Gradient Based Histogram Equalization in Grayscale Image Enhancement

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Abstract

- This paper presents a new method of parameterized histogram equalization for grayscale images, which is called the gradient based histogram equalization (GB-HE).
- The histogram equalization is performed on the low-pass filtered image by means of a symmetric gradient operator.
- The proposed method is simple, fast, and the preliminary experimental examples with different images show that the method is effective for image enhancement.
- While preserving the range and mean intensity of the image, the new method reduces the standard deviation and significantly straightens the graph of the histogram, when comparing with the traditional (or global) histogram equalization (HE).

Gradients in Histogram Equalization

The proposed method is called the gradient based histogram equalization (GB-HE). The 3×3 gradient operators are considered in this presentation, but other sizes 5×5, 7×7, … of gradients can be also used.

Different symmetric and asymmetric gradient operators are applied and their effectiveness is analyzed in the proposed method GB-HE in comparison with traditional HE.

While always preserving the mean of brightness for both traditional method of HE and proposed one, we will try to find the parameter of GB-HE, that minimizes the standard deviation of the enhanced image.

The GB-HE is parameterized by $\alpha \in (0,1]$.

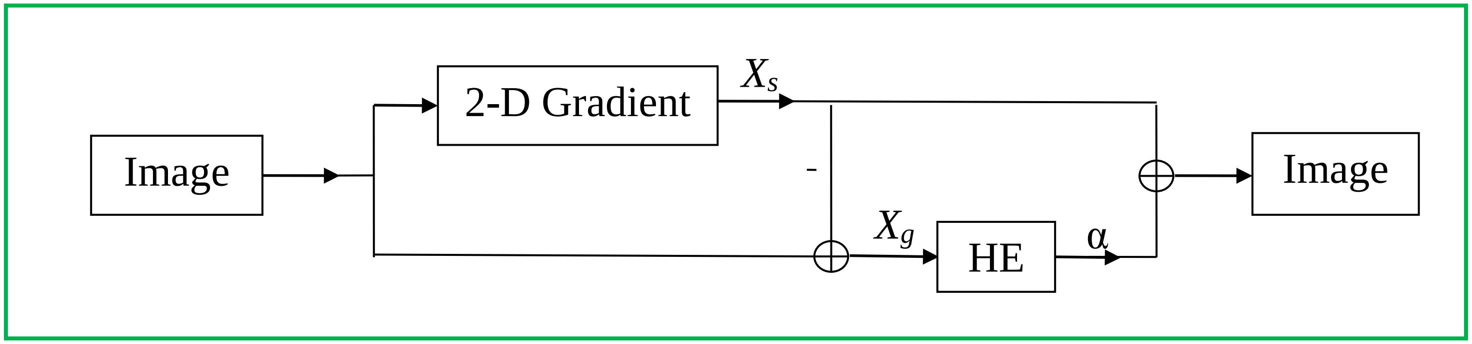


Figure 1. *The block-diagram of the parameterized GB-HE.*

We consider a gradient operator, for instance, one of the symmetric Laplacian gradients with the 3×3 matrices:

$$[G] = \frac{1}{4}\begin{bmatrix} 1 & 0 & 1 \\ 0 & -4 & 0 \\ 1 & 0 & 1 \end{bmatrix}, \quad \frac{1}{4}\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix}, \quad \frac{1}{8}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix},$$

and parameter α; a given number from the interval (0,1].

*The case α=1 corresponds to the traditional HE.

The algorithm of the parameterized GB-HE:

1. Calculate the convoluted image, or the gradient image $X_s = X * G$.
2. Calculate the difference image $X_g = X - X_s$.
3. Calculate the histogram equalization of image, $X_g \rightarrow X_g' = HE(X_s)$.
4. Calculate the new image $Y = \alpha X_g' + X_s$.

The output image Y is the result of the GB-HE.

** In stage 3, instead of the traditional HE, other methods of histogram equalization can also be used. For instance, the method of BI-HE.*

** The selection of the value of α for GB-HE can be based on the STD of the image.*

Example 1: The 512×512 pixel image ‘trucks7.1.10.tiff’ and the image of the GB-HE with parameter $\alpha = 0.54$. The result of the traditional HE of this image is also shown.

(a) (b) (c)

Figure 2. *(a) The grayscale image and (b) the GB-HE of the image with parameter* $\alpha = 0.54$*, and the traditional HE of the image.*

* One can notice the high quality of the GB-HE and many details in the “trucks” image are clearly visible; no such clarity in the image in part (c) for the traditional HE.

The mean value for all images is 0.0047=1/212, where 212 is the maximal value of the "trucks" image.

The standard deviation for the original image is 0.0089, and for the HE is 0.0091, and 0.0018 for the GB-HE, i.e., the STD for the GB-HE is 5 time smaller than for the HE.

