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Underwater Image Restoration Based on Improved Background Light Estimation and Automatic White Balance

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***Abstract*—A new algorithm for underwater image restoration based on improved background light estimation and automatic white balance is proposed in order to overcome the shortage of classical dark channel prior algorithm for underwater image restoration. The improved background light estimation method can reduce the influence of light and white objects in the water and improve the accuracy of the background light. The improved automatic white balance algorithm can reduce the color distortion and get a clear image with the color correction of the restored image. According to the contrast experiments of four different underwater images, we can see that the algorithm has some advantages on subjective and objective evaluation indexes, and the sharpness and the color fidelity of the enhanced image are better.**

Keywords-underwater image restoration; background light estimation; automatic white balance; color correction

I. INTRODUCTION

In order to make better use of marine resources and develop marine economy, a great deal of information in the ocean world needs to be fully understood. Underwater imaging is one of the important ways for human to master useful information. Through the clear processing of underwater images, more useful information can be grasped, so as to better explore and develop marine resources. Image restoration is a main method of underwater image sharpening. According to the prior knowledge of light in the process of water degradation, a known or derived underwater imaging model is used to complete the image restoration. Grosso [1] and Voss [2] have obtained the propagation function of light in water by experimental method. The use of the tool is tedious and does not have practical application value. This method has many data and high precision, but because of the inability to have the excellent conditions of the laboratory in the bad underwater environment, the experimental method is less operational [3]. In addition, the mathematical modeling method can also be used to describe the degradation process, and it can make up for the poor generality of the experimental method. For example, Roser and so on use sparse three-dimensional mapping to get the characteristics of the original image, establish underwater imaging model, correct the color of underwater image, make the underwater image color rich and stereo, and improve the contrast of [4]. He first processed the dark channel prior algorithm to deal with foggy images and achieved good results [5]. Yang and so on use the dark channel prior algorithm in the underwater image processing, and use the median filter to find the transformation function of the original image, and estimate the atmospheric light value. By adjusting the green channel and the red channel, the problem of the underwater image is blue. The problem [6] is solved by the adjustment of the green channel and the red channel. Chiang and so on by judging whether the artificial light is used to correct the color, prevent the distortion, and then combine the dark channel prior algorithm to restore the image, but the image contrast after processing is still not high [7].

The dark channel prior theory proposed by He, et al. in [5] is based on physical models in the atmosphere, so many researchers apply it to underwater image processing. However, because of the different propagation characteristics of light in the atmosphere and water, it is very limited to directly apply the dark channel prior theory to underwater, which needs to be improved and perfected. In this paper, an improved background light estimation method and automatic white balance algorithm are proposed to deal with the shortage of underwater image by dark channel prior algorithm. The real color of the image is reduced, the details of the image are enriched.

II. A PRIORI THEORY OF DARK CHANNEL FOR UNDERWATER IMAGES

The underwater imaging model is [9-12]:

$$I(x)=J(x)t(x)+B\left(1-t(x)\right) \tag{1}$$

where x denotes the pixel position in the image; I is the obtained image; J is the unknown clear image; t represents the transmission capacity for the transmission of the light in the underwater environment; B represents the intensity of the infinite distance in the image, usually called the background .

A. Classical dark channel theory

To restore the real clear image J, we need to estimate t and B first. He and others believe that background light exists in the region of the most dense fog in the image [5]. The estimation method of background light is proposed and the concentration of fog is judged according to the value of dark channel, and its value is proportional to the concentration. The first 0.1% pixels of the brightness in the dark channel are used as the thickest area of the fog. According to the location of these points, the brightest points are found in the original map, and the point is selected as the background light. The background light obtained by this method is robust and reasonable. After estimating the

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background light, transmittance is also needed. The dark channel is defined as [5]:

$$J^{dark}(x) = \min_{y\in\Omega(x)}\left(\min_{\lambda\in\{R,G,B\}} J_\lambda(y)\right)$$

where λ denotes any RGB color channel and $\Omega(x)$ is the neighborhood of the pixel x. Eq. (1) is minimized as:

$$\min_{y\in\Omega(x)} I(y) = \min_{y\in\Omega(x)}\left(J(y)t(y) + B\left(1-t(x)\right)\right) \qquad (2)$$

