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NON-LINEAR MODEL FOR COLOUR CORRECTION OF UNDERWATER OBJECTS BASED ON LIGHT ABSORPTION ESTIMATION

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ABSTRACT

The underwater objects provide a different quality of colour when taken from the sea's surface or in the air. The colour quality of underwater objects is deficient due to colour distortion. The leading causes of colour distortion of underwater objects are discoloration and light scattering. The colour change of underwater objects is also very dependent on the intensity of the underwater image and the wavelength of each colour of the underwater object. This article used the non-linear model approach to improve the colour quality of underwater objects based on light absorption estimation. It examined the relationship between the colour intensity of objects on the surface with a certain depth under the sea, using least squares to determine specific coefficients. Determination of coefficients in a non-linear approach using least squares. Measurement of the colour quality of underwater objects using Peak Signal Noise to Ratio (PSNR), wherein a non-linear approach the colour of underwater objects produces a PSNR value of 19.84. Visually, the results of this non-linear approach based on light absorption estimation, the quality of underwater objects up to a depth of seven meters below sea level has a colour quality similar to the colour of objects on the sea surface.

Keywords: *Non-Linear Model, Least Square, Colour Quality, Underwater Object, Light Absorption*

1. INTRODUCTION

The colour quality of underwater object images is deficient due to colour distortion caused by light scattering and object colour changes [1-4]. Any light that hits the sea surface partly be transmitted and some will be reflected depending on the refractive index of seawater and particles in the underwater environment, as shown in Figure 1. [3-6]

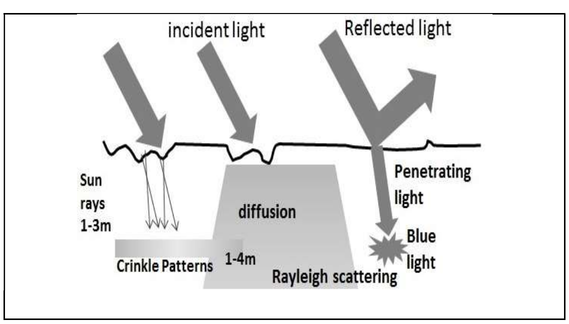

Figure 1. Light scattering in the sea

The scattering and absorption on the sea surface produce a particular color according to the color's intensity and wavelength of the underwater object [4-5]. Figure 2 shows the object's color is at a depth of six meters; most of the red light is absorbed, while the green and blue light channels are transmitted to a certain depth under the sea.

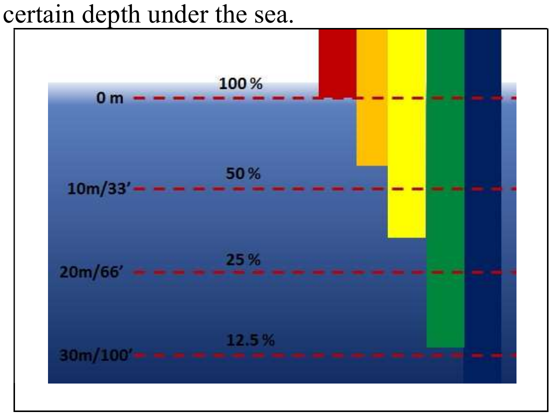

Figure 2. Light absorption in seawater

Currently, several approaches have not been able to deal with light scattering and improve the color quality of underwater objects with a high degree of accuracy [1][4]. The challenge is to carry out experiments that can produce models for improving the color quality of underwater objects. This paper proposes a non-linear model for color correction of underwater objects based on light absorption estimation. Non linier model approach is conducted through two steps: first, determining the relation between the color intensity of an image on the seawater 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 seawater surface and the color intensity of an image in a certain depth by using least square. Measurement of the colour quality of underwater objects using Peak Signal Noise to Ratio (PSNR)

2. RELATED WORKS

Chiang, J.Y., and Chen, Y.C.[1] The main problem with low image quality is the presence of scattering and color changes that cause color distortion. The Wavelength Compensation and Image Dehazing (WCID) algorithm effectively stabilize the image's color in the water.