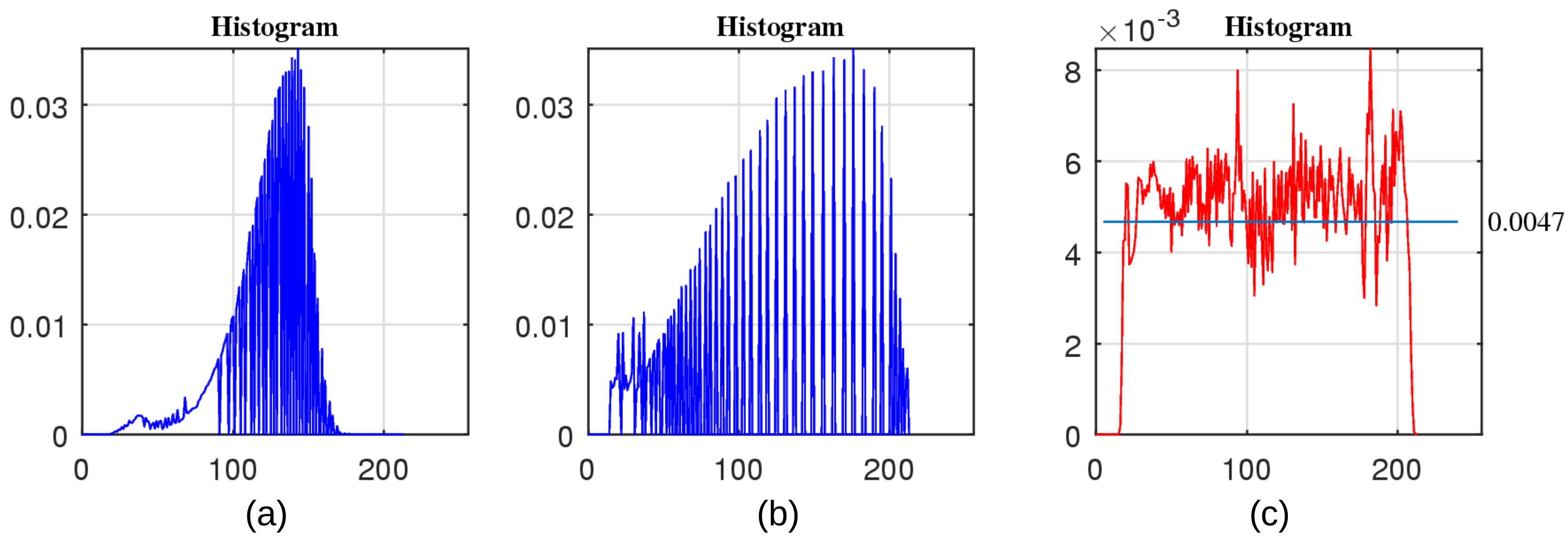


Figure 3. *The histograms of (a) the original image, (b) the GB-HE of the image, when* $\alpha = 0.54$*, and (c) the traditional HE of the image.*

The enhanced image is calculated by

$$X \to Y = Y(\alpha) = \alpha \times HE\left[X_g\right] + X * [G]. \qquad (1)$$

To select the value of α, we consider the value that minimizes the standard deviation (STD) of the histogram of Y image.