Then minimization is conducted in any RGB color channel and divided by B_∞, finally we have:

$$\begin{aligned}&\min_{\lambda\in\{R,G,B\}}\left(\min_{y\in\Omega(x)}\left(I(y)/B\right)\right)\\ &= \min_{\lambda\in\{R,G,B\}}\left(\min_{y\in\Omega(x)}\left(J(y)t(y)/B\right)\right) + \left(1-t(x)\right)\end{aligned} \qquad (3)$$

According to the prior principle of dark channel theory, $J^{dark}(x)$ is near to zero, so we have:

$$J^{dark}(x) = \min_{\lambda\in\{R,G,B\}}\left(\min_{y\in\Omega(x)} J_\lambda(y)\right) \approx 0 \qquad (4)$$

and

$$t(x) = 1 - \min_{\lambda\in\{R,G,B\}}\left(\min_{y\in\Omega(x)}\left(I(y)/B\right)\right) \qquad (5)$$

There are more or less some atomization effects in real images, hence completely removing the fog from the images will make the images stiff and unnatural, so a parameter whose value is between zero and one is set to adjust the degree of mist:

$$t(x) = 1 - \omega\cdot\min_{\lambda\in\{R,G,B\}}\left(\min_{y\in\Omega(x)}\left(I(y)/B\right)\right) \qquad (6)$$

Finally, the restored image is obtained by:

$$J(x) = \frac{I(x) - B}{\max\left(t(x), t_0\right)} + B \qquad (7)$$

B. Transmittance estimation for underwater images

When the light is propagating under water, the attenuation degree increases with the increase of the wavelength. The red light has the maximum attenuation coefficient and the first attenuation in the water, so the transmittance of the red channel is also the smallest. When solving underwater transmittance, the transmittance of red channel and blue green channel is also different. The two sides of Eq. (1) for $\lambda = R$ and $\lambda \in \{G, B\}$ are minimized as follows respectively:

$$\min_{y\in\Omega(x)}\left(\frac{1-I_\lambda(y)}{1-B}\right) = t_\lambda(x)\min_{y\in\Omega(x)}\left(\frac{1-J_\lambda(y)}{1-B}\right) + \left(1-t_\lambda\right) \qquad (8)$$

$$\min_{y\in\Omega(x)}\frac{I_\lambda(y)}{B} = t_\lambda(x)\min_{y\in\Omega(x)}\frac{J_\lambda(y)}{B} + \left(1-t_\lambda(x)\right) \qquad (9)$$

In [12], it states that

$$J^R = \min\left(\min_{y\in\Omega(x)}\left(1-J_R(y)\right), \min_{y\in\Omega(x)} J_G(y), \min_{y\in\Omega(x)} J_B(y)\right) \approx 0 \quad (10)$$

Because the attenuation of red light is the most serious and its transmittance is the smallest and then from Eq. (8) and (9) we can estimate its transmittance by:

$$t_R = \min\left(\min_{y\in\Omega(x)}\left(\frac{1-I_R(y)}{1-B}\right), \min_{y\in\Omega(x)}\frac{I_G(y)}{B}, \min_{y\in\Omega(x)}\frac{I_B(y)}{B}\right) \qquad (11)$$

