

Image Contrast Enhancement based Sub-histogram Equalization Technique without Over-equalization Noise

Hyunsup Yoon, Youngjoon Han, and Hernsoo Hahn

Abstract—In order to enhance the contrast in the regions where the pixels have similar intensities, this paper presents a new histogram equalization scheme. Conventional global equalization schemes over-equalizes these regions so that too bright or dark pixels are resulted and local equalization schemes produce unexpected discontinuities at the boundaries of the blocks. The proposed algorithm segments the original histogram into sub-histograms with reference to brightness level and equalizes each sub-histogram with the limited extents of equalization considering its mean and variance. The final image is determined as the weighted sum of the equalized images obtained by using the sub-histogram equalizations. By limiting the maximum and minimum ranges of equalization operations on individual sub-histograms, the over-equalization effect is eliminated. Also the result image does not miss feature information in low density histogram region since the remaining these area is applied separating equalization. This paper includes how to determine the segmentation points in the histogram. The proposed algorithm has been tested with more than 100 images having various contrasts in the images and the results are compared to the conventional approaches to show its superiority.

Keywords—Contrast Enhancement, Histogram Equalization, Histogram Region Equalization, Equalization Noise

I. INTRODUCTION

CONTRAST enhancement is acquiring clear image through brightness intensity value redistribution. In other words, that is enhancing features as stretching interval between dark and brightness area. Enhanced image which was result of contrast enhancement processing in preprocessing stage will provide clear image to eyes or assist feature extraction processing in computer vision system.

They can be categorized by two approaches, global and local ones [1-3]. Global approaches improve image quality by extending dynamic range of intensity using the histogram of the whole image. Global histogram equalization(GHE) [4,5] is a good example of this approach that is widely used. GHE is achieved by normalizing the intensity distribution using its

F. Hyunsup Yoon is with the Electrical Engineering Department, Soongsil University, 511 Sando-dong, Dongjak-ku, Seoul 156-743, Korea (e-mail: beat83@ssu.ac.kr).

S. Youngjoon Han is with the Electrical Engineering Department, Soongsil University, 511 Sando-dong, Dongjak-ku, Seoul 156-743, Korea (e-mail: young@ssu.ac.kr).

T. Hernsoo Hahn is with the Electrical Engineering Department, Soongsil University, 511 Sando-dong, Dongjak-ku, Seoul 156-743, Korea (e-mail: hahn@ssu.ac.kr).

cumulative distribution function so that the result image may have a uniform distribution of intensity. Since GHE is basically using the intensity distribution of the whole image, it may cause washed-out effect by changing the average intensity to middle level [5-12]. And when equalization applying in the image which has severely crowded distribution in narrow region the many noise pixel value occurs as over-equalization processing.

To solve these problems involved in global contrast enhancement techniques, local histogram equalization techniques have been proposed. AHE (Adaptive Histogram Equalization) technique which is one of basic local histogram equalization techniques divides the original image into several non-overlapped sub-blocks and proceeds a histogram equalization operation on individual sub-blocks. The result image is produced by merging the sub-blocks using the bi-linear interpolation method [13]. In this case, a discontinuity problem, called a blocking effect, occurs near the boundaries of the sub-blocks. It occurs since a local contrast enhancement technique uses only local information inside each sub-block without considering the intensity balance of a whole image [13, 14]. For solving a blocking problem, sub-blocks are overlapped so that the boundary pixels may be included in the neighboring sub-blocks at the same time. But according to block size this process need many calculation and memory quantity[14].

In this paper, we propose sub-histogram equalization based new contrast enhancement algorithm which are preventing over-equalization and acquiring global contrast enhanced effect.

They divide optimized number of histogram based on histogram density function. And divided sub-histogram region are enhanced by sub-histogram equalization. Finally we get result image by merging each enhanced sub-images. Proposed contrast enhancement technique has an advantage that prevent over-equalization effect in concentrated histogram regions and contrast enhancement in sub-histogram region since uniformly equalization execute in low density region.

