Shallow Water Image Enhancement using Predominant Colour Scheme

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***Abstract*—Heavy non-uniform light attenuation in water across visible spectrum causes dramatic hue shifts towards blue, the predominant color in underwater images and this make capturing underwater imaging a challenging task to do. The motivation for this project is to investigate the underwater images, obtained as low quality images due to imaging scenario or underwater species, which could affect the object recognition in underwater environment, i.e. distinguishing fish species or aquatic life. Image reconstruction goal is to recover the image quality related to specific aquatic environment, including perhaps stock assessment, so that the resultant image can be further used for either object detection or abundance studies i.e. satisfied the user. Resultant images could improve the visual interpretability of human viewers by increasing the information acuity within an image**

***Keywords*—image reconstruction; visual interpretability; colour correction; colour image enhancement; mean opinion score**

I. INTRODUCTION

In terms of visibility, the images taken underwater environment is poor although there is some use of art equipment. With the aid of modern digital cameras, the colors of the tropical that are seen in the beautiful water appeared to be flat and mostly blue. Water acts as a filter that shift images colour towards blue, reducing warm red and yellow [1]. Image processing consist of two main purposes, being (1) to improve the visual appearance of images to human observer, and (2) to prepare images for the features and structures measurement which they reveal. Image processing contains the same amount of data with some simple rearrangement of data done to an image [2]. Blue color has the shortest wavelength in natural and hence will the longest time to travel in water. Therefore, blue became the dominant color in any underwater images [3]. Apart from that, the reason why underwater image undergoes colour deterioration is due to the scattering and absorption effect in the aquatic world. When the ambient light passes through water surface from air, some light spectrum reflects back along its reverse path causing lightning scattering effect [4]. The motivation of this project is to get the natural color of any objects in underwater across underwater imaging as underwater imaging is important to oceanic engineering, surveillance and underwater navigation.

The main objective of the project is to propose a method to remove predominant blue and green colours that exist in underwater images, being a constraint to underwater images. The resultant images, from the proposed system, were encouraging, and we later performed the mean opinion score (MOS) analysis, for confirmation of performances.

II. METHODOLOGY

A. Methodology

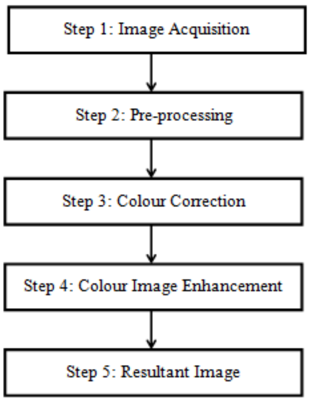


Fig. 1. System Flow

1) Step 1: Image Acquisition: Fig. 2 shows the equipment built for underwater video acquisition. String was used to tied up the equipment as well as being a control to measure the depth of the water while being released into water for acquisition. Weighs were added so that the equipment will sink into water. The experimental data used herein were obtained from an underwater video sequence obtained during a research cruise filming different parts of the coast off Bachok Kelantan in Malaysia.

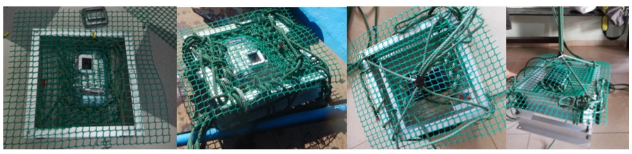


Fig. 2. Equipment for data acquisition

2) Step 2: Image Pre-processing: Image pre-processing method is enhanced captured images, prior further processing, being a mandatory step.

a) RGB Adjustment: The image will be segmented and compared to the RGBs between (1) the objects of the segmented image (data collected), and (2) the ground truth colour of the actual object obtained from Internet.

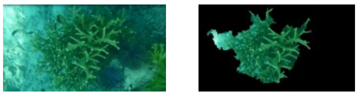


Fig. 3. RGB Adjustment: Original Image (left) Segmented Image (right)

b) Histogram Equalization (HE): HE will stretch the range of intensities in an image to improve the contrast of an image.

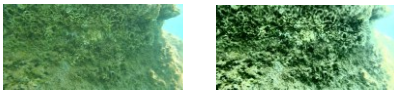


Fig. 4. *HE*: Original Image (left) *HE* Image (right)

c) Gray World: Gray World algorithm estimates the illumination by computing the mean of each channel of an image to enchance the image. Notice that this process could cause a divergent in the pixels and distort the actual colour value of the image. Rigorous testing is required to avoid the aforementioned distortion.