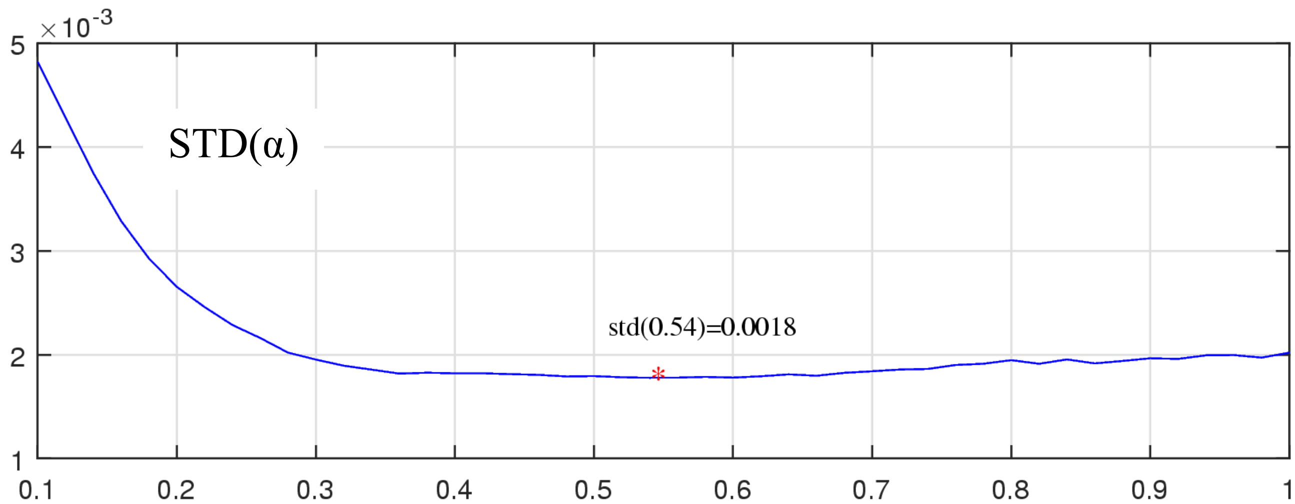


Figure 4. *The graph of the STD for images of the GB-HE of the 'tracks' image.*

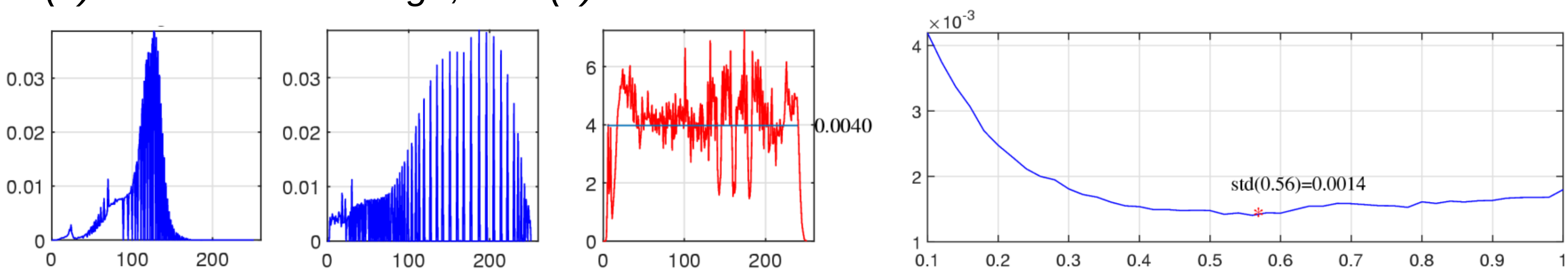
The value of such α is 0.54 and the STD at this point equals 0.0018.

* The characteristics as PSNR and EME measure of enhancement are linear functions of α.

Example 2: The 512×512 pixel grayscale image “truck”

(a) (b) (c)

Figure 5. (a) The grayscale image “truck 7.1.01.tiff” (from http://sipi.usc.edu/database/), (b) the HE of the image, and (c) the GB-HE calculated for $\alpha = 0.56$.



(a) (b) (c) (d)

Figure 6. *The histograms of (a) the original image, (b) HE, and (b) GB-HE calculated for* $\alpha = 0.56$*, and (d) the graph of the STD for images of the GB-HE of the ‘truck’ image.*

*The mean value for all images is 0.0040. STD at this point is 0.0014. The standard deviation for the original image is 0.0082, and for HE is 0.0083.

Comments: In model (3), different values of alpha can be used, including the negative values.

Such examples with "truck" image are shown in Fig. 7 for $\alpha = 0.4$, -0.4, and -0.8, in parts (a), (b), and (c), respectively. All these images have good qualities.

(a) (b) (c)

***Figure 7**. The image "truck 7.1.01.tiff" (from http://sipi.usc.edu/database/), after processing by the GB-HE with parameters (a) $\alpha = 0.4$, (b) $\alpha = -0.4$, and (c) $\alpha = -0.8$.*

Example 3: The 512×512 pixel grayscale 'tank2' image in Fig. 8. The GB-HE image was calculated for $\alpha = 0.36$. The result of the traditional HE is also shown for the comparison in part (b).

The high quality of the GB-HE

(a) (b) HE (c) GB-HE

Figure 8. *(a) The grayscale image "tank2", (b) the HE of the image, and (c) the GB-HE of the image with parameter $\alpha = 0.36$.*

The mean value for all images is 0.0040=1/249, where 249 is the maximum value of the “tank2” image. The standard deviation for the original image is 0.0075, and for HE is 0.0076, and for the GB-HE this number is much smaller, 0.0016.