The rest of this paper is organized as follows. In Section 2, the advantages and drawbacks of the conventional contrast enhancement techniques based on global and local contrast enhancement techniques are described. In Section 3, density measuring method for divide histogram region explained and in Section 4, sub-histogram equalization range and result image recovery methods will be explained. And in Section 5, proposed algorithm is proved by the experiments where it is

compared with those of the conventional algorithms and finally Section 6 presents the conclusion.

II. CONVENTIONAL APPROACHES

Global histogram equalization techniques [1] acquire the scale factor from the normalized cumulative distribution of the brightness distribution of the original image and multiply this scale factor to the original image to redistribute the intensity.

An image is represented as a set of data, $X = \{X(i,j) | X(i,j) \in \{X_0, X_1, \dots, X_{L-1}\}\}$, where each component may have one of L intensity levels. That is, $X(i,j)$ represents the normalized intensity of the (i,j) th pixel in the image plane and X_k is the k -th intensity level. To equalize the brightness histogram of a given image X , it is normalized first to obtain the probability density function (PDF) of the image, represented by Eq. (1).

$$p_X(X_k) = \frac{n_k}{n} \quad (1)$$

$$0 \leq X_k \leq 1 \text{ and } \sum_{k=0}^{L-1} p_X(X_k) = 1$$

Where n is the total number of pixels in the input image, n_k is the number that X_k appears in X .

To obtain a histogram equalization function, the cumulative distribution function (CDF) of X_k is calculated first from probability density function using the following Eq(2).

$$s_k = T(X_k) = \sum_{j=0}^k p_X(X_j) \quad (2)$$

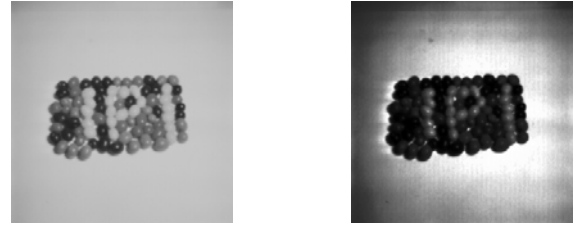
$$= \sum_{j=0}^k \frac{n_j}{n}$$

Where $k=0,1,\dots,L-1$ and $T(X_{L-1})=1$. S_k is the value of the cumulative distribution function at the k -th intensity level in the image. Since an equalized image has a histogram having a uniform distribution, the output image may also have a density function equally distributed over the entire range.

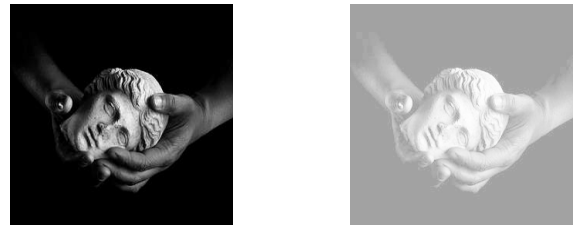
Global contrast enhancement scheme generates different effects depending on the characteristics of original images. In a complex image as shown in Fig. 1(a), the bright and dark areas are emphasized but there is no difference inside the individual local areas having similar brightness. In this case, the result image may be evaluated as the image quality is enhanced. However, those examples in Fig. 1 (b) and (c) where a single object is located on simple background shows that the global contrast enhancement techniques may deteriorate the image quality. A washed-out effect also appears since global histogram equalization changes the mean brightness of input image to the middle level.



(a) Complex object and background



(b) Complex object and simple background



(c) Simple object and simple background

Fig. 1 Results of applying the histogram equalization function to the whole image: left is the original image and right is the result image

If an image is consisting of those areas having similar brightness, then global histogram equalization scheme may generate deteriorated result images having poor quality.

