Contrast enhancement using sub-image histogram equalization

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Abstract

This paper presents an empirical method to enhance the contrast of an image by applying histogram equalization to a sub-image, which consists of pixels within a particular intensity range. Histogram equalization runs on the pixel within the selected intensity range of the image while the other part remains unchanged. Then, the equalized and unchanged parts of the image are combined into a single image. Applying histogram equalization only on a part of the image with a different intensity range changes the global intensity of the image. We introduce a naive but empirically effective approach to find an intensity region to apply histogram equalization for high global contrast. For a given input image, we generate three histogram equalized images whose intensity ranges are the whole, the first half, and the second half of the image, and compute their contrast values including the input. Comparing several contrast values, we can empirically determine the intensity range, the size and shift, for better global contrast than ever computed four contrast values. We describe our empirical approach based on the preliminary observation for experimental examples. According to our experiments, differently from the normal histogram equalization, our method is particularly useful when the input image has reasonably high contrast, and therefore our method is used as a preprocessing step for high quality vision techniques.

Keyword: Histogram equalization, Contrast enhancement, Image decomposition, Empirical method

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1. Introduction

Histogram equalization (HE) is one of the well-known methods to improve the quality of an image by enhancing its contrast [1]. HE tries to spread out the pixel intensities over the whole range by using the cumulative density function. HE allows for lower local contrast areas to take higher contrast and therefore, it makes unseen details visible. HE is primarily useful when backgrounds and foregrounds are both bright or both dark in whole image. Adaptive HE (AHE) is one of the generalizations of HE to enhance local contrast when an image has wide range of histogram [2]. AHE uses multiple histograms, each of which corresponds to a distinct part of an image. However, AHE would enhance noise unnecessarily in relatively homogeneous regions of an image.

This paper presents a method to enhance the global contrast of an image by applying HE to a selected part of the image according to the intensity range, where we call the range as a histogram window (or window unless ambiguous). Note that a histogram window is a 1-dimensional region such that [a:b] while an image window is usually rectangular 2-dimensional region such that [x_1:x_2, y_1:y_2]. Given an input image whose intensity range is [0:255], first, we partition the intensity range into [0:a-1], [a:b], and [b+1:255], where b and e vary from 0 to 255. Then, normal HE is applied to the selected window of the image [a:b] while the other parts remains unchanged. Combining the histogram equalized and unchanged parts generates a new single image whose contrast value is different from that of the input image. It is obvious that we can find the maximum intensity if we tries all the 32,385 different intensity range cases. In this paper, we describe an empirical approach to find the intensity region [a:b] to apply HE for obtaining a high contrast value.

The method proposed in this paper can be considered as a variation of AHE. However, the parts of an image are designated automatically to apply HE and are not necessarily rectangular or connected. AHE, in general, is for enhancing image contrast locally within multiple regions but our method is for enhancing global image contrast.

2. Related Works

Many researchers proposed various HE methods on image contrast enhancement. Brightness Preserving Bi-Histogram Equalization (BBHE) [3] decomposes an original image into two sub-images base on the mean of the whole image. Then the sub-images are equalized independently, i.e. one of the sub-images is equalized over the range up to the mean and the other one over the range from the mean. As a result, the equalized sub-images are bounded by each other around the input mean. Consequently, BBHE preserves brightness of the image and enhances its contrast making it possible to use it in consumer electronics.

Range Limited Bi-Histogram Equalization (RLBHE) [4] partitions the input histogram into two sub-histograms by a threshold, separating objects from the background. RLBHE limits the range of the equalized image to keep the mean output brightness almost equal to the input brightness. This method preserves the original brightness well and gives more natural enhancement, so that it can be used in consumer electronic products.

Dualistic Sub-Image Histogram Equalization (DSIHE) [5] is a method, where an input image is decomposed into two equal area sub-images based on its gray level probability density function. Sub-images are equalized individually then they composed into one image. This method enhances the image visual information effectively. Moreover, it keeps the original image luminance well enough making it possible to utilize it in video system directly.

Histogram equalization method for digital image enhancement and brightness preservation (HEDIEBP) [6] divides the image histogram into two sub-histograms. Then, a total 6 plateau limits of both sub-histograms are computed and used to modify sub-histograms. Histogram equalization is applied separately on the two sub-histograms to get a clean and enhanced image. The simulation results show that this method is simple and performs well in terms of brightness preservation and image enhancement which results in a better visual quality.

