Illumination Estimation Based Color to Grayscale Conversion Algorithms

Wei Hong Lim and Nor Ashidi Mat Isa
Imaging and Intelligent Systems Research Team (ISRT)
School of Electrical and Electronic Engineering, Universiti Sains Malaysia
14300 Nibong Tebal, Penang, Malaysia
limweihong87@yahoo.com, ashidi@eng.usm.my

Abstract— **In this paper, a new adaptive approach, namely the illumination estimation approach is introduced into the color to grayscale conversion technique. In this approach, some assumptions will be made to calculate the weight contribution of red, green, and blue components during the conversion process. Two color to grayscale conversion algorithms are developed under this approach, namely the Gray World Assumption Color to Grayscale Conversion (GWACG) and Shade of Gray Assumption Color to Grayscale (SGACG) conversion algorithms. Based on the extensive experimental results, the proposed algorithms outperform the conventional conversion techniques by producing resultant grayscale images with higher brightness, contrast, and amount of details preserved. For this reason, these proposed algorithms are suitable for pre- and post- processing of digital images.**

Keywords—Color-to-grayscale conversion, illumination estimation, image pre-processing

I. Introduction

A color image is a digital image that is characterized by a three dimensional phenomenon, known as the hue, saturation and intensity [1]-[2]. On the other hand, the only attribute that is used to characterize a grayscale image is the intensity component [3]. Although the color images can reveal more visual information than the corresponding grayscale image, the grayscale image still plays an important role in the image processing field as most of the image processing algorithms developed are referred to the grayscale images [1], [4]-[6].

The color to grayscale conversion process is a dimensional reduction process as the color image with three dimensional color information (24-bit) is reduced into one dimension of the grayscale representation (8-bit) [2], [5]. This process is very useful in the monochrome devices such as the grayscale printer or scanner, which export the color images into grayscale [2], [7]-[8]. The resultant grayscale images produced can be used in the legacy recognition systems [4], [7], the stylization of video and for display on monochromatic medical display [9].

Conventionally, the Averaging and National Television System Committee (NTSC) methods are two widely used conversion techniques in the red, green, and blue (RGB) color space due to their simplicity of implementation and the ability to produce reliable results. These two methods employ the linearly weighted transformation approach, where the constant weight contribution values will be assigned to red (R), green (G), and blue (B) components of input color images respectively during the conversion process.

Consider an input color image, I and let the $R(x, y)$, $G(x, y)$, and $B(x, y)$ represent the red, green, and blue color channels' intensity at coordinate (x, y) respectively. The resultant grayscale image J can be determined as follow:

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

connoting that the values of a, b, and c represent the weight contribution values assigned to the R, G, and B channels respectively during the conversion process.

For the NTSC method, the values of a, b, and c assigned to the R, G, and B components of a color image are 0.299, 0.587, and 0.144 respectively. This is due to the fact that human eyes are most sensitive to green, followed by red and finally the blue for equal amount of color [1]. These values of a, b, and c are constant, regardless of the type of color image used.

Conversely, the weight contribution assigned to R, G, and B components in the Averaging method are the same and constant, i.e. $a = b = c = 1/3$. The intensity of the resultant grayscale image produced is the average intensity levels of the three RGB image planes of the input color images.

Although in general these two conventional methods perform well, their credibility is questionable in certain circumstances such as in single dominant color and low illumination images due to the constant weight contribution that is assigned to the R, G, and B components. Single dominant color image referring to a color image with the pixel distribution is strongly biased to certain color components, while low illumination color image referring to color image with pixel distribution is concentrated at low intensity levels. For example, the NTSC method has failed in the face detection system as the human skin color pixels' distributions are strongly biased to red [10]. This dominant component (i.e. red) will be suppressed due to the low weight contribution assigned to the red component by the NTSC method. Thus, a weakened grayscale face signal is produced, which characteristics lie in the low brightness, contrast and

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interpretability. For the Averaging method, the loss of important visual cues of an original image is imminent [2], [4], [8]. For example, a pie chart may look well distinguishable in color. But when printed in the grayscale format, a red color may have same shade of gray with the blue color if their intensities are notably similar.

