Color to Grayscale Conversion Based On Neighborhood Pixels Effect Approach for Digital Image

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Abstract

Conventional color to grayscale conversion algorithms cannot perform well in certain circumstances and the resultant grayscale images produced have low contrast and interpretability. Thus, we propose a new adaptive approach to overcome the drawback, namely the neighborhood pixels effect approach. In this approach two algorithms are proposed under this approach, namely the Neighborhood Effect Color to Grayscale (NECG) and Stretched Neighborhood Effect Color to Grayscale (SNECG) conversion algorithms. The experiment results show that the resultant grayscale images produced by the proposed algorithms have higher level of brightness, contrast, and amount of details revealed compared with those proposed by conventional methods. These promising findings suggest that the proposed algorithms are potentially useful for pre- and post-processing stages of digital images.

1. Introduction

Despite the advancement of modern technologies in consumer electronic devices, there are some monochrome devices that still play important roles nowadays. For example, the monochrome printing device is used to exports the color images into grayscale [1]-[2]. The grayscale images produced by monochrome devices can be used for many purposes, such as printed textbooks and catalogues [3], aesthetic intents [4] etc.

In addition, some machine vision systems tend to convert the input color images into grayscale. The corresponding grayscale images will then be used for the subsequent processing steps as most of the current available image processing techniques are referred to the grayscale images [4]-[7].

For the red, green, and blue (RGB) color model, the most widely used conventional conversion techniques are the Averaging and National Television System Committee (NTSC) methods. Both of these two methods employ the linearly weighted transformation approach, where the red (R), green (G), and blue (B) components of color images will be assigned with fixed weight contribution during the conversion process.

For the NTSC method, consider an input color image, *I* to be converted to a grayscale image, *J*. Let *R, G,* and *B* to be the intensity level of three color channels of input color image *I*. Classically, the grayscale image *J* is obtained using a linearly weighted transformation and can be determined as follow:

$$J(x,y) = [a \times R(x,y)] + [b \times G(x,y)] + [c \times B(x,y)] \quad (1)$$

where the values of a, b, and c indicate the weight contribution of each color channel of R, G, and B respectively during the conversion process. The paired values of (x, y) indicate the pixel location of input image *I*. In the NTSC technique, the values of a, b, and c assigned to R, G, and B components of the color images are 0.299, 0.587, and 0.144 respectively. This is because for equal amount of color, human eye is most sensitive to green, followed by red and finally blue [6].

Similarly, the grayscale image *J* produced by the Averaging method is obtained using (1). The grayscale intensity level produced by this method is the average of three image planes that correspond to RGB primary colors. In the Averaging method, the weight contribution assigned to R, G, and B components are all the same, where $a = b = c = \frac{1}{3}$.

Although these two methods generally work well and able to produce promising results of grayscale images, these two methods will fail in certain cases, for example in single dominant color or low illumination color images. Single dominant color image refers to color image with the pixel distribution strongly biased to certain color components, while low illumination color image refers to color image with pixel distribution concentrated at low intensity levels. The resultant grayscale images produced have low brightness, contrast and amount of details revealed due to the weight contribution that is assigned to R, G, and B components in these two methods are fixed, regardless of the type of input color images used.

Thus, in this paper, color to grayscale conversion algorithms work based on the neighborhood pixels effect approach, are proposed. Two algorithms are developed under this approach, namely the Neighborhood Effect Color to Grayscale (NECG), and Stretched Neighborhood Effect Color to Grayscale (SNECG) conversion algorithms. These algorithms have adaptive characteristic and are able to improve the brightness, contrast, and details contained in the resultant grayscale images.

The rest of this paper is organized as follows. Section 2 discusses the implementation of algorithms developed under the neighborhood pixels effect approach. The results and discussion will be presented in Section 3. Finally, this paper comes to the end with the conclusion.

