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Contrast Enhancement Pipelines for Digital Image Captured in Dark Environment

[1]Seng Cheng Yeoh, [1]Haidi Ibrahim and [2]Theam Foo Ng
[1]School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia
[2]Centre of Global Sustainability Studies, Universiti Sains Malaysia, 11800 Penang, Malaysia

Abstract: Images that have been captured in dark environments may suffer from insufficient or uneven lighting conditions. This conditions mostly will make the captured images to have low contrast. Therefore, to reduce this problem, contrast enhancement algorithms have been suggested to improve the image quality. In this study, two contrast enhancement pipelines have been observed. Because histogram equalization method is an image enhancement method commonly used nowadays, these pipelines are using histogram equalization-based methods. These contrast enhancement pipelines have been developed by cascading Exposure Sub-image Histogram Equalization (ESIHE) with Contrast Limited Adaptive Histogram Equalization (CLAHE) in two possible sequences. ESIHE is one of global histogram equalization methods. It uses only one single transformation function, created from global statistics of the image. On the other hand, CLAHE is one of the local histogram equalization methods. CLAHE uses local transformation functions which are created from local statistics of the image. CLAHE applies histogram clipping to avoid extreme enhancement of the contrast. These pipelines have been evaluated based on four objective measures which are Noise Standard Deviation (NSD), Image Variance (IV), Speckle Index (SI) and Contrast Per Pixel (CPP). From the assessments by using 30 input images and comparisons with seven other histogram equalization-based methods, it is found that the contrast enhancement pipeline that utilizing ESIHE first than followed by CLAHE has performed better the other methods.

Key words: Digital image processing, global histogram equalization, local histogram equalization, adaptive histogram equalization, night image, low contrast image

INTRODUCTION

Image captured in low light conditions such as during night and inside a dark room might lead to low contrast images (Khan *et al*., 2015a, b). Night images normally require longer exposure time but it causes the images to be more prone to noise. As the results, night images are typically in low quality and suffer from loss of information (Zhang and Wan, 2016). In contrast, day images details can be seen clearly as they have been provided with sufficient amount of light. Fortunately, image enhancement methods can be applied to improve the image quality, so that, the output image will subjectively appear better than the original image, accordingly to a specific application. Histogram Equalization (HE) is one of the popular image enhancement methods (Gonzalez and Woods, 2008), where the basic idea of HE is to stretch out the narrow range intensity levels to a wider range. This method is also known as the Global Histogram Equalization (GHE) because it uses only one transfer function to change the intensity of all pixels in the image. However, a direct use of HE results in a huge difference in the mean brightness of the image that might leads to over enhancement problem (Kim, 1997).

Many GHE based methods have been proposed. Many of these GHE based methods divide the input histogram into two sub-histograms (Kim, 1997; Wang *et al*., 1999; Singh and Kapoor, 2014) or more (Khan *et al*., 2015a, b; Santhi and Banu, 2015; Chiu and Ting, 2016) and equalize these sub-histograms independently in order to maintain the mean brightness of the image. However, the contrast improvement that is obtained for an image is not significant when the sub-histogram has a narrow range.

Another type of HE is the Local Histogram Equalization (LHE). LHE is able to improve the local details and generate sharper images (Ibrahim and Hoo, 2014). Non-Overlapped Block Histogram Equalization (NOBHE) divides images into several non-overlapped

Corresponding Author: Haidi Ibrahim, School of Electrical and Electronic Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia

small windows and performs HE process on these windows. However, this causes a serious blocking effect on output images. To overcome this problem, Block Overlapped Histogram Equalization (BOHE) was introduced to divide images into overlapped window but only the center pixel is updated in HE processes. These two methods amplify the noise when increasing the image contrast. Therefore, Contrast Limited Adaptive Histogram Equalization (CLAHE) has been proposed to limit the noise amplification due to contrast enhancement process (Pizer *et al*., 1987).