After obtaining the transmittance of the red channel, it is necessary to estimate the transmittance of the other two color channels to restore the underwater image scene. In underwater imaging, the transmittance $t_\lambda(x)$ of a pixel x is inversely proportional to the product of the distance $d(x)$ away from the camera and the attenuation coefficient c_λ of the corresponding band, i.e. $t_\lambda(x) = \exp(-c_\lambda d(x))$. For the same pixel, the distance away from the camera is the same, but the corresponding attenuation coefficients are different. The transmittance of the blue and green channel is calculated respectively:

$$t_G(x) = e^{-c_G d(x)} = e^{-c_R d(x)\frac{c_G}{c_R}} = \left(t_R(x)\right)^{\frac{c_G}{c_R}} \qquad (12)$$

$$t_B(x) = e^{-c_B d(x)} = e^{-c_R d(x)\frac{c_B}{c_R}} = \left(t_R(x)\right)^{\frac{c_B}{c_R}} \qquad (13)$$

where t_R, t_G and t_B denote the transmittance of red channel, green channel and blue channel, respectively; and c_R, c_G and c_B denote the attenuation coefficient of red, green and blue light, respectively. Background light $B_{\lambda,\infty}$, scattering coefficient b_λ and attenuation coefficient c_λ have the following three relationships:

$$B_\lambda \propto b_\lambda / c_\lambda \qquad (14)$$

According to this, the attenuation coefficient of green and blue red can be calculated:

$$\frac{c_G}{c_R} = \frac{b_G/B_G}{b_R/B_R} \qquad (15)$$

$$\frac{c_B}{c_R} = \frac{b_B/B_B}{b_R/B_R} \qquad (16)$$

In order to calculate the attenuation ratio, we also need to know the scattering coefficient ratio. The relationship between the

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underwater scattering coefficient b_λ and the wavelength λ is [12]:

$$b_\lambda = \left(-0.00113\lambda + 1.62517\right)\tilde{b}_\lambda \tag{17}$$

where $\tilde{b}_\lambda$ is the reference wavelength. The attenuation ratio can be obtained without knowing the exact value for $\tilde{b}_\lambda$. Suppose the wavelength of three color channels of RGB is 620nm, 520nm and 450nm respectively. The attenuation coefficient ratio can be obtained by substituting the scattering coefficients of green-red and blue-red with the ratio of the original background light into Eq. (15) and (16). The transmittance of the green channel and blue channel is obtained from Eq. (12) and (13), and then all channel are refined by the guided filter [10, 12].

III. Proposed Method

This paper achieves a clear image by improving the background light and automatic white balance to restore the underwater image. The improved background light estimation is embedded in the classical dark channel algorithm process to achieve the initial restoration of underwater images; the improved automatic white balance is used for further color correction, and the clear underwater image is finally obtained.

A. *Improved estimation method for background light*

Background light can cause backscattering of underwater images. It is usually the farthest point from the camera, in the deepest and farthest background area of the image. When the underwater image is processed, the overall atomization effect of the image is more serious because of the heavy underwater fog, so the dark channel map will be brightened. It is easy to estimate the background light in this large area and high luminance area, which will affect the background light value. It is necessary to improve the solution of the background light. The specific process of our estimating background light is as follows:

(1) To reduce the time complexity of the algorithm, the improved dark channel graph is divided into four blocks, and the average and standard deviation of each block are calculated:

$$Q = \alpha \cdot \mu^2 - \left(1-\alpha\right)\sigma \tag{18}$$

where μ is the mean, σ is the standard deviation. The larger the value of Q, the greater the mean value and the smaller the standard deviation. According to different test images, after repeated experiments, we find that the effect is best when α is set to be about 0.86.

(2) Select the corresponding image block with the maximum Q. Then calculate the average of RGB channel in this block and the estimation is obtained. and the average value of the three channel pixels is obtained, and the estimation results are obtained.

The above method is expected to reduce the influence of noise and underwater white objects on the calculation of background light and improve the accuracy of estimation.

B. *Improved automatic white balance*

Because of the quickest attenuation of red light and the longest distance of blue light, the underwater image is mostly blue and green. In order to improve the color deviation of the underwater image after the last restoration, the white balance algorithm can be used to correct the color of the image. The algorithm has a good effect and simple calculation. In the process of image processing, the position of the reference white balance pixel is constantly changing. In this paper, the following improved automatic white balance method is proposed:

(1)First, the color space is transformed from the RGB color space to the YCrCb color space;

(2)Then the watershed segmentation method is used to segment the image into N regions $S_i\left(i=1,\cdots,N\right)$;

(3) Calculate the mean value M_i of the Y component for each region;

(4) The number of white balance points selected within S_i is:

$$\ell_i = \frac{M_i}{\sum_i M_i} \cdot \ell \tag{19}$$

where ℓ is the total number of white balance points selected is (usually set to 10%-20% of all pixels). The ℓ_i white balance points within S_i are selected from the Y component value from large to small.