2. Proposed Color to Grayscale Conversion Algorithms

This section covers the details surrounding the neighborhood pixels effect approach and the implementation of the proposed algorithms. In this approach, the intensity levels of R, G, and B components of neighborhood pixels of the considered pixel will be considered during the conversion process. The algorithms that are developed under this approach have adaptive property, where the weight contributions of R, G, and B components for each color are different. In addition, the proposed algorithms are able to perform the brightness, contrast, and details enhancement simultaneously during the conversion process. The implementation of the NECG and SNECG methods are presented in the next subsection:

2.1. Neighborhood Effect Color to Grayscale (NECG) Method

First of all, the proposed NECG method will determine the contribution of each color component by summing up the intensity levels of the red channel, $R\ (x, y)$, the green channel, $G\ (x, y)$, and the blue channel, $B\ (x, y)$ for every spatial location of (x, y). The total intensity levels for red, green, and blue channels are assigned as T_{red}, T_{green}, and T_{blue} respectively and defined as follow:

$$T_{red} = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} R\ (x,y) \quad (2)$$

$$T_{green} = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} G\ (x,y) \quad (3)$$

$$T_{blue} = \sum_{x=0}^{M-1}\sum_{y=0}^{N-1} B\ (x,y) \quad (4)$$

Next, the ratio of R, G, and B components (assigned as W_{red}, W_{green}, and W_{blue} respectively) in the given color image will be calculated to determine the weight contribution that needs to be assigned to R, G, and B components. These W_{red}, W_{green}, and W_{blue} have values between 0 to 1 and are defined as follow:

$$W_{red} = \frac{T_{red}}{T_{red}+T_{green}+T_{blue}} \quad (5)$$

$$W_{green} = \frac{T_{green}}{T_{red}+T_{green}+T_{blue}} \quad (6)$$

$$W_{blue} = \frac{T_{blue}}{T_{red}+T_{green}+T_{blue}} \quad (7)$$

In the final step of the NECG method, the values of W_{red}, W_{green}, and W_{blue} obtained will be used to convert the color pixel to its respective grayscale pixels based on:

$$J\ (x,y) = [W_{red} \times R\ (x,y)] + [W_{green} \times G(x,y)] + [W_{blue} \times B(x,y)] \quad (8)$$

2.2. Stretched Neighborhood Effect Color to Grayscale (SNECG) Method

The proposed SNECG method has an additional feature of stretching effect, where the linear stretching operation will be performed on the color components of each color pixel to increase the contrast of the resultant grayscale images.

The proposed SNECG method will first determine the maximum and minimum values of intensity levels for red, green, and blue channels, assigned as R_{max}, R_{min}, G_{max}, G_{min}, B_{max}, and B_{min} respectively. These values are essential in determining the stretched values of R, G, and B components for each color pixel during conversion and defined as follow:

$$R_{max} = max\ \{R\ (x,y)\} \quad (9)$$

$$R_{min} = min\ \{R\ (x,y)\} \quad (10)$$

$$G_{max} = max\ \{G\ (x,y)\} \quad (11)$$

$$G_{min} = min\ \{G\ (x,y)\} \quad (12)$$

$$B_{max} = max\ \{B\ (x,y)\} \quad (13)$$

$$B_{min} = min\ \{B\ (x,y)\} \quad (14)$$

where $x = \{0, 1, 2, \ldots, M\text{-}1\}$ and $y = \{0, 1, 2, \ldots, N\text{-}1\}$.

The proposed SNECG method will then consider the contribution of each R, G, and B channel of a given color image. Similar with the NECG method, the values of T_{red}, T_{green}, and T_{blue} can be calculated using (2), (3), and (4) respectively.

In the next step, the values of T_{red}, T_{green}, and T_{blue} will be used to calculate the weight contribution values of R, G, and B components (assigned as W_{red}, W_{green}, and W_{blue} respectively). using (5), (6), and (7) respectively.

Finally, the values of W_{red}, W_{green}, and W_{blue} obtained will be substituted into (8) to convert the color pixels into their respective grayscale pixels. In addition, the proposed SNECG algorithm modifies the values of $R\ (x, y)$, $G\ (x, y)$, and $B\ (x, y)$ for each color pixel in (8) in order to produce the stretching effect on the resultant grayscale images. The modified equation in converting the color pixel into its respective grayscale pixel is defined as follow:

$$J\ (x,y) = [W_{red} \times R^*\ (x,y)] + [W_{green} \times G^*(x,y)] + [W_{blue} \times B^*(x,y)] \quad (15)$$

where the modified values of $R*\ (x, y)$, $G*\ (x, y)$, and $B\ *(x, y)$ are calculated as follow:

$$R^*(x,y) = 255 \times \frac{R\ (x,y) - R_{min}}{R_{max} - R_{min}} \quad (16)$$

$$G^*(x,y) = 255 \times \frac{G\ (x,y) - G_{min}}{G_{max} - G_{min}} \quad (17)$$

$$B^*(x,y) = 255 \times \frac{B\ (x,y) - B_{min}}{B_{max} - B_{min}} \quad (18)$$

As shown in (16), (17), and (18), the modified values of $R*\ (x, y)$, $G*\ (x, y)$, and $B\ *(x, y)$ are greater as the difference between the maximum and minimum values of red, green, and blue channel are smaller. This suggests that the values of $R*\ (x, y)$, $G*\ (x, y)$, and $B\ *(x, y)$ will be increased significantly in the low contrast images, which defines the simple contrast enhancement property.