Recently, Lim and Isa [11] developed a new Adaptive Color to Grayscale (ACGS) conversion algorithm, to tackle the drawback of the conventional approaches. Similar with the NTSC and Averaging methods, the ACGS method employs the linearly weighted transformation approach and it is developed in the RGB color space in order to preserve its nature of simple implementation. Unlike the conventional approaches, the ACGS method is able to adaptively determine the weight contribution of R, G, and B components for a given color images. To be specific, an extensive pixels' distribution analysis of the input color image will be performed by the ACGS method to calculate the weight contribution of R, G, and B components during the conversion process.

In this paper, we introduced a new approach, namely the illumination estimation approach, to adaptively determine the weight contribution of R, G, and B components for a given color image. Two algorithms are proposed under this approach, namely the Gray World Assumption Color to Grayscale (GWACG) and Shade of Gray Assumption Color to Grayscale (SGACG) conversion algorithms.

The rest of this paper is organized as such: Section II discusses the implementation of algorithms developed under the illumination estimation approach (i.e. the GWACG and SGACG methods). The results and discussion will be presented in Section III. Finally, a conclusion will be provided in Section IV.

II. PROPOSED COLOR TO GRAYSLACE CONVERSION ALGORITHMS

This section covers the details of the illumination estimation approach and the implementations of the proposed GWACG and SGACG algorithms. This approach is conventionally used in the color correction techniques. In this paper, the same idea is employed by deriving some assumptions to calculate the weight contribution of R, G, and B components during the conversion process. This is due to the fact that, if an image is illuminated by a certain non-white surrounding color during the image capturing process, the whole image will be prone to have higher intensity of that color. By converting the image using the fixed weight contribution of R, G, and B components (i.e. as in the conventional methods), an insignificant resultant grayscale image could be obtained especially if the dominant illumination color in the image is suppressed (i.e. red color in the NTSC method). Thus, this study proposes to determine the degree of illumination color percentage of a color image to adaptively calculate the weight contribution of R, G, and B components. The implementations of these algorithms are presented in the next subsection:

A. *Gray World Assumption Color to Grayscale (GWACG) Method*

Gray World Assumption [12]-[13] is the illumination color estimation technique used in color correction process. It provides information about the surrounding illumination of an image during the correction process to produce a more natural- looking image.

The proposed GWACG method begins with the calculation of the mean intensity levels of R, G, and B components for a given color images assigned as R_{mean}, G_{mean}, and B_{mean} respectively. Mathematically, these values are defined as follow:

$$R_{mean} = \frac{1}{M \times N} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} R(x, y) \quad (2)$$

$$G_{mean} = \frac{1}{M \times N} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} G(x, y) \quad (3)$$

$$B_{mean} = \frac{1}{M \times N} \sum_{x=0}^{M-1} \sum_{y=0}^{N-1} B(x, y) \quad (4)$$

Based on the values of R_{mean}, G_{mean}, and B_{mean}, the weight contribution of R, G, and B components of a given color images (i.e. assigned as a, b, and c respectively) are calculated as follow:

$$a = \frac{R_{mean}}{R_{mean} + G_{mean} + B_{mean}} \quad (5)$$

$$b = \frac{G_{mean}}{R_{mean} + G_{mean} + B_{mean}} \quad (6)$$

$$c = \frac{B_{mean}}{R_{mean} + G_{mean} + B_{mean}} \quad (7)$$

Finally, these a, b, and c values are substituted into (1) to convert each color pixel into its respective grayscale pixel. As shown in (2)-(4), the color components with a higher mean intensity value will give a higher contribution during the conversion process. This explains the adaptive capability of the proposed GWACG method.

B. *Shade of Gray Assumption Color to Grayscale (SGACG) Method*

The proposed SGACG method employs the Shade of Gray assumption [14] in determining the weight contribution of R, G, and B components during the conversion process. Based on this assumption, the q-th Minkowski norm of a given color image is achromatic. Thus, the respective grayscale intensity levels for a given color image can be estimated using the q-th Minkowski norm of the R, G, and B components.