(5) The channel gains for RGB are calculated respectively as follows:

$$\begin{cases} R_{gain} = Y_{max} / R_{avg} \\ G_{gain} = Y_{max} / G_{avg} \\ B_{gain} = Y_{max} / B_{avg} \end{cases} \tag{20}$$

where Y_{max} is the brightest of the original to be white-balanced; R_{avg}, G_{avg}, B_{avg} are the average RGB values of the selected white balance points.

(6) Finally, the whole image is adjusted by the channel gain:

$$\begin{cases} \tilde{R} = R_{gain} \cdot R \\ \tilde{G} = G_{gain} \cdot G \\ \tilde{B} = B_{gain} \cdot B \end{cases} \tag{21}$$

where $\tilde{R}$, $\tilde{G}$ and $\tilde{B}$ are the RGB values after white-balanced, respectively.

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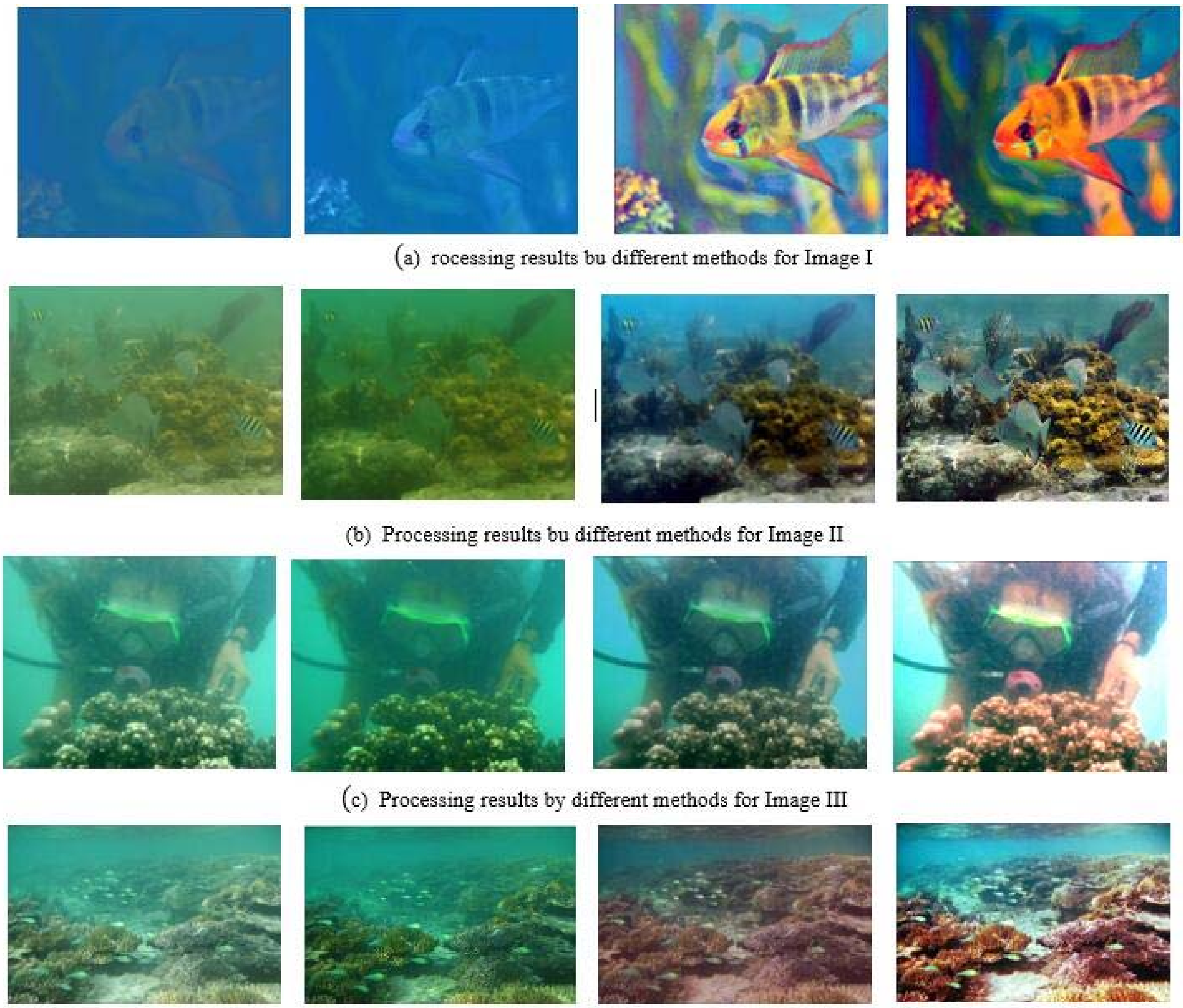
IV. EXPERIMENTAL RESULTS