In order to solve this problem and enhance contrast in particular region local histogram which divides an input image into sub-blocks having the same size and equalizes the brightness distributions of individual sub-blocks is applied. As done for the global equalization process, Eq.(3) generates the cumulative distribution function of X_k of the i -th block first.

$${}^i s_k = {}^i T(X_k) = \sum_{j=0}^k {}^i p_X(X_j) \quad (3)$$

$$= \sum_{j=0}^k \frac{{}^i n_j}{{}^i n}$$

$$0 \leq X_k \leq 1, \quad {}^i T(X_{L-1}) = \sum_{j=0}^{L-1} {}^i p_X(X_j) = 1$$

In Eq. (3), ${}^i n$ is the number of pixels in i -th block and ${}^i n_k$ represents the number of pixels having the k -th level in i -th block. Fig. 2 shows the result image acquired by applying a block-based histogram equalization scheme where the original Lena's image having 512x512 pixels is divided by small blocks having 32x32 pixels. Fig. 2 shows an extreme example of blocking effect generally occurring in a block-based contrast enhancement technique where the blocks are not connected smoothly. To reduce this blocking effect, some approaches divide the blocks so that the boundary pixels of the neighboring blocks are overlapped [1-2]. But blocking effect and calculation amount are depended on block size and overlapping amount.



Fig. 2 Result of applying the histogram equalization schemes to individual blocks differently

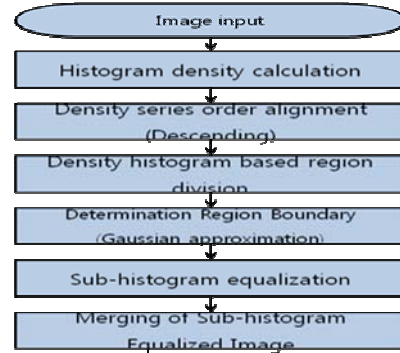


Fig. 3 Block diagram of the proposed algorithm

In order to minimize losing information lose and distortion amount and enhance contrast in low density region, sub-histogram equalizations were proposed earlier [5-12]. These methods have in common to preserve mean brightness but number of sub-histogram regions and threshold decision algorithms used were different.

Firstly, BBHE [5] separates the input histogram into two parts based on its mean brightness, and then equalizes the two sub-histograms independently. And separating point x_B is calculated by Eq(4),and (5).

$$x_B = \int_0^1 rP_r(r)dr \quad (4)$$

$$P_z(z) = \begin{cases} \frac{1}{x_B} \int_0^{x_B} P_r(r)dr & , 0 \leq z < x_B \\ \frac{1}{1-x_B} \int_{x_B}^1 P_r(r)dr & , x_B \leq z < 1 \end{cases} \quad (5)$$

It is found that BBHE can preserve the mean brightness, if the input histogram has a symmetrical distribution around its mean. But every image doesn't have this property, mean brightness preserving was depended on input image.

DSIHE[6] is very similar to BBHE, except that the separating point x_D is selected as the median gray level of the input image, i.e., x_D satisfies Eq (6).

$$\int_0^{x_D} P_r(r)dr = 0.5 \quad (6)$$

Also RMSHE(Recursive Mean-Separate Histogram Equalization)[7], and RSIHE(Recursive Sub-Image Histogram Equalization)[11] are recursive algorithms of BBHE and DSIHE. These two recursive methods have improved results comparing with previous methods and mean brightness was similar to input image's but equalization effect was reduced. And they have another weak point that has not flexible interval of number of region and also its decision is manual. And they cannot solve over-equalization effect problem in specific image that has high density distribution narrow range.

As shown in Fig. 3, the proposed algorithm analyze whole histogram density of the image and divide histogram regions and perform sub histogram equalization in divided regions finally merges these sub equalized images.

III. HISTOGRAM DENSITY ANALYSIS BASED ON HISTOGRAM DIVISION

As a first step in the proposed algorithm, in order to split the entire image, histogram density based analysis method is explained by referring to Fig.4.

Fig. 4 (a) shows image histogram that has rapid variation and high density in specific histogram area. When GHE process through this image, the dark area around the cameraman which has high-density histogram has a wild interval as Equalization processing. And the sky around the area also has a large gap and increases the contrast as Equalization processing. (Reference Fig. 4(f)) However, as the histogram analysis of equalized image's light area and between dark area around the cameraman and ground area show the brightness information was missed. And Fig. 4(g) shows more flat histogram distribution as local histogram equalization, but the light area's missing information and distorting pixel value were increased.