An Improved Image Contrast Enhancement in Multiple-Peak Images based on Histogram Equalization method (ICEMPI) [7] uses Gaussian filter convolving the image to reduce the difference in brightness between adjacent elements and blocking effects. Then the image histogram is segmented into different sub-layers by local minimum gray level. Histogram equalization method is applied on each segment separately. The algorithm used in this method showed good results in image enhancement making it possible to apply it in simple hardware and consumer electronics.

3. Contrast Enhancement using Histogram Equalization

We briefly overview a HE method and its application over a selected intensity range [8]. Given a grayscale image X, a sub-image X_S with intensity range $[a:b]$ is defined by

$$X_S = \{X(i,j) | a \leq X(i,j) \leq b, \forall X(i,j) \in X\},$$

and the other sub-image $X_{\underline{S}}$ by

$$X_{\underline{S}} = \{X(i,j) | 0 \leq X(i,j) < a \text{ or } b < X(i,j) \leq 255, \forall X(i,j) \in X\}.$$

Based on the cumulative distribution function $C_S(X_i)$, the transformation function $F_S(X_i)$ of the sub-image histogram equalization can be shown as

$$F_S(X_i) = X_a + (X_b - X_a)C_S(X_i);\ i = a, .., b.$$

Applying HE to the sub-image X_S and combining it with the unchanged sub-image $X_{\underline{S}}$ generates a new image such that

$$Y = \{Y(i,j)\} = F_S(X_s)\ \cup X_{\underline{S}}.$$

The contrast of Y can be different from X. The contrast is one of the important qualitative attributes to measure how an object in an image is distinguishable from background. We adopt RMS (Root Mean

Square) contrast [9] such that

$$\text{RMSC} = \sqrt{\frac{1}{MN}\sum_{i=0}^{N-1}\sum_{j=0}^{M-1}\left(X(i,j)-\overline{X}\right)^2},$$

where $\overline{X}$ is the mean intensity of the 2-dimensional image X with size M and N. For the RMS contrast, we assume that the intensity of a pixel is normalized between [0:1].

3.1 Preliminary Observation

The motivation of this paper came from the preliminary observation of contrast change with respect to the size and position of a histogram window. For given two histogram windows with different sizes, shifting two windows from lower intensity to upper shows similar-looking changes on their contrast values. For a Lena image as an example input image, Figure 1 shows the graph of contrast values with respect to different window sizes and shift positions. If we set the window with range [0:255] and apply HE to the range, the result is the same to that of normal HE. We denote applying HE to whole range by WHE. Setting the window of size 128, there exist 129 different offset positions such that [a:a+127] for a=0…128. We denote applying HE to the range [0:127] by LSHE when a=0 and to the range [128:255] by RSHE when a=128. The input image can reach its maximum contrast value when we apply HE only to the intensity range [40:255].

Input image WHE[0:255] LSHE[0:127] RSHE[128:255] MAX[40:255]

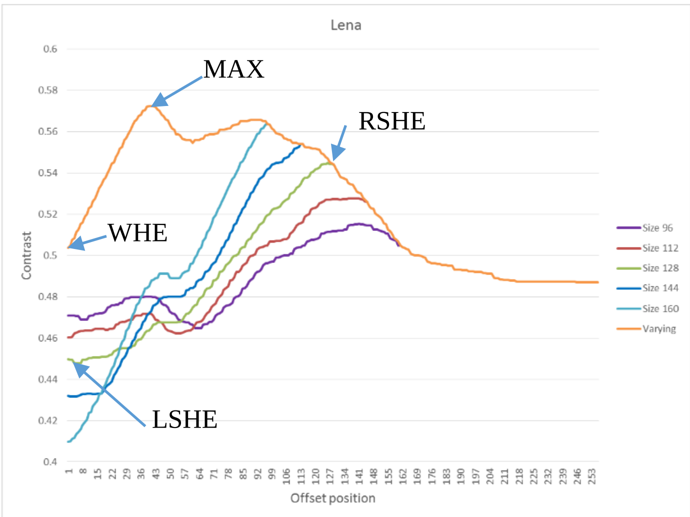

Figure 1. For a given image, the graph of image contrast with different histogram windows. The contrast values of images shown in the first row are 0.487134, 0.503581, 0.449621, 0.543915, and 0.572469.