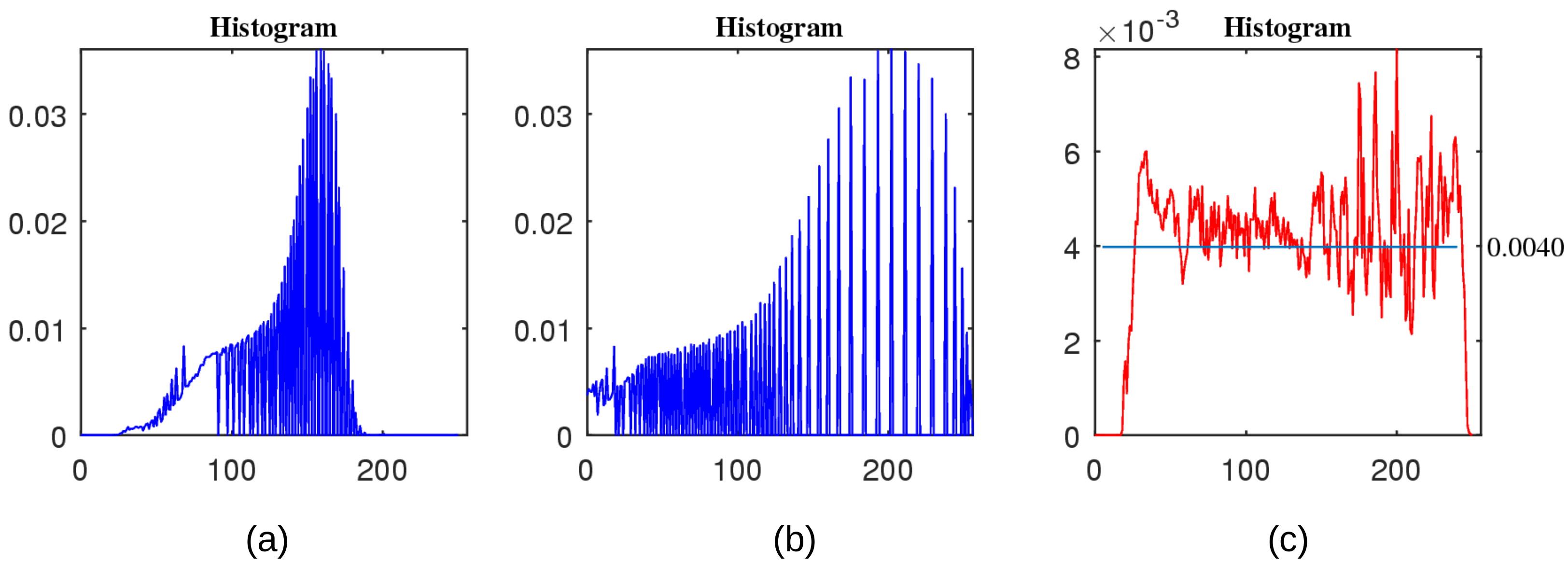


Figure 9. *The histograms of (a) the original ‘tank2’ image, (b) the traditional HE of the image, and (b) the GB-HE of the image with parameter* $\alpha = 0.36$.

The value 0.36 of parameter α is used, to minimizes the standard deviation (STD) of the histogram of image Y, as shown in the graph of the STD function.

