.

Lee et al. [22] proposed an algorithm to enhance the overall contrast of the image based on discrete wavelet transform (DWT). Although, the algorithm performs well, it has many parameters that has to adjust with the operator.

In summary, an acceptable image contrast enhancement method should produce a natural looking image based on using the dynamic range effectively through a low computational cost algorithm. In this paper, we try to meet these expectations simultaneously.

The rest of this paper is organized as follows: In section II, the proposed image contrast enhancement algorithm is explained. Simulation results and discussion are described in section III. At the end, the conclusion is provided.

2. PROPOSED ALGORITHM

The proposed method is based on the three following facts: i) Similar to HE, to fully exploit the intensity dynamic range, the histogram of the enhanced image is as close as possible to a uniform distribution. ii) An enhanced image with smooth histogram is robust to problems created by histogram spikes such as strong repelling fixed points. iii) To preserve the useful details, the modified histogram is closed to the original histogram.

The first two facts are ultimately the same constraint, because a smooth modified histogram will tend to be flat or uniformly distributed. In other words, if we smooth the histogram, it will be close to the uniform distribution and also leads to have less spikes. Arici et al. [11] ignored this fact and considered these two redundant criteria in the optimization problem with constant balancing weights. They used the simple back-ward difference of the histogram to measure its smoothness. This optimization problem has been rewritten based on two dimensional histogram [12] and suffer from the mentioned drawbacks.

On the other hand, to preserve general brightness and obtain a natural looking image, we should preserve the total shape of the original histogram.

Considering the mentioned facts, in order to determine the modified histogram, h, we combined these goals by a bi-criteria optimization problem as a weighted sum of the two objectives as follows:

$$h^* = \arg\min_h (\underbrace{\sum_{i=1}^{n} \left| h_i - \hat{h}_i \right|^2 + \sum_{i=1}^{n} \sum_{j\in N(i)} w_{ij} \left| h_i - h_j \right|^2}_{E(h)}) \tag{1}$$

In this function, $\hat{h}$ and h indicate the n×1 original and modified histogram vector, respectively. *N(i)* is a neighborhood of the ith bin of histogram. n is the number of distinct gray-levels of the input image.

Despite objective functions presented in [11, 12], the smoothing term i.e. the second term in the energy function, *E(h)* weighted the difference of every possible pair of the original histogram bins by w_{ij}. Arici et al. [11] and Celik et al. [12] used the back-ward difference of the histogram or bi-diagonal difference matrix to measure the smoothness of the modified histogram, respectively. In addition, despite constant balancing weights Arici et al. [11] and Celik et al. [12], w_{ij}s determined adaptively.

We define the elements of a $n \times n$ weighted matrix, W, as follows:

$$W = \begin{cases} c & if \;\; i = j \\ w_{ij} & if \; i \neq j, \; j \in N(j) \\ 0 & if \; i \neq j, \; j \notin N(j) \end{cases} \tag{2}$$

Intuitively, we choose w_{ij} such that when the difference of consequent bins i and j of the histogram is increased, the corresponding element of weighted matrix, w_{ij} decreases. Also, w_{ij} decreases as $|i-j|$ increases. In addition, $c \in [1,10]$ is a constant to adjust the level of enhancement.

$$w_{ij} = \exp\left(-\frac{\left|\hat{h}(i)-\hat{h}(j)\right|^2}{2\sigma_h^2}\right).\exp\left(-\frac{|i-j|^2}{2\sigma_i^2}\right) \tag{3}$$

where σ_h^2 and σ_i^2 are two factors to control the contribution of w_{ij} and depend on the size of appropriate neighborhood, K, around the bins of histogram.

Chen et al. [23] proposed a similar energy function for edge preserving image denoising. According to analysis presented by Chen et al. [23], to solve the optimization problem, we define D be a $n\times n$ diagonal matrix with the ith entry as $D_{ii} = \sum_{j=1}^{n} w_{ij}$. Then, the globally optimal solution for the minimization of the energy function in Equation (1) is:

$$h^* = D^{-1/2}(D^{-1} + 2\bar{L})^{-1} D^{-1/2}\hat{h} \tag{4}$$

where $\bar{L}$ is a $n\times n$ matrix as follows:

$$\bar{L} = D^{-1/2}(D-W)D^{-1/2} \tag{5}$$

The proof of the above solution is given by Chen et al. [23].

