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MATHEMATICAL MODEL FOR UNDERWATER COLOR CONSTANCY BASED ON POLYNOMIAL EQUATION

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ABSTRACT

Nowadays, the underwater researches become one of the distinguish researches since the ocean are considered as the lungs of this world. Therefore, underwater image processing researches should be encouraged especially in the differences of color analysis between underwater and on the air objects. The colors of objects are changed when the objects are put underwater. This is due to discoloration from light scattering, refractive index, the wave, the distance of camera and environmental underwater effect. Discoloration in water is highly dependent on the intensity level and wavelength of each color image. In this paper propose polynomial equation approach to enhancement underwater color constancy. Polynomial approach is conducted through two steps: first, determining the relation between the color intensity of an image on the water surface and the color intensity of an image in a certain depth, second, determining the coefficient of constant function relation between the color intensity of an image on the water surface and the color intensity of an image in a certain depth by using least square. The result of polynomial approach is measured by using Peak Signal to Noise Ratio, yielding an average value of 19.64 and visually the result of the image color approximates its original color. It can be concluded that polynomial approach can determine the color constancy level which in turns can enhance the underwater image just as its original color.

Keywords: *Mathematical Model, Underwater Color Constancy, Polynomial Equation, Peak Signal to Noise Ratio*

1. INTRODUCTION

The underwater and air images are different in discoloration. There have been factors affecting the image color changes underwater which are light scattering, refractive index, water wave, distance of the camera and environmental underwater effect. Light scattering and color changes in the water are the main factors affecting underwater color image quality [1] [2]. Light toward the water line is partly transmitted and reflected back due to the influence of the refractive index and underwater environment, as represented in Figure 1 [3] [4] [5].

The level of intensity and wavelength of each color image underwater affect the absorption process and light scattering causing one color which dominates the others. In Figure 2, the red light is largely absorbed at 5 meters depth, while the green and blue will be passed to a depth below the water [4]. It occurs since the red has a greater wavelength than the green and blue. Current research of underwater image color quality becomes very important and is in a great challenge to marine and photography techniques [1] [2] [3].

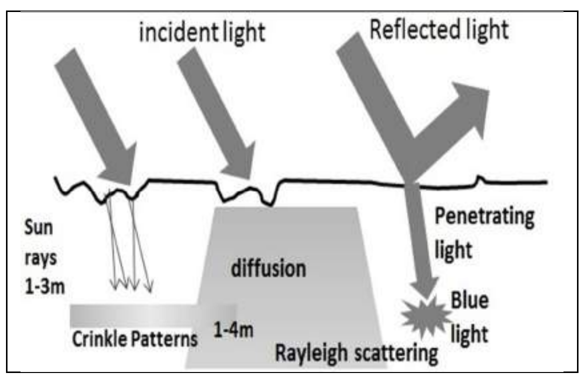

Figure 1: Water line effects

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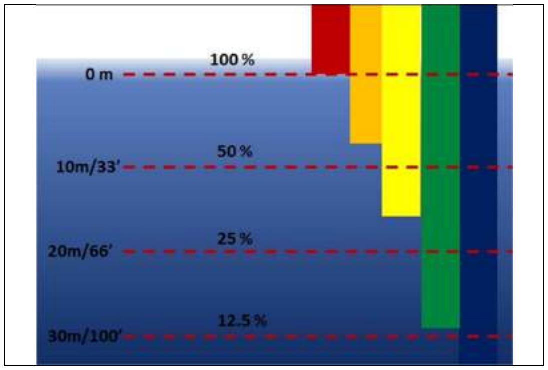

Figure 2: Absorption Of Light By Water

Nowadays, light scattering and underwater color changing keep being the main problem since there is no technique of processing to achieve the high accuracy result [1]. Thus, it is necessary to perform research that is capable of increasing the underwater image quality.

This paper introduce mathematical model for underwater color constancy based on polynomial equation. The polynomial equation 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 cofficient of constant function by using least square

2. RELATED WORKS

Chiang, J.Y., and Chen, Y.C. [1] perform research by using Wavelength Compensation and Image Dehazing (WCID) algorithms, which effectively restores image color balance and removes haze, though there is no best technique which is able to handle the two main sources of color underwater image distortion, light scattering and underwater image discoloration.

