International Journal of Multimedia and Ubiquitous Engineering
Vol.11, No.11 (2016), pp.403-412
http://dx.doi.org/10.14257/ijmue.2016.11.11.37

A New Approach for Underwater Color Image Enhancement Based on Light Absorption Using Exponential Equation

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Abstract

Low quality of underwater image due to color spread and absorption deals with the propagation of light wave length. In this paper we propose exponential equation approach to enhance underwater image color and maintaining color constancy. Exponential approach is conducted through two steps: first, determining the relation between the color intensity of an image underwater and the color intensity of an image in a certain depth; second, determining the coefficient of underwater image color absorption by using least square. The result of exponential approach is measured by using Peak Signal to Noise Ratio, yielding an average value of 19.18 and visually the result of the image color approximates its original color. We concluded that exponential approach can determine the color constancy level which in turns can enhance the underwater image just as its original color.

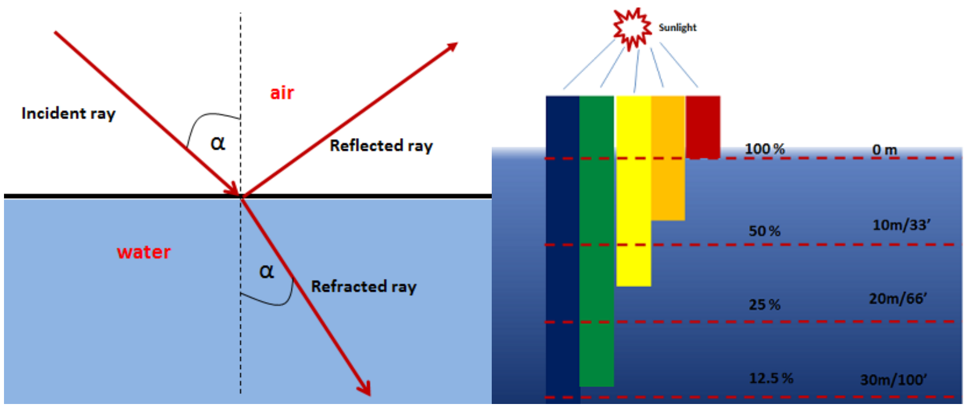
Keywords*: Underwater Image, Enhancement, Light Absorption, Color Constancy, Exponential Equation*

1. Introduction

Nowadays, many areas of research especially marine biology and marine engineering are interested in high quality of underwater image [1]. In water medium, the level of color visibility is so low that the quality of underwater image becomes limited. The light penetrating the water will interact not only with water molecule but also with the influence of suspended particle and air bubble so that it causes light spread and absorption [2]. Two main causes of distortion in underwater photography are light spread and color change [3]. Light spread is caused by light reflected and absorbed by underwater objects so that it lowers the underwater image contrast [1,3]. Meanwhile, the color change deals with the underwater image propagation due to the difference in light wavelength [1,3].

The color reflected by water varies and depends on the water surface structure and environment. Some light is reflected and some is penetrated into the water [5] as seen in Figure 1(a). Figure 1(b) illustrates the level of color absorption in the water. For each 10 m increase in underwater depth the, level of sun light will decrease to half. Almost all red light disappears and blue light is penetrated into the water, hence green and blue dominate in the lowermost underwater image [6].

ISSN: 1975-0080 IJMUE



(a) (b)

Figure 1. (a). Water Surface Effects and (b). Absorption of Light by Water

Several studies related to underwater image color enhancement have been conducted among others by J. Y. Chiang, Y. C. Chen, and Y. F. Chen [1]. They proposed WCID algorithm which is very effective in restoring image colors and removing haze. In 2012, J.Y. Chiang, and Y.C. Chen [3] conducted a research, arguing that two main sources of distortion in underwater image taking are color spread and color change. Color spread is caused by light reflection due to particles in underwater environment, whereas color change by light propagation in the water with different wave lengths. The proposed WCID algorithm is able to restore underwater image color quality effectively.