As both GHE and LHE have their own advantages and disadvantages, we are interested to see the performance of the image enhancement by combining these two approaches. In this study, we investigated two contrast enhancement pipelines which are created by cascading the GHE based method with LHE based method in different sequences. GHE based method used in this evaluation is Exposure Sub-Image Histogram Equalization (ESIHE) (Singh and Kapoor, 2014) while the LHE based method used is CLAHE (Pizer *et al*., 1987). The idea of cascading these methods is to take advantage of both methods to improve the quality of image.

MATERIALS AND METHODS

Figure 1a and b show the flowcharts for ESIHE and CLAHE, respectively. ESIHE which is an LHE method, was proposed by Singh and Kapoor (2014) to enhance the contrast of low exposed images including nigh images. CLAHE which is a GHE method was proposed by Pizer *et al.* (1987). CLAHE used non-overlapped blocks to perform its algorithms. GHE and LHE are two different branches of researches under image enhancement techniques.

By cascading the GHE with LHE method, the advantages of both methods can be combined together. However, their drawbacks are also might be amplified as well. Therefore, modified GHE and LHE methods that can minimize the drawbacks will be chosen. ESIHE is able to increase the image contrast but the local details might not be emphasized properly. On the other hand, CLAHE enhances the local detail but produce low contrast images. With the idea of cascading both methods, two contrast enhancement pipelines have been developed as shown in Fig. 1c and d. Both pipelines will be examined qualitatively and also quantitatively. The results will be presented in this study.

