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Underwater Image Enhancement Based on Multiscale Fusion

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Abstract. To improve the visibility and clarity of images in underwater environment, this paper proposes an underwater image enhancement method based on multi-scale fusion. Firstly, the white balance method is used to correct the color of the underwater image, and the original color of the underwater elements is restored as much as possible. Secondly, the dark channel prior algorithm is used to solve the underwater image blur problem. Then, the CLAHE algorithm is used to enhance the contrast of the image. Finally, using weight allocation or fusion rules, multi-scale information and multi-stage fusion of the image are used to generate the final enhanced underwater image. Quantitative image quality evaluation indexes PSNR, SSIM and UIQE are used to evaluate underwater image quality. The results show that the proposed method can effectively solve the problem of underwater image color deviation, make the color of the image more accurate and natural, improve the contrast and brightness of the underwater image, and have better visual effect and richer detail information.

Keywords. Multi-scale fusion, white balance, CLAHE

1. Introduction

Underwater image acquisition is subject to factors such as absorption, scattering, and fluctuations in water bodies, resulting in challenges in image visibility and detail. Improving the quality and visualization of underwater images is essential to achieve accurate target detection, target recognition and image analysis. To overcome the problems in the underwater environment, many researchers have proposed various underwater image enhancement methods.

Mishra et [1] al. has improved and applied CLAHE to underwater image enhancement, this method enhances the contrast of underwater images, but in some cases, the method may cause some details of the image to become blurred. Drews et al. [2] improved the classic dark channel prior (DCP) algorithm [3] combined with underwater characteristics and achieved remarkable results in underwater image denoising and fog removal, but it did not get sufficient improvement for the common color distortion problem in underwater images. Zhang Wei et al. [4] proposed low-illumination underwater image enhancement based on white balance and relative total variational, which improved the color performance of underwater images and further improved the image quality. However, underwater images still face serious problems of atomization and low contrast. In recent years, deep learning methods can generally obtain clear

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underwater images. Li et [5] al used generative adversarial network to correct the color bias problem, Wang Haotian et [6] al proposed cyclic generative adversarial network to correct the color, and Xu Yan et[7] al used convolutional neural network to improve the image quality based on the underwater image imaging model. All these methods have made remarkable progress in underwater image processing. However, these methods usually require a large amount of paired training data, which is very difficult and expensive to obtain, limiting the universality and application of deep learning methods.

Ancuti et [8] al. is an effective method for multi-scale fusion of images that have been processed in different ways, which can produce better processing results. The research in this paper and other fusion strategies can effectively improve the quality of underwater images, to improve the observation effect of images more comprehensively and provide a better foundation for underwater image processing and related applications.

2. Underwater image enhancement algorithm

Due to the special nature of underwater optical imaging, the acquired images generally have problems such as color distortion, low contrast, and blurred details. To solve these problems, the underwater image processing flow designed in this paper is shown in Figure 1.

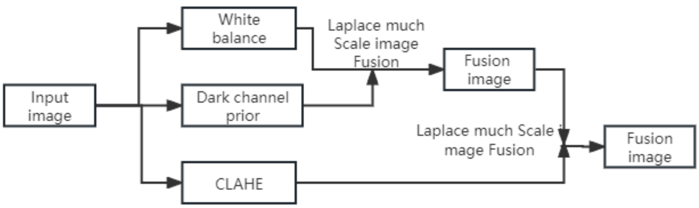

Figure 1. underwater image processing flow

Firstly, using the white balance algorithm to process the image can improve the visual effect of the underwater image, restore the image color, and adjust the color bias, eliminate the image noise and retain the image details; Secondly, the dark channel prior algorithm is used to solve the problem that the underwater image appears fuzzy due to a large number of suspended particles. Then, using CLAHE algorithm to effectively suppress the noise amplification and enhance the local contrast of the image, can improve the clarity and color brightness of the image, and has a good effect on the image atomization phenomenon; Finally, according to the weight allocation or fusion rules, Laplacian multi-scale image fusion is used in multiple stages to generate the final enhanced image. The principle of each step is described in detail next.

2.1. White Balance algorithm

Adaptive white balance is an algorithm used to correct the color of an image, aiming to eliminate color bias problems in the image. Its principle is based on the color perception features of the human eye. The human eye has a strong perception of light color temperature and can automatically adjust the color deviation in visual perception according to the light conditions in the environment, so that the colors seen remain consistent. Specifically, the algorithm will adjust the color value of each pixel in the image according to the perceived light color temperature information by increasing or reducing the color value of the three channels of red, green and blue in each pixel. In this way, the white object in the image can show the true white under different light conditions, and other colors can also maintain relatively accurate colors. Fig. 2 Results of adaptive white balance. (a) Original image; (b) processing results of gray world algorithm; (c) processing results of adaptive white balance, the proposed method corrects the color distortion of underwater images and effectively removes the color bias of green, blue and yellow.