Chiang, JY, Chen, YC, and Chen, YF [2] Wavelength Compensation and Image Dehazing (WCID) algorithm effectively maintain image color stability with the level of suspended particles and salinity in seawater vary according to location and time of year or season.

Bt Shamsuddin, N. and et al. [3] improved the image's color in water using manual enhancement and auto-correction techniques. There is a significant effect between manual and auto enhancement techniques for improving color quality in water. The manual enhancement technique has a high level of accuracy and precision when compared to the auto enhancement technique.

Pujiono, Yuniarno, EM, Purnama, IKE, Purnomo, MH, Hariadi, M., [4] used a polynomial approach to improve underwater image quality at a depth of 5 meters, resulting in image quality with peak signal noise to a ratio of 19.64.

Iqbal K, Regards RA. Osman A and Talib AZ [5] conducted research to improve underwater colors' scattering and absorption by Contrast Stretching, where the RGB-based Contrast Stretching algorithm stabilizes image colors, and HSV-based Contrast Contrast Stretching to improve color quality and image lighting.

Andono, P.N, Purnama, I.K.E., and Hariadi, M [6] stated that underwater image quality is very decisive in the scale-invariant feature transform (SIFT) method based on Contrast Limited Adaptive Histogram Equalization (CLAHE) in registering underwater images. The CLAHE method with Rayleigh distribution can improve underwater image quality compared to the ability of the Contrast Stretching algorithm, which is 41%.

Iqbal K, Odetayo M, James A, Salam RA, and Talib AZ [10], lighting problems due to absorption, turbidity, and light scattering affect the low quality of underwater images. The difference in the level of light absorption in water causes the effect of the color of the underwater image, especially for the primary colors, namely red, green and blue. The Unsupervised Color Correction Method (UCM) method based on RGB and HSI contrast can improve underwater image quality more effectively than the Gray World method, Histogram Equalization using Adobe Photoshop and White Patch.

Padmavathi, G, Subashini, P., Kumar, M. M., and Thakur, S.K. [11] argued that The problem of decreasing the quality of underwater images is due to low lighting and color changes image requires pre-processing before further processing. Using three filtering models is homomorphic, anisotropic diffusion, and wavelet denoising by an average filter. The use of wavelet denoising by average technique produces a better mean square error and peak signal to noise ratio than the homomorphic filter and anisotropic diffusion techniques.

Yussof, W.N.J.H.W., Hitam, M.S., Awalludin, E.A., and Bachok, Z [12] said that the main problem of underwater imagery is the low quality of underwater images due to color distortion of underwater images. The Contrast Limited Adaptive Histogram Equalization (CLAHE) method based on Red, green and blue colors, and HSV improves performance for improving underwater image quality. CLAHE performance measurement based on RGB and HSV is measured using Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR), where the MSE gave lower value and the PSNR higher.

Black, M.S., Yussof, W.N.J.H.W, Awalludin, E.A., Bachok, Z [13], the low level of visibility of underwater imagery has received much attention for research in recent decades. The contribution of this research is to combine the Contrast Limited Adaptive Histogram Equalization (CLAHE) approach based on RGB and HSV channel space with the Euclidean norm. The performance measurement of this approach is carried out with mean square error and peak signal noise to ratio with low MSE and high PSNR results so that it can effectively increase the visibility of underwater images.

Beohar, R. and Sahu, P. [14], the low underwater image quality and the lack of lighting for underwater objects make it difficult to carry out a more in-depth analysis of the objects in question. Contrast Limited Adaptive Histogram Equalization (CLAHE) with a 2D median filter can increase the level of stability and equalize the contrast of underwater image quality more efficiently.

SwarnaLakshmi R. and Loganathan B. [15] used a color constancy algorithm approach to improve the quality of underwater images due to color distortion due to light scattering and color changes. The test results prove that the underwater image results are accurate.