S. Bazelle, I. Quidu, and L. Jaulin [4] proposed a new approach for object recognition in the context of underwater context, namely object recognition based on color feature. To perform a color-based recognition of an object, develop an algorithm robust with respect to the attenuation which takes into account the light modification during its path between the light source and the camera. The given underwater object can be identified in an image by detecting all colors that are compatible the colors previously given. This method works rapidly and powerfully, and it needs fewer computer resources. K. Iqbal, R.A. Salam, A. Osman and A.Z. Talib [5] in their research argued that underwater color spread and absorption caused an image to degrade. The contrast stretching algorithm in RGB and HIS color models can enhance the quality of underwater image. This algorithm is developed by using an interactive software to enhance underwater image and to solve lighting problems

W.N.J.H.W. Yussof, M.S. Hitam, E.A. Awalludin, and Z. Bachok [6] in their paper used Contrast Limited Adaptive Histogram Equalization (CLAHE) combination applied to RGB and HSV color models to enhance underwater image. The result proved effective to enhance the visibility of underwater image. The measurement using Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) results in lower MSE and higher PSNR.

R. SwarnaLakshmi and B. Loganathan [7] proposed color constancy based algorithm to enhance underwater image. The first purpose of this approach is fiture extraction, *i.e.* determining the characteristics and parameters of the features, while the second is color constancy algorithm, *i.e.* the optimized constancy mapping is extended to incorporate the statistical nature of images. The proposed algorithm was tested on synthetic images as well as real images.

According to M.S. Hitam, W.N.J.H.W. Yussof, E.A. Awalludin, and Z. Bachok [8] in the last decade underwater image quality enhancement has become a topic of interest due to the low image visibility. It is caused by the influence of physical characteristics of water medium. The mixture approach of CLAHE is specifically developed to enhance the underwater image quality. The result shows that the underwater image quality is enhanced by increasing contrast and reducing noise and artifacts.

N. bt. Shamsuddin, W. F.bt Wan Ahmad, B. b. Baharun, M. K. b. M. Rajuddin, F. bt Mohd [9] argued that the research on underwater image becomes a challenge in photography since there are several problems such as low contrast, reduced color, blurring, noise, and different lighting. The research focuses on color diminished and stretched, with manual enhanced technique and auto enhanced technique that results in a better underwater image application. K. Iqbal, M. Odetayo, A. James, R.A. Salam and A.Z.H. Talib [10] proposed Unsupervised Colour Correction Method (UCM) approach to enhance underwater image. This approach is based RGB and HSI, which in turn can enhance illumination and contrast.

Pujiono, Yuniarno E.M, Purnama, I. K. E and Hariadi M. [11], proposed polynomial equation approach to enhancement underwater color constancy. Polynomial approach can enhance the underwater image just as its original color.

So far there has been no underwater image processing technique that can handle light spread and underwater image color change distortion simultaneously [3]. This paper we propose exponential equation approach to enhance underwater image color and maintaining color constancy. Exponential approach is conducted through two steps: first, determining the relation between the color intensity of an image underwater and the color intensity of an image in a certain depth; second, determining the coefficient of underwater image color absorption by using least square [2-3].

2. Materials and Method

2.1. Data Acquisition Location

The data were taken in Semarang, Central Java, Indonesia, specifically at Watugong pool, at 5 m depth underwater. The tools that were used include a Sony DSC – RX 100 M2, A : F28, ISO 125, SS : 1/2000 camera, a set of diving apparatus, and a color model of 50 cm x 50 cm size containing basic colors namely red, green, blue, cyan, magenta, and yellow. These tools are shown in Figure 2.

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

Figure 2. Location and Tools for Data Acquisition (a) Swimming Pool, (b) Diving Apparatus, (c) Color Model and (d) Camera

The images were taken on the water surface, then in 1 m depth, 2 m – 5 m depth underwater respectively below water surface, where the distance from camera to the object is 1 meters, as seen in Figure 3