The image that represents over-equalization effect has several characteristics that histogram distribution change quickly and hardly focus on some histogram areas. Therefore the reason of over-equalization can be known by analyzing histogram CDF function which is standard of brightness value redistribution.

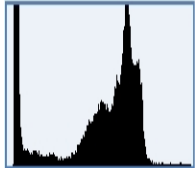
Firstly, characteristics of PDF that has abrupt change or high density show CDF's change is also abrupt. Therefore, the gap between redistribution pixels is also wild. As this interval grows, parts that have seen continuously with small Differences are relocated with large interval. This resulted image is looks discontinued and damaged. As seen in the equalization region that has distribution ranging from high and low, high distribution areas are relocated with wild intervals and where as low distribution areas have broaden distribution and lost the focus.

These characteristic let lose low distribution area's pixel information and damage extremely as growing difference between high and low distribution histogram area.

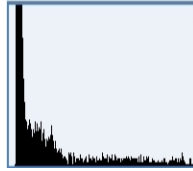
Therefore to enhance low distribution histogram area's contrast and prevent these distortion effects as equalization, some sub-histogram area's equalization have to be performed independently. And these areas include low and high distribution areas and rapid change distribution area.



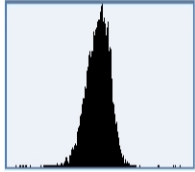
(a) Original Input Image



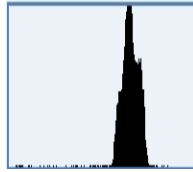
(b) Histogram of whole image



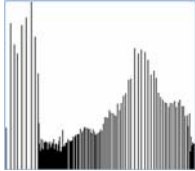
(c) Histogram of man region



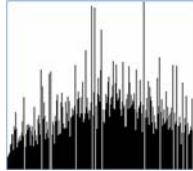
(d) Histogram of ground region



(e) Histogram of sky region



(f) After global equalization



(g) After local equalization

Fig. 4 Histogram of the objects in the original image as shown in (a)

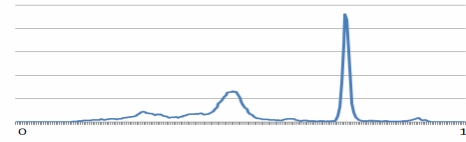
A. Density calculation of histogram region

To divide low and high density distribution area, sum of distribution quantity was used based on neighborhood histogram's distribution as define Eq. (7). Each intensity's density reference neighborhood brightness based on defined window size. By referring to the neighborhood pixel information, histogram density which can divide low and high density histogram area was calculated without error which caused sudden change.

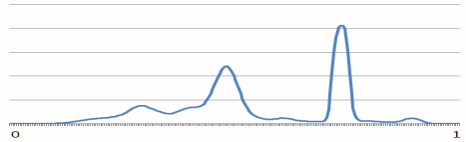
$$D_n = \sum_{i=n-\frac{w}{2}}^{n+\frac{w}{2}} f(x_i) \quad (7)$$

n in above eq(7) represent brightness value, and normalized brightness value n can have a value of $\frac{w}{2 \times 255} \sim 1 - \frac{w}{2 \times 255}$. And $f(x_i)$ represents frequency of x_i th brightness.

For example Fig. 5 shows histogram of input image (a) and density function (b) that was acquired from sum of neighborhood histogram with window size of 6. Density function was referenced sixth histogram and flatted than original histogram.



(a) Histogram of input image



(b) Density function

Fig. 5 (b) Density function acquired from (a) the example histogram using a window size of 6

B. Region Separation Based on Density

To divide region which has different density calculated density function, region which has similar density was grouped one region with considering neighborhood density function. High density area was main region because high density area cause over-equalization effects and rest area was assumed low density area.

Firstly, calculated density function was sorted descending order because high density area is cause over-equalization effects.

