A study on the validation of Histogram Equalization as a contrast enhancement technique

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Abstract: **-Our study uncovers that histogram equalization (HE) - in a striking contrast to it's claim - is not related to enhancement of contrast. To understand this view, we start with real world images which have varying degree of image quality that almost invariably require processing to improve image contrast. For this purpose, histogram equalization including its variants is a frequently relied upon technique. HE processes image by calculating pixel density of its constituent gray levels. This mathematical model, described by HE, is neither linked to contrast nor is contrast directly included in HE equations. Therefore, the study aims to find out the factual nature of transformation functions used by HE. To understand these mathematical calculations thoroughly, the paper dismantles HE into it's building blocks. These blocks are, then, critically analyzed to understand the true relationship between HE fundamentals and contrast. This analysis' determines that HE manipulates density – not contrast - which, in turn, achieves density changes but no contrast enhancement. Hence the study concludes that HE is not a valid contrast enhancement technique.**

Keywords: -Histogram Equalization, HE, Cumulative density function, Probability density, contrast.

I. INRODUCTION

Contrast is the difference in gray levels of object and its neighborhood. It could be the difference between two gray levels at object boundary or the difference in gray level groups in regions of dissimilar brightness. So the difference in gray level is the only factor which completely describes contrast. HE attempts to enhance contrast in given images, but it does not consider differential of gray levels, instead HE forms its basis on density [1]. Density is the number of occurrences for a specific gray level which when divided by total number of pixels gives us probability density (PD). When PD is added for successive gray levels, the outcome is cumulative density (CD) which is then normalized by multiplying with maximum gray level value of 255 - this is known as cumulative density function (CDF). This CDF spreads the dynamic range of gray level to full spectrum. This stretching is different from linear stretching. Linear stretching, proportionally, expands histogram resulting in contrast enhancement. Whereas, CDF replaces this proportionality ratio by density ratio which randomizes the distribution pattern of gray levels. This, inconsistent pattern of spread, introduces unpredictability in contrast changes. With such uncertainty, in contrast enhancement, HE is untrustworthy.

Additionally, density based processing is indiscriminate; it disregards considerations like non uniform contrast requirements in different parts of the image. In response to the drawbacks of global processing, researchers attempted to limit the effect of global scope by dealing with the image in partitions. Image was divided in parts, which were processed separately and then rejoined. In the initial attempts, the image was divided into two parts; implementing this method, Kim [3] proposed brightness preserving bi histogram equalization (BBHE) in 1997; It was followed by dualistic sub-image histogram Equalization (DSIHE) presented by Wan et al [4]; whereas, authors of [5] came up with minimum mean brightness error bi-histogram equalization (MMBEBHE). Division of image in two parts was insufficient to solve the problem therefore researchers resorted to dividing the image further into multiple parts [6]–[17]. Authors of [6] proposed, multi-peak histogram equalization (MPHE), next researchers introduced recursive mean-separate histogram equalization (RMSHE) [7] and recursive sub-image histogram equalization (RSIHE) [8]. Further, dynamic histogram equalization (DHE) [9] and brightness preserving DHE (BPDHE) [10][11] were proposed. Then this multi sectioning was implemented by fast implementation of adaptive histogram equalization (FIAHE)[12], multi histogram equalization (MHE) [13], brightness preserving weight clustering histogram equalization (BPWCHE) [14], dynamic range separate histogram equalization (DRSHE) [15], piecewise linear approximation of cumulative distribution function (PLACDF) [16] and a new Novel Approach for Contrast Enhancement Based on Histogram[17]. All these methods differed, only, on the criterian which they used to divide the image and the number of divisions made. Overall these methods were so intesely committed towards image divisions that no worthwhile enhancement could be achieved. Moreover, after partitioning while enhancing contrast of individual parts, all the above methods, still, used HE with no relevance to local neighborhood. So to enhance local details, pixel neighbourhoods were considered by some, new, local processing methods [18]-[20]. These methods include, contrast enhancement a weighted histogram equalization (CEWHE)[18], contrast limited adaptive histogram equalization (CLAHE) [19] and

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image sharpening using sub-regions histogram equalization (ISUSRHE) [20]. To find out neighborhood attributes these methods, however, have additional processing cost. Hence their practical viability has to be ascertained for each application. Overall, the above methods have not been able to resolve the issues of image contrast, to an acceptable limit. Practically image contrast issues, stemming out of HE, remain unresolved in entirety. Therefore a fresh approach is needed to pin point and fix these issues at the root level. These real root causes can be understood by detailed analysis of basic HE foundation. This detailed study is carried out in the rest of this paper.