The proposed SGACG method begins with the calculation of the q-th Minkowski norm of R, G, and B components for a given color images which are assigned as R^q, G^q, and B^q respectively. According to Gijseniji and Givers' [15], the value of q = 6 will give the most accurate estimation of color. Mathematically, R^q, G^q, and B^q can be defined as follow:

$$R^q = \frac{1}{M \times N}\left\{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}[R(x,y)]^q\right\}^{\frac{1}{q}} \tag{8}$$

$$G^q = \frac{1}{M \times N}\left\{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}[G(x,y)]^q\right\}^{\frac{1}{q}} \tag{9}$$

$$B^q = \frac{1}{M \times N}\left\{\sum_{x=0}^{M-1}\sum_{y=0}^{N-1}[B(x,y)]^q\right\}^{\frac{1}{q}} \tag{10}$$

Next, these R^q, G^q, and B^q values are used to determine the weight contributions of the R, G, and B components (assigned as a, b, and c respectively) based on:

$$a = \frac{R^q}{R^q + G^q + B^q} \tag{11}$$

$$b = \frac{G^q}{R^q + G^q + B^q} \tag{12}$$

$$c = \frac{B^q}{R^q + G^q + B^q} \tag{13}$$

Finally, these a, b, and c values are substituted into (1) to convert each color pixel into its respective grayscale pixel.

III. RESULTS AND DISCUSSIONS

In this paper, the capabilities of the proposed GWACG and SGACG methods are tested on two categories of color images. One single dominant color image, namely "Fishes" and one low illumination color images, namely "Weave" are selected to demonstrate the performance of the proposed algorithms. The performance of the proposed algorithms will be compared with the conventional methods, i.e. Averaging and NTSC methods, as well as the recent proposed ACGS method [11].

A. *Qualitative Analysis*

The resultant images for "Fishes" and "Weave" are illustrated in Figs. 1 and 2 respectively. In each figure, the important visual findings that support the capabilities of the proposed algorithms (i.e. GWACG and SGACG methods) are highlighted by arrows.

Based on the visual inspections of "Fishes" and "Weave" images as illustrated in Figs. 1 and 2 respectively, the conventional methods do not perform well in the single dominant color and low illumination color images. All the resultant grayscale images produced have low brightness, as illustrated in images (b) and (c) in Figs 1 and 2. This is due to the constant weight contribution that is assigned to the R, G, and B components during the conversion process. The assignment of constant weight contribution may lead to the suppression of the dominant color component and enhancement of the non-dominant color component.

In addition, the resultant grayscale images produced by the Averaging and NTSC methods have low contrast and little amount of details revealed. This can be shown in "Fishes" and "Weave" (represented by Figs. 1 to 2 respectively). For the resultant grayscale images of "Fishes" as illustrated in Fig.1, it can be observed that the difference in intensity levels between the bright part and the dark part at the background (i.e. sea) is not significant. Thus, the patterns of wave are not clearly displayed. In addition, the body of fish at the right hand side is hardly distinguishable from the background as the edge of the fish is not sufficiently sharp. For the resultant grayscale images of "Weave" as illustrated in Fig. 2, the contrast levels between the weave and the background of images are quite similar, which leads to the weave, the weave handle and the background hardly distinguishable from each other. As a conclusion, both the Averaging and NTSC methods perform poorly in the single dominant color and low illumination color images.

Meanwhile, the resultant grayscale images produced by the proposed GWACG method have shown improvement as compared to the conventional methods. Visually, the resultant grayscale images produced by the GWACG method have higher mean intensity than those produced by the Averaging and NTSC methods. This can be observed in all images (i.e. "Fishes" and "Weave" images) as illustrated in Figs. 1 to 2. This is because the weight contribution of R, G, and B components in the GWACG method are determined in an adaptive procedure as compared to the conventional methods.

