Single Underwater Image Enhancement Based On UCIQE

Jun Ao¹, Mingming Zhang¹ and Chunbo Ma¹*
¹Guilin University of Electronic Technology, Guilin, Guangxi, P.R.China:
*Corresponding author’s e-mail: 1257114687@qq.com

Abstract. In order to deal with the problems of low contrast and color distortion of underwater images, a single underwater image enhancement method based on UCIQE is designed in this paper. It estimates background light intensity by a quad-tree search algorithm and divides the image into many blocks based on the assumption that the transmittance of local blocks is equal. The objective function of each block is composed of UCIQE and the information loss function, and the transmittance is obtained at maximum value of the objective function. The global optimization of the overall transmittance image is carried out by using the guided filter. Experimental results demonstrate that this method can effectively solve the problem of color deviation and blur of underwater degraded images.

1. Introduction

In recent years, people need more and more information with the increasing frequency of ocean exploration activities. However, due to the influence of insufficient light and suspended particles in the underwater environment, the images always exhibit serious degradation, color distortion and loss of effective information. Therefore, it is crucial to study how to improve the underwater image quality. In the complex underwater environment, there are three main reasons lead to the poor image quality: First of all, the degree of absorption for each component of light is different in water, and the red is the fastest in that, which causes the underwater image to appear blue-green in most cases. Secondly, the underwater image is blurred and has low contrast in appearance, because of the scattering of light by suspended particles in water and the refraction of light by soluble molecules. The last is the influence of artificial light source. It would lead to uneven brightness of the image.

In this paper, a new underwater image enhancement method based on the optimization algorithm is proposed. In order to make the restored image more suitable for human visual perception, the underwater color image quality evaluation function (UCIQE)[5] in Lab color space is used as the optimization function. This method is mainly divided into two parts: the background light and the local optimal transmittance estimate.

The rest of this paper is organized as follows: Section 2 describes the related work about this field. Section 3 introduces the underwater optical imaging models and the relationship of transmittance within three channels. The proposed method is described in Section 4. Section 5 evaluates and compares experimental results with other algorithms. Finally, Section 6 summarizes the conclusions.

2. Related work

In recent years, the study of single underwater image enhancement have the great progress, and many classic and effective methods have emerged. These methods are mainly divided into two categories: based on physical and non-physical model.
The method of underwater image enhancement based on the physical model is mainly according to the underwater imaging model. Through the prior estimation of some parameters and then solve the model, after that, we will get the enhanced image with less distortion from the degraded image. In 2010, Bianco etc[2] proposed a method to enhance image based on the different attenuation rate of light. It estimated the depth of field by the difference between the maximum value of the red channel and blue-green channel in underwater image, and then the underwater optical imaging model is solved to obtain a clear image. In 2016, Li etc[4] proposed a method for blue-green channel enhancement and red channel compensation. This method based on a dark channel prior and the gray world algorithm. The experimental results show that this method would solve the problem of color distortion and improve the clarity, but it does not distinguish the transmittance within blue and green channels.

The method based on non-physical model mainly operates on the pixel value of degraded image directly, and achieves the goal of image quality improvement by global adjustment. In 2012, Ancuti etc[7] proposed an method based on multi-scale fusion. Firstly, the gray world algorithm is used to correct the color distortion; secondly, the contrast is processed by using the bilateral and histogram filter; finally, it will design the weight factor and do the multi-scale fusion operation for the images.

Although the above methods have a certain effect for image enhancement, there are still some problems. Most methods based on physical model have the problem of estimating underwater optical model is not properly, and the prior condition estimation method has universality. Most of the methods based on non-physical model does not consider the factors of underwater image degradation, which will cause the result image to produce uneven brightness.

