Performing Contrast Limited Adaptive Histogram Equalization Technique on Combined Color Models for Underwater Image Enhancement

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Abstract—This paper describes method to improve the visibility of underwater images. Using Contrast Limited Adaptive Histogram Equalization (CLAHE) technique, our method derives the enhanced image from combination of outputs performed on RGB color model and HSV color model that is done through Euclidean norm. The underwater images for this study were taken from Redang Island and Bidong Island in Terengganu, Malaysia. Experimental results indicate that the proposed method significantly improves the visual quality of underwater images by enhancing contrast, as well as reducing noise and artifacts.

Index Terms—underwater image enhancement, histogram equalization, color models.

1 INTRODUCTION

A current protocol that is being adapted by marine scientists for on-site coral reefs monitoring is by using video capture [1]. When the images are ready in a laboratory, marine scientists use visual cues of coral images such as color, texture and structure for classification or recognition of coral reefs. However, there are inherent difficulties in applying pattern recognition techniques directly to actual underwater images.

Underwater images suffer from degradation due to poor visibility conditions and effects such as light absorption, light reflection, bending of light and scattering of light [2]. For instance, when discuss about light absorption, it is well known that water absorbs light in ways that air does not. The amount of light will drop off as it passes through water. Different wavelengths of light (blue, green, red) will penetrate water to a varying degree [3]. Fig. 1 shows an illustration about the absorption of light by water. For every 10m increase in depth the brightness of sunlight will drop by half. Nearly all red light is gone by 50% from the surface but blue continues to great depth. That is why most underwater images are dominated by blue-green coloration.

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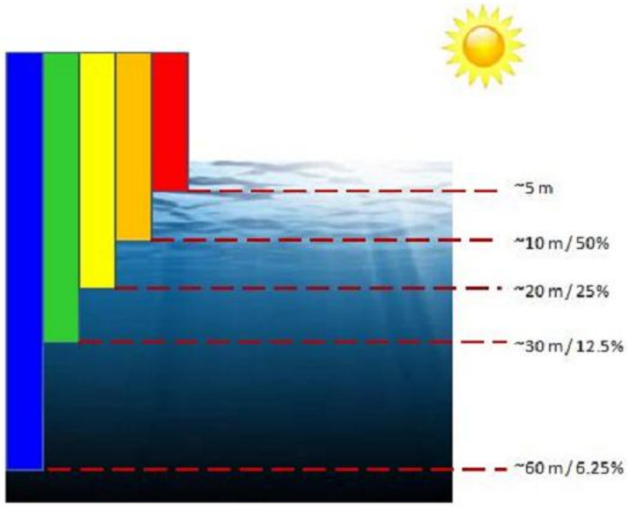

Fig. 1. Absorption of light by water.

Due to disappearing of colors in an underwater image, sophisticated techniques are therefore required to restore the colors and contrast that lost from absorption. Common contrast-enhancement technique uses standard histogram equalization [4]. This method increases the contrast of an image globally by spreading out the most frequent intensity values. However, it suffers from noise amplification in relatively homogeneous regions.

An adaptive histogram equalization (AHE) [5] and contrast limited adaptive histogram equalization (CLAHE) [6] were proposed to overcome the over amplification of noise problem. They differ from standard histogram equalization in the respect that both methods computes several histograms, each corresponding to a distinct section of the image and use them to redistribute the lightness values of the image. AHE and CLAHE improve local contrast of an image more than standard histogram equalization does by bringing out more details but still has tendency to amplify noise.

This paper proposes a new method which combine two images of CLAHE that are applied onto two color models of RGB and HSV. The main goal is to reduce significant noise introduced by CLAHE in order to ease a subsequent process of underwater images.

The outline of this paper is as follows: Section II presents CLAHE technique on RGB and HSV color models. In the next section, the proposed method is presented. Section 4 compares the quality of the results from different methods. Finally, Section 5 concludes the paper.

2 Contrast Limited Adaptive Histogram Equalization

Constrast Limited Adaptive Histogram Equalization (CLAHE) is a generalization of Adaptive Histogram Equalization (AHE). CLAHE was originally developed for enhancement of low-contrast medical images [7]. CLAHE differs from ordinary AHE in its contrast limiting. CLAHE limits the amplification by clipping the histogram at a user-defined value called clip limit. The clipping level determines how much noise in the histogram should be smoothed and hence how much the contrast should be enhanced. A histogram clip (AHC) can also be applied. AHC automatically adjusts clipping level and moderates over-enhancement of background regions of images. One of the AHC that normally used is Rayleigh distribution which produces a bell-shaped histogram. The function is given by

$$\text{Rayleigh } g = g_{min} + \left[2(\alpha^2)\ln\left(\frac{1}{1-P(f)}\right)\right]^{0.5} \quad (1)$$

where g_{min} is a minimum pixel value, $P(f)$ is a cumulative probability distribution and is a nonnegative real scalar specifying a distribution parameter. In this study, clip limit is set to 0:01 and value in Rayleigh distribution function is set to 0:04.