Chiang, J.Y., Chen, Y.C., and Chen, Y.F. [2] conduct research in sea water where the Wavelength Compensation and Image Dehazing (WCID) algorithm effectively restore color image and remove haze, but the comparison of salinity level and particle amount suspended in sea water varied with time, location and season causing accurate estimation of problematic energy attenuation rate.

bt Shamsuddin, N. et.al. [3] compare the manual methods and auto correction enhancement technique to improve the quality of underwater color. Manual or auto enhancement techniques has a significant influence for the improvement of color quality underwater at the level of 5%, though the manual has better precision compared to the application of the auto.

Iqbal, K., Salam, R.A., Osman, A., and Talib, A.Z., [4] uses Contrast Stretching-based approach to improve the scattering and absorption of underwater color. Contrast Stretching RGB-based algorithm is used to equate the color contrast in the underwater image while HSV-based Contrast Stretching is used to improve the color and illumination of underwater image.

According to Andono, P. N., Purnama, I.K.E. and Hariadi, M. [5], register of underwater image by using scale-invariant feature transform (SIFT) is highly dependent on the image quality. Registration of SIFT Contrast Limited Adaptive Histogram Equalization (CLAHE) approach with Rayleigh distribution in improving the underwater image quality produced 41% of better result than Contrast Stretching.

According to Iqbal, K., Odetayo M., James A., Salam RA and Talib AZ [6], underwater color image is influenced by the high blue, low red and low illumination problems due to absorption, turbidity and light scattering in the underwater environment. The approaches of Unsupervised Color Correction Method (UCM) based on RGB and HSI contrast are more effective than the methods of Gray World, Histogram Equalization using Adobe Photoshop and White Patch in improving underwater image quality.

According to Padmavathi, G., Subashini, P., Kumar, M.M. and Thakur, SK [7], the pre-processing is absolutely necessary for the further processing of underwater images, since the underwater experience deterioration in image quality due to a decrease in the quality of light and color. Three filters are used to improve underwater image quality that are homomorphic filter, anisotropic diffusion and wavelet denoising by average filter, in which the technique of wavelet denoising by average results mean square error and peak signal to noise ratio better than the homomorphic filters and anisotropic diffusion.

Yusof, W.J.H.W., Hitam, M.S., Awaludin, E.A. and Bachok, Z [8], state that it is more effective to use a combination of CLAHE with RGB and HSV color-based for underwater image enhancement. Measurements were performed by using Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR), in which the value of MSE is lower and PSNR is higher.

According to Hitam, M.S., Yussof, W.N.J.H.W., Awaludin, E.A., Bachok, Z., [9], the underwater image enhancement in the last decade has a lot of attention since the visibility level of underwater

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image is very low. The approach of CLAHE with RGB and HSV color-based in which their results are combined by using Euclidean Norm which effectively increase the visibility of underwater image and result lower value for MSE and higher for PSNR.

Beohar, R. and Sahu, P. [10], the underwater objects have lower brightness level in image quality. This gives difficulty to do more detailed analysis of the object concerned. The method of Contrast Limited Adaptive Histogram Equalization (CLAHE) with 2D median filter has the capability to enhance the image contrast and efficiently equalizes the underwater image histogram.

SuwarnaLakshmi, R., and Loganathan, B., [11], the distortion of color under water due to the light and diffusion resulted in one color which dominates the others. The approach of constancy algorithm color-based is used to improve the observation of underwater images. Its aims are the feature extraction, i.e. capturing characteristics of the image and feature parameters, and color constancy algorithm which is the optimized constancy mapping extended to incorporate the statistical nature of images. The proposed algorithm is tested on synthetic images and produces fine result as the real image.

Rai, R.k., et al. [12] found that the low contrast of underwater image and light propagation are the main obstacles in segmenting underwater image. They proposed the underwater image segmentation method enhancing the image quality by using Contrast Limited Adaptive Histogram Equalization (CLAHE) and segmenting objects by using histogram thresholding technique. CLAHE is not only able to improve contrast but it also equalizes the image histogram efficiently