From this point on ward, in the second section, the paper breaks down HE into its building blocks to understand it's foundation clearly and completely. Further, based on this knowledge, section three presents critical analysis. In the fourth section article conclude the study by establishing that density based HE is not a contrast specific method and without fixing the fundamental problem, HE cannot be employed reliably as a contrast enhancement technique.

II. HE FORMULATION

As mentioned above, HE is based on probability density. Take a raw image R probability density function d is given by

$$d(R_k) = \frac{n^k}{n} \tag{1}$$

Where $K = 0, 1, 2 \ldots L-1$ and n^k is the occurrence for gray level k and n is the total number of pixels in image R. Next for each gray level cumulative density $c(\overline{\boldsymbol{R}})$ is calculated which is given by

$$c(\overline{\boldsymbol{R}}) = \sum_{j=0}^{k} d(R_j) \tag{2}$$

Where $R_k = r$ for $k=0, 1, 2 \ldots L-1$. Further, CDF is used to calculate new gray levels for the processed image [1]. A single grey level $f(r)$ is given by the authors of [3] as

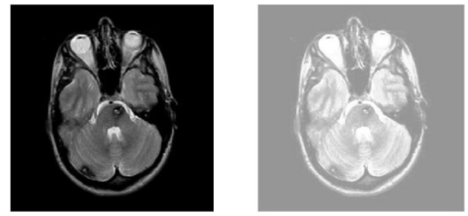
$$f(r) = R_0 + (R_{L-1} - R_0)c\,(r) \tag{3}$$

The processed image **P** = {P (i, j)} which is expressed by

$$\overline{\boldsymbol{P}} = f(R) \tag{4}$$

$$= \{f(R(i,j)) \mid \forall\, R\,(i,j) \in \boldsymbol{R}\} \tag{5}$$

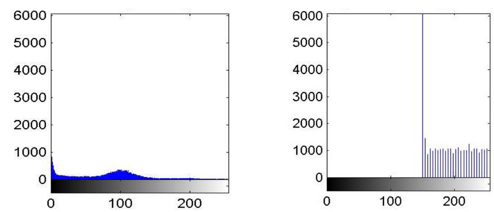
The description show HE - during formulation of its process - does not account for contrast at any place. To examine the results, we have chosen a critical field of brain MRIs where confirmation of HE validity is vital to human health. HE is applied to a brain MR image and results are as shown in figure 1.



(a) (b)

Figure 1: Result of density based processing by HE

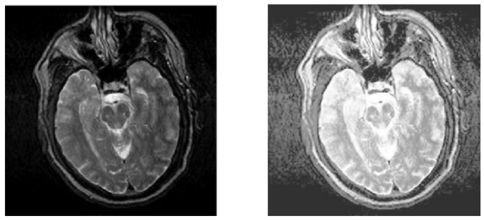
Figure 1(a) presents image before processing and figure 1(b) shows image after processing. HE application has reduced the image contrast which made it monotonic. Significant gray level shift is clearly visible between these images. Large section of input image in figure 1(a) constitutes dark gray levels. For these dark gray levels, transformation function (based on cumulative density) is calculated by (2). This calculation yields large shift to brighter gray levels. This large shift from dark to bright gray levels is represented - in image histograms - by washouts in initial gray levels. This washout is shown in figure 2.



(a) (b)

Figure 2: HE graph is flat with washed out lower levels.