2.1 CLAHE on RGB color model

RGB color space describes colors in terms of the amount of red (*R*), green (*G*) and blue (*B*) present. It uses additive color mixing, because it describes what kind of light needs to be emitted to produce a given color. Light is added to create form from out of the darkness. The value of *R*, *G*, and *B* components is the sum of the respective sensitivity functions and the incoming light:

$$R = \int_{300}^{830} S(\gamma)R(\gamma)d\gamma$$
$$G = \int_{300}^{830} S(\gamma)G(\gamma)d\gamma$$
$$B = \int_{300}^{830} S(\gamma)B(\gamma)d\gamma$$

where S(γ) is the light spectrum, R(γ), G(γ), B(γ) are the sensitivity functions for the R, G and B sensors respectively.

In RGB color space, CLAHE can be applied on all the three components individually. The result of full-color RGB can be obtained by combining the individual components. Fig. 2 shows output images before and after applying CLAHE.

(a) Before (b) After

Fig. 2. The output of CLAHE applied on RGB color model.

2.2 CLAHE on HSV color model

HSV color space describes colors in terms of the Hue (*H*), Saturation (*S*), and Value (*V*). The model was created by A.R. Smith in 1978. The dominant description for black and white is the term, value. The hue and saturation level do not make a difference when value is at max or min intensity level.

The HSV model takes an RGB components to be in the range [0; 1]. The value *V* is computed by taking the maximum value of RGB or can be described formally by:

$$V = \max(R, G, B) \quad (2)$$

$$S = \frac{V - \min(R, G, B)}{V} \quad (3)$$

The saturation *S* is controlled by how widely separated the RGB values are. When the values are close together, the color will be close to gray. When they are far apart, the color will be more intense to pure.

Finally, hue *H*, which determines whether the color is red, blue, green, yellow and so on, is the most complex to compute. Red is at 0°, green is at 120°, and blue is at 240°. The maximum RGB color controls the starting point, and the difference of the colors determines how far we move from it, up to 60° away (halfway to the next primary color). To calculate the hue, we must calculate *R’, G’*, and

B':

$$R' = \frac{V - R}{V - \min(R, G, B)} \quad (4)$$

$$G' = \frac{V - G}{V - \min(R, G, B)} \quad (5)$$

$$B' = \frac{V - B}{V - \min(R, G, B)} \quad (6)$$

If $S = 0$ then hue is undefined, otherwise

$$H = \begin{cases} 5 + B' & R = \max(R, G, B) \text{ and } G = \min(R, G, B) \\ 1 - G' & R = \max(R, G, B) \text{ and } G \neq \min(R, G, B) \\ R' + 1 & G = \max(R, G, B) \text{ and } B = \min(R, G, B) \\ 3 - B' & G = \max(R, G, B) \text{ and } B \neq \min(R, G, B) \\ 3 + G' & B = \max(R, G, B) \\ 5 - R' & \text{otherwise} \end{cases} \quad (7)$$

Since there is a hue discontinuity around 360°, arithmetic operations is difficult to perform in all components of HSV.

Therefore, CLAHE can only be applied on V and S compo-nents. The enhanced image obtained from CLAHE technique that was applied on HSV color model is presented in Fig. 3.

(a) Before (b) After

Fig. 3. The output of CLAHE applied on HSV color model.

3 THE PROPOSED METHOD

In previous section, we noted that when applying CLAHE on each component of an RGB model, it corrupts the human sense of color (see Fig. 2). A more logical approach is to spread the color intensities uniformly, leaving the colors themselves (e.g., hues) unchanged. As can be seen in Fig. 3, the overall color is more sensible than the result image from Fig. 2. However, the overall image is much brighter and looks unnatural to underwater image. Moreover, the unavoidable enhancement of noise in smooth regions is identified.

In this section, we try to reduce the undesired artifacts as well as brightness in Fig. 3 by introducing a new method which combine two color models. The aim is twofolds: One is to enhance the image contrast and the other one is to produce natural look underwater image and yet, smooth.