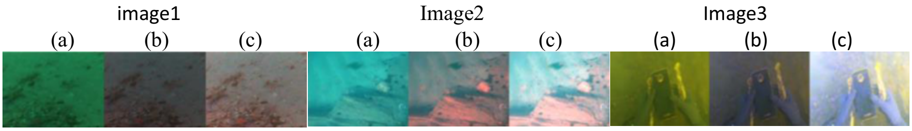

Figure 2. Results of adaptive white balance

2.2. Dark channel prior

Dark channel prior aims to remove fog and improve image clarity and contrast by analyzing dark channel features in images. Its principle can be briefly summarized as follows: First, calculate the dark channel, for the input image, calculate the minimum value of each pixel on different channels, and assign to the corresponding pixel in the dark channel image, recompose the grayscale image, and then carry on the minimum filtering to the image to obtain the dark channel image. Secondly, according to the dark channel image, select the area with higher brightness in the image, and estimate the atmospheric light intensity. Finally, using the estimated atmospheric light intensity, the original image is de-fogged and enhanced. FIG. 3 Results of dark channel prior. (a) The original image; And (b) the result of the dark channel prior algorithm.

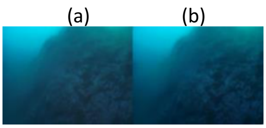

Figure 3. Results of dark channel prior

2.3. CLAHE

CLAHE is an algorithm for image enhancement, full name Contrast Limod Adaptvo Hislogram Equalizatlon, its principle is summarized as follows: First, the image is divided into many small pieces, each of which is the size of NxN; Secondly, histogram equalization is performed on each small block, so that the distribution of pixel values in each small block is more even; Then, the equalized image cable is restricted to avoid excessive enhancement. Finally, all the small pieces are stitched together to get the enhanced image. This algorithm can enhance the contrast of the image and make the details clearer by equalizing and limiting the image with local hundred squares. FIG. 4 Results of CLAHE algorithm. (a) The original image; And (b) the results of CLAHE's algorithm.

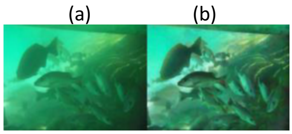

Figure 4. Results of CLAHE algorithm

3. Experimental results and analysis

The hardware system of the experiment is Intel Core i5-12500H, and the memory is 16GB; The software environment is Python and Win11 operating system. In order to verify the feasibility of this method, multiple images with different degradation characteristics were selected from the underwater image dataset UIEB[9] , as shown in FIG. 5 (a). The first, second and third images showed obvious green, blue or yellow color deviation with low clarity, while the fourth, fifth and sixth images showed obvious insufficient illumination and low visibility. The algorithm in this paper is compared with other algorithms, and the experimental results of different algorithms are analyzed from both subjective and objective aspects.

3.1. Subjective evaluation

In this paper, 6 kinds of images under different underwater environments are selected for comparison experiment, and the processing results are shown in Figure 5. As can be seen from FIG. 5 (e), the algorithm in this paper can solve the problem of color decay in different underwater environments on the whole on the premise of avoiding excessive enhancement. The contrast is greatly improved, and the local details of the image are clear and obvious, which accords with the image under natural light.