Benxing, G., Wang, G. [18], In this study, an underwater image recovery approach uses structured light and a CCD camera. Albeno surface convolution and illumination function resulting from image and image integration. By integrating the scanned frame images, we generate an integration image which can be formulated as the convolution of the surface albedo and the illumination function. Thus, underwater image acquisition is addressed as an optimization problem of image recovery and resolved by deconvolution, rather than the traditional geometric manipulation of frame tiling. The significance of the proposed method is that the forward scattering effect in the recovered image is fully eliminated by the integration operation and collection of the forward scattered light enhances the total imaging energy.

Chen, Y., Zeng, Z., Pan, Y [19] The main factors that affect the quality of underwater images are light scattering and turbulence. In the research approach, the degradation approach is carried out by calculating the transfer factor including the distribution of intensity per light, turbulent fluid media and suspended particles. Validation and approach of the model approach carried out by a controlled laboratory simulation system degradation of air turbulence by measuring transfer factors and compared with image restoration and reconstruction. The results showed that the model produced by the effect of image restoration and reconstruction can be substantially improved and at the same time proves the proposed model approach

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3. MATERIALS AND METHOD

3.1 Data Acquisition and Location

Researchers conducted data collection in the waters of Karimunjawa, Semarang, Central Java, Indonesia at locations 5°53'49.12"S and 110°25'4.06"T with a depth of up to 10 meters below sea level. Using equipment includes Camera Canon G15 F5.0, ISO 500, SS: 1/160 WB (A7 M3), and a set of diving equipment and colour models measuring 50 cm x 50 cm with red, green, blue, cyan, magenta, and yellow, where these colours are standard often used.

The diving team from the marine department of the University of Diponegoro took pictures during the day between 09.00 WIB to 13.00 WIB to get the best image quality. Taking colour model images is done manually with diving equipment, as shown in Figure 3, by taking the distance between the object and the camera approximately 1 (one) meter to capture the colour model object ideally camera. Figure 3 shows the image capture scheme.

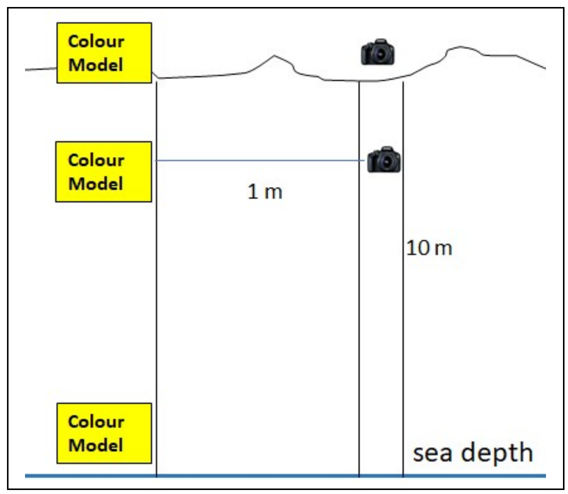

Figure 3 Schematic drawing of the underwater object colour model

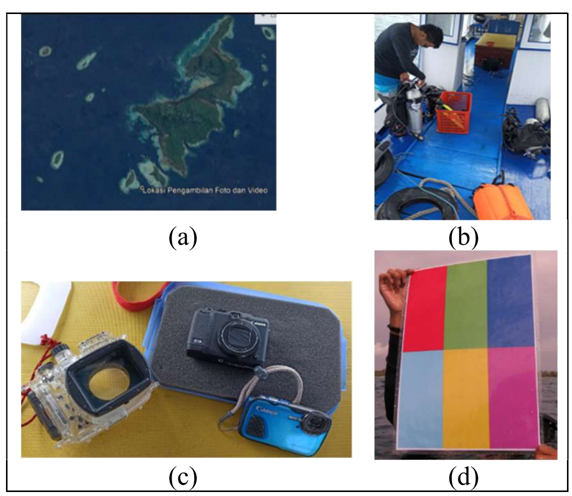

Figure 4. Location and equipment for underwater image data collection (a) Karimunjawaw waters, (b) diving equipment, (c) camera and (d) colour model