Besides that, the resultant grayscale images produced by the GWACG method have higher contrast and details contained than those produced by the conventional methods. For "Fishes" in Fig. 1, the wave patterns have improved contrast and can be clearly presented. For "Weave" in Fig. 2, the weave, the weave handler and the background can be easily distinguished due to the increase of contrast of images.

For the proposed SGACG method, the resultant grayscale images produced have slightly lower mean intensity as compared to those produced by the GWACG method. However, these mean intensity values are still higher than those produced by the conventional methods. The observation can clearly be seen for "Fishes" and "Weave" as illustrated in Figs. 1 and 2.

In addition, the proposed SGACG method can enhance the contrast and details of the resultant grayscale images. However, the amount of improvement produced by the SGACG method is not as significant as the GWACG method. For "Fishes" in Fig. 1, the background image produced by the SGACG method is successfully enhanced. In addition, the body of the fish at the right hand side is distinguishable from the background as the edge of its body is sharpened. The contrast of "Weave" as shown in Fig. 2 is enhanced as well, where the line patterns in the weave are clearly represented.

On the other hand, we observe that the recent proposed ACGS method also achieves some improvements on the resultant grayscale images produced, as compared to the conventional approach. Nevertheless, the improvements are less significant than those accomplished by the proposed GWACG and SGACG methods, as illustrated in Figs. 1 and 2. More specifically, we observe that the overall intensity

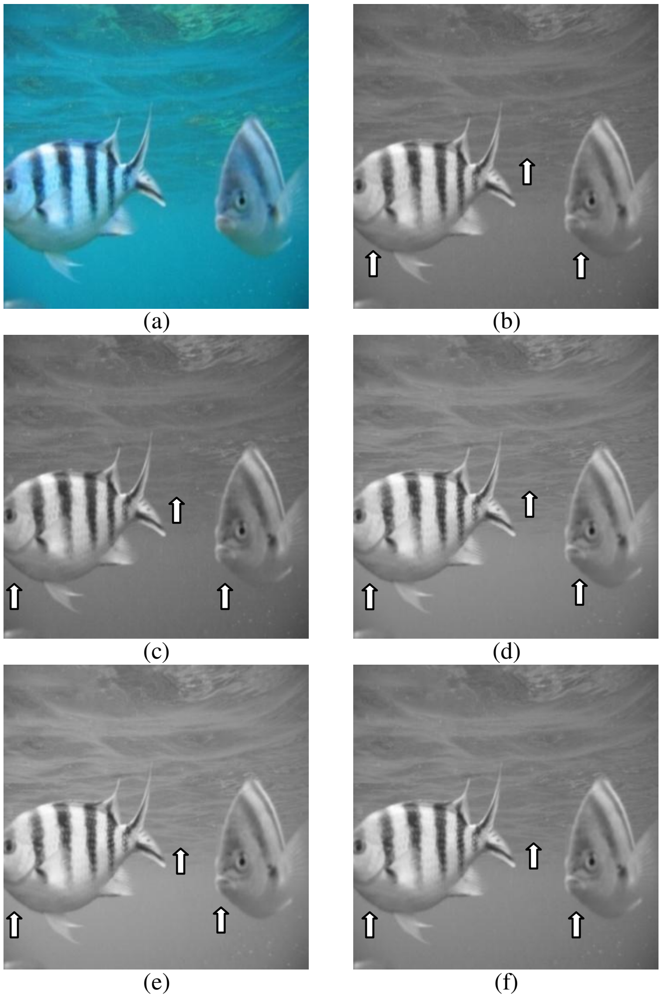

Fig. 1. (a) Original "Fishes" image. The resultant grayscale images produced by (b) Averaging, (c) NTSC, (d) ACGS, (e) GWACG, and (f) SGACG methods