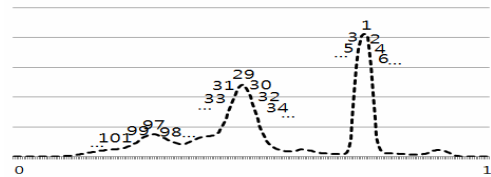


Fig. 6 Labeling the intensity in a descending order

Next, to make group of high density area, group area was extended from the center point of the group. Basic window size was not suitable to every density function, so reference histogram range has to change. To adjust range of region, compared between average change and momentary change amount as increasing window size(i). If momentary change amount large than average change rate window size was increased. Conversely, if its momentary change rate less than average change rate range extension operation was suspended.

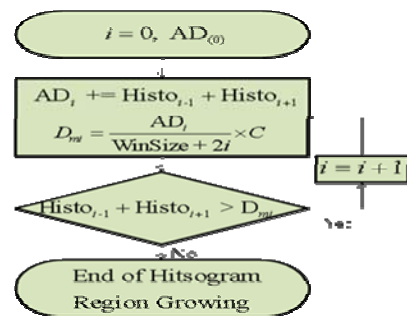


Fig. 7 Flowchart of the density region expanding algorithm

Finally range extension was performed based on density order and while modifying the range of next order region density, the overlapping of two areas are checked. Most of similar density histogram exists in neighborhood area. Like this overlapped area represent same area in histogram density based region grouping, so only middle value was used. Fig. 8 shows non overlapped region separation result with high density order.

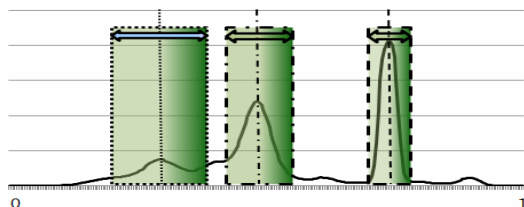


Fig. 8 Regions acquired as the result of applying the density region expanding algorithm

IV. EQUALIZATION OF DIVIDED SUB-HISTOGRAM

A. Determine range of sub-histogram

Histogram region was divided by similar density regions and then real range of equalization need to be determined.

For example Fig. 8 represents three regions which have high density, but actually there exist seven regions because another four regions which were exists in between three regions. These four regions which are placed between high density regions can prevent over-equalization effect. But these low density region can be removed without distorted result according to around high density region's change and distribution. And calculated equalization value and memory size are reduced by reducing number of unnecessary region.

This paper using Gaussian function approximation which defines Eq. (9) with region's mean and variation which defined Eq. (8) for remove unnecessary regions and redefine new region range.

$$\sigma_n^2 = \sum_{x=N_S}^{n_E} (x - \mu_n)^2 \times f'(x) \quad (8)$$

$$g_n(x) = \frac{1}{\sigma_n \sqrt{2\pi}} \exp\left(-\frac{(x - \mu_n)^2}{2\sigma_n^2}\right) \quad (9)$$

σ_n^2 in above Eq. (8) represent variation of selected region, μ_n is center value of selected region and Gaussian distribution was generated with center value μ_n . When two equations are applied, Gaussian approximation function can be obtained like Fig.9.

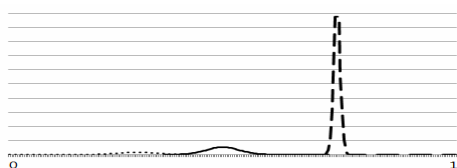
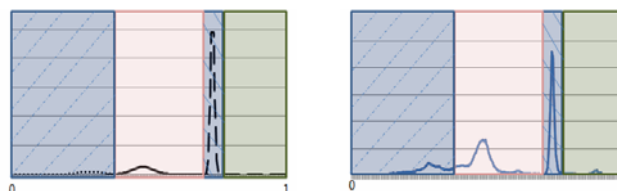


Fig. 9 The density function approximated by Gaussian function taking into account the selected regions

Finally, meeting point between approximated Gaussian functions is used boundary value for sub histogram equalization. Areas are divided as shown in Fig. 10 in approximated result as Fig. 9. Fig. 10(a) represent founded region in approximated Gaussian region, and Fig. 10(b) represent applied finding region information in input image's histogram.