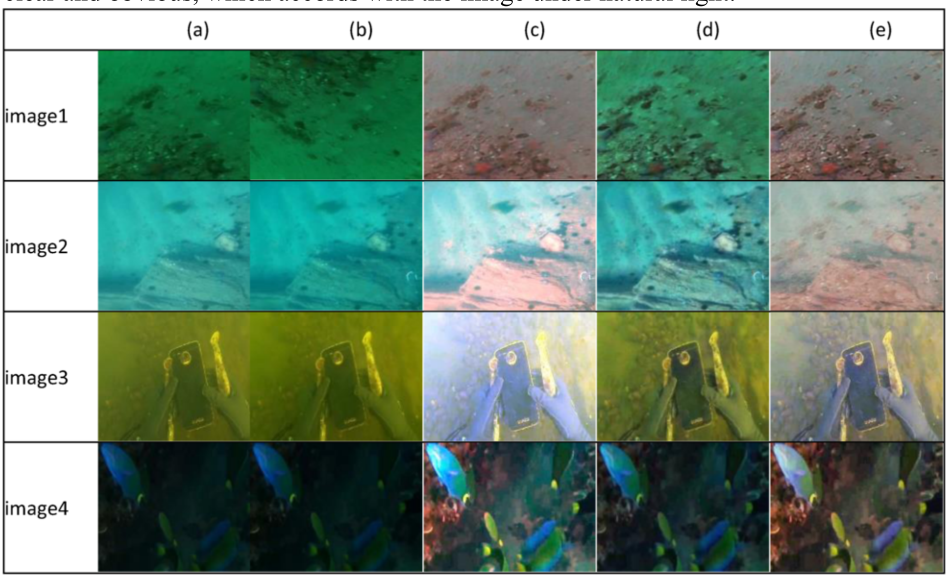

Figure 5. Results of six different image enhancement algorithms

3.2. Objective evaluation

This paper uses three performance indicators to evaluate underwater image quality, namely PSNR, SSIM and UIQE[10] . PSNR is based on the error calculation between corresponding pixel points, mainly calculating the ratio between the maximum signal and the background noise. The larger the value, the smaller the distortion. The calculation formula is as follows:

$$MSE = \frac{1}{H*W}\sum_{i=1}^{H}\sum_{j=1}^{W}[X(i,j) - Y(i,j)]^2 \tag{1}$$

$$PSNR = 10\log_{10}\left(\frac{(2^n-1)^2}{MSE}\right) \tag{2}$$

Where: MSE represents the mean square error of the image; H and W represent the width and height of the image; n represents the number of bits of the image pixel. SSIM is a measure of the similarity of two images and is calculated by the formula.

$$SSIM = \frac{(2x_1x_2+C_1)(2y_{1,2}+C_2)}{(x_1^2+x_2^2+C_1)(y_1^2+y_2^2+C_2)} \tag{3}$$

Where: x_1,y_1 represents the mean value and standard deviation of the input image; y_1、y_2 represents the mean value and standard deviation of the enhanced image; $y_{1,2}$ Represents the covariance of the input image and the enhanced image; C_1,C_2 is a constant. The larger the SSIM value, the smaller the structural loss of the input original. UIQE is a special index used to evaluate the quality of underwater images. Usually, different weight parameters are fine-tuned for the three components of color fidelity, contrast and sharpness according to the underwater environment. The determination of the three weight parameters needs to be calculated by multivariate linear regression, and finally the final index is obtained by linear addition of different components.

$$UIQE = C_1 * \alpha + C_2 * \beta + C_3 * \gamma \tag{4}$$

Where: C_1 , C_2 , C_3 are the weights of different components; α Represents the measurement index of color fidelity; β Represents the contrast measurement index; γ Represents a measure of clarity. The objective evaluation data of the above experiments are shown in Table 1. It can be seen from Table 1 that the values of the three evaluation indexes of the algorithm in this paper are almost optimal. Objectively, it shows that the algorithm in this paper retains more original image information. Among them, the larger the UIQE value, the better the color fidelity, clarity, and contrast of the image.

Table 1. Objective quality assessment of Figure 5

Metric	method	image1	image 2	image 3	Image4	image5	image6
PSNR	*WB*	12.6239	9.1141	6.3107	12.4238	15.8898	8.7089
	DCP	25.1648	22.4377	27.4336	41.5086	21.2399	23.9710
	CLAHE	21.4773	22.0480	23.9710	22.0350	21.4857	20.256
	OURS	26.4460	22.3580	28.2080	42.0512	25.1876	24.0019
SSIM	*WB*	0.7034	0.7431	0.5770	0.3700	0.3700	0.4329
	DCP	0.8649	0.8466	0.8704	0.9484	0.9484	0.8745
	CLAHE	0.7873	0.8048	0.8447	0.7045	0.7045	0.7591
	OURS	0.8207	0.8038	0.8892	0.9722	0.8722	0.8911
UIQE	*WB*	0.4522	0.2296	0.36164	0.76715	0.3383	0.3530
	DCP	0.5810	0.33513	0.42771	0.2345	0.4233	0.4723
	CLAHE	0.3017	0.3409	0.5129	0.6235	0.3707	0.5538
	OURS	0.6537	0.3559	0.5467	0.6613	0.5121	0.6305

4. Conclusion

This study proposes an underwater image enhancement method based on multi-scale fusion, aiming to improve the visibility and clarity of images in underwater environments. Through a combination of steps such as white balance, dark channel prior, CLAHE algorithm processing and multi-stage and multi-scale fusion for underwater images, underwater noise and interference components can be more comprehensively suppressed, and useful image details and structures can be highlighted. The experimental results verify the effectiveness of the image enhancement method, which makes the color of the image more accurate and natural, improves the contrast and brightness of the underwater image, and has better visual effect and richer detail information.

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