Figure 2(a) depicts the histogram of original image and figure2 (b) presents histogram of HE image. Due to cumulative density calculations by (2), initial range of gray levels till about 150 is washed out and pixels are accumulated from 150 to 255 in a flat pattern [2]. In fact, mathematically whenever few gray levels cover large section of image, (2) will result in either washouts or excessive brightness[3]. This makes the image monotonic and contrast fades out. Moreover, an examination of original histogram in figure 2(a) shows that density peak occurs at about gray level 100 and then histogram diminishes after gray level 130. To achieve appropriate contrast, image post processing procedures are required to shift the histogram peak to the right and also stretch it to cover complete spectrum till gray level 256. HE histogram, however, in same figure 2(b) shows that HE does not compensate for this contrast deficiency. Additionally, in some images this large shift in gray levels, as in figure 2(b), and flat histogram may produces nonexistent artifacts in output image as shown in figure 3.



(a) (b)

Figure 3 Deterioration in image after applying HE

Figure 3(a) presents original image and figure3 (b) shows artifacts in histogram equalized image. The observed deterioration will exist at all places where effected gray levels occur. At some places it will be more visible than others. This deterioration may, be misleading for interpreters where it is mixed with other image features. This may be a crucial limitation for HE application in medical field.

Further, HE does not consider pixels spatial relation to its surroundings. HE processes image as a whole, indiscriminately, using a transform function which is based on density distribution. This global processing may result in loss of image quality in some neighborhoods [6]. To limit the effect of this issue, local variants of HE are developed. These local processing techniques divide the histogram, as a pre processing step. Some methods divide the histogram in two parts [3]-[5] and some others divide it in multi parts [6]-[17]. Some methods attempted to divide the image based on local neighborhoods [18]-[20]. All these methods, attempted to resolve global scope of HE application but most of them, put so much constraints on dividing criteria that no worthwhile image enhancement is achieved[20].

III. DISCUSSION AND ANALYSIS

The study observed that HE, foundation, is completely defined in (1)-(5). These equations establish that HE is purely based on density distribution which does not include contrast, at any stage, in its formulation. During HE application, as shown in figure 1 and 2, contrast changes are visible. These contrast changes are, actually, an outcome of density based stretch as per (3). Equation (3), further, shows that output contrast changes will always be uncertain and would not conform to any pattern. This trend of HE is clearly visible in figure 1-3. Both images in figure 1 and 2 follow different and unexpected pattern of contrast changes.

HE processes image indiscriminately as one piece, without considering local neighborhoods. To curtail the impact of this global characteristic, local processing was presented, by researches, which introduced some pre processing steps. In pre-processing, image is divided into partitions before HE is applied. The study made a, critical, observation that for each sub part contrast is, still, calculated by using HE (with known drawbacks). Therefore, all local processing methods, in reality, inherit all the HE drawbacks. Local processing, only limits some of HE's affects. Actual root cause is neither analyzed nor resolved. Hence, all HE drawbacks exist at both levels - in it's basic form and in its variants.

In a nutshell, HE and it's variants form their foundation on density distribution without including or referring to image contrast.

To attempt a fix, a revisit to HE foundation seems necessary. However, if HE is fixed by modifying it's foundation, it might technically lead to the birth of a new technique.

IV. CONCLUSION

HE is widely claimed technique for contrast enhancement. Study reveals that HE is formed on the basis of density of occurrence of pixels. HE applies this intensity based transform function indiscriminately at global level. Critical analyses confirmed that HE does not include contrast in it's foundation blocks. Further, during processing HE does not consider spatial relation of pixel with its neighborhood. Such processing produces inconsistent results. Output contrast changes are uncertain which do not adhere to deficiency in contrast for given image. Practically, with such performance, HE cannot be used for a step wise, systematic and predictable, solution for image processing.

Hence HE, with its current foundation is not a valid technique for contrast enhancement.

REFERENCES

[1] Rafael C. Gonzalez, and Richard E.Woods, "*Digital Image Processing*".3rd ed., New Jersey : Pearson Education Inc., 2010. pp. 144 - 150.

[2] Manpreet Kaur, Jasdeep Kaur and Jappreet Kaur, "Survey of Contrast Enhancement Techniques based on Histogram Equalization", *International Journal of Advanced Computer Science and Applications (IJACSA),* vol. 2, no. 7, 2011

[3] Yeong-Taeg Kim, "Contrast enhancement using brightness preserving bihistogram equalization", *IEEE Trans. Consumer Electronics,* vol. 43, no. 1, pp. 1 - 8, February 1997.