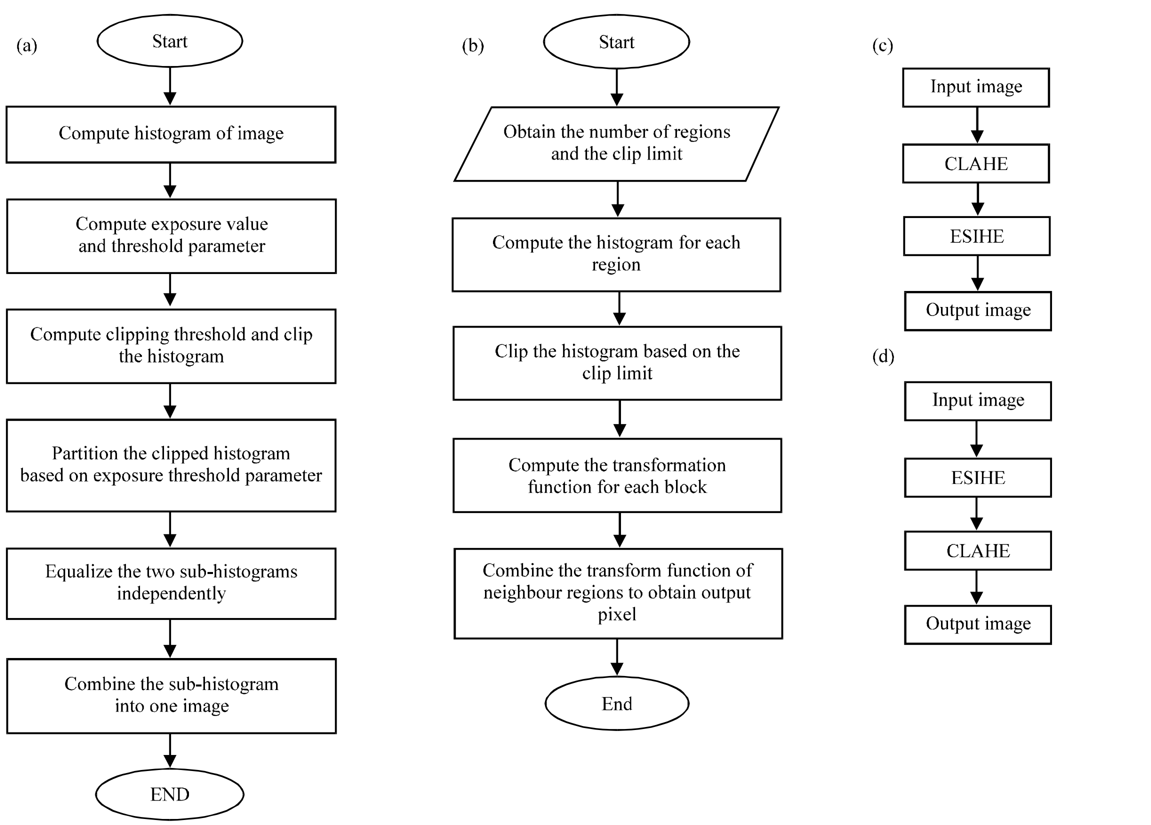

Fig. 1: a) Flowchart for ESIHE; b) Flowchart for CLAHE; c) Block diagram for pipeline 1 and d) Block diagram for pipeline 2

RESULTS AND DISCUSSION

This study discussed the experimental results obtained from the implementation of the proposed contrast enhancement pipelines. The two proposed pipelines were compared with seven existing methods based on HE algorithms, i.e., HE, Brightness Preserving Histogram Equalization (BBHE) (Kim, 1997), Dualistic Sub-Image Histogram Equalization (DSIHE) (Wang *et al*., 1999), ESIHE, Non-Overlapped Block Histogram Equalization (NOBHE), Block Overlapped Histogram Equalization (BOHE) and CLAHE. A total of 30 images, captured during night are used as the input images in this experiment.

Qualitative assessment: The quality of images was assessed visually for qualitative assessment. This assessment helps to perform a thorough check based on the natural look of images, noise level, over enhancement problem and image details. Figure 2 shows the result from one of the test images. In the original image, the car, threes and the part of the building are difficult to be observed clearly. Pipeline 1 has improved the contrast but with speckle noise around. Pipeline 2 is able to improve the details of the building at the center of the image.

Quantitative assessment: The performance metrics used for quantitative assessments are Noise Standard Deviation (NSD), Image Variance (IV), Speckle Index (SI) and Contrast Per Pixel (CPP). These metrics are non-reference metrics where they do not need the ground truth. NSD is used to quantify speckle noise presented in the image (Sivakumar *et al*., 2010):

$$\text{NSD} = \sqrt{\frac{1}{MN}\sum_{j=0}^{M-1}\sum_{i=0}^{N-1}\left|f(j,k)-\text{NMV}\right|^2} \text{ with} \quad (1)$$

$$\text{NMV} = \frac{1}{MN}\sum_{j=0}^{M-1}\sum_{i=0}^{N-1} f(j,k)$$

Where:

$f(j, k)$ = Pixel value at coordinates (j, k)
M = The height of the image
N = The width of the image
NMV = The noise mean value

A smooth image with less speckle will give a low value of NSD. The box and whisker plot for NSD is shown in Fig. 3a. Enhancement process usually will increase the noise in an image. The median value of NSD for the pipeline 2 is the second lowest after CLAHE whereas pipeline 1 produces more noise than pipeline 2.

Fig. 2: a) Input image; The corresponding output from; b) HE; c) BBHE; d) DSIHE; e) ESIHE; f) NOBHE; g) BOHE; h) CLAHE; i) Pipeline 1 and j) Pipeline 2

