Underwater Image Enhancement by Adaptive Gray World and Differential Gray-Levels Histogram Equalization

Siaw-Lang WONG[1], Raveendran PARAMESRAN[1], Akira TAGUCHI[2]
[1]*Department of Electrical Engineering, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia*
[2]*Department of Computer Science, Tokyo City University, Tokyo Japan*
wong.siawlang@gmail.com

***Abstract*—Most underwater images tend to be dominated by a single color cast. This paper presents a solution to remove the color cast and improve the contrast in underwater images. However, after the removal of the color cast using Gray World (GW) method, the resultant image is not visually pleasing. Hence, we propose an integrated approach using Adaptive GW (AGW) and Differential Gray-Levels Histogram Equalization (DHE) that operate in parallel. The AGW is applied to remove the color cast while DHE is used to improve the contrast of the underwater image. The outputs of both chromaticity components of AGW and intensity components of DHE are combined to form the enhanced image. The results of the proposed method are compared with three existing methods using qualitative and quantitative measures. The proposed method increased the visibility of underwater images and in most cases produces better quantitative scores when compared to the three existing methods.**

***Index Terms*—digital images, image processing, image enhancement, image color analysis, image fusion.**

I. Introduction

Capturing clear and high contrast images in underwater environment is always a challenging task. When specialized hardware such as lasers, range gated camera systems or polarized cameras are not available, image quality has to be enhanced through software processing. Physical properties of the water medium caused degradation effects due to the water substance which is denser than air. Visibility and depth are the key considerations to obtain the quality of underwater images. Light attenuation and color change are two main sources of distortion for underwater photography. Light is exponentially attenuated when travels in the water as it is deflected and scattered for several times by water particles before reaching the camera. All these in turn cause the underwater images to be low in contrast and hazy. Haze is caused by suspended particles such as sand, minerals and plankton that exist in lakes, oceans and rivers [1]. Furthermore, different wavelengths of light that travel in the water are attenuated at different degrees [2]. When increases in water depth, the amount of light reduces and the colors drop off dramatically, depending on their wavelengths. That is the reason why most of the underwater images have color distortion and dominated by bluish and greenish tint.

Underwater image processing has attracted attention in recent years as many techniques have been developed to enhance the images as well as restore the images after distortions have been removed [3]-[6]. Ghani and Isa [7], [8] proposed a method that combined the modification of the image histogram in *RGB* and *HSV* where the histograms of the color channel in the *RGB* color model are enhanced and remapped to follow the Rayleigh distribution. After that, the image is converted to *HSV* color model with *S* and *V* components are adjusted within a certain limit. Further, they [9] proposed a two-stage method to enhance the quality of underwater images, where the first stage is the contrast correction technique and the second stage is the color correction technique.

Li et al. [10] developed a physics-based method using quad-tree subdivision and graph-based segmentation to forcefully estimate the global background light and based on minimum information loss principle and optical properties of underwater imaging to estimate the medium transmission map. Further, Li et al. [11] proposed another underwater image enhancement method which includes an underwater image dehazing algorithm that is built on a minimum information loss principle and a contrast enhancement algorithm based on histogram distribution prior. Carlevaris-Bianco, Mohan and Eustice [12] proposed a simple yet effective prior that exploits the major difference in attenuation among three color channels in water to estimate the scene depth.

In the case of color cast in underwater images, several techniques have been developed to remove it. Ancuti, Ancuti, Haber and Bekaert [13] presented an approach based on the fusion principle for enhancement of images and videos obtained under different lighting conditions. Color correction is performed by a white balancing process to remove the color casts and recover the white and gray shades of the image based on the gray-world assumption. Further, Ancuti, Ancuti, Vleeschouwer and Bekaert [14] revised the practical implementation of the fusion approach by proposing an alternative and simplified definition of the inputs and associated weight maps to improve the quality of the image.

One of the most well-known algorithms that used to adjust the Automatic White Balance (AWB) is based on GW hypothesis that was proposed by Buchsbaum [15]. It assumes that the average value (global mean) of each channel of the image should be averaged out to a common gray-value (achromatic). GW method has been widely used in atmospheric images [16]-[18] to remove color cast. In

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some cases, after the removal of the color cast, color correction is applied [19]. In underwater image enhancement method, Bianco et al. [20] proposed a color correction method for underwater imaging in the Ruderman opponent color space *lαβ* that based on GW with uniform illumination assumptions. In underwater images, GW method has not been widely explored and reported. One of the reasons could be just applying the GW method only in *RGB* color space to remove the color cast may not produce a visually pleasing image.