(a) region adjustment using approximated Gaussian functions (b) its application to region adjustment in the histogram

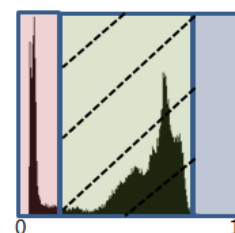
Fig. 10 Finally obtained sub-histogram regions

B. Merge of Contrast Improved Sub Images

Fig. 11 shows each sub equalized image. Sub histogram equalization was performed by each region's brightness values and each region's CDF function. And each sub histogram equalized image was merged in final result image. Fig. 11 shows three divided histogram(b), and each (c),(d),(e) images show sub equalized result which each use unnormalized brightness range of 0~46, 47~195, 196~255. Finally result image is obtained by merging of (c),(d),and (e) image.



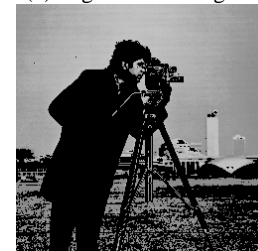
(a) Original image



(b) Segmented histogram



(c) Result images of regional histogram equalization(0~46)



(d) Result images of regional histogram equalization(47~195)



(e) Result images of regional histogram equalization(196~255)



(f) Final result image

Fig. 11 Merge of contrast improved sub images

V. EXPERIMENTS

The proposed algorithm has been implemented using VC++ in a Pentium IV PC having Windows XP operating system. Experiments with the local and global image characteristics of images which are airplane with sky background image and complex building images are performed. In order to evaluate the proposed method previous algorithms image results and proposed algorithm's result image are compared by represented features of object's edge and histogram results.

Initially, previous and proposed contrast enhancement algorithm's extracting edge performance evaluations are compared using canny edge detector. Fig. 12 shows result image of comparing edge detection characteristic with original image, GHE, RSHIE and proposed algorithm applying image. Fig. 12(a) shows a letter written blurry in the plane as original input image which is hard to classify because the contrast level in plane is low. Fig. 12(b) shows edge characteristic in original input image. There only exist between plane and sky region without edge of inner plane. Global equalization result image in Fig. 12(c) shows as over-equalization effect in relatively dark area with inner plain and bright area with sky region. Therefore contrast in GHE result image is getting poor as inner plane region was darker and sky region was brighter. As result inside of the plane was changed similar brightness, as shown in Fig. 12(d) edge property was disappeared and increased ring noise effect which exist in bound between plane and sky than original image. Fig. 12(e) shows result image which is applied RSHIE algorithm. Number of RSHIE algorithm's iteration is 2 and 4 regions are divided. Over-equalization is not prevented perfectly so blocking effect appears in right sky region. And the edge feature is improved than original input image but the fine feature of inner plane was not detected as shown Fig. 12. Enhanced result image of proposed algorithm in Fig. 12(g) can do to prevent over-equalization as split high density region which is a reason of over-equalization and perform sub equalization. And also as shown Fig. 12(h) detail edge feature of inner plane region is appeared as flattening low density region. Comparing detailed part and letter written in the inner plane region, these features was well represented in result image which is applied proposed method.