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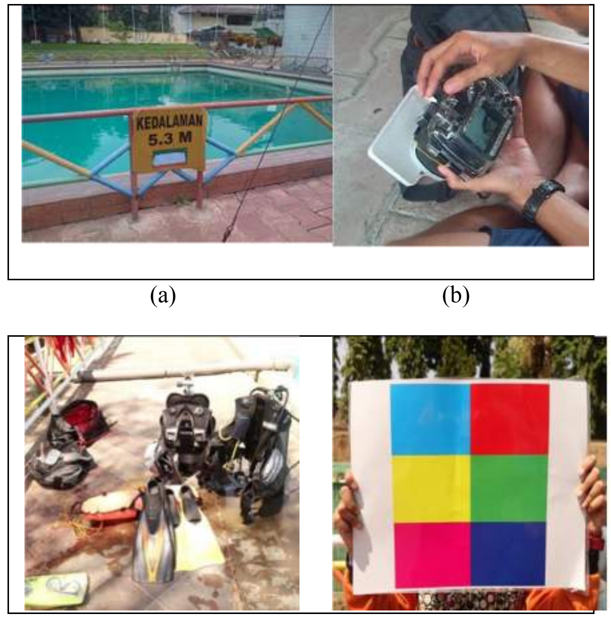
3. MATERIALS AND METHOD

3.1 Data Acquisition and Location

The data were taken in watugong pool, at 5 meters depth underwater. Watugong pool is located in Kodam IV Diponegoro, Semarang, Central Java, Indonesia. Equipment that used in data collection was Sonny camera DSC-RX 100 M2, A: F28, ISO 125, SS: 1/2000, a set of diving apparatus. The supporting equipment was color models size 50 cm x 50 cm containing six types of sample colors of red, green, blue, cyan, magenta and yellow (the standard colors), seen in Figure 3.

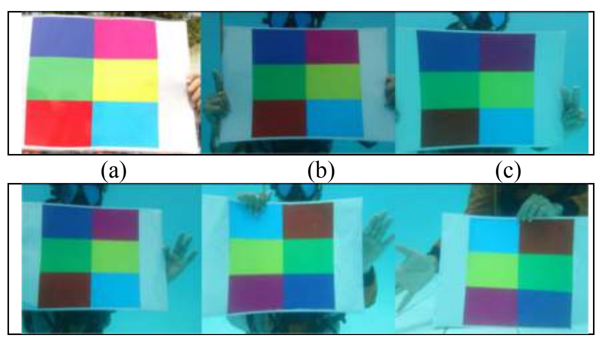


(a) (b)

(c) (d)

Figure 3:Location and tools for data acquisition (a) 5.3 m depth swimming pool, (b) camera, (c) diving apparatus and (d) color model

The images were taken on the water surface, and then to a depth of 1, 2, 3, 4 and 5 meters as shown in Figure 4.



(a) (b) (c)

(d) (e) (f)

Figure 4: The Process Of Data Acquisition (a) Image On The Water Surface, (B) Image At 1 M Depth, (C) Image At 2 M Depth, (D) Image At 3 M Depth, (E) Image At 4 M Depth And (F) Image At 5 M Depth.

3.2 Polynomial Equation

In general, kth degree polynomial equation is stated as [13] :

$$f(x) = a_0 + a_1 x + a_2 x^2 + \cdots + a_k x^k \quad (1)$$

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The residual is given by :

$$R^2 = \sum_{i=1}^{N} \left[y_i - \left(a_0 + a_1 x_i + \cdots + a_k x_i^k \right) \right]^2 \qquad (2)$$

By applying partial differensial in equation (2) then it is stated in matrix [14] [15],

$$\begin{bmatrix} 1 & x_1 & \cdots & x_1^k \\ 1 & x_2 & \cdots & x_2^k \\ \vdots & \vdots & \vdots & \vdots \\ 1 & x_n & \cdots & x_n^k \end{bmatrix} \begin{bmatrix} a_0 \\ a_1 \\ \vdots \\ a_k \end{bmatrix} = \begin{bmatrix} y_1 \\ y_2 \\ \vdots \\ y_n \end{bmatrix} \qquad (3)$$

Equation (3) is least square equation and executed by linear equation in matrix.

3.3 Beer-Lambert Law

Beer-lambert law for the light absorption [16][17][18], is stated in equation (4),

$$I = I_0 e^{-\mu x} \qquad (4)$$

In which I and I_0 are the certain material intensity and intensity on the surface. If μ is function wavelength, then,

$$I(\lambda) = I_0(\lambda) e^{-\mu(\lambda) x} \qquad (5)$$

3.4 Proposed Methods

The proposed method in this paper is to find underwater color constancy which is predicted by finding the relation of color intensity level on the water surface to each depth by using polynomial approach.

$$f(x) = a_0 + a_1 x_k + a_2 x_k^2 + \ldots + a_n x_k^n \qquad (6)$$

Assuming that there is a proportional relation between the color intensity on the water surface to each certain depth, according to the Beer-Lambert law in equation (4), then:

$$I_p C_k = I_k \qquad (7)$$

$$I_p = I_k \frac{1}{C_k} \qquad (8)$$

or

$$I_p = I_k K_k \qquad (9)$$

in which $K_k = \frac{1}{c_k}$, I_p is the color intensity on the water surface and I_k is color intensity at certain depth to k.