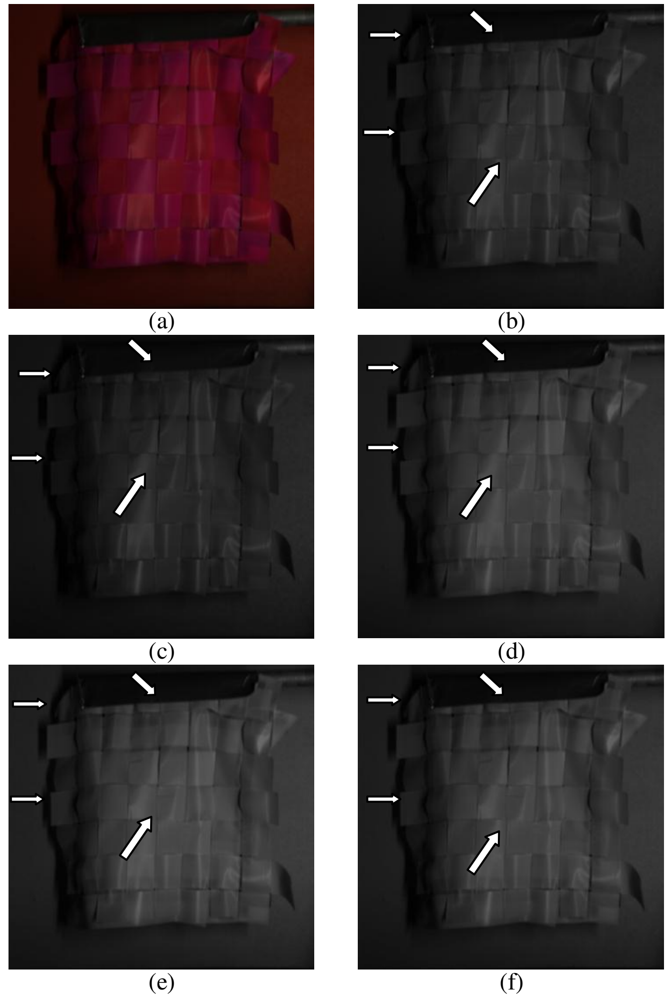

Fig. 2. (a) Original "Weave" image. The resultant grayscale images produced by (b) Averaging, (c) NTSC, (d) ACGS, (e) GWACG, and (f) SGACG methods

level of the resultant grayscale images (i.e. "Fishes" and "Weave") produced by the ACGS method is slightly lower than the proposed GWACG and SGACG methods. This implies that the latter methods have better brightness enhancement capability than the former. Moreover, we also observe that the weave handler and the background of the resultant grayscale "Weave" images (Fig. 2) produced by the proposed GWACG and SGACG methods are easier to be distinguished than the ACGS method. This observation reveals that the former methods have more remarkable contrast enhancement and details preservation capabilities than the latter.

B. *Quantitative Analysis*

In this section, three quantitative analyses are performed to further investigate the capability of the proposed color to grayscale conversion algorithms. The quality of the resultant grayscale images produced will be evaluated in terms of the mean brightness, contrast, and the amount of details revealed.

The first quantitative analysis used is the Mean Intensity (MI) test [16]. The MI test is used to determine the mean brightness of the resultant grayscale images produced. The brighter resultant grayscale images will have higher values of *MI*. Consider a resultant grayscale image $\mathbf{J} = \{J(x, y)\}$, with a total number of pixels of T, the MI values of this image is defined as follow:

$$MI = \frac{1}{T}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} J(x, y) \tag{14}$$

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

$$AMI = \frac{1}{S}\sum_{s=0}^{S} MI_s \tag{15}$$

The standard deviation (SD) analysis [16] is used to measure the contrast of the resultant grayscale images. The grayscale images with greater SD values have greater contrast. The SD values of a given grayscale image with probability density function (PDF) of $P(l)$, where l represents the grayscale intensity levels of pixels, is defined as follow:

$$SD = \sqrt{\sum_{l=0}^{L-1} (l-\mu)^2 \times P(l)} \tag{16}$$

TABLE I. QUANTITATIVE MEASUREMENT FOR *FISHES* AND *WEAVE* IMAGES

Algorithms	*Fishes*			*Weave*		
	MI	***SD***	***E(bits)***	***MI***	***SD***	***E(bits)***
Averaging	117	**24.50**	6.140	28	14.36	5.729
NTSC	116	23.75	6.122	25	12.26	5.535
ACGS	131	24.06	6.233	38	18.89	6.097
GWACG	**142**	24.05	**6.320**	**43**	**21.35**	**6.249**
SGACG	129	24.10	6.220	40	19.72	6.151