3. Results and Discussions

The performance of the proposed NECG and SNECG methods are tested on two categories of color images. In this paper, one single dominant color image, namely "Red Lanterns", and one low illumination color image, namely "Fruits" are selected to demonstrate the capability of the proposed methods. The qualitative and quantitative analyses involve the performance comparison with two conventional color to grayscale conversion algorithms, namely the Averaging and NTSC methods.

3.1. Qualitative Analysis

The resultant images for "Red Lanterns" and "Fruits" are illustrated in Figs. 1 and 2 respectively. In each figure, the

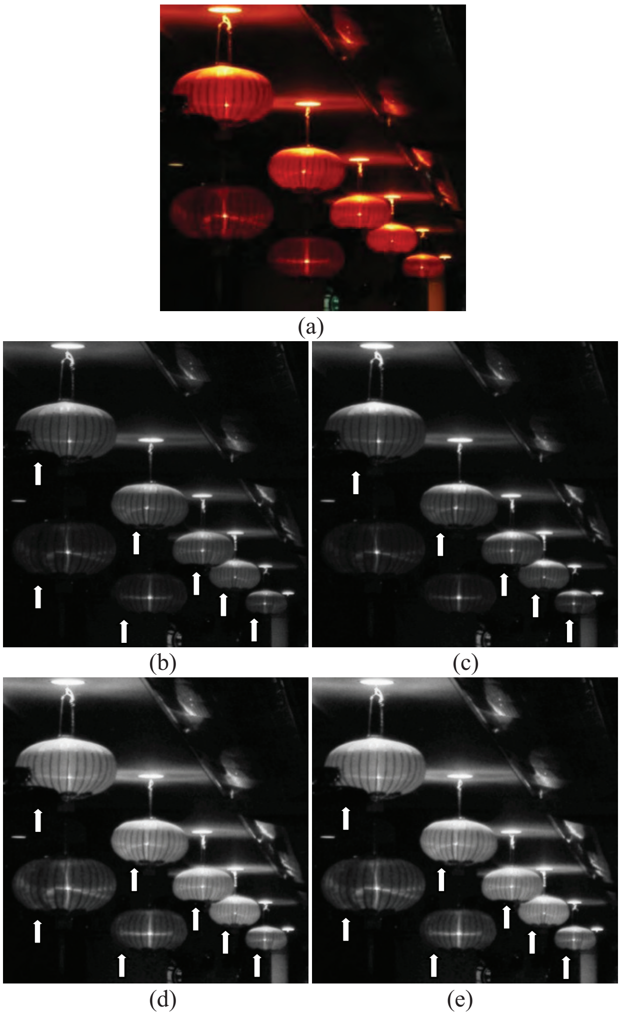

Fig. 1. (a) Original "Red Lantern" image. The resultant grayscale images produced by (b) Averaging, (c) NTSC, (d) NECG and (e) SNECG methods