From equation (4) and (9) this research is estimating the value change of K based on polynomial equation in certain depth. For $K(x)$ is constant function in depth of x so the polynomial equation $K(x)$ is :

$$K(x) = a_0 + a_1 x + a_2 x^2 + \ldots + a_n x^n \qquad (10)$$

Equation substitution (10) to (9), results :

$$I_p = I_k \left(a_0 + a_1 x_k + a_2 x_k^2 \ldots + a_n x_k^n \right) \qquad (11)$$

or

$$\hat{I}_k = \frac{I_p}{I_k} = \left(a_0 + a_1 x_k + a_2 x_k^2 + \cdots + a_n x_k^n \right) \qquad (12)$$

In which I_p is color intensity on the water surface, I_k is color intensity at the depth of k and x_k is observed water depth. $\hat{I}_k$ is the color intensity normalization on the surface of I_p to color intensity at the depth of I_k. Parameter estimation $a_0, a_1, \cdots, a_n$ is determined by minimizing the function of chi square.

$$\chi^2(a_0, a_1, \cdots, a_n) = \sum_{k=1}^{N} \left(\hat{I}_k - f(1, x_k, x_k^2, \cdots, x_k^n; a_0, a_1, \cdots, a_n) \right)^2 \qquad (13)$$

Equation (13) was solved by using linear equation in matrix [14] [15], as in equation (14).

$$I = X.A \qquad (14)$$

in which :

$$\mathbf{I} = (\hat{I}_1 \quad \hat{I}_2 \quad \cdots \quad \hat{I}_n)^T$$

$$\mathbf{A} = (a_0 \quad a_1 \quad \cdots \quad a_n)^T$$

$$\mathbf{X} = \begin{pmatrix} 1 & x_1 & x_1^2 & \cdots & x_1^n \\ 1 & x_2 & x_2^2 & \cdots & x_2^n \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1 & x_N & x_N^2 & \cdots & x_N^n \end{pmatrix}$$

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4. EXPERIMENT AND RESULTS

4.1. Mathematical Model

Image were taken on the water surface, in 1 meters until 5 meters underwater respectively, that is by taking images the basic colors of red, green and blue, as seen in Figure 5

Figure 5 : Color Samples

The next step is determinig the average value of red, green and blue color intensity of the image on the water surface at a depth of 1, 2, 3, 4 and 5 meters. From the experiment, it gave data result as shown in Table 1.

Table 1 : Intensity value of RGB

Color / Depth(m)	red	green	blue
0	254.38	226.57	199.08
1	72.04	126.51	116.79
2	47.8	160.39	140.64
3	78.86	162.81	143.51
4	115.91	204.36	180.93
5	83.37	200.73	177.94

By applying the equation (12) and (13) in Table 1, the coefficient values constant function K_k for red, green and blue was as in Table 2.

Table 2 : Coefficient value of constant function

Color	Red	Green	Blue
a_0	-11.23	4.33	3.86
a_1	25.30	-4.52	-3.89
a_2	-12.92	2.52	2.23
a_3	2.55	-0.60	-0.54
a_4	-0.17	0.05	0.05

.

By applying equation (11) in table 2, the following equation can be obtained :

$$I_{pr} = I_{kr}\,(-11.23 + 25.30k - 12.92k^2 + 2.55k^3 - 0.17k^4) \qquad (15)$$

$$I_{pg} = I_{kg}\,(4.33 - 4.52k + 2.52k^2 - 0.60k^3 + 0.05k^4) \qquad (16)$$

$$I_{pb} = I_{kb}(3.86 - 3.89k + 2.23k^2 - 0.54k^3 + 0.05k^4) \qquad (17)$$

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

Equations (15), (16) and (17) are mathematical model for underwater color constancy based on polynomial equation. If the color intensity of red, green and blue in k depth is identified, then the color intensity of red, green, and blue on the water surface can be determined. The intensity of red, green and blue is the color basic of an image. If the color image in k depth is identified, by using mathematical model based on polynomial equation then the color image on the water surface can be determined.