Fig. 5. *Gray World*: Original Image (left) Gray world without pre-processing (center) Gray world with *HE* (right)

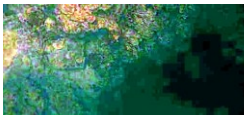
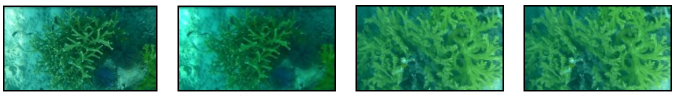


Fig. 6. Distorted image caused by *Gray World*

3) Step 3: Colour Correction: Colour correction is the method used to shift underwater image's colour.

a) Image Dehazing: Image Dehazing is used to enhance underwater images caused by artificial light causing colour change in an image. The method compensates the attenuation discrepancy along the propagation path.



(a) (b) (c) (d)

Fig. 7. Dehazing: (a) (c) Original Image; (b) (d) Output Image

4) Step 4: Image Enhancement: Image enhancement is used to enhance the resultant image from *Step 3*, as the contrast and visibility of the image could be reduced after the use of *dark pixel* in *Step 3*.

a) Colour Balance: Colour Balance improves the quality of an image by adjusting (1) the values of the input percentile from low value to lower value, and (2) high value to higher value, i.e., brighter pixels to appear brighter and darker pixels to appear darker.

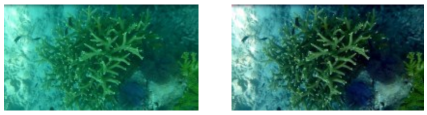


Fig. 8. Color Balance: Original Image (left) Output Image (right)

B. Predominant Colour Scheme (PCS)

1) PCS 1: PCS1 consists of colour balance, histogram equalization and dehazing algorithms.

a) Histogram Equalization (HE): HE algorithm needs colour channel to be converted to YCrCb format so that the luminance, Y can be used for equalization. Equation (1) shows the general equation of *HE*.

$$p_n = \frac{number\ of\ pixels\ with\ intensity\ n}{total\ number\ of\ pixels\ n} \quad \text{where } n = 0, 1, \ldots, L-1, \tag{1}$$

p in (1) represents the normalized histogram of image and L represents the image pixel intensity in a matrix. The equalization effect takes place when remapping is performed on the cumulative distributive function (*cdf*). The cumulative distribution for histogram *H(i)* is *H'(i)*, i.e. $H'(i) = \sum_0 H'(i)$, is normalized and the maximum value for the intensity of the image is set to 255. The remapping procedure used to obtain the intensity values of the equalized image being *Equalized(x, y) = H'(src(x, y))*. The overall equation for the remapping procedure is as follows:

$$T(k) = floor\,[\,(L-1)\sum_{n=0}^{k} Pn \tag{2}$$

$$T(X) = (L-1)\int_{0}^{x} px\,(x)\,dx \tag{3}$$

$$p(X) = \frac{1}{L-1} \tag{4}$$

Equation (2) is to transform the pixel intensity, *k* of the image. Equation (3) assumes the transformation as a continuous random variables where *T(X)* is cumulative distribution function of $X * (L-1)$ and p_x is probability density function. Equation (4) assumes T is differentiable and invertible and *T*(*X*) is uniformly distributed.

b) Dehazing: Estimate transition map (depth map) by using the dark channel, i.e., to get the minimum value for each R, G and B from the image.

$$Dark(x) = min_{r,g,b}\,[\mathrm{I}(x) - R(x)t(x)] \approx min_{r,g,b}(min_{patch} J_c(y)) \tag{5}$$

In (5), J_c refers to the image to recover and *c* refers to colour channel. Experimental results shows that patch must be set as odd number and larger than 1 to obtain good effects. Median blur is used to preserve the edges (smoothing) and remove noise by correcting non-uniform illumination of an image. Maximum airlight (*A*) is estimated with the source image, being the minimum pixel value and the maximum pixel value, as the input parameters. These input parameters are used to obtain the maximum or brightest pixels from the dark image. The transmission map is then obtained using both dark channel and max airlight values. Equation (6) is the equation for transmission map.

$$t(x) = 1 - w * \frac{\text{eq (i)}}{A} * 255 \tag{6}$$

In (6), *w* is set to 0.75, i.e., according to the rates of colour attenuated in water, after rigorous experimental. Different parameter, *w* is set and a normalized histogram is computed for each resultant image to compare the distributions between each graphs.