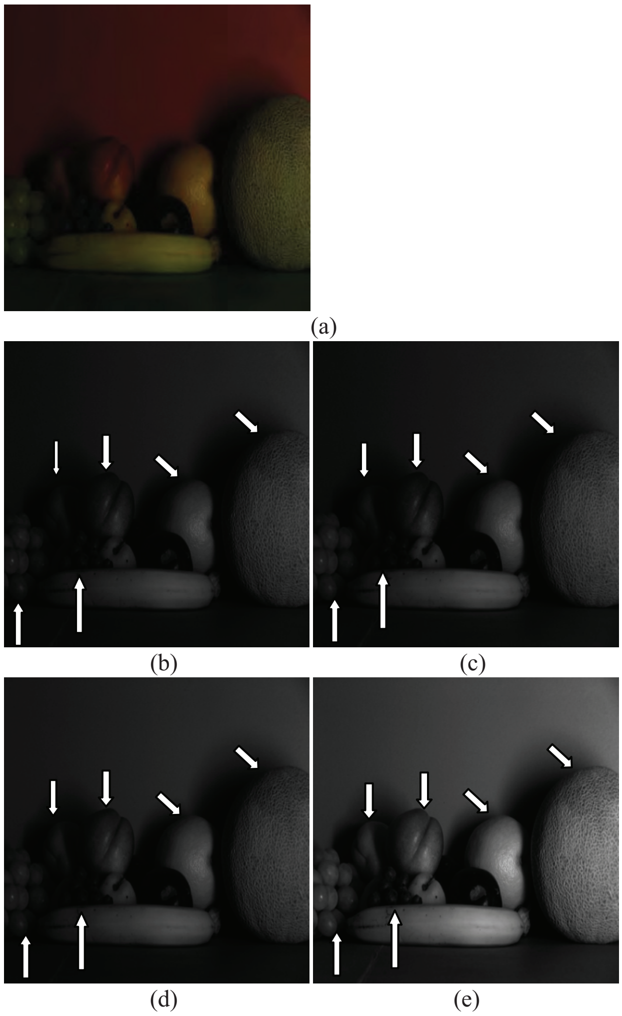

Fig. 2. (a) Original "Fruits" image. The resultant grayscale images produced by (b) Averaging, (c) NTSC, (d) NECG, and (e) SGECG methods

important visual findings that indicate the capability of the tested algorithms (i.e. NECG and SNECG methods) are highlighted by arrows.

By observing the qualitative results of "Red Lanterns" and "Fruits" as illustrated in Figs. 1 and 2 respectively, the results clearly show that the conventional algorithms, i.e. Averaging and NTSC methods perform poorly in the conversion process. The resultant grayscale images produced by both the Averaging and NTSC methods have low intensity levels as shown in the grayscale image of "Red Lanterns" and "Fruits" (represented by images (b) and (c) in Figs. 1 and 2). The low intensity of grayscale images is due to the fixed weight contribution assigned to the R, G, and B components during the conversion process. This may cause the suppression of the dominant color component and the enhancement of non- dominant color component.

Moreover, the grayscale images produced by the Averaging and NTSC methods have low contrast and details revealed. This can be shown in "Red Lanterns" and "Fruits" (represented by Figs. 1 and 2 respectively). For the resultant grayscale images of "Red Lantern" as shown in Fig. 2, it can be observed that the intensity levels of the bottom lanterns and the background does not differ significantly. The edges of the bottom lanterns are not properly preserved, leading to the bottom lanterns undistinguished from the background. For resultant grayscale images of "Fruits" in Fig. 2, the similar intensity levels causes the shadow of fruits hardly differentiated from each other as the fruits' edges are blurry. As a conclusion, both the conventional methods perform poorly in single dominant color and low illumination color images.

Resultant grayscale images produced by the NECG method have demonstrated improvement as compared to the conventional methods. The overall intensity levels of resultant grayscale images produced by the NECG method are brighter than those produced by the NTSC and Averaging methods. This can be observed from the resultant grayscale images of "Red Lanterns" and "Fruits" that represented by Figs. 1 and 2 respectively. The ability of the NECG method in producing resultant images with higher intensity levels are due to fact that the weight contribution assigned to R, G, and B components of color images are decided adaptively. In this case, the dominant components will always be assigned with the highest weight contribution and will never be suppressed.

In addition, the NECG method is also able to increase the contrast and amount of details. As shown in Figs. 1 and 2 for images "Red Lanterns" and "Fruits", in all resultant grayscale images produced by the proposed NECG method, the bright region becomes brighter and dark region become darker, which could significantly increase the contrast of images. The edges of the object are successfully sharpened, thus, the objects can be distinguished from the background. For "Red Lanterns" in Fig. 1, two lanterns at the bottom part are brighter and could easily be distinguishable from the background. For "Fruits" as illustrated in Fig. 2, it can be observed that both peaches at the left hand side can be distinguished from each other and both of them are more distinguishable from their shadow and background.

Similar to the NECG method, the SNECG method is also able to produce grayscale images with improved brightness. In the case of low illumination color images, the overall brightness of the resultant grayscale images produced are higher than those produced by the NECG method. This is shown in image "Fruits" represented by Fig. 4.