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Figure 4 shows the location and some of the equipment needed for the data collection process. The shooting process starts from the surface, then continues at a depth of 1 meter, 2 meters, 3 meters, 4 meters, and 6 meters below the water surface, as shown in Figure 5

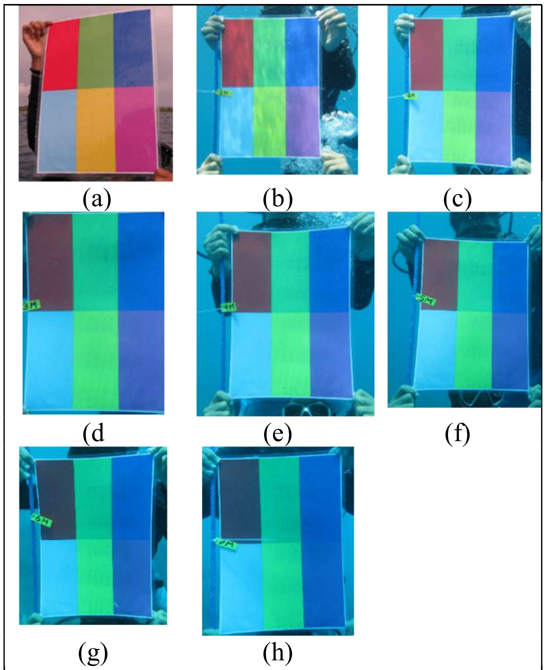

Figure 5. Underwater color model data acquisition image above seawater surface, (b) image at 1 m depth, (c) image at 2 m depth, (d) image at 3 m depth, (e) image at 4 m depth, (f) image at 5 m depth, (g) image at 6 m and (h) image at 7 m

3.2 Polynomial Equation

The polynomial equation of degree k [7] wrote as:

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

The residual is given by :

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

By minimizing R^2 and using partial differential in equation (2), it can write in matrix form,

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

Equation (3) is the least square fit equation and is solved by a linear equation in matrix form [7][8]

3.3 Beer-Lambert Law

Beer-Lambert's law that light entering a particular particle will be absorbed exponentially [16][17] can be expressed by equation (4),

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

The I and I_0 are the intensity in a particular material and the intensity at the surface. If μ is a function of wavelength, then,

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

3.4. Proposed Method

This paper proposes a method to find the level of the color intensity coefficient of the image in a certain depth estimated by finding the relationship between the color intensity level on the sea surface and the color intensity at each depth. By using the polynomial function approach [7][8][9]:

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

through the beer-lambert law equation (4) and the assumption that there is a correlation between the color intensity at sea level and the color intensity at a certain depth, then:

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

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

or

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

where $K_k = \frac{1}{C_k}$, I_p is the color intensity at the surface and I_k is the color intensity at depth k.

From equations (4) and (9), K is constant at the same depth. This study estimates the change in the value of K based on polynomial equations at a certain depth. For K(x) is a constant function at depth x, then the form of the polynomial equation K(x) is:

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

substitution of equation (10) into equation (9), shows the following result:

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

or

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

Where I_p, the color intensity on the sea surface, I_k is the color intensity at depth k, and x_k is the depth of the observed marine object. $\hat{I}_k$ is the normalization of the color intensity at the surface (I_p) to the color intensity at the depth (I_k).

Parameter estimation $a_0, a_1, \cdots, a_n$ is determined by minimizing the chi square function.

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

Equation (13) uses the solution of linear equations in matrix form,[7][8] as in equation (14).