Pluging this result into Equation (4), we get:

$$h^* = \{I + 2(D-W)\}^{-1}\hat{h} \tag{6}$$

where I is the identity matrix.

Through this way, the input gray-level **s** is mapped to the output gray-level ***t*** such that the input image with histogram $\hat{h}$ is transformed to the contrast enhanced image with histogram h^*.

To this end, the input gray-level **s** is mapped to the output gray-level ***t*** according to:

$$t = \arg\min_{l=0,1,\dots,255} \left|P_{h^*}(s) - P_u(l)\right| \tag{7}$$

where P_{h^*} and P_u is the cumulative distribution function formed using the h^* and uniform distribution, respectively.

The proposed algorithm is summarized as follows:

Input: a low contrast image, K, σ

Output: an improved image

Step 1: compute the histogram $\hat{h}$ of the input image

Step 2: compute the matrix W and D.

Step 3: compute the improved histogram h^*.

Step 4: determine the intensity mapping function based on Equation (7).

Step 5: construct the output image

3. EXPERIMENTAL RESULTS

To evaluation the performance of our algorithm -both qualitatively and quantitatively- we compare our algorithm with our implementations of related algorithms: HE [8], 2DHE [12] and WTHE [11]. In implementation of the proposed algorithm, to adjust the level of enhancement, the parameter $c \in [1,10]$ in Equation (2) and $\sigma = (K-1)/2$ in Equation (3) are selected empirically. K (the size of the neghborhood) varies in [3].

We exploit the images from two data bases which are available in web site[2,3].

In this paper, discrete entropy, mean brightness and contrast measure are used as quantitatively measures. Based on this criterion, in Celik et al. [12], 2DHE compared with the algorithms MWCVMHE [24], FHSABP [25], the weighted histogram approximation of WTHE [11] and CEBGA [20].

Some results of the proposed algorithm are provided in Figure 1 and Figure 2 (the proposed algorithm is applied only to the luminance component of color images). These results demonstrate that the proposed algorithm generates the high contrast images. It is easily seen, that the proposed algorithm does not produce excessive effects on bright and black area in enhanced image.

3. 1. Subjective Evaluation

Some example contrast enhancement results for grey-scale images and color images are shown in Figures 3-4 and Figures. 5-7, respectively.

- Gray-Scale Images:

Figure 3 and Figure 4 show the original images and enhanced images using HE [8], 2DHE [12], WTHE [11] and the proposed algorithm.

a b

Figure 1. Contrast enhancement result for Motion (a gray scale image). (a) Original image, (b) enhanced image using the proposed method.

[2] Retrieved on April 2014 from the World Wide Web < http://r0k.us/graphics/kodak/>

[3] Retrieved on April 2014 from the World Wide Web < http://sipi.usc.edu/database/>

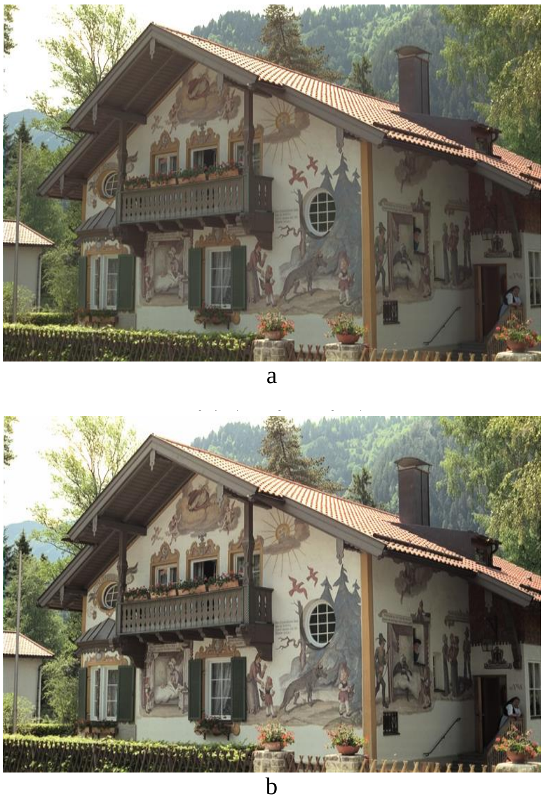


Figure 2. Contrast enhancement result for Painted house (a colour image). (a) Original image, (b) enhanced image using the proposed method.