Besides increasing the overall brightness, the resultant grayscale images produced by the SNECG method have shown higher contrast and reveal more information than those produced by the NECG method. This is because in the SNECG method, the linear stretching effect has been integrated into the algorithm during the conversion process. For "Red Lantern" in Fig. 1, the edges of the lanterns are more sharpen than those produced by the proposed NECG method; making the lanterns are more distinguishable from background. In addition, the surface of the lanterns can be observed in detail. For "Fruit" in Fig. 2, the purple color of grapes can be observed more easily than that produced by the proposed NECG method. The stretching effect brings the grayscale image of the purple color grapes to become darker, while the grayscale image of fruits surrounding it such as green grapes, banana, and peaches appear to be brighter, which could increase the contrast of the whole image.

3.2. Quantitative Analysis

In this section, three quantitative analyses are employed to evaluate the performance of the proposed algorithms. The resultant grayscale images are evaluated in terms of the mean brightness, contrast, and the amount of information revealed.

The first quantitative test used is the Mean Intensity (MI) test [8]-[9]. The MI test is used in the assessment of the mean brightness of the resultant grayscale images. The greater the values of *MI*, the brighter the resultant grayscale images produced. Assume that T is the total number of pixels in the resultant grayscale image $\mathbf{J} = \{J(x, y)\}$, the mean intensity (*MI*) of a resultant grayscale images is calculated as follow:

$$MI = \frac{1}{T}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} J\,(x,y) \tag{19}$$

For S numbers of sample images used, the average mean intensity (*AMI*) value is defined as follow:

$$AMI = \frac{1}{S}\sum_{s=0}^{S} MI_s \tag{20}$$

The standard deviation (SD) test is used to evaluate the contrast values of a given grayscale image [8]. The greater value of the *SD* indicate greater contrast of the grayscale image. For a grayscale image with mean intensity level of μ and probability density function (PDF) of $P(l)$, where l is the grayscale intensity levels of pixels, the standard deviation can be obtained as follow:

$$SD = \sqrt{\sum_{l=0}^{L-1}(l-\mu)^2 \times P(l)} \tag{21}$$

For S numbers of sample images used, the average standard deviation (*ASD*) value is defined as:

$$ASD = \frac{1}{S}\sum_{s=0}^{S} SD_s \tag{22}$$

Finally, the entropy (E) analysis is used to measure the richness of detail of a grayscale image. [9]-[12]. Higher value of the E indicates the more details revealed by the resultant grayscale images. For a grayscale image with the PDF of $P(l)$, where l is the grayscale intensity levels of pixels, the entropy, E is defined as:

$$E = -\sum_{l=0}^{L-1} P\,(l)\log_2\,P(l) \tag{23}$$

For S numbers of sample images used, the average entropy (*AE*) value can be defined as follow:

$$AE = \frac{1}{S}\sum_{s=0}^{S} E_s \tag{24}$$

Table 1. Quantitative measurement for *Red Lanterns* and *Fruits* images

Algorithms	*Red Lanterns*			*Fruits*		
	MI	*SD*	*E(bits)*	*MI*	*SD*	*E(bits)*
Averaging	22	33.89	5.740	21	14.60	5.700
NTSC	22	35.74	5.760	23	16.40	5.785
NECG	**38**	**52.74**	**6.389**	27	17.35	5.988
SNECG	**38**	**52.74**	**6.389**	**53**	**33.89**	**6.952**

For *MI* analysis shown in Table 1, both the proposed algorithms have higher brightness enhancement capability as they produce higher *MI* values than the conventional methods. The proposed SNECG method has the best performance as it produces two highest *MI* values for "Red Lanterns" and "Fruits".

Next, for the *SD* analysis, the results show that both of the proposed methods have better contrast enhancement capability as they produce higher *SD* values than the conventional methods. The SNECG method has best contrast enhancement capability as it produces two highest *SD* values for "Red Lanterns" and "Fruits".

Finally, for E analysis, it shows that all the proposed algorithms have a better detail-preserving capability as they produce higher E values than the conventional methods. In addition, the proposed SNECG method has the best detail-preserving capability as it produces highest values for all images.

Besides using "Red Lanterns" and "Fruits" for quantitative analysis, a total of 75 images are used to further evaluate their average values of mean intensity (*AMI*), standard deviation (*ASD*), and entropy (*AE*). These values are tabulated in Table 2.