In this paper, we propose an integrated parallel structure to remove the color cast and improve the contrast in underwater images using AGW and DHE respectively. The chromaticity component outputs of AGW and intensity component outputs of DHE are combined to form the enhanced underwater image. In taking this approach, our proposed method achieves better visual quality and natural appearance of the underwater image by removing undesirable color casts and artifacts.

The rest of the paper is organized as follows. In Section 2, the background study which consists of the relationship between *RGB* and *rgb* chromaticity and color cast removal in images using GW method are reported. Next, the proposed method for color cast removal and contrast improvement based on chromaticity and intensity constancy are provided in Section 3. Section 4 presents the experimental studies and the results of the comparison between the proposed method and three existing methods. Section 5 concludes the paper.

II. BACKGROUND STUDY

A. Relationship between RGB and rgb Chromaticity

Color images consist of not only the intensity component but also the chromaticity component. Generally, the enhancement techniques for the underwater image are operated on pixel intensities, but in this study, the proposed method deals on the chromaticity and intensity components independently. Chromaticity is an objective specification of the quality of a color in which there is no luminance information. It involves two independent parameters, often specified as hue and colorfulness. The chromaticity coordinates of *RGB* color space are defined as

$$r = \frac{R}{(R+G+B)} \qquad g = \frac{G}{(R+G+B)} \qquad b = \frac{B}{(R+G+B)} \tag{1}$$

where the color signal (R, G, B) is regarded as vector signal. The chromaticity coordinates (r, g, b) is the cross point between vector signals (R, G, B) and $r + g + b = 1$, as shown in Fig. 1. In other words, the *RGB* color space can be represented by the coordinates (r, g, I). I is a brightness or intensity which is computed as

$$I = \frac{1}{3}\cdot\left(R+G+B\right) \tag{2}$$

where I shows the length of the vector (R, G, B) and (r, g) shows the direction of the vector (R, G, B). Hence, the vector (R, G, B) can be reconstructed back by combining the

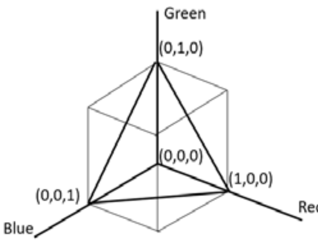


Figure 1. *RGB* color space and *rgb* chromaticity.

(1) and (2) as follows:

$$R = 3\cdot r\cdot I \qquad G = 3\cdot g\cdot I \qquad B = 3\cdot b\cdot I \tag{3}$$

B. Color Cast Removal using Gray World Method

In this section, we show the results of using GW method to remove the color cast in underwater images. In GW algorithm, scaling factors are derived by reference to one of the color channels. A commonly chosen reference is the green channel in the *RGB* color space [21]. The average pixel intensities of red, green and blue channels are calculated using

$$\overline{R} = \frac{1}{MN}\sum_{i\in M}\sum_{j\in N}R(i,j) \qquad \overline{G} = \frac{1}{MN}\sum_{i\in M}\sum_{j\in N}G(i,j) \qquad \overline{B} = \frac{1}{MN}\sum_{i\in M}\sum_{j\in N}B(i,j) \tag{4}$$

where $\overline{R}$, $\overline{G}$, $\overline{B}$ are the global mean for each color channel of the input image of size $M \times N$. The GW assumption keeps the green channel unchanged and defines the correction ratio for the red β_r and blue β_b channels as

$$\beta_r = \frac{\overline{G}}{\overline{R}} \qquad \beta_b = \frac{\overline{G}}{\overline{B}} \tag{5}$$

Then, the red and blue channels are adjusted by

$$\hat{R}(i,j) = \beta_r\cdot R(i,j) \qquad \hat{B}(i,j) = \beta_b\cdot B(i,j) \tag{6}$$

while the green channel remains as $G(i, j)$.

Fig. 2 shows the five underwater images and their enhanced versions using GW method. The GW method has removed the color cast. However, the performance of using GW for underwater images leaves some room for further improvement. In the next section, we introduce an adaptive GW together with DHE to remove the color cast as well as increase the contrast.