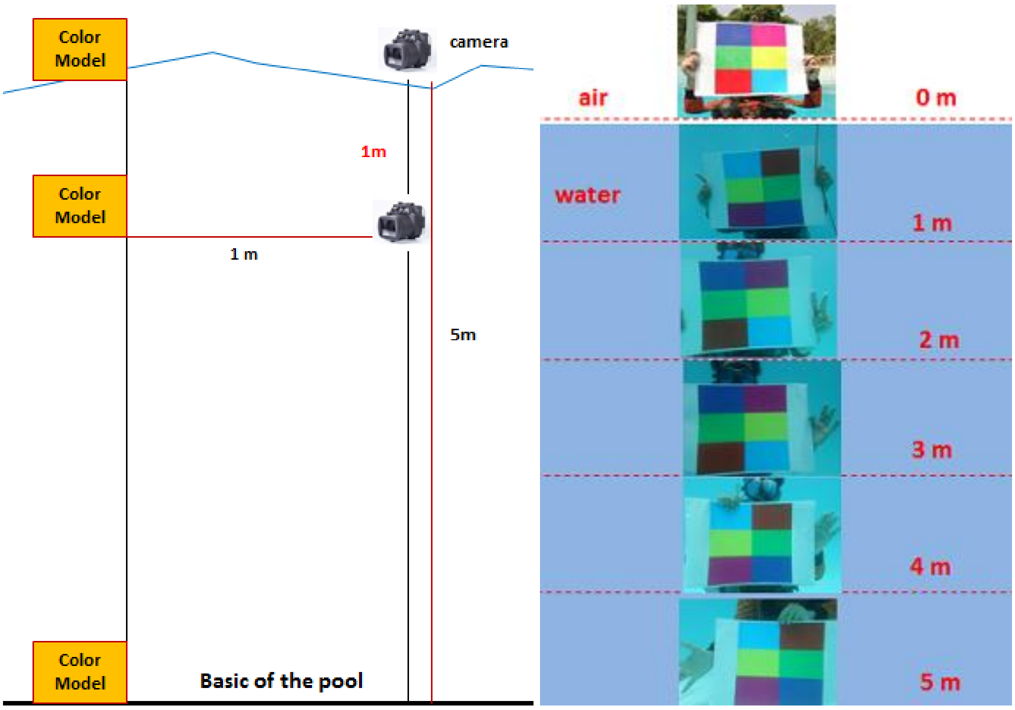


Figure 3. The Process of Data Acquisition

2.2. Proposed Method

Beer-Lambert law states that light penetrating a certain material is absorbed exponentially [4]. Mathematically, it can be stated as follows:

$$I_{\lambda,d} = I_{\lambda,0}\, e^{-c_\lambda d} \quad (1)$$

where λ is the wavelength, $I_{\lambda,d}$ is the observed intensity of light of wavelength λ at the distance d from the light source, $I_{\lambda,0}$ is the intensity at the light source, c_λ is the beam attenuation coefficient for a wavelength λ

If equation (1) is applied to water medium with I_p being the color intensity on the water surface, I_k being color intensity at k depth, c being absorption coefficient, and x being underwater depth, mathematically the following equation can be stated:

$$I_k = I_p e^{-cx} \quad (2)$$

By applying logarithm equation and minimizing with least square [3-4,13] to equation (2), the absorption coefficient can be determined as follows:

$$L_n\, I_k = L_n\, I_p - cx \quad (3)$$

$$\min \sum_{i=1}^{k} \left(L_n\, I_i - \left(L_n\, I_p - cx_i\right)\right)^2 \quad (4)$$

$$\min \sum_{i=1}^{k} \left(\left(L_n\, I_i - L_n\, I_p\right) + cx_i\right)^2 \quad (5)$$

$$\frac{d\, min\; \sum_{i=1}^{k}\left(\left(L_n\, I_i - L_n\, I_p\right) + cx_i\right)^2}{dc} = 0 \quad (6)$$

$$2\sum_{i=1}^{k} x_i \left(L_n\, I_i - L_n I_p\right) + 2c \sum_{i=1}^{k} x_i^2 = 0 \quad (7)$$

$$c = \frac{-\sum_{i=1}^{k} x_i (L_n I_i - L_n I_p)}{\sum_{i=1}^{k} x_i^2} \quad (8)$$

Given that I_p and I_k are color intensity on the water surface and that in k depth respectively, the value of c, which is the absorption coefficient, can be determined. Therefore, the exponential model of underwater image color absorption can be identified.

3. Experiment and Result

3.1. Underwater Color Enhancement Using Exponential Equation

Images were taken on the water surface, in 1 m depth, 2 m – 5 m depth underwater respectively, that is by taking pictures the basic colors of green, blue and red, as seen in Figure 4.

Figure 4. Basic Color Samples : Green, Blue and Red

The next step is determining the average value of red, green, and blue color intensity of the image on the water surface, in 1 m depth, 2 m – 5 m depth underwater respectively, the result is shown in Table 1.