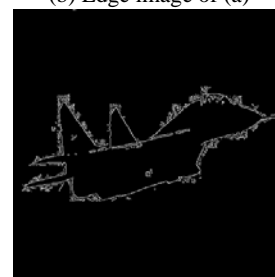
(a) Original image



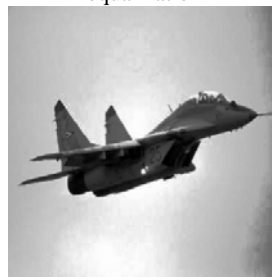
(b) Edge image of (a)



(c) Result of global histogram equalization



(d) Edge image of (c)



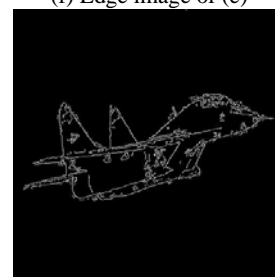
(e) Result of RSHIE



(f) Edge image of (e)



(g) Result of proposed method



(h) Edge image of (g)

Fig. 12 Performance comparison of the proposed algorithm with the conventional approaches based on edge features

Next, proposed algorithm and previous contrast enhancement algorithm are measured by analyzing of histogram. Experimental image which is constructed person and background is shown Fig. 13(a), and its histogram is represented in Fig. 13(b). Most of intensity level of background region is placed around 140 level. When performing GHE of image which has these property, histogram of unimportant background region which is takes most part will redistributed across wider region. Resultant over-equalized background region make many noise. Also person region's contrast is reduced and average intensity became lower. Fig. 13(f) shown result image which is applied RSHIE algorithm. Number of

RSHIE algorithm's iteration is 2 and 4 regions are divided. But it cannot get large contrast enhanced effect in the inner person region as comparing original input image.

which has narrow and high density histogram distribution is distortion of region which has low density and wide distribution. To solve these problems, input images histogram region was divided based on histogram density and sub histogram equalization was performed by each region equalization function. Proposed algorithm divides many areas for small equalization effect in histogram region which has narrow and high densities. And other region's histogram equalization is performed normally. As a result proposed algorithm's superiority can be proved by improving feature which has low density and broadly distributed without distortion. Our future work involves extending the proposed method to variety of electronic appliances where contrast improvement is necessary.

REFERENCES

- [1] A. K. Jai, *Fundamentals of Digital Image Processing*, Prentice-Hall, 1989.
- [2] J. Y. Kim, L. S. Kim, S. H. Hwang, "An Advanced Contrast Enhancement Using Partially Overlapped Sub-Block Histogram Equalization," *IEEE Transactions on Circuits and Systems for Video Technology*, Vol. 11, No. 4, pp.475-484, 2001.
- [3] C. C. Sun, S. J. Ruan, M. C. Shie, T. W. Pai, "Dynamic Contrast Enhancement based on Histogram Specification," *IEEE Transactions on Consumer Electronics*, 51(4), pp.1300-1305, 2005.
- [4] J. A. Stark, "Adaptive Image Contrast Enhancement Using Generalizations of Histogram Equalization," *IEEE Transactions on Image Processing*, 9(5), pp.889-896, 2000.
- [5] Y. T. Kim, "Contrast Enhancement Using Brightness Preserving Bi-Histogram Equalization," *IEEE Transactions on Consumer Electronics*, 43(1), pp.1-8, 1997.
- [6] Y. Wan, Q. Chen, B.-M. Zhang, "Image enhancement based on equal area dualistic sub-image histogram equalization method", *IEEE Trans. Consum. Electron.* 45 (1) (1999) 68-75.
- [7] S. D. Chen, A. Rahman Ramli, "Contrast Enhancement using Recursive Mean-Separate Histogram Equalization for Scalable Brightness Preservation," *IEEE Transactions on Consumer Electronics*, 49(4), pp.1301-1309, 2003.
- [8] Soong-Der Chen, A. Rahman Ramli, "Preserving brightness in histogram equalization based contrast enhancement techniques," *Digital Signal Processing*, 12(5), pp.413-428, September 2004.
- [9] Chao Wang and Zhongfu Ye, "Brightness Preserving Histogram Equalization with Maximum Entropy: A Variational Perspective," *IEEE Transactions on Consumer Electronics*, 51(4), pp.1326-1334, 2005.
- [10] K. S. Sim, C. P. Tso, and Y. Y. Tan, "Recursive sub-image histogram equalization applied to gray scale images", *Pattern Recognition Letters*, 28(10), pp. 1209-1221, 2007.
- [11] Z. Chen, B. R. Abidi, D. L. Page, M. A. Abidi, "Gray-Level Grouping (GLG): An Automatic Method for Optimized Image Contrast Enhancement-Part I : The Basic Method," *IEEE Transactions on Image Processing*, 15(8), pp.2290-2302, 2006.
- [12] S. M. Pizer, E. P. Amburn, J. D. Austin, R. Cromartie, A. Geselowitz, T. Greer, B. H. Romeny, J. B. Zimmerman, K. Zuiderveld, "Adaptive Histogram Equalization and Its Variations," *Computer Vision Graphics and Image Processing*, Vol. 39, pp.355-368, 1987.
- [13] F. Lamberti, B. Montrucchio, A. Sanna, "CMBFHE_a novel contrast enhancement technique based on cascaded multistep binomial filtering histogram equalization," *IEEE Transactions on Consumer Electronics*, 52(3), pp.966-974, 2006.
- [14] Z. Q. Wu, J. A. Ware, I. D. Wilson, J. Zhang, "Mechanism analysis of highly overlapped interpolation contrast enhancement," *IEEE Proceedings Vision, Image & Signal Processing*, 153(4), pp.512-520, 2006.