III. PROPOSED PARALLEL STRUCTURE FOR COLOR CAST REMOVAL AND CONTRAST ENHANCEMENT

In this paper, a parallel structure consisting of AGW and DHE methods, as shown in Fig. 3, is proposed to remove the color cast and enhance the image contrast respectively. The color cast in the underwater image is removed by using AGW method, while the DHE method enhances the contrast in the image by operating on the intensity component of the

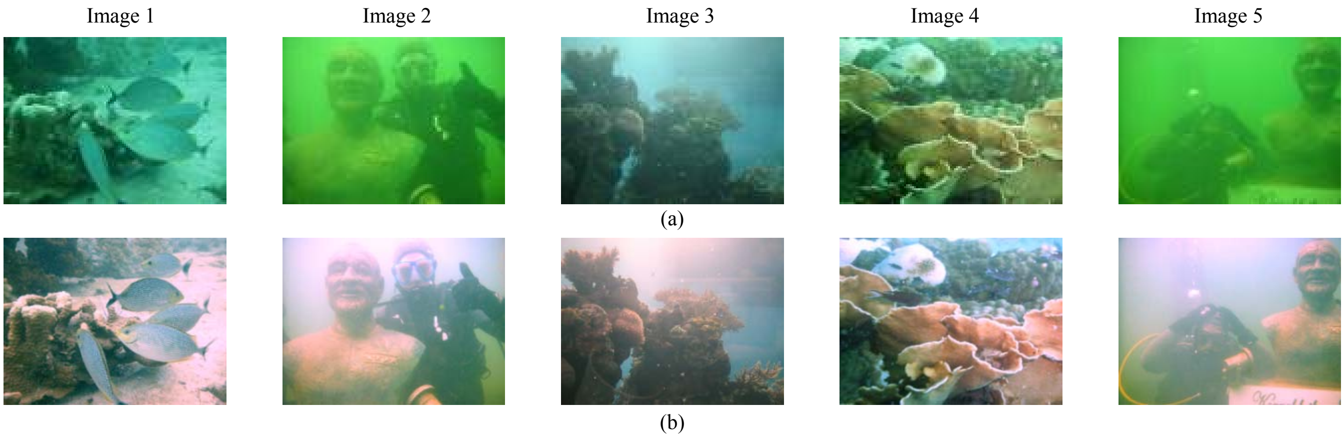


Figure 2. Visual comparison for five underwater images. (a) raw underwater images and (b) enhanced images that are processed with GW method.

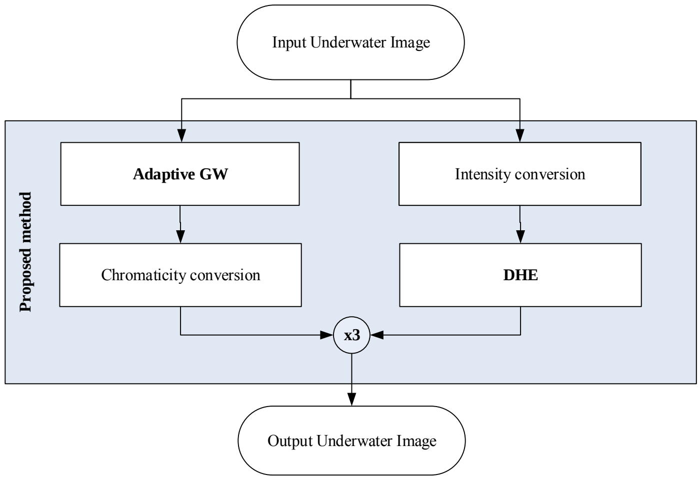


Figure 3. Flowchart of the proposed underwater image enhancement method.

raw underwater image. Next, the outputs of the chromaticity components of the AGW and the intensity components of the DHE are combined to form the new underwater image. The details of each step in the method are described next.

A. *Adaptive Gray World*

AGW is an adaptive version of GW, which apart from computing the global mean of each channel of an image, the local mean of each channel is also considered and both are weighted before combining them. The global mean of each channel of the underwater image is calculated using (4). As discussed in the previous section, although the color cast can be removed by just using the global mean (GW method), the enhanced image is not visually pleasing. The global enhancement method might not work well in underwater images due to the attenuation of light is not globally uniform in the underwater images, hence there is a need to improve further. Local mean is introduced to combine with the global mean to further enhance the image. By using local enhancement based method while preserving global consistency is likely to improve the results. The local mean of each channel is computed using

$$\begin{aligned}\overline{R}^{L}(i,j) &= \frac{1}{(2L+1)^2}\sum_{(i,j)\in W_L} R(i,j)\\ \overline{G}^{L}(i,j) &= \frac{1}{(2L+1)^2}\sum_{(i,j)\in W_L} G(i,j) \quad (7)\\ \overline{B}^{L}(i,j) &= \frac{1}{(2L+1)^2}\sum_{(i,j)\in W_L} B(i,j)\end{aligned}$$

where W_L is the moving local average window size for $(2L + 1) \times (2L + 1)$ region with L is set to 10. This calculation, otherwise known as local averaging operation, where the value of each pixel is replaced by the average of all the values in the local neighborhood. The edge borders of the processing images are padded with mirror reflections of themselves.