To verify the efficiency of the proposed algorithm, it is compared with the dark channel theory algorithm [5] and the automatic red dark channel restoration algorithm (RDCP) [12], and the results are shown in Figure 1. There are three different algorithms to deal with four different underwater images. For each image in Fig.1, from left to right is the original degraded underwater image, and the results are restored with the dark channel theory algorithm [5], RDCP algorithm [12] and the proposed algorithm.



(a) rocessing results bu different methods for Image I

(b) Processing results bu different methods for Image II

(c) Processing results by different methods for Image III

(d) Processing results by different methods for Image IV

Fig.1 Processing effects for four images by different methods

Through observation, we can see that each algorithm can effectively improve the image quality and achieve clearness effect. As we can see, the dark channel theory method can remove the atomization effect and reduce the influence of backscatter to a certain extent, but it does not notice that the attenuation degree of the light in the water is different, which makes the color of the underwater image aggravated: the color of the image is serious and the restoration effect is not ideal; The atomization phenomenon is improved, but it is seriously green. The white and green spots on the coral in the picture make the restoration image uneven, which greatly affects the visual effect of the image. We can see that the RDCP algorithm takes into account the fastest red light attenuation factor, the image after processing is higher, the visibility is higher, and the underwater deviation can be corrected, but there are some limitations as well. It can be seen from the map that the image processed by the RDCP algorithm is dark and affects the visual perception. In this paper, the algorithm can remove the blue and green bias of the underwater image, the color becomes more vivid, the image after the restoration is clear, the contrast is also enhanced, and the subjective visual effect is better.

Based on these four images, the experimental results of each algorithm are analyzed and compared subjectively. In order to

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better compare the results of each algorithm, it is necessary to evaluate the quality of the simulation results. In Table 1, four performance indicators, i.e. mean (M), standard deviation (D), information entropy (E) and average gradient (G), are given to compare each algorithm with [12].

From Table 1, it can be seen that the average value of underwater image processed by this algorithm is improved, which can improve the color bias of underwater image and make the color of the image colorful and rich. The image standard difference after the algorithm is improved, which shows that the contrast is higher and more conforms to the visual effect of the human eye; the image is more consistent with the visual effect of the human eye; The entropy of information is also improved. The image information entropy is highest after the algorithm is processed in this paper. It shows that it can enrich the details of the edges, have higher visibility and better clarity on the basis of maintaining the essential features of the original image; the underwater image obtained by this algorithm has a higher average gradient and an underwater image. The color deviation is well improved and the image level is distinct.