The proposed method takes both result images from RGB and HSV models. On RGB color model, instead of apply-ing CLAHE on full channels, our proposed method applies CLAHE only on R channel since the loss of red color is more critical than green and blue colors. Then, the normalization of result image from RGB is obtained by

$$\begin{aligned} r_{c_1} &= \frac{R_c}{R_c + G_c + B_c} \\ g_{c_1} &= \frac{G_c}{R_c + G_c + B_c} \\ b_{c_1} &= \frac{B_c}{R_c + G_c + B_c} \end{aligned} \quad (8)$$

The result image of HSV is converted to RGB by finding chroma

$$C = V * S \quad (9)$$

$$H' = \frac{H}{60°}. \quad (10)$$

and

Then, by using *C* and *H'*, *X* is determined as follows:

$$X = C(1 - |H' \bmod 2 - 1|) \quad (11)$$

The conversion from HSV to RGB which is denoted by (r_{c2}; g_{c2}; b_{c2}) is based on the following conditions:

$$(r_{c_2}, g_{c_2}, b_{c_2}) = \begin{cases} (0,0,0) & \text{if } H \text{ is undefined} \\ (C, X, 0) & \text{if } 0 \leq H' < 1 \\ (X, C, 0) & \text{if } 1 \leq H' < 2 \\ (0, C, X) & \text{if } 2 \leq H' < 3 \\ (0, X, C) & \text{if } 3 \leq H' < 4 \\ (X, 0, C) & \text{if } 4 \leq H' < 5 \\ (C, 0, X) & \text{if } 5 \leq H' < 6 \end{cases} \quad (12)$$

Finally, the normalized CLAHE on RGB with CLAHE on

$$RGB_n = \left[\sqrt{r_{c_1}^2 + r_{c_2}^2}, \sqrt{g_{c_1}^2 + g_{c_2}^2}, \sqrt{b_{c_1}^2 + b_{c_2}^2}\right] \quad (13)$$

HSV which has been converted to RGB are integrated using a Euclidean norm:

To produce a full-color RGB, each channel of R_n, G_n and B_n are combined together to form a three-dimensional space.

Fig. 4 shows output image from the proposed method. Note that from the figure, the output resulted from the proposed method offers a balance between the output images in Fig. 2 and Fig. 3.


(a) Before (b) After

Fig. 4. The output of CLAHE applied using the proposed method.

4 Experimental Results

The images for the experiment were taken from two different islands in Terengganu, Malaysia namely Redang Island and Bidong Island. Image 1 and Image 2 were taken from Bidong Island whereas Image 3 and Image 4 were taken from Redang Island. The quality of the enhanced images was judge both in subjective way from their visual appeal and the presence of unwanted color artifacts as well as by using objective statistical measures using Mean Square Error (MSE) and the Peak Signal to Noise Ratio (PSNR). The MSE represents the cumulative squared error between the improved image and the original image, whereas PSNR represents a measure of the peak error. The good method will produce lower MSE and higher PSNR values.

The MSE is calculated using the following equation:

$$\mathrm{MSE} = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M * N} \qquad (14)$$

where I_1 and I_2 denotes the original image and the improved image, respectively. The size of the input images must be same and are denotes by $M * N$. To compute the PSNR, we can use the MSE in Eq. 14. The following equation defines the PSNR:

$$\mathrm{PSNR} = 20\log_{10}\left(\frac{2^{\beta}-1}{\sqrt{(MSE)}}\right) \qquad (15)$$

where β represents the bits per sample. In this work, β is equal to 8 because color images that range from 0 to 255 are used for the experiment. The values of MSE and PSNR are shown in Table I. Based on the values shown in the table, it is clear that the results of the proposed method are better than the results produced by applying CLAHE on RGB and CLAHE on HSV. The proposed method produces the lowest MSE values and the highest PSNR values for all test images.

In Fig. 5, the results of the CLAHE technique applied on RGB and HSV and the proposed method are presented. It is clear that, when CLAHE applied on RGB model, the result images introduce new artifact colors from the original images. When CLAHE applied on HSV, the results look much better and the contrast of the images are also increased. However, both approaches distort the original images. The distortion can be seen clearly in Fig. 6 (a close-up of Image 4 in Fig. 5). The proposed method refines both approaches by treating them equally as a Euclidean norm. As a result, the proposed method produce slightly better result by reducing the distortion and unwanted artifacts from the first and second approaches.