Table 1. The Value of RGB Color Intensity in Each Depth

Depth (meters)		0	1	2	3	4	5
Color	Red	254.4	72.04	47.8	78.86	115.9	83.37
	Green	226.6	126.5	160.4	162.8	204.4	200.7
	Blue	199.1	116.8	140.6	143.5	180.9	177.9

By applying equation (2) and (8) in Table 1, the absorption coefficient for red (c_r), green (c_g), and blue (c_b) can be obtained as follows:

$$c_r = 0.3062 \quad (9)$$

$$c_g = 0.0597 \quad (10)$$

$$c_b = 0.0573 \quad (11)$$

Therefore,

$$I_{kr} = I_{pr}\, e^{-0.3062x} \quad (12)$$

$$I_{kg} = I_{pg}\, e^{-0.0597x} \quad (13)$$

$$I_{kb} = I_{pb}\, e^{-0.0573x} \quad (14)$$

In which I_{kr}, I_{kg} and I_{kb} are image color intensity in k depth for red, green, and blue, whereas I_{pr}, I_{pg} and I_{pb} are color intensity on the water surface for red, green, and blue, and x is depth.

Equations (12), (13), and (14) are exponential model for underwater color constancy to 5 m depth underwater. If red, green, and blue intensity in a certain depth is identified, the red, green, and blue intensity on the water surface or image color in a certain depth can also be identified. In other words, if the image color in a certain depth is identified, the color image on the water surface can also be identified.

3.2. Evaluation Procedure

The criteria testing of exponential approach for underwater image color constancy is conducted by using Peak Signal to Noise Ratio (PSNR) [6,12]. PSNR can be written mathematically as follows:

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

with

$$MSE = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M * N} \tag{16}$$

where β represents bits per sample, in this case β equals 8 since the image color size used in this experiment is between 0 – 255. Meanwhile, I_1 dan I_2 represents original image and resulted image respectively. The input size must also be equal, represented by $M * N$

Figure 5 shows five bar of Peak Signal to Noise Ratio of underwater images, underwater images processed using Histogram Equalization (HE), using CLAHE approach, polynomial approach and underwater images processed using Exponential approach. The average value of PSNR for underwater images, underwater images using HE, underwater images using CLAHE, underwater images using Polynomial and underwater images using Exponential approach is 15.75, 17.75, 15.96, 19.64, and 19.18 respectively. It can be seen that the PSNR of the images processed with exponential approach higher than the PSNR of the images processed with HE and CLAHE approach, but still below of Polynomial approach [11].