The problem handled in this paper is to design a method to find the intensity range that makes the input having its maximum contrast. In this paper, we show our preliminary result based on our empirical formula from a lot of experiments.

3.2 Empirical Approach

To design a method to find the intensity range [a:b] for an input image, we categorize images into one of eight different groups according to the size of the histogram window and its offset position. Table 1 shows the groups of images, their sizes and shifts, example images, and their contrasts at a particular histogram window configuration. The size of the histogram window is defined by $|a-b|$ and denoted by "=256" when the size is exactly 256, by "<128" when the size is less than 128, and by ">128" when the size is greater than 128. The sift of the histogram window depends on the values of a and b, and denoted by W when a=0 and b=255, by LS when a=0 and $b \neq 255$, RS when $a \neq 0$ and b=255, and by MS when $a \neq 0$ and $b \neq 255$.

Table 1. Groups of images according to the histogram window size and its shift.

Group	Shift	Size	Example	C	C[0:255]	C[0:127]	C[128:255]	CMAX
1	W	=256	Arch	0.331327	0.500044	0.400200	0.325198	0.500044
2	LS	< 128	Pirate	0.604225	0.484215	0.618157	0.562753	0.618698
3	LS	> 128	Magnifier	0.643595	0.493279	0.666496	0.596287	0.666864
4	RS	< 128	Ship	0.533540	0.504655	0.533500	0.604983	0.607158
5	RS	> 128	Cameraman	0.463593	0.504664	0.480058	0.532654	0.536840
6	MS	< 128	Jet	0.697317	0.507661	0.678551	0.679204	0.739264
7	MS	> 128	Bicycle	0.721689	0.507640	0.716160	0.634355	0.738323

Figure 2. Sample images: (top) Arch, Pirate, and Magnifier; (bottom) Ship, Cameraman, Jet, and Bicycle.

Figure 2 shows the example images for each of the groups. Figure 3 shows the graph of image contrast values with respect to the various histogram window sizes and shifts for each image shown in Figure 2.