TABLE II. AVERAGE QUANTITATIVE MEASUREMENT

Algorithms	Tests		
	AMI	***ASD***	***AE(bits)***
Averaging	110	53.4467	7.22321
NTSC	111	53.9389	7.23515
ACGS	113	53.8823	7.23244
GWACG	**114**	**54.0188**	**7.23862**
SGACG	113	53.9444	7.23251

where μ represents the mean intensity levels of the resultant grayscale images. For S numbers of sample images used, the average standard deviation (*ASD*) value is defined as:

$$ASD = \frac{1}{S}\sum_{s=0}^{S} SD_s \tag{17}$$

Finally, the entropy (E) analysis [17]-[18] is used to measure the richness of details revealed by a grayscale image. A grayscale image with higher value of E has richer details and greater detail preserving capability. The E values of a given grayscale image with PDF of $P(l)$, where l is the grayscale intensity levels of pixels are defined as follow:

$$E = -\sum_{l=0}^{L-1} P(l)\log_2 P(l) \tag{18}$$

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

$$AE = \frac{1}{S}\sum_{s=0}^{S} E_s \tag{19}$$

Based on the *MI* analysis result as shown in Table I, both the proposed algorithms have higher brightness enhancement capability than the conventional methods. Meanwhile, the *MI* values produced by the SGACG method are comparable with the state-of-art ACGS method, revealing the competitive brightness enhancement capability of our proposed method. The proposed GWACG method has the best performance as it produces the highest *MI* values for both images.

Next, for *SD* analysis, the results reveal that both proposed methods have better contrast enhancement capability as the *SD* values produced are higher than the conventional NTSC method. Similar observation could be observed in the "Weave" image, whereby the *SD* values attained by our proposed methods outperform the ACGC method. Although the *SD* values produced by the GWACG and SGACG methods are smaller than the Averaging method, the visual inspection results favor the proposed algorithms.

Finally, the results of E analysis indicate that all the proposed algorithms have a better detail preserving capability as the E values produced by the proposed algorithms are higher than the conventional methods and the recent proposed ACGS method. The results of E analysis verify the earlier observations reported in the qualitative analysis. The proposed GWACG method has the best performance as it produces the highest E value in all images.

Besides using "Fishes" and "Weave" for the 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 II.

Based on Table II, it reveals that the proposed GWACG method produces the highest *AMI*, *ASD*, and *AE* values. This shows that the proposed GWACG method generally has the highest brightness enhancement, contrast enhancement, and detail-preserving capabilities. These results are consistent with the visual inspection results performed in the previous subsection. Although the *AE* value produced by the proposed SGACG algorithm is lower than the conventional methods, the qualitative results in the previous subsection favor the proposed methods. As a conclusion, the proposed methods in general outperform the conventional methods and the state-of-art ACGS method, since the former are able to produce resultant grayscale images that have higher brightness, contrast, and details than the latter.

IV. CONCLUSION

In this paper, a new adaptive approach, namely the illumination estimation approach is introduced to adaptively determine the weight contribution values of R, G, and B components for a given color image during the color to grayscale conversion process. Two color to grayscale conversion algorithms are developed under this approach, namely the Gray World Assumption Color to Grayscale (GWACG) and Shade of Gray Assumption Color to Grayscale (SGACG) methods. The experimental results have proven that the proposed algorithms are able to produce resultant grayscale images with higher brightness, contrast, and amount of details revealed as compared to the conventional methods and the recent proposed ACGS method. For this reason, the proposed algorithms are suitable to be implemented as pre- and post- processing techniques of digital image.

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