Although HE expands the gray-level of image, but it doesn't generate the visually pleased images, as seen in Figures 3(b) and 4(b). 2DHE reduces the excessive effects of HE, as shown in Figures 3(c) and 4(c), however, it produces many unnatural details and cannot preserve the general brightness of the image. WTHE enhanced the image contrast at airframe only, but not at desert area, as shown in Figure 3(d).

The proposed method improves overall contrast while sharpening the image details, as we can see on the snow road of airport in Figure 3(e) and contextual information of the road of dessert in Figure 4(d). In addition, adjusting the level of enhancement leads to remove the artifacts and excessive effect compared with the other methods.

The input-output gray-level mapping function resulted from these methods are shown in Figures 7(a) and 7(b) of Plane and Tank images, respectively. We achieve smoother mapping function which is shown in Figure 8. It is easily seen that by utilizing the weighted smooth term in this paper, the proposed mapping function is smoother than resulted from HE and 2DHE. Having smoother mapping function, leads to have less spikes and avoid producing the repelling fixed point.

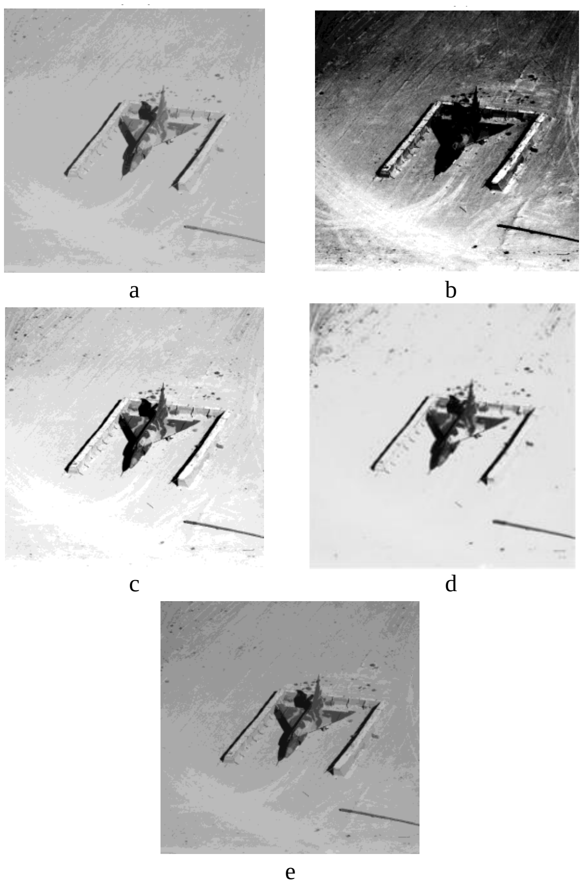


Figure 3. Contrast enhancement results for Plane. (a) Original image, enhanced images obtained using: (b) HE [8], (c) 2DHE [12], (d) WTHE [11], (e) Proposed method