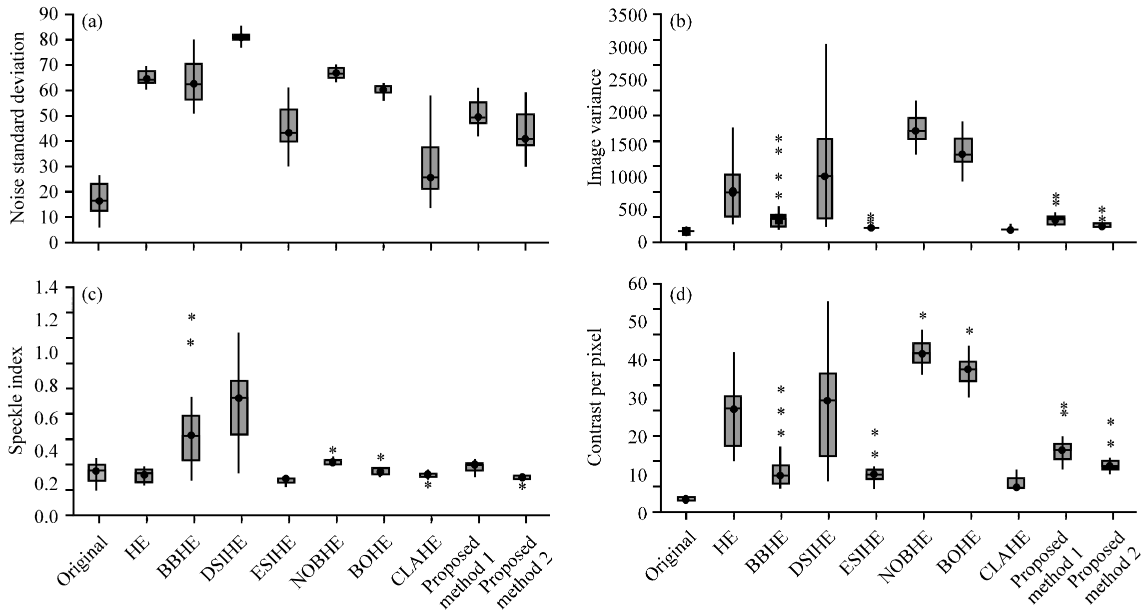

Fig. 3: Box and whisker plot for: a) Noise Standard Deviation (NSD); b) Image Variance (IV); c) Speckle Index (SI) and d) Contrast Per Pixel (CPP)

Image Variance (IV) determines the content of the speckle in an image (Sivakumar *et al*., 2010). IV is defined as:

$$IV = \frac{1}{MN}\sum_{j=0}^{M-1}\sum_{i=0}^{N-1}\left|f(j, k)-\mu(j, k)\right|^2 \quad (2)$$

where, $\mu(j, k)$ is the local mean from an image block of size 3×3 pixels. If more speckle has reduced, the IV value is small. Figure 3b shows the box and whisker plot for IV. Pipeline 2 is one of the methods that give low median value of IV.

Speckle Index (SI) is used to measure the speckle removal from an image in term of its average contrast (Loizou *et al*., 2006). The formula to calculate SI is given as:

$$IV = \frac{1}{MN}\sum_{j=0}^{M-1}\sum_{i=0}^{N-1}[\sigma(j, k)/\mu(j, k)] \quad (3)$$

where, $\sigma(j, k)$ is the local standard deviation of an image block of size 3×3 pixels. Low value of SI indicates that the image quality is improved. Figure 3c shows the box and whisker plot for SI. Pipeline 2 gives low median value of SI and performs better than pipeline 1.

Contrast Per Pixel (CPP) is used to measure the average intensity difference of a pixel with its neighboring pixels (Santhi and Banu, 2015). This measure is defined as:

$$CPP = \frac{1}{q\times MN}\sum_{j=0}^{M-1}\sum_{i=0}^{N-1}\left(\sum_{(m,n)}\left|f(j, k)-f(m, n)\right|\right) \quad (4)$$

Where,
$f(m, n)$ = The neighboring pixels around $f(j, k)$
q = The number of the neighboring pixels

A high value of CPP indicates the high contrast. As shown in Fig. 3d, all tested methods are able to increase the image contrast as indicated by higher CPP values.

CONCLUSION

Two contrast enhancement pipelines have been proposed in this study. From the experimental results, it is shown that pipeline 2 performed better than pipeline 1. Generally, pipeline 2 produces lower noise and higher contrast than pipeline 1. The former also able to improve the local details of the image. In short, pipeline 2 has successfully improved the quality of the images.

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