On the graph of constant K_k function of each color represented in Figure 6, 7 and 8. At 5 meters depth below the water surface, constant K_k function for red had a greater value in comparison with green and blue, because of the absorption process. Meanwhile, constant K_k function for green and blue tended to be smaller since they were forwarded to 5 meters depth.

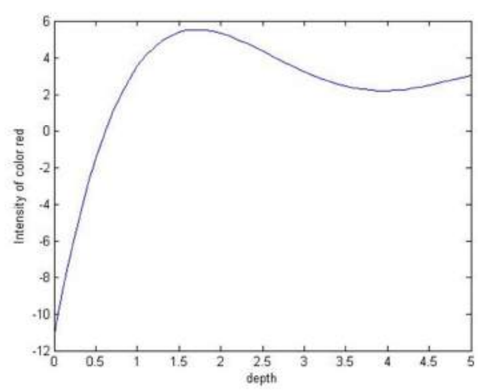

Figure 6 : The Graph of constant function for red

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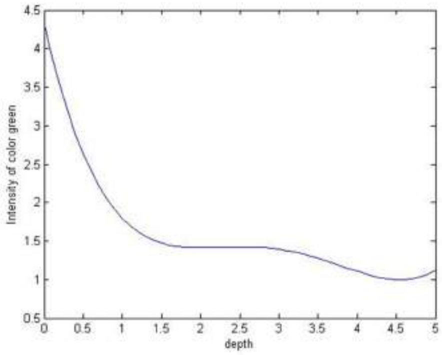

Figure 7 : The Graph of constant function for green

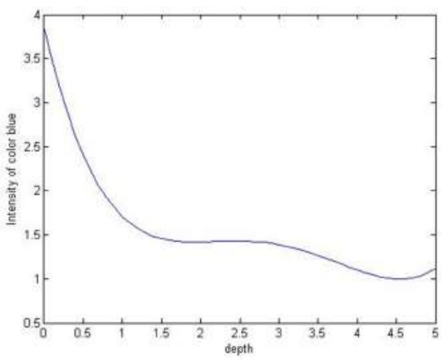

Figure 8 : The Graph of constant function for blue

4.2. Evaluation Procedure

The constancy of red, green and blue in underwater images depends on its intensity value measured from underwater up to a certain depth. Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE) was used to measure the level of RGB color constancy underwater images by polynomial approach, according to the equation (15) and (16) [8] .

$$PSNR = 20\ Log_{10}\left(\frac{2^{\beta}-1}{\sqrt{MSE}}\right) \quad (18)$$

with

$$MSE = \frac{\sum_{M,N}[I_1(m,n) - I_2(m,n)]^2}{M * N} \quad (19)$$

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 $M * N$

Results was represented in Figure 9, three plots of Peak Signal to Noise Ratio of underwater image, underwater images processed using Contrast Limited Adaptive Histogram Equalization [5][8] and images processed using polynomial equation approach. It can be seen that the PSNR of the images processed using polynomial equation approach higher than the PSNR of images processed using CLAHE approach.

Visually, the underwater color quality images with polynomial equation approach is closer to its original color image which is image on the water surface (the original image), as shown in Figure 10.

5. CONCLUSION

This paper has presented mathematical model for underwater color constancy based on polynomial equation. It is conducted through two steps : first, determining the relation between the color intensity of an image on the water surface and the color intensity of an image in a certain depth, second, determining the coefficient of constant function relation between the color intensity of an image on the water surface and the color intensity of an image in a certain depth by using least square. The result of polynomial approach is measured by using Peak Signal to Noise Ratio, yielding an average value of 19.64 and visually the result of the image color approximates its original color. It can be concluded that polynomial approach can determine the color constancy level which in turns can enhance the underwater image just as its original color.

Further research was required to determine the relation of color intensity on the water surface to the depth of more than five meters by using approach which had better accuracy.