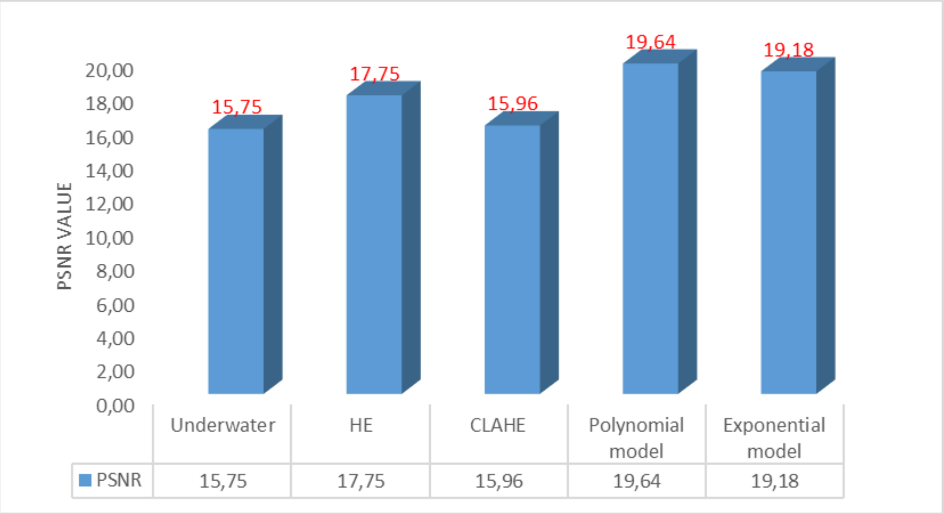


Figure 5. Peak Signal to Noise Ratio

Figure 6 shows the visualization of color images at different depths to a depth of five meters below the water surface using HE approach, CLAHE approach, Polynomial approach and Exponential approach. Figure 6 (a) color image in the depth of five (5) meter consisting six different colors: red, green, blue, cyan, yellow and magenta. Figure 6(b) shows the results of the application of HE method 6(c) shows the result CLAHE approach, where in Figure 6 (a), (b), (c) image noise still present. Figure 6(d) shows the result of the polynomial approach and Figure 6(e) shows the result of the proposed approach, exponential approach. Visually, the image approximate the image of the original image, the image on the water surface Figure 6(f).

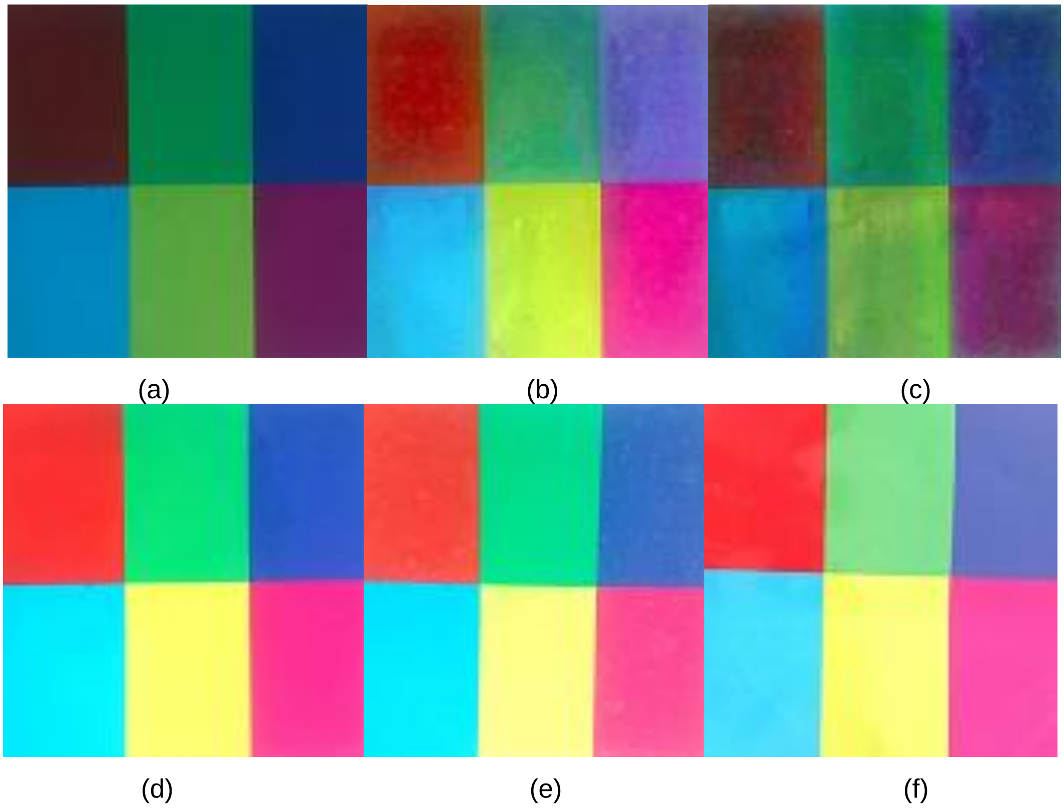


Figure 6. (a) Underwater Color Image, (b) Color Image Using HE, (c) Color Image Using CLAHE, (d) Color Image Using Polynomial (e) Color Image Using Exponential Approach (d) Original Image, Color Image on the Water Surface

4. Conclusion

We have presented a new approach exponential model to enhance underwater color image based light absorption. It is conducted through two steps: first, determining the relation between color intensity on the water surface and that in a certain depth, second, determining the absorption coefficient of underwater image color by using least square. The result is measured by using Peak Signal to Noise Ratio. We found that the PSNR yielding an average value of 19.18. Visually, the color of the resulted image approximates the color of the original image. We concluded that exponential approach is able to enhance color constancy level which in turn is able to enhance underwater color image.

Further research needs to be conducted to enhance underwater image color in more than 5 m depth by using another approach that may have higher accuracy.

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