TABLE 1 PERFORMANCE COMPARISON OF DIFFERENT METHODS

image	method	M	D	E	G
Image I	Original image	99.255	56.493	11.238	2.847
	Dark Channe	104.731	54.920	11.272	1.998
	RDCP [12]	115.448	69.741	13.393	7.582
	Proposed	123.204	70.968	15.093	8.368
Image II	Original image	95.409	32.974	13.946	3.821
	Dark Channel	71.304	38.213	13.866	3.924
	RDCP [12]	85.021	48.797	14.726	6.256
	Proposed	97.645	56.107	14.912	10.807
Image III	Original image	113.966	51.581	14.310	6.171
	Dark Channel	89.484	58.787	14.243	6.480
	RDCP [12]	99.674	56.113	14.395	7.918
	Proposed	126.360	65.135	14.538	8.330
Image IV	Original image	111.537	55.396	14.770	8.880
	Dark Channel	80.556	52.927	14.884	9.326
	RDCP [12]	109.813	54.077	14.831	8.806
	Proposed	124.399	58.530	14.895	10.918

To sum up, the proposed method has high efficiency in both subjective vision and objective simulation data. It can eliminate the underwater blue-green bias well, reduce the color distortion, and make the contrast and clarity of the image further improved.

V. CONCLUSION

To overcome the shortcomings of classical dark channel prior algorithm, an underwater image restoration algorithm based on improved background light estimation and automatic white balance is proposed. The improved background light estimation method can reduce the influence of light and white objects in the water and improve the accuracy of the background light. The improved automatic white balance algorithm can reduce the color distortion and get a clear image with the color correction of the restored image. According to the contrast experiments of four different underwater images, we can see that the algorithm has some advantages on subjective and objective evaluation indexes, and the sharpness and the color fidelity of the enhanced image are better.

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REFERENCES

[1] V. D. Grosso, “Modulation transfer function of water,” IEEE Oceans, 1975:331-347.

[2] K. J. Voss, A. L. Chapin, “Measurement of the point spread function in the ocean,” Applied Optics, 1990, vol. 29, pp. 3638-3642.

[3] S. Wang, Y. Xu, Y. Pang, “A fast underwater optical image segmentation algorithm based on a histogram weight fuzzy c-means improved by PSO,” Journal of Marine Science and Application, 2011, Vol. 10, pp. 70-75.

[4] M. Roser, M. Dunbabin, A. Geiger, “Simultaneous underwater visibility assessment, enhancement and improved stereo,” IEEE International Conference on Robotics and Automation. IEEE, 2014, pp. 3840-3847.

[5] K. He, J. Sun, X. Tang, “Single image haze removal using dark channel prior,” IEEE Trans Pattern Anal Mach Intell, 2011, vol. 33, pp.2341-2353.

[6] H. Y. Yang, P. Y. Chen, C. C. Huang, et al., “Low complexity underwater image enhancement based on dark channel prior,” Second International Conference on Innovations in Bio-Inspired Computing and Applications. IEEE, 2012:17-20.

[7] J. Y. Chiang, Y. C. Chen, “Underwater image enhancement by wavelength compensation and dehazing,” IEEE Transactions on Image Processing, 2012, vol. 21, pp. 1756-1769.

[8] S. Emberton, L. Chittka, A. Cavallaro, “Hierarchical rank-based veiling light estimation for underwater dehazing,” British Machine Vision Conference, 2015:125.1-125.12.

[9] S. Serikawa, H. Lu, “Underwater image dehazing using joint trilateral filter,” Pergamon Press, Inc. 2014.

[10] X. Zhao, T. Jin, S. Qu, “Deriving inherent optical properties from background color and underwater image enhancement,” Ocean Engineering, 2015, vol. 94, pp. 163-172.

[11] G. R. Jr, R. A. Arnone, P. M. Martinolich, “Spectral dependence of the scattering coefficient in case 1 and case 2 waters,” Applied Optics, 1999, vol. 38, pp. 2377-2383.

[12] A. Galdran, D. Pardo, A. Picon, et al., “Automatic red-channel underwater image restoration,” Journal of Visual Communication and Image Representation, 2015, vol. 26, pp. 132-145.

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