Table 2. Average quantitative measurement

Algorithms	**Tests**		
	AMI	***ASD***	***AE(bits)***
Averaging	110	53.4467	7.22321
NTSC	**111**	53.9389	7.23515
NECG	**111**	53.1946	7.21278
SNECG	110	**55.4701**	**7.28399**

From Table 2, it shows that in overall, the proposed NECG and NTSC methods produces the highest *AMI* values. This indicates that both of these methods in general has the highest brightness enhancement capability. For *ASD* and *AE* analyses, the proposed SNECG method produces the highest values, indicating that this method generally has the best contrast enhancement and detail preserving capabilities. This result is reasonable as the linear stretching effect has been integrated into the SNECG method during the conversion process. Although the *ASD*, and *AE* values produced by the NECG method and *AMI* value produce by the SNECG method are lower than the conventional methods, the qualitative results in the previous section favor the proposed methods. In conclusion, the proposed methods in general are able to produce resultant grayscale images that have higher brightness, contrast, and details than conventional methods.

4. Conclusion

In this paper, a new approach in determining the weight contribution values assigned to R, G, and B components for a given color image during the conversion process is introduced. This approach is known as neighborhood pixels effect approach and it has an adaptive property as the values of weight contribution obtained are not fixed but they depend on the type of input color images used. Two color to grayscale conversion algorithms are developed under this approach, namely the Neighborhood Effect Color to Grayscale (NECG) and Stretched Neighborhood Effect Color to Grayscale (SGECG) methods. The effect of intensity levels of the R, G, and B components of neighborhood pixels for each pixel will be considered during the color to grayscale conversion process. The experimental results have proven that the resultant grayscale images produced by the proposed algorithms have higher brightness, contrast, and details than those produced from conventional methods. With these aforementioned advantages, the proposed algorithms are suitable to be implemented as the pre- and post-processing techniques of digital image.

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6. References

[1] M. Grundland and N. A. Dodgson, "The decolorize algorithm for contrast enhancing, color to grayscale conversion", *Technical Report UCAM-CL-TR-649*, University of Cambridge, 2007.

[2] R. Bala and R. Eschbach, "Spatial color-to-grayscale transformation preserving chrominance edge information", *Proceedings of the Society for Imaging Science and Technology (IS&T) Twelfth Color Imaging Conference*, pp. 82-86, Nov. 2004.

[3] K. Smith, P-E. Landes, J. Thollot and K. Myszkowski, "Apparent greyscale: a simple and fast conversion to perceptually accurate images and video", *Computer Graphics Forum*, vol. 27, pp. 193–200, 2008.

[4] A. Gooch, J. Tumblin, and B. Gooch, "Color2gray: salience-preserving colour removal", *ACM Trans. Graphic,* vol. 24, no. 3, pp. 634-639, 2005.

[5] M. Cadik, "Perceptual evaluation of color-to-grayscale image conversions", *Computer Graphics Forum*, vol. 27, no. 7, pp. 1745-1754, 2008.

[6] R. C. Gonzalez, and R. E., Woods, *Digital Image Processing*, 2nd ed., Prentice Hall, 2002.

[7] T. Kawakami, K. Murahira, and A. Taguchi, "Modified histogram equalization with variable enhancement degree for image contrast enhancement", *International Symposium on Intelligent Signal Processing and Communication Systems (ISPACS) 2009*, pp.570-573, Jan. 2009.

[8] D. Menotti, L. Najman, J. Facon, and A. d. A. Araujo, "Multi-histogram equalization methods for contrast enhancement and brightness preserving", *IEEE Trans. Consumer Electronics*, vol. 53, no. 3, pp. 1186-1194, Aug. 2007.

[9] N. M. Kwok, Q. P. Ha, L. Dikai, and F. Gu, "Contrast enhancement and intensity preservation for gray-level images using multiobjective particle swarm optimization", *IEEE Trans. on Automation Science and Engineering*, vol. 6 , no. 1, pp. 145-155,Jan. 2009.

[10] M. Kim, and M. G. Chung, "Recursively separated and weighted histogram equalization for brightness preservation and contrast enhancement", *IEEE Trans. Consumer Electronics*, vol. 54, no. 3, pp. 1389-1397, Aug. 2008.

[11] C. H. Ooi and N. A. Mat Isa, "Adaptive contrast enhancement methods with brightness preserving", *IEEE Trans. Consumer Electronics*, vol. 56, no. 4, pp. 2543-2551, Nov. 2010.

[12] C. H. Ooi and N. A. Mat Isa, "Quadrants dynamic histogram equalization for contrast enhancement", *IEEE Trans. Consumer Electronics*, vol. 56, no. 4, pp. 2552-2559, Nov. 2010.