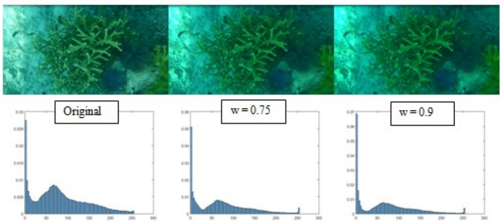


Fig. 9. Test Set 1: Image Dehaze with normalized histogram

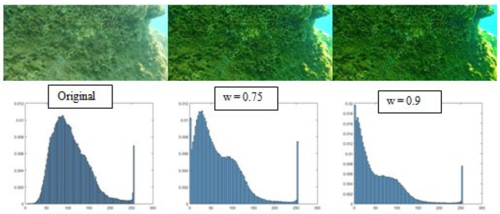


Fig. 10. Test Set 2: Image Dehaze with normalized histogram

From Fig. 9 and Fig. 10, it can be seen that with *w*=0.75 a better distribution histogram graph is obtained. *max(t(x))* is obtained from the transmission map and the first channel (blue) value is divided by 255. The absolute value is calculated using (7) to obtain a dehazed image.

$$\frac{(I(x) - A)}{\max(t(x), t_0)} + A \tag{7}$$

2) PCS 2: PCS2 consists of histogram equalization grayworld, dehazing and color balance.

a) Gray World: The mean of each channel of the image is calculated to estimate the illumination. The pixel value is scaled using (8).

$$s_1 = \frac{avg}{avg_i} \tag{8}$$

In (8), avg_i is channel mean and *avg* is the illumination estimate. The image is normalized using (9)

$$r_i = \frac{\max(avg_R, avg_G, avg_B)}{avg_i} \tag{9}$$

III. Results

A. PCS 1 Results

From Fig. 11's MOS analysis, majority of the 60 respondents, being 35, of them have the opinion that the image processed with proposed method had the best quality among the 4 shown images.

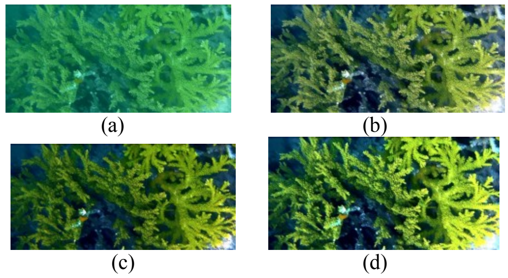


Fig. 11. Test Set 1: (a) original image (b) preprocessed (colour balance) (c) colour correction (d) PCS 1

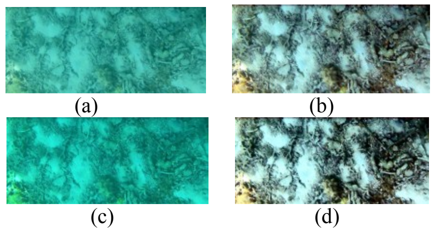


Fig. 12. Test Set 2: (a) original image (b) preprocessed (colour balance) (c) colour correction (d) PCS 1

36 respondents preferred over Fig. 11 (d) and Fig. 12 (d) as the dominant colour of the water was removed and the image details are being sharpen. However, according to the respondents, the image appears to be slightly not natural. Therefore, the other 16 respondents prefer over Fig. 11 (b) and Fig. 12 (b) with blue remove but without sharpening. The other 4 and 5 respondents prefer the original image and colour corrected image, respectively. However, not all underwater images has good resultant image with PCS 1 as shown in Fig. 13.

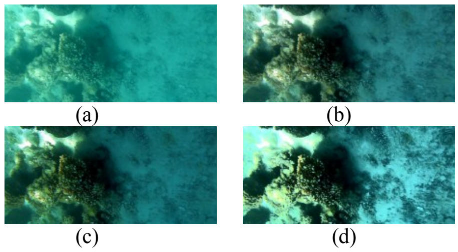


Fig. 13. Test Set 1: (a) original image (b) preprocessed (colour balance) (c) colour correction (d) PCS 1

Fig. 14. PCS 1 method with *HE* omitted.