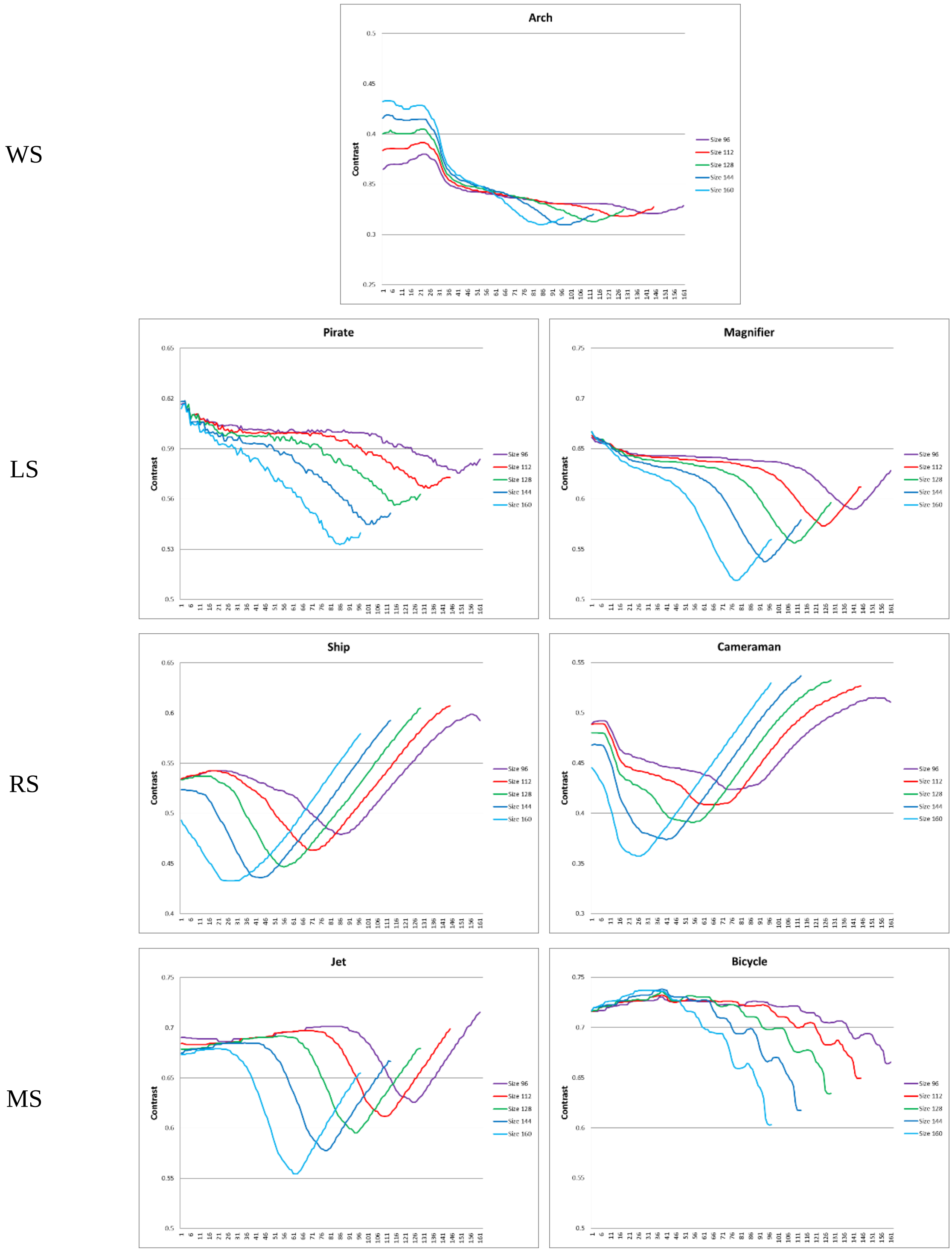

Figure 3. The graph of image contrast values with respect to various histogram window sizes and shifts.

From the preliminary observations in Table 1 and Figure 3, we can design an empirical method to determine the size and shift of the histogram windows. For a given input image, we first apply HE to the range [0:255], [0:127], and [128:255], then compute the contrasts, C_I, C_W, C_L, C_R, for the original input, the ranges [0:255], [0:127], and [128:255]. When C_I < MAX{C_W, C_L, C_R}, the image can be categorized into either of groups 1 to 5. Otherwise, the image is categorized into either of groups 6 or 7. Once an image is determined to categorized into either of groups 1 to 5, when C_W = MAX{C_W, C_L, C_R} the shift is WS (group 1); when C_L = MAX{C_W, C_L, C_R} the shift is LS (group 2 or 3); and when C_R = MAX{C_W, C_L, C_R}the shift is RS (group 4 or 5). In order to determine the size of the histogram window for groups 2 and 3, we need two more contrasts C_{128+} and C_{128-} when applying HEs with histogram windows [0, 127+Δ] and [0, 127-Δ] for a positive small integer Δ, respectively. If $C_{128+} < C_L < C_{128-}$, the image categorized into the group 2; otherwise, group 3. Similarly, for the groups 4 and 5, we compute the contrasts C_{128+} and C_{128-} when applying HEs with histogram windows [128-Δ, 255] and [128+Δ, 255] for a positive small integer Δ, respectively. If $C_{128+} < C_R < C_{128-}$, the image categorized into group 4; and otherwise, group 5.

4. Experimental Results

For more than 190 input images, we apply our empirical method to find the intensity range for an input image maximizing the image contrast after applying HE to the sub-image of the selected range. For qualitative comparison, we show some of our experimental results as in Figure 4 and 5.

Figure 4. Magnifier: From top to bottom and left to right, the input image, WHE, MAX, LSHE, RSHE and histogram when reaching the maximum contrast value 0.666864 at the range [0:150].

Figure 5. Ship: From top to bottom and left to right, the input image, WHE, MAX, LSHE, RSHE and histogram when reaching the maximum contrast value 0.607158 at the range [139:255].

5. Discussion and Future Work

In this paper, we described an empirical method to enhance the image contrast by applying HE only to the sub-image, which is determined by the histogram windows size and its shift. Although our empirical method could not be guaranteed to find the histogram window exactly, the method categorized an input image into a particular group according to the histogram window size and its shift. Therefore, we can reach the maximum contrast within a few iterative trials.

The proposed method is applicable to GPU-based contrast enhancement. The WHE can exploit the parallelism using GPU [10] rather easily than the AHE. It is also easy to implement AHE with rectangular pixel blocks using GPU; however, the resulting image may show abrupt changes along with the boundary of blocks. Since our empirical method does not depends on applying HEs to different histogram windows, we can extend our method to the GPU-based global contrast enhancement using sub-image histogram equalization.

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