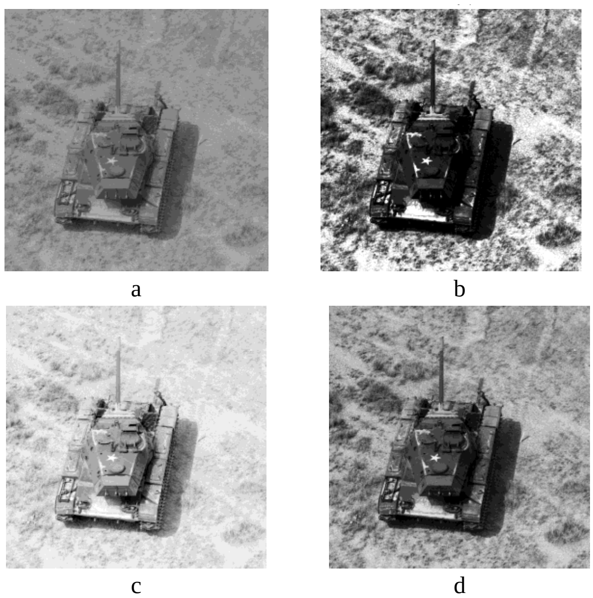


Figure 4. Contrast enhancement results for Tank. (a) Original image, enhanced images obtained using: (b) HE [8], (c) 2DHE [12], (d) Proposed method.

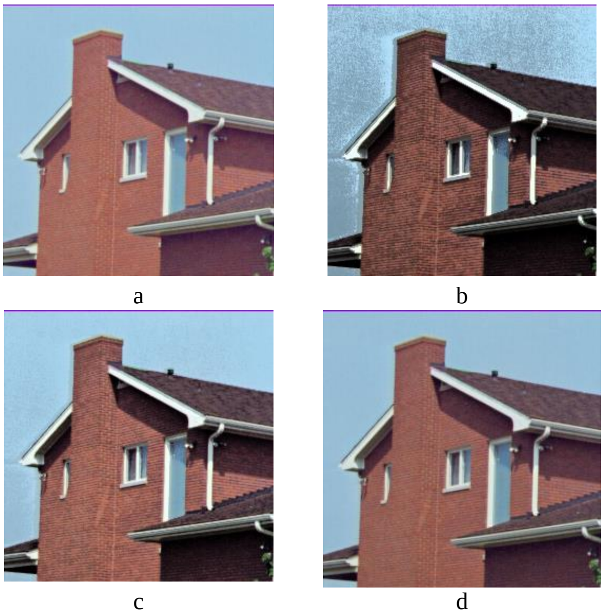


Figure 5. Contarst enhancement result for House. (a) Original image, enhanced mages obtained using: (b) HE [8], (c) 2DHE [12], (d) Proposed method

Figure 6. Contarst enhancement result for Girl. (a) Original image, enhanced mages obtained using: (b) HE [8], (c) 2DHE [12], (d) Proposed method

Approximate modified histogram by combining the original histogram and weighted smooth term to actuate the uniform distribution, improves images to look more natural and pleased and have overall uniform illumination. Hence, the enhanced image obtained by the proposed method has more quality and clarity than HE and 2DHE.

- Color Images:

In the case of color images, the proposed algorithm is applied to the lightness/value component only which extracted from V-channel in HSV color space. In this way, the chrominance components are preserved. Figure 5 and Figure 6 show the results of the proposed method in comparison with HE and 2DHE.

Figure 5(b) shows the resulted image of histogram equalization from House image. This enhanced image suffers from sample bleach and blacken, because of unnecessary stretching of the gray-level. 2DHE as shown in Figure 5(c) decreases the adverse effects of HE by considering the contextual information in computing the mapping function. It's clear to see, in addition to the existence of the repelling fixed point in flat area of sky, 2DHE has changed the appearance of the bricks.

Our proposed method expands the gray level of image with visible details on the bricks and without image degradation in the sky. This method eliminates the severe changes in mapping function using the weighted smooth term.

Figure 6 shows the other example of outperformance of the proposed algorithm in comparison with HE and 2DHE. These examples demonstrate the performance of our algorithm which improves the contrast of image without making artificial effects.

The input to output mapping functions of two color images (House and Girl) are shown in Figure 7(c) and Figure 7(d) respectively. The proposed mapping function in both of them are smoother than resulted mapping functions from HE and 2DHE, consequently, produce no unrealistic effects on the output images.

In Figure 8, we show results from HE, WTHE [11], OCTM [16], FLHM [21], ROHIM [15] and the proposed method. Obviously, the proposed method give more reasonable results than the others.