The number of respondents selecting Fig. 13 (b) and Fig. 13 (d) are only one number in difference which is 26 and 27 respectively. Comparing with original image, image Fig. 13 (d) enhanced the overall image quality; however, the colour of the coral in the image appears to be downgraded as compared to the original image. The original image was bright enough and therefore after image enhancement has caused loss of details in the brighter side of the image. Fig. 14 shows the result by omitting the *HE*. The object in underwater appear to be clearer with the help colour balance algorithm and the colour of the object is being corrected by the colour correction method used. The overall quality of Fig. 14 is better compared to Fig. 13 (d).

B. PCS 2 Results

From Fig. 15 and Fig. 16, it is obvious that both PCS 1 and PCS 2 shows better quality images compared to the original images, which appear to be hazy and covered by the predominant colour of the water. PCS2's resultant images has better quality in terms of clarity in the image details and it has achieved the objective of the project, i.e., to reduce the predominant blue colour in underwater images. However, the image turned unnatural and there were certain images became colourless, i.e. black and white, whereby the colour appears to be very different from the image colour ground truth.

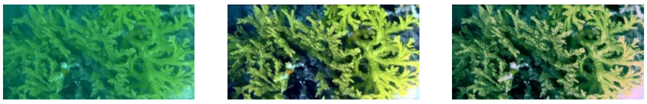


Fig. 15. Test Set 1: Original image (left) PCS 1 (center) PCS 2 (right)

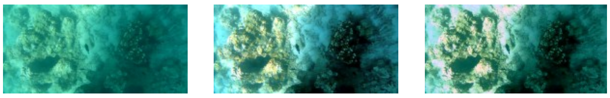


Fig. 16. Test Set 2: Original image (left) PCS 1 (center) PCS 2 (right)

IV. DISCUSSION

A. (PCS 1 and PCS 2 Results Comparison)

Consolidating the opinion from different observers, majority of 7 out of 9 respondents preferred over PCS 1 because the images appear to be more realistic or natural, brighter and clearer.

TABLE I. MEAN OPINION SCORE FOR TEST SETS

Image Type	Numberof Respondents
PCS 1	7
PCS 2	2
Total	9

Only minority of 2 out of 9 preferred PCS 2 with the reason that more blue predominant colour is removed resulting the image to appear sharper although it could unnatural. Those who preferred over PCS 1 critic that the PCS 2 caused the image to be not natural and owing to the high contrast, the image became less colourful, i.e. the some part of the resultant image could appear as black and white. The respondents also mentioned that for certain images, the enhancement of the colour is beyond nice causing the image to be too sharp.

B. Colour Correction Method Tested Unuseful

1) RGB Adjustments: The RGB of the two segmented images were compared and adjusted accordingly. The difference between the RGB values of the plant with ground truth colour and RGB values of the plant in the underwater scenario were computed, and then added back into the RGB values of image of the plant in the underwater scenario. However, their histogram showed no corresponding fluctuation after the changed in the RGB values. In [5], Verne mentioned that colour correction can be helpful to redistribute colour saturation, i.e. to correct for illumination artefacts in intensity channel. Colour hue is one of the difficult attributes to correct as it cannot be corrected using simple gamma curves and RGB colour space.

2) Removing Blue from Image: Split an image into RGB channels and then set the blue channel to *0* before merging them together again. Removing blue will leave the second predominant colour becoming the only colour displayed, i.e., pure green display.

V. CONCLUSION

Underwater imaging possesses predominant colours that filter other colours in any underwater images. Hence, predominant colour in underwater images should be reduced to allow the original colour of an image to be displayed as well as having a better quality underwater image. PCS 1, consisting of color balance, histogram equalization and dehazing algorithms, shows an improved results when there exist colourful underwater plants or rocks (corals). Although the algorithms proposed in this work may not be able to apply to all underwater scenarios, preliminary results shows promising results. Meanwhile, the PCS 2 resultant image emerged to be unnatural, being very different from the ground truth colours. Besides that, this method could present side effects, i.e. pixels could become divergent and may not reflect the actual colour value of the image.

ACKNOWLEDGMENT

This work is supported by the UTAR Research Fund Project No. IPSR/RMC/UTARRF/2013-C2/L03 "A New Framework for the Identification of Biodiversity Abundances for Underwater Species in Malaysian Waters" from the Universiti Tunku Abdul Rahman, Malaysia.

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