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

wherein:

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

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

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

4. EXPERIMENT AND RESULTS

4.1. Determining the RGB Intensity Value of an Underwater Image

From the process of taking images on the sea water surface, at a depth of 1 (one) meter, 2 (two) meters, 3 (three) meters, 4 (four) meters, 5 (five) meters, 6 (six) meters and 7 (seven) meters below sea level, each depth is taken for the colour of the object for the primary colours, namely red, green, and blue as shown in Figure 6

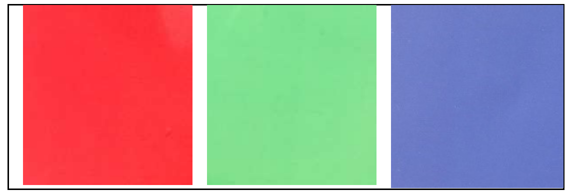

Figure 6 Samples of Red, Green and Blue Colours

The next step is to determine the average value of the intensity of the red, green, and blue colours in the image above sea level, at a depth of 1 (one) meter, 2 (two) meters, 3 (three) meters, 4 (four) meters5 (five) meters, 6 (six) meters and 7 (seven) meters, as shown in Table 3.1

Table 1. RGB colour intensity average value

Depth (meters)	Colour		
	Red	Green	Blue
0	215.84	192.61	199.95
1	165.76	201.13	217.17
2	151.38	218.60	218.47
3	94.94	189.85	191.75
4	116.56	224.85	229.20
5	108.32	226.45	235.67
6	79.74	215.42	216.04
7	35.66	183.57	194.86

By applying equation (12) to the average value of the intensity of the red, green, and blue colors in Table 1, the coefficient of the K_k absorption function for the red, green, and blue colors can be determined as in Table 2.

Table 2. Value of absorption function coefficient K_k

Colour/ Coeff	Red	Green	Blue
a_0	22.885	6.380	5.551
a_1	-48.797	-12.070	-10.396
a_2	39.989	9.739	8.441
a_3	-15.641	-3.778	-3.262
a_4	3.179	0.760	0.650
a_5	-0.325	-0.077	-0.064
a_6	0.013	0.003	0.002

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By applying equation (11) in Table 2, we get equations (15), (16), and equation (17) which are sixth-degree polynomial equations, where this sixth-degree polynomial is an optimal form of the absorption function based on the data in Table 1.

$$I_{pr} = I_{kr}\,(22.885 - 48.797k + 39.989k^2 - 15.641k^3 + 3.179k^4 - 0.325k^5 + 0.013k^6) \quad (15)$$

$$I_{pg} = I_{kg}\,(6.380 - 12.070k + 9.379k^2 - 3.778k^3 + 0.760k^4 - 0.077k^5 + 0.003k^6) \quad (16)$$

$$I_{pb} = I_{kb}(5.551 - 10.396k + 8.441k^2 - 3.262k^3 + 0.650k^4 - 0.064k^5 + 0.002k^6) \quad (17)$$

I_{pr}, I_{pg}, I_{pb} are the intensity values at sea level for red, green, and blue, respectively. While I_{kr}, I_{kg}, I_{kb} are the intensity value at depth to $\boldsymbol{k}$ under the sea for red, green, and blue colour. Equations (15), (16), and (17) are mathematical models for repairing underwater objects using *High Order Polynomials*. The intensity of red, green, and blue is the primary color of the image of an object. If we have known the object's color by a high-order polynomial model, then the object's color at sea level can be determined.

Figure 7, 8 and 9 is a graph of the absorption function of a mathematical model with a High Order Polynomial (HOP) approach. The horizontal line describes the depth of the sea water, while the vertical line describes the intensity values of the basic colors, namely red, green and blue

Figure 7, 8 and Figure 9 illustrate absorption's level of the intensity of red, green, and blue, where at a depth of 7 meters, the level of absorption of the intensity of Red is greater than that of green and blue. In comparison, the green and blue colors tend to be absorbed to a depth of 7 meters. So that visually it appears that the red object model is dominated by green or blue, based on the estimated level of absorption or absorption of this color, the performance of the HOP model will perform a transformation based on the level of color intensity of the absorbed object to a certain depth.