Next, both the global and local mean values are scaled and combined as follows:

$$\begin{aligned}\overline{R}^{\theta}(i,j) &= \alpha\cdot\overline{R} + (1-\alpha)\cdot\overline{R}^{L}(i,j)\\ \overline{G}^{\theta}(i,j) &= \alpha\cdot\overline{G} + (1-\alpha)\cdot\overline{G}^{L}(i,j) \quad (8)\\ \overline{B}^{\theta}(i,j) &= \alpha\cdot\overline{B} + (1-\alpha)\cdot\overline{B}^{L}(i,j)\end{aligned}$$

where $0 \leq \alpha \leq 1$ and $\overline{R}^{\theta}(i, j)$, $\overline{G}^{\theta}(i, j)$, $\overline{B}^{\theta}(i, j)$ represent the compensation mean value for Red, Green and Blue channels, respectively. Subsequently, the AGW is obtained by averaging out the input underwater image with compensation mean which can be expressed as

$$\begin{aligned}\hat{R}(i,j) &= \frac{R(i,j)}{\overline{R}^{\theta}(i,j)}\\ \hat{G}(i,j) &= \frac{G(i,j)}{\overline{G}^{\theta}(i,j)} \quad (9)\\ \hat{B}(i,j) &= \frac{B(i,j)}{\overline{B}^{\theta}(i,j)}\end{aligned}$$

(a)

(b)

Figure 4. Visual comparison for five underwater images. (a) enhanced images that are processed with GW method and (b) enhanced images that are processed with our proposed method AGW only.

If the compensation mean values are smaller than the original pixels, the new $\hat{R}(i, j)$, $\hat{G}(i, j)$, $\hat{B}(i, j)$ values will yield values that are greater than 1 and vice versa.

A reason for using AGW method is to slightly reduce the impact of the red channel. However, as shown in Fig. 4, the GW method shows slightly better visually pleasing enhanced images when compared to the enhanced images using AGW method.

The chromaticity of the AGW can be obtained using

$$r_o(i,j) = \frac{\hat{R}(i,j)}{\left(\hat{R}(i,j) + \hat{G}(i,j) + \hat{B}(i,j)\right)}$$
$$g_o(i,j) = \frac{\hat{G}(i,j)}{\left(\hat{R}(i,j) + \hat{G}(i,j) + \hat{B}(i,j)\right)} \quad (10)$$
$$b_o(i,j) = \frac{\hat{B}(i,j)}{\left(\hat{R}(i,j) + \hat{G}(i,j) + \hat{B}(i,j)\right)}$$

where $\hat{R}(i, j)$, $\hat{G}(i, j)$, $\hat{B}(i, j)$ are the channels of the AGW, $r_o(i, j)$, $g_o(i, j)$, $b_o(i, j)$ represent the proportion of chromaticity component of AGW in red, green and blue and their total sum is equivalent to 1. To improve the contrast, the chromaticity component of these images is combined with the intensity component after the DHE operation to make them visually pleasing.

B. Differential Gray-Levels Histogram Equalization

In general, the Histogram Equalization-based method does not produce better quality results for low contrast images when compared to DHE because it relies on the distribution of gray-levels of the input image, while the DHE uses the edge information of the image. The edge information is an important image shape feature.

In this paper, the DHE is adopted from [22] which uses the differential gray-level histogram. It is applied to intensity component to improve the contrast of the image. The intensity component, $I(i, j)$, also known as brightness is computed using (2). The differential gray-level histogram denoted as $h_d(r)$ can be computed by

$$h_d(r) = \sum_{(i,j)\in D_r} d(i,j) \quad (11)$$

where

$$d(i,j) = round\left(\sqrt{d_H(i,j)^2 + d_V(i,j)^2}\right), \quad (12)$$

$$d_H(i,j) = \left[I(i+1,j+1) + 2\cdot I(i+1,j) + I(i+1,j-1)\right] - \left[I(i-1,j+1) + 2\cdot I(i-1,j) + I(i-1,j-1)\right]$$

$$d_V(i,j) = \left[I(i+1,j+1) + 2\cdot I(i,j+1) + I(i-1,j+1)\right] - \left[I(i+1,j-1) + 2\cdot I(i,j-1) + I(i-1,j-1)\right]$$

and D_r is a region composed of pixels whose value is r that takes the values between 0 and 255. The variance range of $d(i,j)$ is from *0* to $round(2\sqrt{5}\cdot(L-1))$ where L is 256. Hence, the horizontal axis of DH is gray-level r and the vertical axis is the total different gray-levels of $I(i, j)$ points. The DHE maps an input gray-level r into an output gray-level s using the following transformation function $T_{DH}(r)$.