[4] Yu Wang, Qian Chen, and Baeomin Zhang, "Image enhancement based on equal area dualistic sub image histogram equalization method", *IEEE Trans. Consumer Electronics,* vol. 45, no. 1, pp. 68 - 75, February 1999.

[5] Soong-Der Chen, and A. R. Ramli, "Minimum mean brightness error bihistogram equalization in contrast enhancement", *IEEE Trans. Consumer Electronics,* vol. 49, no. 4, pp. 1310 - 1319, November 2003.

[6] K. Wongsritong, K. Kittayaruasiriwat, F. Cheevasuvit, K. Dejhan, and A.Somboonkaew, "Contrast enhancement using multipeak histogram equalization with brightness preserving", *The 1998 IEEE Asia-Pasific Conference on Circuit and Systems,* pp. 24-27, November 1998.

[7] S–D Chen and A. R. Ramli, "Contrast enhancement using recursive mean-separate histogram equalization for scalable brightness preservation."*IEEE Transactions on Consumer Electronics.,* Vol. 49, pp. 1301-1309, 2003.

[8] K. S. Sim, C. P. Tso and Y. Y. Tan. "Recursive sub-image histogram equalization applied to gray scale images", *Pattern Recognition Letters,* vol.28, no. 10, pp. 1209-1221, July 2007.

[9] M. Abdullah-Al-Wadud, M. H. Kabir, M. A. A. Dewan, and Oksam Chae, “A dynamic histogram equalization for image contrast enhancement”, *IEEE Trans. Consumer Electronics,* vol. 53, no. 2, pp. 593 - 600, May 2007.

[10] Haidi Ibrahim, and Nicholas SiaPik Kong, “Brightness preserving dynamic histogram equalization for image contrast enhancement”, *IEEE Trans. Consumer Electronics,* vol. 53, no. 4, pp. 1752 - 1758, November 2007.

[11] Nicholas SiaPik Kong, and Haidi Ibrahim, “Color image enhancement using brightness preserving dynamic histogram equalization”, *IEEE Trans. Consumer Electronics,* vol. 54, no. 4, pp. 1962 - 1968, November 2008

[12] W Zhiming and T. Jianhua."A fast implementation of adaptive histogram equalization."*Proc.IEEE International Conference on Signal Processing.* 2006.

[13] D Menotti, L Najman, J Facon, and A A de Araujo."Multi-Histogram equalization methods for contrast enhancement and brightness preserving."*IEEE transactions for Consumer Electronics.* 53, 2007, Vol. 3, pp. 1186-1194.

[14] NymlkhagvaSengee and Heung Kook Choi, “Brightness preserving weight clustering histogram equalization”, *IEEE Trans. Consumer Electronics,* vol.54, no. 3, pp. 1329 - 1337, August 2008.

[15] Gyu-Hee Park, Hwa-Hyun Cho, and Myung-Ryul Choi, “A contrast enhancement method using dynamic range separate histogram equalization”, *IEEE Trans. Consumer Electronics,* vol. 54, no. 4, pp. 1981 - 1987, November 2008.

[16] Sang-Yeon Kim, Dongil Han, Seung-Jong Choi, and Jong-Seok Park, “Image contrast enhancement based on the piecewise linear approximation of CDF”, *IEEE Trans. Consumer Electronics,* vol. 45, no. 3, pp. 828 - 834, November 2008.

[17] Yeganeh, Hojat, Ziaei, Ali and Rezaie, Amirhossein. "A Novel Approach for Contrast Enhancement Based on Histogram" *Proc. of the International Conference on Computer and Communication Engineering 2008* Kula Lampur : IEEE, pp. 256-260, 2008..

[18] S. Yun, J. Kim, and S. Kim. "Contrast Enhancement a weighted histogram equalization.*"Proc. IEEE Internationl conference on consumer electronics* pp. 203-204, 2011.

[19] A. M. Reza.“Realization of the Contrast Limited Adaptive HistogramEqualization (CLAHE) for Real-Time Image Enhancement,”*Journal of VLSI Signal Processing*vol. 38, pp.35-44, 2004

[20] Haidi Ibrahim and Nicholas SiaPik Kong “Image Sharpening Using Sub-Regions Histogram Equalization”,*IEEE Transactions on Consumer Electronics,* vol. 55, no. 2, May 2009