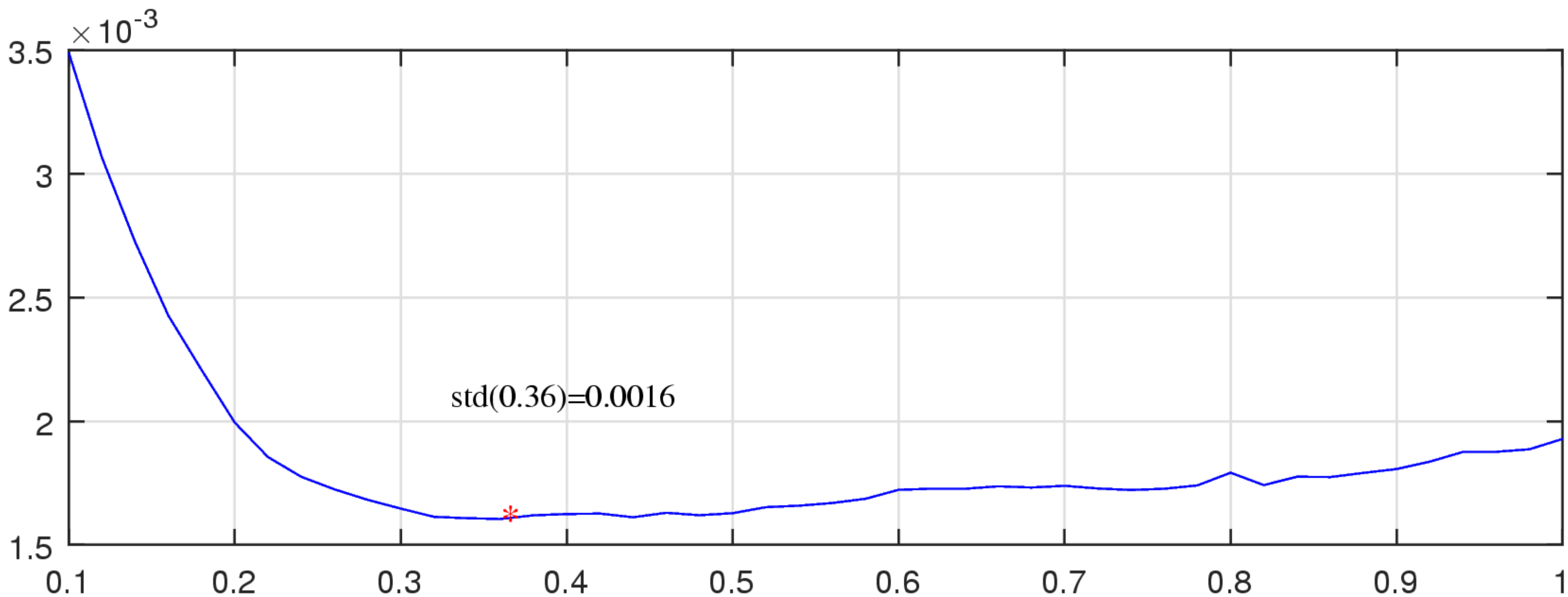


Figure 10. *The graph of the STD for the 'tank2' image.*

Example 4: *“Fountain”* ***I****mage, GB-HE, and Histograms*

The original 768×1024 pixels “fountain” image

GB-HE image, when α=0.62

Fig. 11

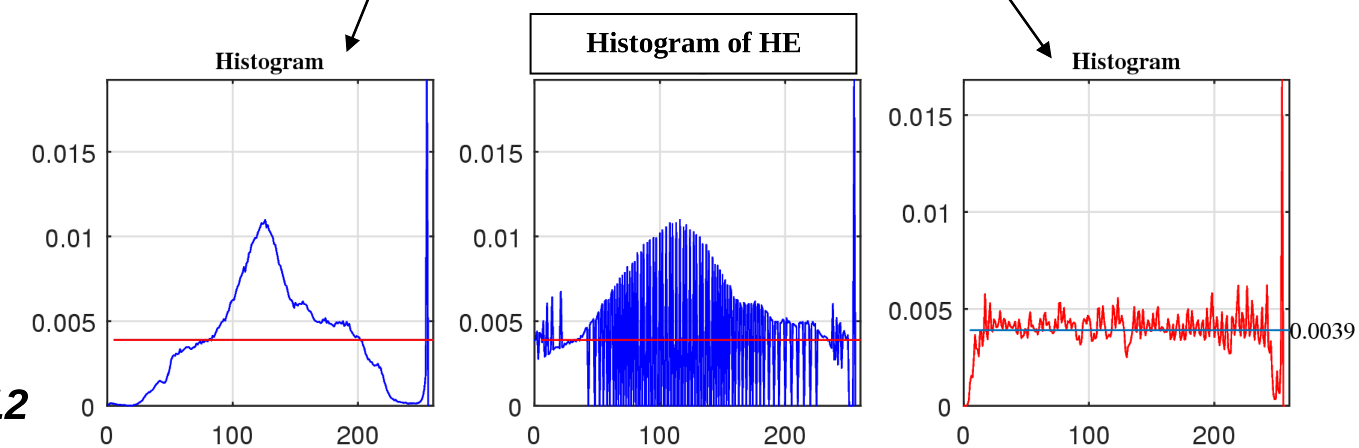


Fig. 12

Five gradient operators with the following 3×3 matrices:

$$[G_1] = \frac{1}{4}\begin{bmatrix} 1 & 0 & 1 \\ 0 & -4 & 0 \\ 1 & 0 & 1 \end{bmatrix}, [G_2] = \frac{1}{4}\begin{bmatrix} 0 & 1 & 0 \\ 1 & -4 & 1 \\ 0 & 1 & 0 \end{bmatrix},$$

$$[G_3] = \frac{1}{8}\begin{bmatrix} 1 & 1 & 1 \\ 1 & -8 & 1 \\ 1 & 1 & 1 \end{bmatrix},$$

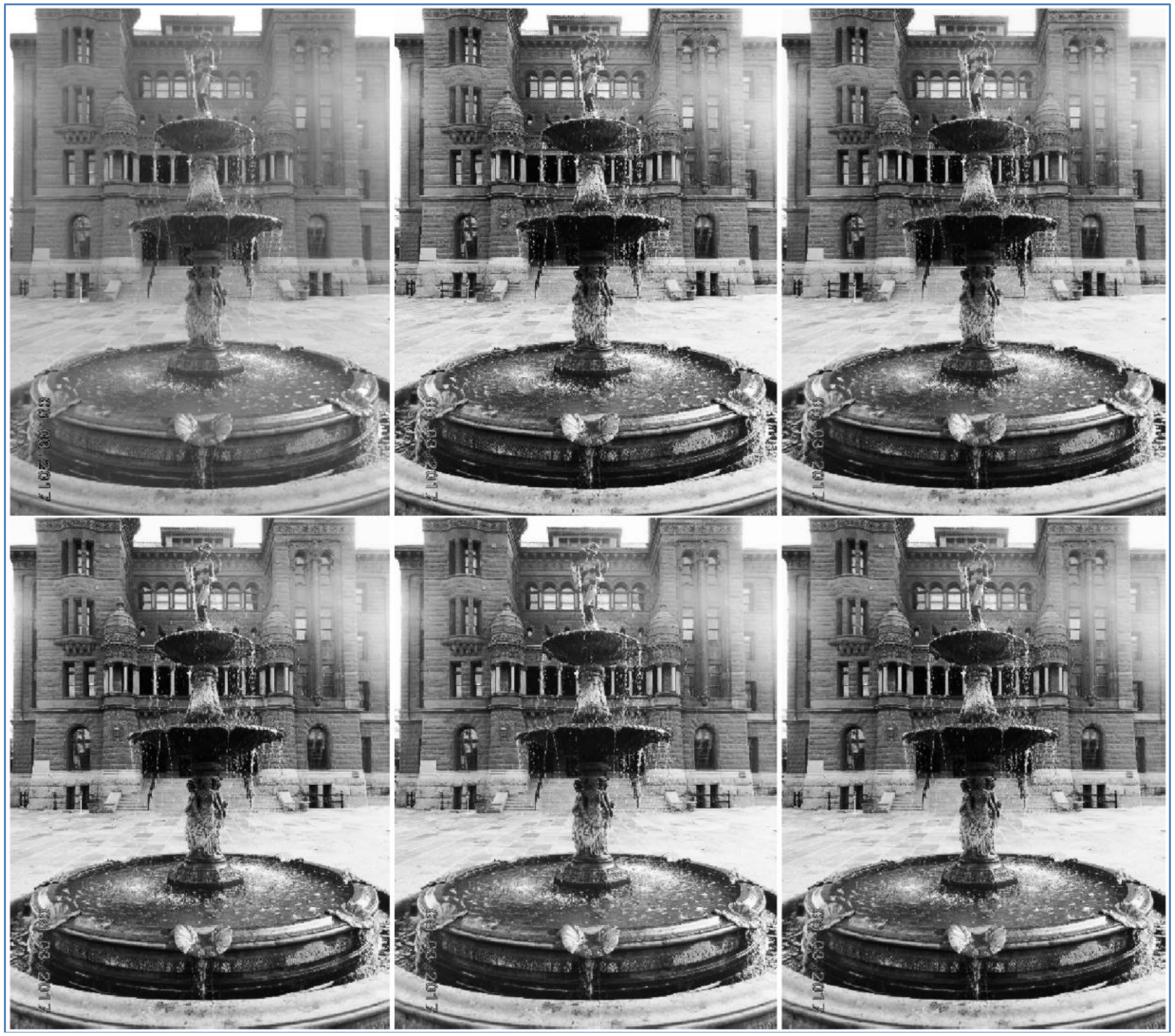
$$[G_4] = \frac{1}{8}\begin{bmatrix} 2 & 1 & 2 \\ -1 & -4 & -1 \\ 2 & 1 & 2 \end{bmatrix}, [G_5] = \frac{1}{20}\begin{bmatrix} 1 & 4 & 1 \\ 4 & -20 & 4 \\ 1 & 4 & 1 \end{bmatrix}.$$