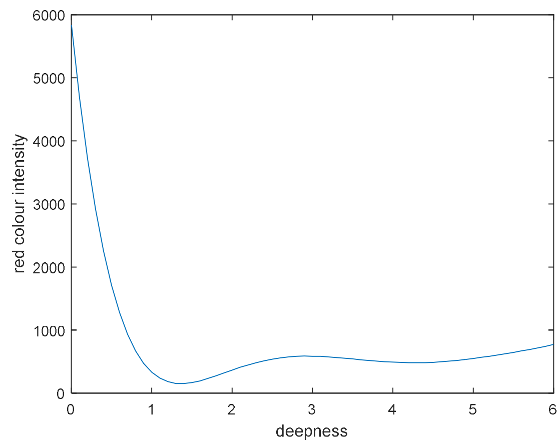


Figure 7 Red absorption function graph

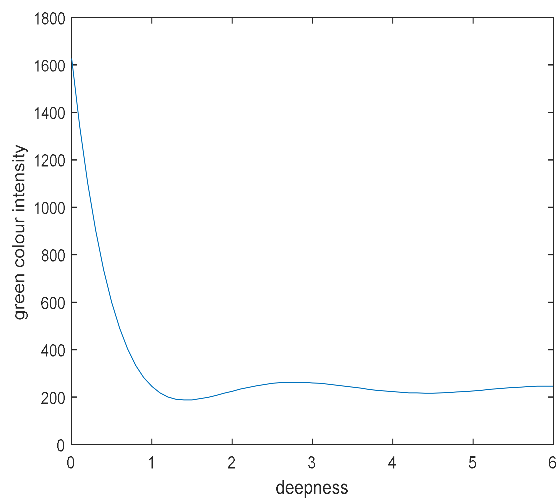


Figure 8. Green absorption function graph

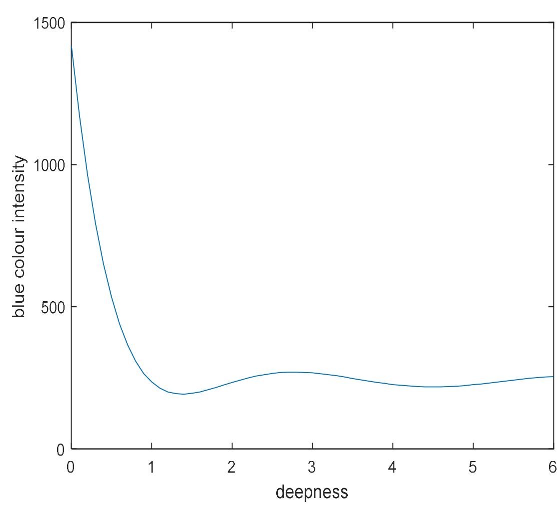


Figure 9. Blue color absorption function graph

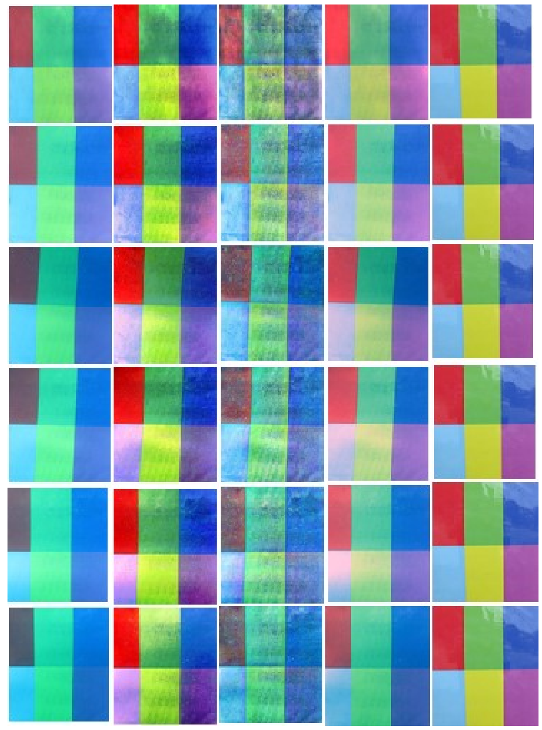
4.2 Measurement of the Quality of Underwater Image Improvement Results Using High Order Polynomial