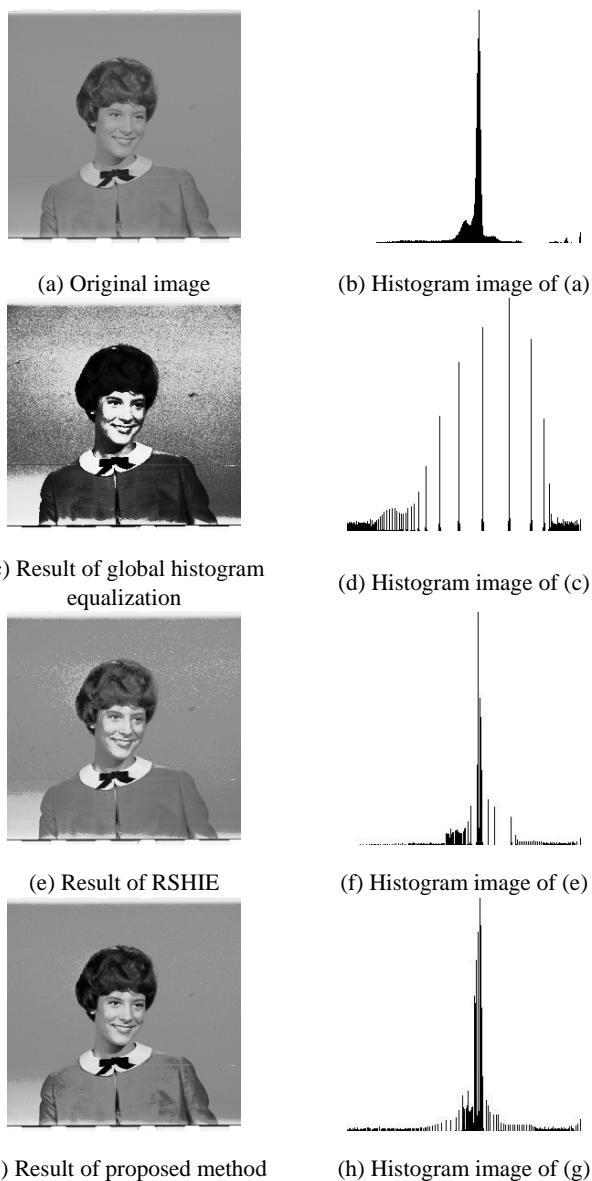


Fig. 13 Performance comparison of the proposed algorithm with the conventional approaches based on histogram analysis

When performing 5 sub histograms equalization, region which has low density and low contrast level get fine result which is emphasized and had high contrast. These results can be obtained by making one region of background region. And this background region's over-equalization is prevented and other region's equalization is performed evenly.

VI. CONCLUSION

This paper proposes a new contrast enhancement technique that performs sub histogram equalization based on histogram density. The most important problem of GHE in some image