	Original	HE	G_1	G_2	G_3	G_4	G_5
STD	0.0032	0.0034	0.0013	0.0015	0.0014	0.0016	0.0014
CCP	16.86	16.05	16.30	16.06	16.10	16.70	16.13
α			0.62	0.96	0.78	0.68	0.80

Table 1. Data for the HE and five GB-HEs of the "fountain" image.

- *CPP – Contrast-per-pixel measure of the image*

STD: 0.0032 0.0013 0.0015



STD: 0.0014 0.0016 0.0014

Figure 13. *The original image and images of GB-HE with 5 different gradients.*

Example 5:

STD: 0.0018 0.0019

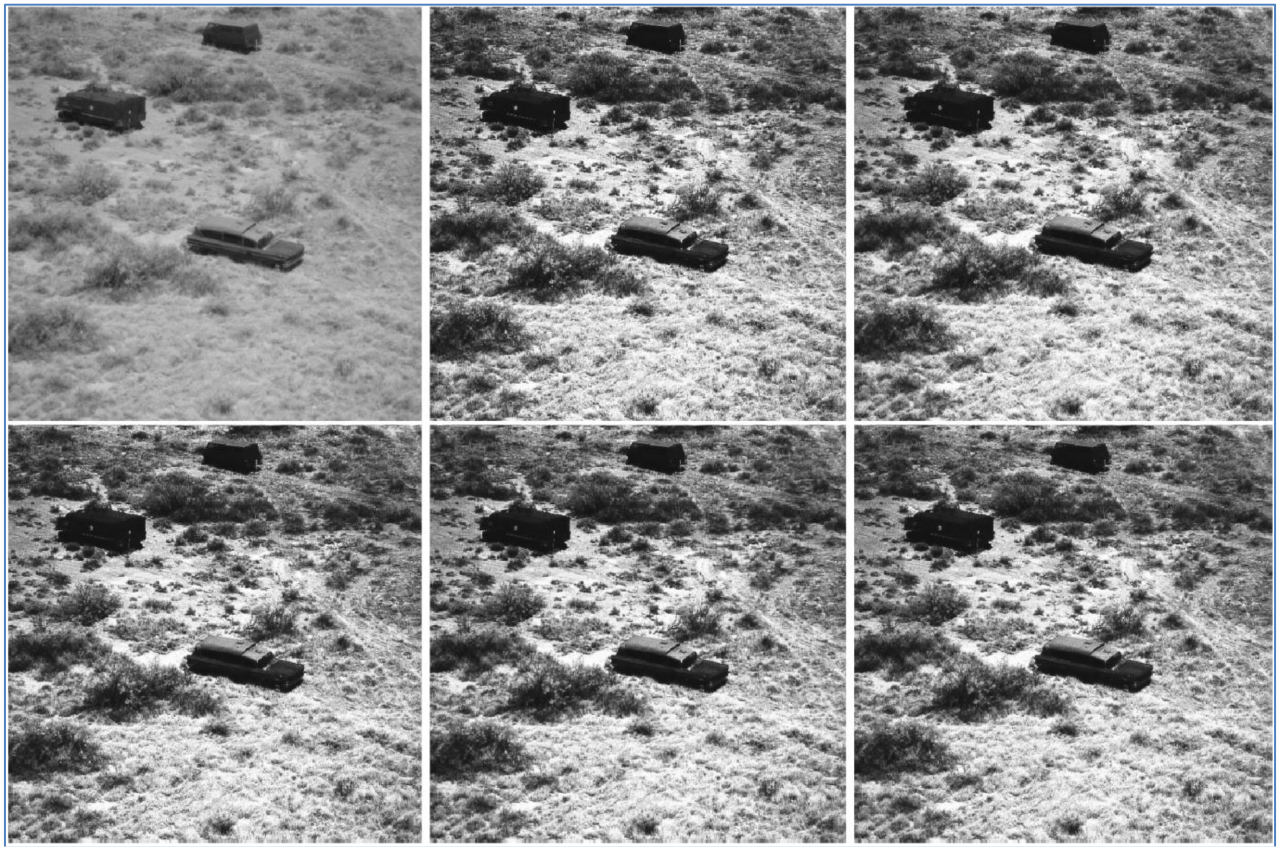


Fig. 14

STD: 0.0018 0.0018 0.0018

	Original	HE	G_1	G_2	G_3	G_4	G_5
STD	0.0089	0.0091	0.0018	0.0019	0.0018	0.0018	0.0018
CCP	14.95	14.23	14.34	14.29	14.28	14.27	14.27
α			0.54	0.62	0.66	0.66	0.66

Table 2. *Data for "trucks7.1.10" image and GB-HE with different 5 gradients.*

Example 6:

STD 0.0081, EME 31.65   *STD 0.0012, EME 36.68*

Enhance-ment measure EME 9.17

Figure 15. *(a) The original grayscale "tank1" image, (b) HE, and (c) GB-HE (α=0.36).*

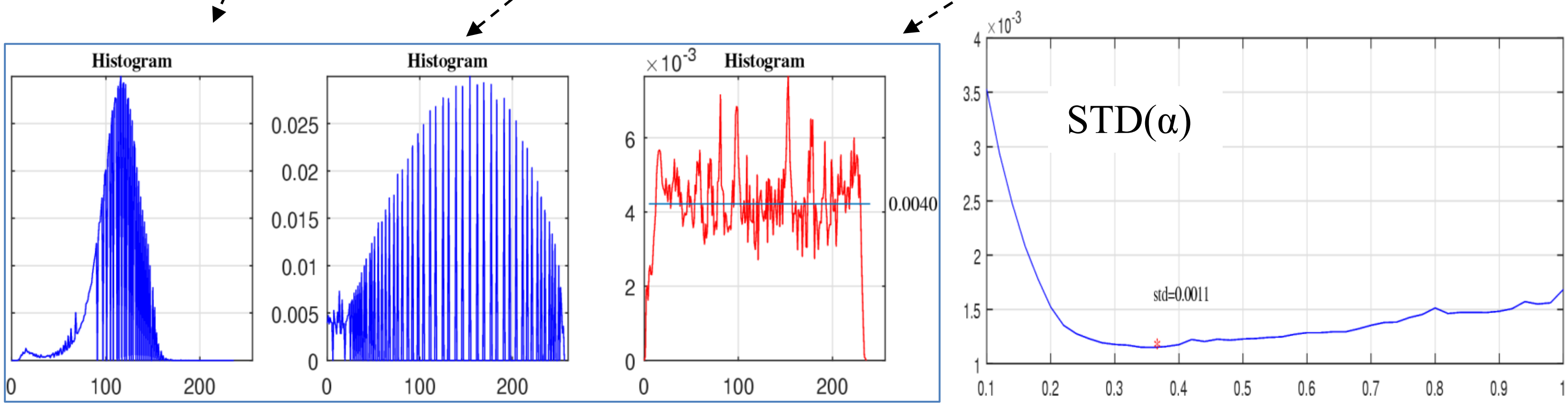


Figure 16*. The histograms and the graph of the standard deviation of the 'tank1' image.*

Data of Experimental Results on 11 Images

Image	Mean	STD (original)	STD (HE)	STD (GB-HE)
Lena	0.0041	0.0034	0.0039	**0.0020**
Truck	0.0040	0.0082	0.0083	**0.0014**
Jet plane	0.0043	0.0066	0.0070	**0.0022**
Pentagon	0.0040	0.0054	0.0057	**0.0024**
Tank1	0.0042	0.0080	0.0081	**0.0011**
Tank 2	0.0040	0.0075	0.0076	**0.0016**
Track 7.1.06	0.0039	0.0052	0.0053	**0.0009**
Track 7.1.10	0.0047	0.0089	0.0090	**0.0017**
Boat	0.0039	0.0047	0.0050	**0.0009**
Fountain SA	0.0039	0.0032	0.0034	**0.0016**
Sos in Alamo	0.0039	0.0027	0.0029	**0.0017**

One can notice that the STD of all images has small values.