In Figure 9, a qualitative comparison between ROHIM [15] and the proposed method is illustrated. Obviously, the proposed method give comparable results.

3. 2. Objective Evaluation We evaluate the performance of the proposed algorithm with two quantitative measurements named Normalized Discrete Entropy, DE_N, and Normalized Absolute Mean Brightness Error, $AMBE_N$, similar to [11, 12]. We know that, as DE_N and $AMBE_N$ increase, the enhanced image is more rich in details and is better from the viewpoint of brightness preservation, respectively.

An experiment is conducted using 15 test images from aforementioned databases[4,5]. The DE_N and $ABME_N$ measurements are depicted in Figure 10 and Figure 11 to compare with HE, 2DHE and WTHE [11].

[4] Retrieved on April 2014 from the World Wide Web < http://r0k.us/graphics/kodak/

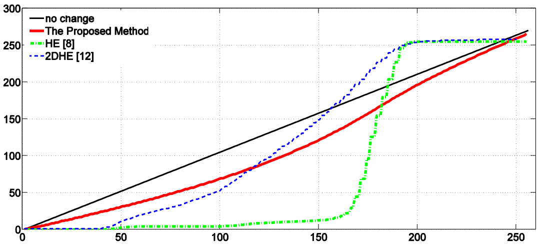
[5] Retrieved on April 2014 from the World Wide Web < http://sipi.usc.edu/database/>

The values of DE_N in proposed method are higher in all images. It means that we enhance the contrast of image with increasing the power of edges and details that is clear from subjective evaluation.

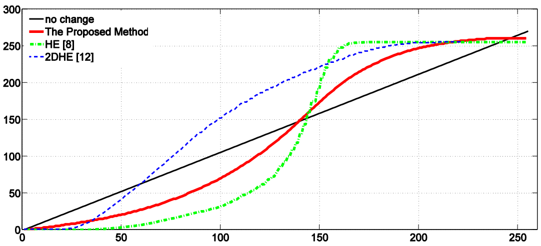
We can see that the DE_N value of the proposed algorithm is not sensitive to the input image in comparison to the other algorithms.

As we can see from Figure 11, the values of $AMBE_N$ in this method are higher, in comparison with HE in all images, with 2DHE in all images except in two images and with WTHE in all images except in three images.

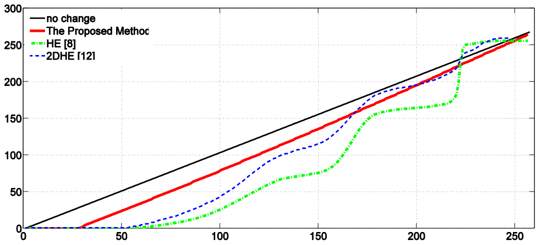
To quantify the amount of variation of these measurements, the average and standard deviation (SD) of these values are calculated and tabulated in Table 1 and Table 2.



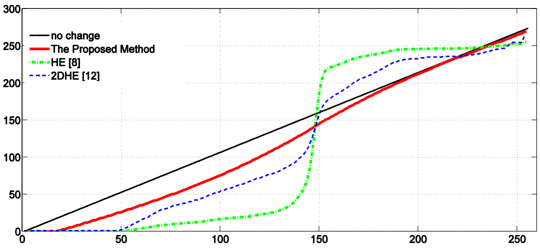
a



b



c



d

Figure 7. Mapping functions for enhanced image resulted from different methods correspond to (a) Figure 3, (b) Figure 4, (c) Figure 5, (d) Figure 6

a

b

c

d

e

f

Figure 8. Contrast enhancement results for Plane. (a) Original image, enhanced images obtained using: (b) WTHE [11], (c) OCTM [16], (d) FLHM [21], (e) ROHIM [15] (f) Proposed method