5 Conclusion and Future Work

This paper presents method to enhance underwater images using a combination of CLAHE that applied on RGB and HSV color models. The enhancement methods effectively improves the visibility of underwater images and produces the lowest MSE values and the highest PSNR values. The enhancement method appears to be useful for a wide range of underwater images applications, but the limitation is that it cannot adapt with varying distances of the captured images. Therefore, our future work will consider to automatically select which channel(s) of RGB color model should CLAHE applied on.

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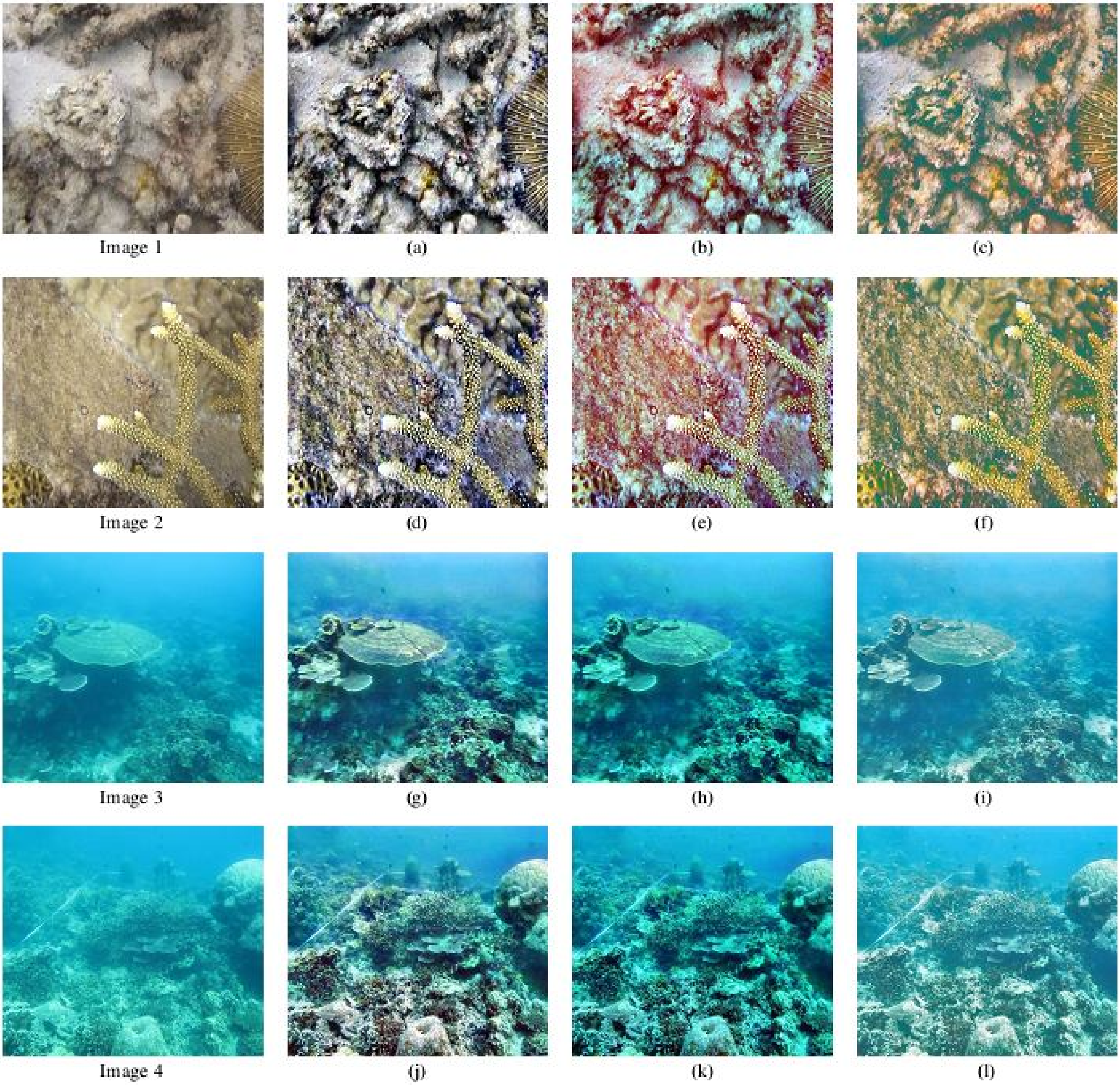

Fig. 5. Comparison of CLAHE on RGB images and HSV images. First column: original underwater images. Second column((a),(d),(g),(j)): CLAHE applied on RGB images. Third column((b),(e),(h),(k)): CLAHE applied on HSV images. Fourth column((c),(f),(i),(l)): The proposed method.