3. Underwater image formation model

Comprehensive consideration all kinds of factors in underwater degraded image, this paper adopt the method based on the physical model. Due to the similarity between the underwater environment and the atmospheric fog environment, this paper use the atmospheric scattering model instead of the underwater optical imaging model:

\[
I(x) = J(x)t(x) + A(1-t(x))
\]

In the above formula, \(x\) is the coordinates of the pixels in the image; \(I\) is the observed degraded image; \(J\) represent the clearly image; \(A\) is the ambient light intensity in the underwater environment; \(t \in [0,1]\) is the transmittance image, it represents the degree of reflection of light by an object, which attenuates exponentially during transmission:

\[
t_i(x) = e^{-\beta_i d(x)}
\]

Where \(i \in \{r,g,b\}\), \(d(x)\) is the distance from the object to the camera (the depth of field), and \(\beta\) is the attenuation coefficient caused by the scattering and absorption of light in the medium. we known that the three-channel attenuation coefficient has the following relationship:

\[
\begin{align*}
\beta_g &= b_g A_g = (c_1 - c_2 \lambda_g) A_g \\
\beta_r &= b_r A_r = (c_1 - c_2 \lambda_r) A_r \\
\beta_b &= b_b A_b = (c_1 - c_2 \lambda_b) A_b
\end{align*}
\]

Where, \(b\) represents the scattering coefficient of light, and \(\lambda\) represents the wavelength of the corresponding color light, \(\lambda_r = 620\text{nm}, \lambda_g = 540\text{nm}, \) and \(\lambda_b = 450\text{nm}\). \(c_1 = 1.62517\), \(c_2 = 0.00113\). According to (2, 3, 4), we can obtain the relationship:

\[
\begin{align*}
t_g(x) &= t_i(x) \frac{\beta_g}{\beta_r} \\
t_b(x) &= t_i(x) \frac{\beta_b}{\beta_r}
\end{align*}
\]

In short, after obtaining the illumination, we only need to estimate the transmittance for one channel, and the others channels can be obtained according to the (5, 6). For the underwater optical
imaging model, our goal is to get the recovered image with good quality. Here, the (1) can be written as:

$$J(x) = \frac{I(x) - A}{t(x)} + A$$  

(7)

From (7), we can know that the result image is determined by the ambient light and the transmittance image together, and the known condition is only the degraded image $I$. So estimative the illumination intensity and transmittance accurately of every channel, which determines the final image quality.

4. The proposed method

The main steps of this method are shown in Figure 1. It mainly consists of four parts: the first is that get the ambient light intensity based on the Quad-tree method; the second is that apply the optimization method to estimate the transmittance image in the local area; the third is that optimize the rough transmittance image by guided filter, and it can eliminate the block effect of the image; finally, the high quality image can be obtained according to the underwater optical imaging model.

4.1. Background Light Estimation

Generally, the brightest point in the image is selected as the background light intensity or based on the dark channel. However, these methods are not suitable for the situations when an object is brighter than the global background in the image. In order to estimate the ambient illumination more accurately, this paper uses the quad-tree algorithm[1] to search candidate region and make the average pixel value of the region as the illumination intensity.

Specifically, we divide the image into four rectangular regions, and compare the difference of the mean value and the standard deviation of pixels in every region; after that, get the biggest difference region and divide it into four equal regions; then, repeat the above process until the area size meet the set requirements; finally, the average value of region is used as the illumination intensity of the image:

$$A_c = \frac{1}{n \times m} \sum_{i=1}^{n} \sum_{j=1}^{m} I_c (i,j)$$  

(8)

Where, $c \in \{r,g,b\}$, $n, m$ are the size of the final selected region.

4.2. Transmission Estimation

After obtaining the global ambient light intensity, the result image $J$ in (7) will be determined only by the transmittance. In this paper, we assume that the transmittance is equal in local area. The observed image is divided into non-overlapping uniform blocks, and then every region is processed separately. In order to obtain the better quality image and make it more suitable for human visual perception, this
paper use the underwater color image quality evaluation function \( \text{UCIQE} \)\(^5\) as the optimization function. This function is a linear combination of image chromaticity, saturation and contrast, which can represent color cast, blur and detail for the image more accurately. Therefore, we can get the appropriate transmittance based on this optimization method, and obtain the best quality image.

\[
\hat{f}_{\text{UCIQE}} = c_1 \times \sigma_c + c_2 \times \text{con}_l + c_3 \times \mu_s
\]  

(9)

Where, \( \sigma_c \) is the standard deviation of the chrominance components; \( \text{con}_l \) is the contrast of the luminance component; \( \mu \) is the average of the saturation.