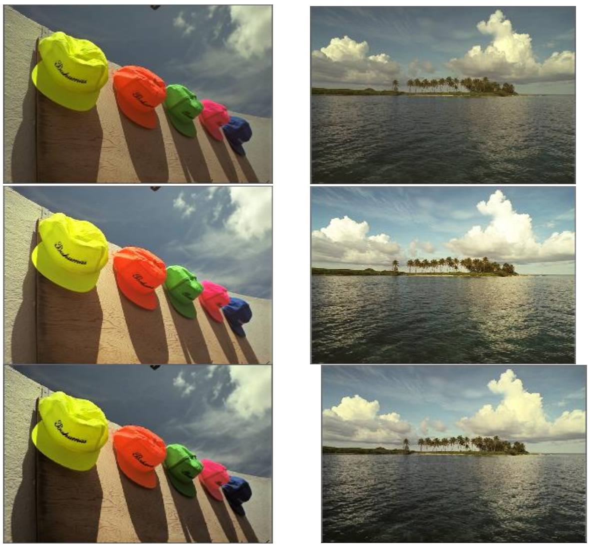


Figure 9. Contrast enhancement results for Original images (first row), enhanced images obtained using: (second row) ROHIM [15], (third row) Proposed method

It is easily observed that the proposed algorithm outperforms HE [8], Weighted Histogram Equalization [11] and 2DHE [12]. It is easily seen, in the proposed method, the average of this measurement is larger than other methods.

TABLE 1. Quantitative measurement results as DE_N

	HE [8]	WTHE [11]	2DHE [12]	Proposed Method
Mean	0.406	0.442	0.481	0.496
SD	0.009	0.004	0.0004	0.000

TABLE 2. Quantitative measurement results as $AMBE_N$

	HE [8]	WTHE [11]	2DHE [12]	Proposed Method
Mean	0.059	0.048	0.087	0.143
SD	0.004	0.001	0.008	0.023

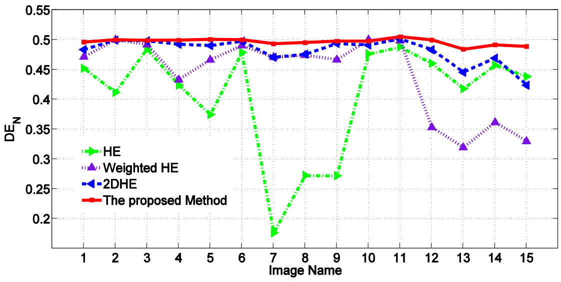


Figure 10. Comparison of quantitative measurement results, DE_N

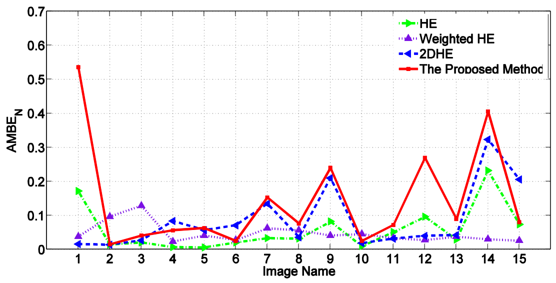


Figure 11. Comparison of quantitative measurement results, $AMBE_N$

4. CONCLUSION

In this paper, we proposed a solution for adjustable contrast enhancement problem which is still an attractive issue in image processing, machine vision. We enhance the contrast by finding the optimal smooth histogram which is close to original histogram and uniform distribution simultaneously. This algorithm preserves the general brightness of image and highlights the useful details on gray/color image. Experimental results demonstrate the performance of the proposed algorithm. For future work, we aim to extend this formulation to 2D histogram modification.

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چکیده

در این مقاله الگوریتمی کلی برای بهبود کنتراست تصویر طی حل یک مساله بهینه‌سازی ارائه شده است. این‌چنین مقادیر شدت روشنایی پیکسل‌های تصویر توزیع بهتری خواهند داشت. ایده پایه الگوریتم پیشنهادی این است که هیستوگرام تصویر بهبودیافته باید هم به هیستوگرام تصویر اولیه و هم به توزیع یکنواخت نزدیک باشد. این‌چنین جواب بهینه بسته‌ای برای هیستوگرام تصویر بهبود یافته بدست آمده است. نتیجه ارزیابی الگوریتم پیشنهادی در بهبود کنتراست تصویرهای گوناگون، کارایی بالای این الگوریتم را تایید کرده است.

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