$$s = T_{DH}(r) = (L-1)\cdot\left(\frac{\sum_{k=0}^{r} h_d(k)}{\sum_{k=0}^{L-1} h_d(k)}\right) \quad (13)$$

Thus, the DHE intensity component $I_o(i, j)$ can be obtained using

$$I_o(i,j) = T_{DH}(I(i,j)) \quad (14)$$

Finally, the chromaticity component of the AGW and intensity component of DHE is combined to obtain the enhanced image $RGB_o(i,j)$ using

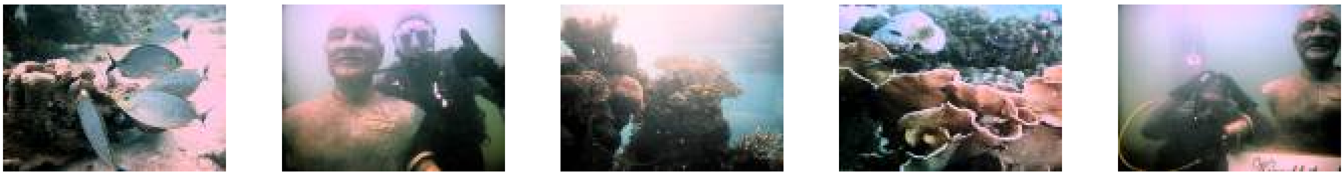
$$R_o(i,j) = 3\cdot r_o(i,j)\cdot I_o(i,j)$$
$$G_o(i,j) = 3\cdot g_o(i,j)\cdot I_o(i,j) \quad (15)$$
$$B_o(i,j) = 3\cdot b_o(i,j)\cdot I_o(i,j)$$

IV. Experimental Studies

In this section, we begin by showing the experimental results obtained using both GW combined with DHE and AGW combined with DHE. Next, the proposed method is compared with three existing methods to show the qualitative differences amongst them. Finally, the quantitative differences between the proposed method and the three existing methods are carried out using the following metrics: Entropy (ENTROPY), Patch-based Contrast Quality Index (PCQI) [23] and Underwater Color Image Quality Evaluation (UCIQE) [24]. Eight images that are commonly used by researchers are used for both qualitative and quantitative evaluations.

A. Performance Analysis of GW and AGW

A qualitative comparison between the enhanced images from the combination of GW (global mean only) with DHE method and combination of AGW (compensation mean) with DHE method is shown in Fig. 5. It is noticeably seen



(a)

(b)

Figure 5. Visual comparison for five underwater images. (a) enhanced images that are processed with GW+DHE method and (b) enhanced images that are processed with our proposed method AGW+DHE (α=0.5).

TABLE I. QUANTITATIVE EVALUATIONS AMONG RAW IMAGES, GW+DHE METHOD AND PROPOSED METHOD AGW+DHE FOR FIG. 5.

	ENTROPY			UCIQE		
	Raw image	GW+DHE	Proposed method	Raw image	GW+DHE	Proposed method
Image 1	7.2835	7.6874	**7.8285**	0.5817	0.7484	**0.7647**
Image 2	6.9297	7.7452	**7.8772**	0.4521	0.7489	**0.7610**
Image 3	7.4842	7.7701	**7.8099**	0.6556	0.7823	**0.7874**
Image 4	7.5339	7.8257	**7.8897**	0.6167	0.7441	**0.7570**
Image 5	6.4303	7.7009	**7.7710**	0.4049	0.7535	**0.7630**

that enhanced images shown in Fig. 5(a) that used global mean, have more reddish casts especially on the background and foreground areas when compared to the enhanced images in Fig. 5(b) that used compensation mean. The quantitative performance evaluations using ENTROPY and UCIQE for Fig. 5 are shown in Table I. Entropy is used to measure the image information content where the higher entropy values of an image indicate more information contained in that particular image. It is computed using

$$Entropy = -\sum_{i=1}^{n} p_i(\log_2 p_i) \quad (16)$$

where p_i is the probability that the difference between two adjacent pixels is equal to i and $\log_2$ is the base 2 logarithm. Furthermore, Yang and Sowmya [24] presented underwater image quality evaluation metrics that effectively evaluate the underwater image quality in accordance with the human perceptions. The UCIQE is defined as