Quantitative Measure of image enhancement (EME)

The quantitative measure of image enhancement that is called EME and has been derived after analyzing the Weber law of human visual system [1]-[3]. EME is the average of the range of $\{f_{n,m}\}$ image of size $N_1 \times N_2$ in the blocks on which the image is divided; of size $L_1 \times L_2$ each. Here, $k_i = \lfloor N_i / L_i \rfloor,\ i = 1, 2$, and $\lfloor . \rfloor$ denotes the rounding floor function.

$$EME(f) = \frac{1}{k_1 k_2} \sum_{k=1}^{k_1} \sum_{l=1}^{k_2} 20 \log_{10} \left[\frac{\max_{k,l}(f)}{\min_{k,l}(f)} \right].$$

$\max_{k,l}(f)$ and $\min_{k,l}(f)$ respectively are the maximum and minimum of the image $f_{n,m}$ inside the (k, l)th block.

EME of the Processed Images

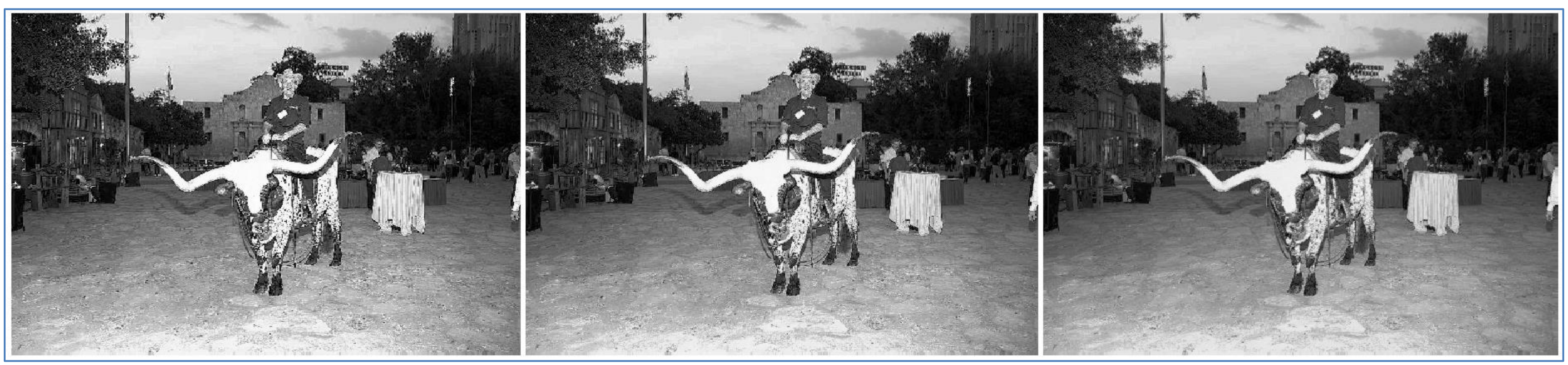
Image	EME (original)	EME (HE)	EME (BG-HE)	α optimal
Lena	5.45	7.46	**8.65**	0.72
Truck	7.43	20.97	**24.19**	0.56
Jet plane	4.89	10.89	**35.57**	0.98
Pentagon	6.27	13.60	**16.41**	0.52
Tank 1	9.17	31.65	**36.68**	0.36
Tank 2	7.70	15.02	**19.57**	0.36
Track 7.1.06	12.24	22.95	**27.60**	0.52
Track 7.1.10	5.94	15.28	**19.33**	0.54
Boat	8.31	16.57	**19.72**	0.54
Fountain SA	6.48	14.14	**15.25**	0.62
Sos in Alamo	15.96	14.37	**18.68**	0.66

One can notice that the EME of the GB-HE has high values.

Example: GB-HE of the Intensity of Color Image

Color image “Sos in Alamo” and its intensity grayscale image

Images processed by the GB-HE with different values



α=0.25 α=0.60 α=1 (HE)

Summary

A new parameterized gradient based histogram equalization was described, which is called the gradient-based histogram equalization (GB-HE). The experimental examples show that the method is effective for image enhancement. While preserving the range and mean intensity of the image, the new method reduces the STD and increases the quality of the enhancement, which can be seen visually, as well as by the image enhancement measure. In the proposed GB-HE, other modification of the HE can also be considered, too.

References

[1] S.S. Agaian, K. Panetta, A.M. Grigoryan, "A new measure of image enhancement, in Proc. of the IASTED Int. Conf. Signal Processing Communication, Marbella, Spain, Sep. 19-22, 2000.

[2] S.S. Agaian, K. Panetta, A.M. Grigoryan, "Transform-based image enhancement algorithms," IEEE Trans. on Image Processing, vol. 10, pp. 367-382, 2001.

[3] A.M. Grigoryan, S.S. Agaian, "Transform-based image enhancement algorithms with performance measure," Advances in Imaging and Electron Physics, Academic Press, vol. 130, pp. 165–242, May 2004.