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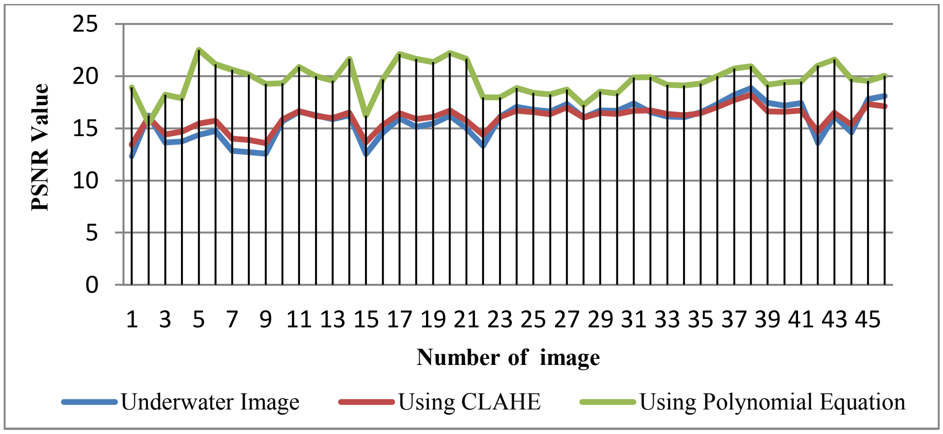

Figure 9 : Peak Signal to Noise Ratio

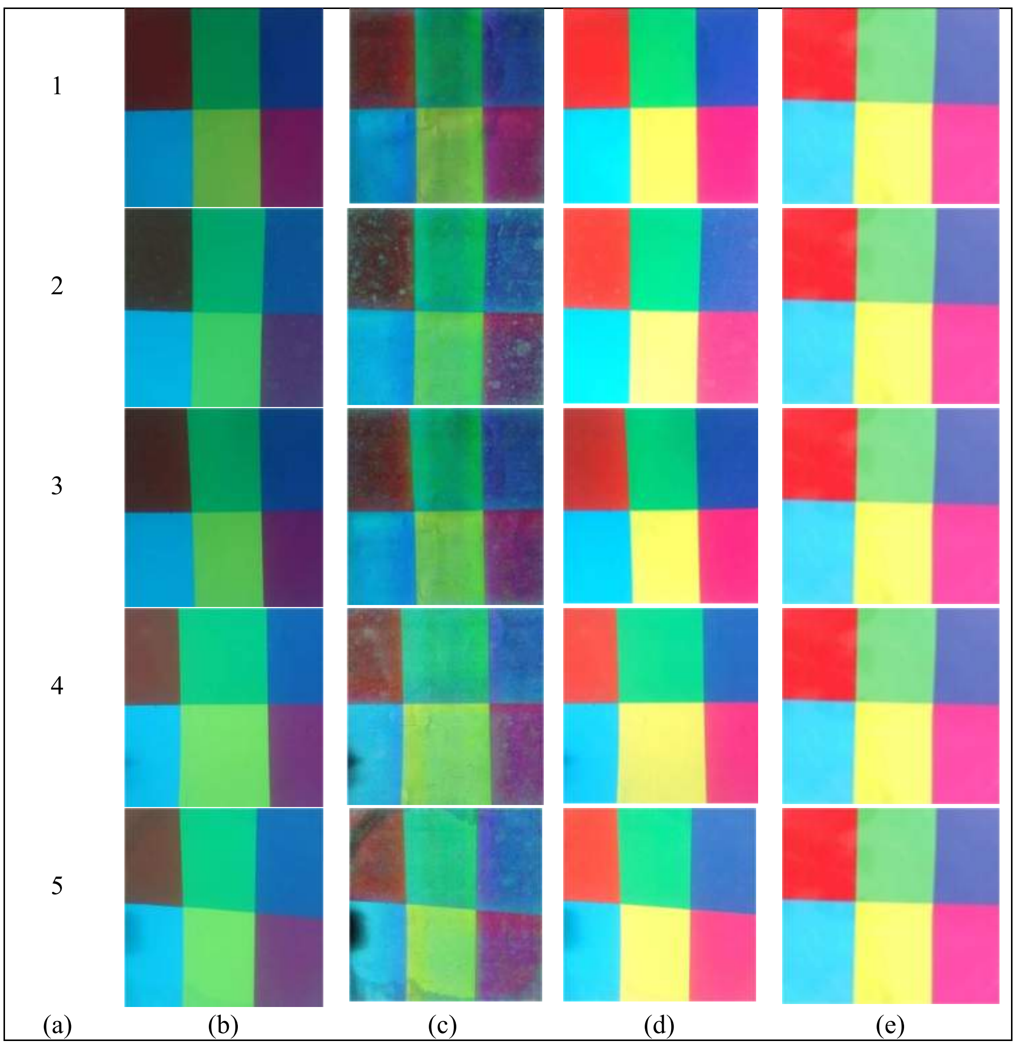

Figure 10 : (a). underwater depth (meter) (b) underwater image, (c) color image using CLAHE (d) color image using polynomial equation (e) image on the water surface