$$UCIQE = c_1 \times \sigma_c + c_2 \times con_l + c_3 \times \mu_s \quad (17)$$

where σ_c is the standard deviation of chroma, con_l is the contrast of luminance, μ_s is the average of saturation, and c_1, c_2, c_3 are weighted coefficients. Refer to [24], the coefficients used in this paper are c_1 = 0.4680, c_2 = 0.2745 and c_3 = 0.2576. The values in bold in the Table I represent the best results. Our proposed method using AGW and DHE gave better Entropy and UCIQE scores when compared to using GW with DHE method.

In this experimental study, the alpha (α) in compensation mean is set to 0.5. To show the effectiveness of using alpha, experiments were carried out by varying the alpha in the compensation mean and the quantitative scores using UCIQE for five images are shown in Fig. 6. Though the UCIQE scores for five images showed higher scores when alpha equals to 0, it may not be the case if other underwater images are used. In all cases, using any alpha values in the AGW method gave better quantitative scores when compared to using only global mean in the GW method.

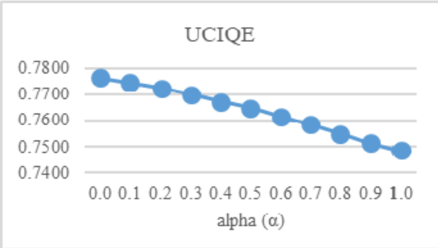
B. Comparative Analysis using Qualitative Evaluation

In the present case of underwater image processing, there is no ground truth image taken with standard illumination available that can be used to compare and evaluate it with any enhanced images. Thus, most of the cited methods for enhancement and restoration are not only relied on quantitative scores but also on visual inspection. Input images [12], [14] that were captured in different locations with different water environments, objects and backgrounds have been chosen for experimental validation. The existing methods of Li et al. [10], Carlevaris-Bianco, Mohan and Eustice [12] and Ancuti, Ancuti, Vleeschouwer and Bekaert [14] are compared with the proposed method.

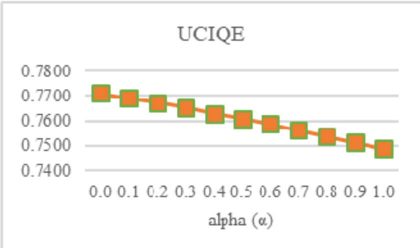
Fig. 7 shows the visual quality of eight input images and their respective enhanced images using the existing methods and the proposed method. As can be seen in the eight raw underwater images, they consist of color cast, haze and lack of contrast. From the visual inspection, it is noticeable that the proposed method and the method of Ancuti, Ancuti, Vleeschouwer and Bekaert [14] have consistently and completely removed the greenish and bluish casts in the whole underwater images as well as characterized by improved visibility, increased brightness and preserved the natural appearance. Although the method of Ancuti, Ancuti, Vleeschouwer and Bekaert [14] has increased contrast and revealed details of raw images, there are some enhanced areas in the images which resulted in brownish or grayish colors left in the images. For the methods of Li et al. [10] and Carlevaris-Bianco, Mohan and Eustice [12], where their methods are focused on dehazing, some greenish casts remain in their enhanced images.

C. Comparative Analysis using Quantitative Evaluation

Before this, no underwater image quality model can be applied to select good images in different marine habitats. Among the enhancement and restoration methods that have been published, the performance of most enhanced images



(a)



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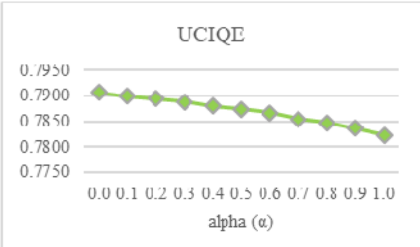

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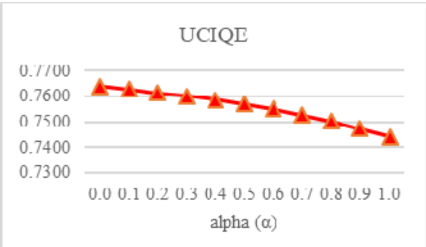

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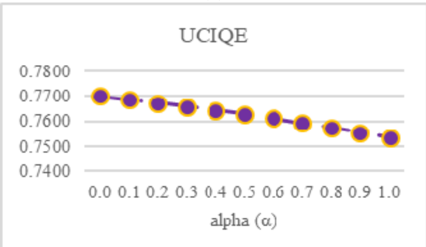