Peak Signal to Noise Ratio (PSNR) is used to measure the quality of the image improvement of underwater objects using the High Order Polynomial approach. The quality of object colour improvement produced by using Histogram Equalization (HE) with a PSNR value of 19.68. Contrast Limited Adaptive Histogram Equalization (CLAHE) an average value of Peak Signal to Noise Ratio (PSNR) of 18.14 while the average PSNR value using this approach High Order Polynomial of 19.84, the greater the PSNR value, the better the performance of the High Order Polynomial approach for improving the colour of underwater objects.

Figure 10 shows the results of visually improving the colour image of underwater objects using the Histogram Equalization (HE) approach, Contrast Limited Adaptive Histogram Equalization (CLAHE), and the High Order Polynomial (HOP) approach.

The first line is the colour of the repaired object at a depth of one meter below sea level; the second line is the colour of the repaired object at a depth of 2 meters, the third line is the object colour improvement at a depth of 3 meters, the fourth line is the colour of the repaired object at a depth of 4 meters, the fifth is the colour of the repair object at a depth of 5 meters, the sixth line is the colour of the repair object at a depth of 6 meters, and the seventh line is the colour of the repair object at a depth of 7 meters.

The first column is the image below the water surface where the colour model looks dark (a), especially the red colour is almost brownish-black, the second column is an image improvement using *Histogram Equalization* (HE) colour model with high contrast with much noise (b), in the third column using *Contrast Limited Adaptive Histogram Equalization* (CLAHE) (c), the colour model shows much noise in the third column of image improvement using the *High Order Polynomial* approach (d), it appears that the colour model resembles the colour of the object on the sea surface or is close to the colour of the image of the original object (e).



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

Figure 10 Visual results of colour correction of underwater objects using the HE, CLAHE and HOP approaches

` Figure 11 shows the average Peak Signal to Noise Ratio (PSNR) for colour images of underwater objects. Three graphs of the Peak Signal to Noise Ratio (PSNR) value from the colour image of underwater objects, the results of improving the image of underwater objects using Histogram Equalization (HE), Contras Limited Adaptive Histogram Equalization (CLAHE), and the average value of Peak Signal to Noise Ratio (PSNR) uses a High Order Polynomial approach.

It appears that the approach using High Order Polynomial gives an average Peak Signal to Noise Ratio (PSNR), which is greater than the Histogram Equalization (HE) and Contrast Limited Adaptive Histogram Equalization (CLAHE) approaches, this shows that the performance of the High Order Polynomial approach bigger or better.

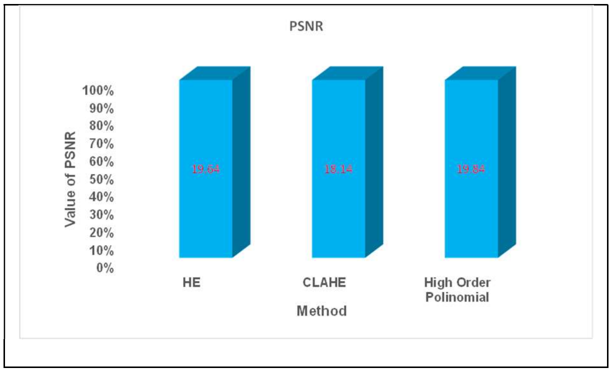


Figure 11 The average value of Peak Signal to Noise Ratio

5. CONCLUSION

The research succeeded in changing the colour of underwater objects by using the development of a mathematical model through the High Order Polynomial (HOP) approach based on light absorption estimation. The measurement results use *Peak Signal Noise to Ratio* (PSNR), where the PSNR value is 19.84. Visually, the colour quality of underwater objects is close to the colour of objects on the water surface (the colour of the original object). Further research Development of a mathematical model with a High Order Polynomial approach to improving the colour of underwater images in the HSL (Hue, Saturation, and Lightness/Luminance) colour space is closer to intuition and human visual perception

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