(e)

Figure 6. Results of UCIQE scores for proposed method with alpha (α) varied from 0.0 to 1.0 for Fig. 5(b). (a) image 1, (b) image 2, (c) image 3, (d) image 4 and (e) image 5.

are evaluated subjectively, which are known to be complicated, time-consuming and expensive Objective assessment is difficult in this case as it requires the availability of ground truth. Based on the previous works [10], [11], ENTROPY and PCQI [23] have been used to verify the performance of the proposed methods. PCQI assessed the image quality of contrast changed based on an adaptive representation of local patch structure. It is defined as

$$PCQI(X,Y) = \frac{1}{M}\sum_{j=1}^{M} q_i(x,y)\cdot q_c(x,y)\cdot q_s(x,y) \qquad (18)$$

where X is the original image, Y is the test image, M is the total number of patches. According to Wang, Ma, Yeganeh, Wang and Lin [23], they represented any image patch in a unique and adaptive way as three conceptually independent components, which are $q_i(x,y)$, $q_c(x,y)$ and $q_s(x,y)$ refer to the mean intensity, signal strength and signal structure, respectively. The higher PCQI values indicate the image has better contrast. On the other hand, UCIQE [24] metric is used to quantify the non-uniform color cast, blurring and low contrast of underwater images.

The quantitative performance evaluations of ENTROPY, PCQI, and UCIQE for Fig. 7 are summarized in Tables II, III and IV, respectively. As shown in Table II, our proposed method gave better average Entropy score when compared to the other methods listed in the table. The Entropy scores demonstrated that our proposed method can effectively increase the information, contrast and visibility of the underwater images. For the PCQI evaluation scores shown in Table III, the method proposed by Ancuti, Ancuti, Vleeschouwer and Bekaert [14] gave the best average quantitative scores. In this case, the average score by our proposed method was slightly lower when compared to the method of Ancuti, Ancuti, Vleeschouwer and Bekaert [14]. Next, UCIQE quantitative scores in Table IV showed that our proposed method gave better average score when compared to the other methods listed in the table. This indicates that the proposed method can restore well-balanced chroma, saturation and contrast of the enhanced underwater images.

TABLE II. QUANTITATIVE EVALUATIONS OF ENTROPY FOR FIG. 7.

	Source	[12]	[14]	[10]	Proposed Method
Ship	7.186	7.218	7.554	7.133	7.728
Fish	6.708	7.815	7.035	6.680	7.824
Reef1	7.252	7.288	7.402	7.217	7.582
Reef2	6.729	7.502	6.707	6.706	7.582
Reef3	7.061	7.711	7.679	7.048	7.903
Ancuti1	6.926	7.153	7.667	7.359	7.852
Ancuti2	6.169	6.314	7.401	6.771	7.823
Ancuti3	6.237	6.516	7.749	6.881	7.678
Average	6.783	7.190	7.399	6.974	7.747

TABLE III. QUANTITATIVE EVALUATIONS OF PCQI FOR FIG. 7.

	Source	[12]	[14]	[10]	Proposed Method
Ship	-	0.446	1.172	0.981	1.048
Fish	-	1.135	1.117	0.980	1.164
Reef1	-	0.996	1.083	0.963	0.996
Reef2	-	1.162	1.075	0.976	1.135
Reef3	-	1.050	1.276	1.028	1.184
Ancuti1	-	0.813	1.022	0.986	1.062
Ancuti2	-	0.778	0.914	1.022	1.072
Ancuti3	-	0.961	1.207	1.003	1.143
Average	-	0.917	1.108	0.992	1.101

TABLE IV. QUANTITATIVE EVALUATIONS OF UCIQE FOR FIG. 7.

	Source	[12]	[14]	[10]	Proposed Method
Ship	0.554	0.810	0.632	0.548	0.739
Fish	0.532	0.747	0.667	0.527	0.695
Reef1	0.578	0.736	0.658	0.571	0.715
Reef2	0.645	0.709	0.711	0.622	0.710
Reef3	0.519	0.746	0.697	0.519	0.713
Ancuti1	0.425	0.458	0.594	0.457	0.699
Ancuti2	0.412	0.433	0.592	0.442	0.689
Ancuti3	0.419	0.435	0.664	0.459	0.731
Average	0.511	0.634	0.652	0.518	0.711

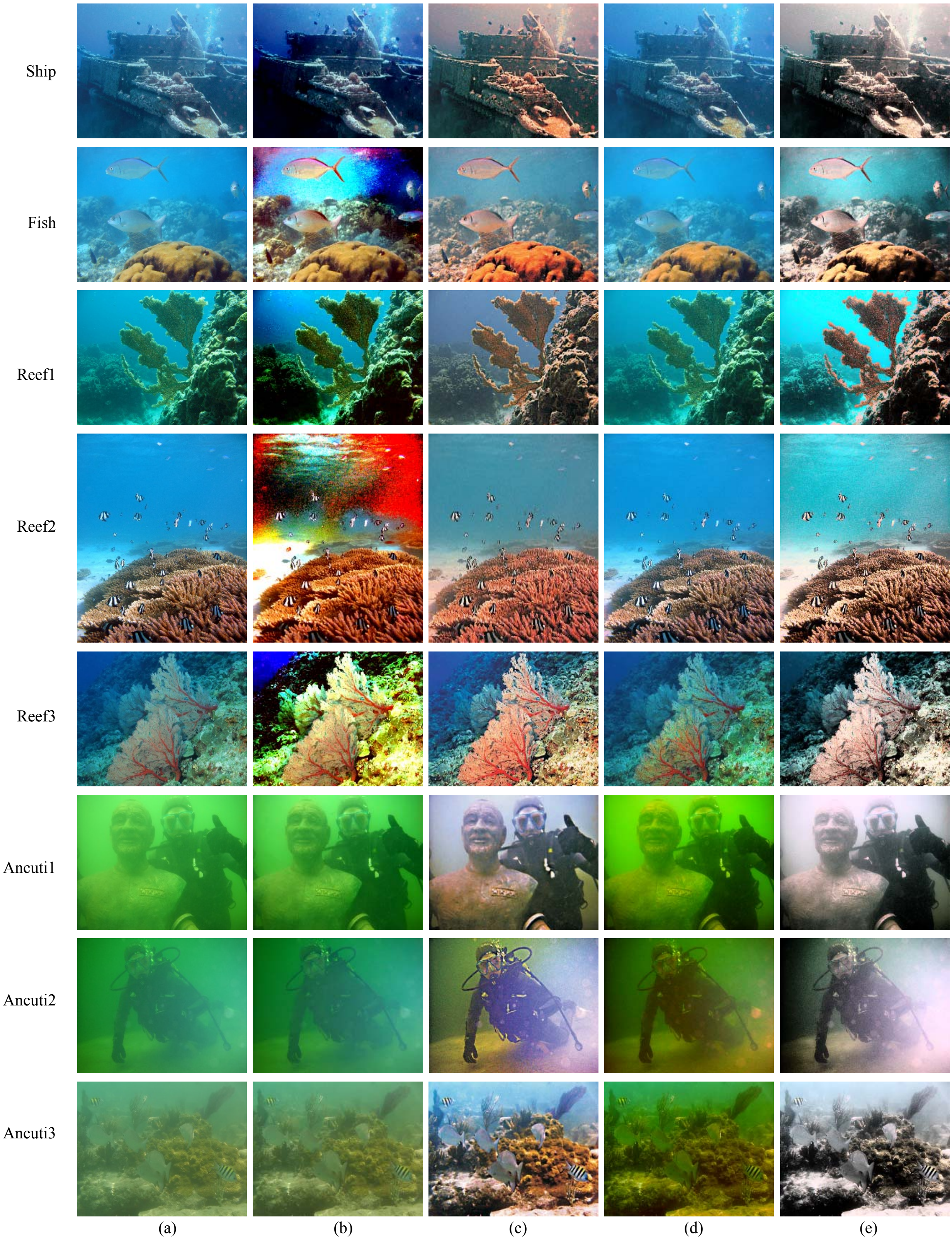

Figure 7. Visual comparison for eight underwater images. (a) source images, (b) enhanced images obtained after processing with [12] method, (c) enhanced images obtained after processing with [14] method, (d) enhanced images obtained after processing with [10] method and (e) enhanced images obtained after processing with our proposed method (α=0.5).

V. Conclusion

In this paper, a parallel structure consisting of AGW and DHE methods is proposed to remove the color cast and enhance the image contrast respectively. AGW uses the global mean and the local mean of the underwater image and both are weighted before combining them for each color channel. After that, the chromaticity component of the AGW and the intensity component of the DHE are combined to form the enhanced image. Based on the experimental results, the proposed method that uses parallel structure has effectively increased the visibility of underwater images and produces better quantitative scores in most cases. For future work, the enhanced image of using AGW with DHE method can still be further improved by increasing the colorfulness of the image.

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