According to (8), after estimating the ambient light intensity \( A \), the recovered image \( J \) is proportional to the reciprocal of the transmittance \( t \). Since the effective pixel of an image should be [0, 255], but there are some pixels whose intensity outside of this range in the actual operation. By calculating the sum of these pixel, we use it as the image information loss function. The expression is as follows:

\[
f_{\text{loss}} = \sum_{c=1}^{C} \sum_{f=1}^{F} \{(\min\{0,J_{c,f}\})^2 + (\max\{255,J_{c,f}\})^2\}
\]  

(10)

About the clear image, we expect that the smaller of the loss function value, and the bigger of the optimization function value. Therefore, the difference of the optimization function and the information loss function is determined as the objective function \( f_{\text{cost}} \). In order to make the object function get the maximum value, we get the most suitable transmittance value in local region by optimizing solution.

\[
t = \arg \max(\hat{f}_{\text{object}} - f_{\text{loss}})
\]  

(11)

After solving the above formula, the transmittance can be obtained from every block. And at the same time, the global transmittance image is also got. In the end, we will get the transmittance images about every channel based on the (5, 6).

4.3. Transmission Refinement

The real transmittance image should have a clear outline of the object. In Section 4.2, we assumed that all pixels have the same transmission value in local region, but it will result in halo phenomenon in the recovered image. So it is necessary to optimize the rough transmittance image. At present, there are two methods to optimize the transmission image: the first is that soft matting algorithm, which can obtain the fine contour of the image effectively, but the time complexity is too high; the other is that the guided filtering algorithm, this method is the improved version of soft matting algorithm in reference, which reduce the complexity of the algorithm effectively on the premise of ensuring the effect. In this paper, we use the guided filtering algorithm to optimize the coarse transmittance image, and the grayscale image as the guide image from the original degraded image.

5. Experimental result and evaluation

In order to show the effectiveness of the proposed method, this method is compared with the algorithms of CLAHE\(^8\), Bianco\(^2\), Bekaert\(^7\) and Galdran\(^3\) in the same running environment. This experiments are implemented with MATLAB R2017b and on a PC with Windows 7 Ultimate 64-bit, the processor is Intel's fourth-generation Core i7-4510U, the memory is 8GB. About the selection of parameters in this experiment, we use the entropy and peak signal-to-noise ratio (psnr) of the recovered image as the comprehensive evaluation indexes. The area size is 200 when gaining the background light intensity; the size of the selected block is 11×11 for transmission estimation.

As shown above, the first column is the degraded image; the second column is the result image by the contrast adaptive histogram equalization (CLAHE)\(^8\); the third column is the effect image of the method based on attenuation difference of color light\(^2\); the fourth column is based on the processing results of multi-scale fusion\(^7\); the fifth column is the recovered image based on red channel inversion\(^3\); The last column show the results by our proposed method. As can be seen from the subjective visual evaluation, Literature\(^8\) increases image detail effectively, but it does not solve the color offset for underwater degradation image; although the method\(^2, 6\) solves the problem of image
color offset, there is no significant improvement in the clarity, because it does not take into account the problem of the image blur optimization; about the method[7], it produces more severe color distortion while restoring the image details. Compared with these methods, our method considers the index such as image saturation and ambiguity, which can solve the problem of image color offset and detail distortion effectively.

In the underwater environment, a better underwater image enhancement method will improve the color effect of the degraded image. The study shows that the color richness of an image can be represented by a function of image statistics effectively. So we use the UCIM to evaluate the color correction performance of every algorithm.

|                | Input   | Method[8] | Method[2] | Method[7] | Method[3] | Proposed |
|----------------|---------|-----------|-----------|-----------|-----------|----------|
| Image1         | -65.702 | -42.223   | -29.784   | -29.198   | -27.490   | -2.6174  |
| Image2         | -40.999 | -20.201   | -27.147   | -3.5334   | -15.391   | 15.391   |
| Image3         | -84.182 | -50.683   | -42.029   | -15.910   | -25.816   | 5.225    |
| Image4         | -80.371 | -6.6736   | -44.982   | -5.3748   | -8.9529   | -0.4234  |
| Image5         | -67.397 | -4.1393   | -55.806   | -19.451   | -18.044   | 2.7766   |

After the processed by the above various enhancement algorithms, it can be seen from Table 1 that the UCIM value has a greatly improved compare with the input image, and our method has the best color correction effect within that.

For a better quality image, in order to express the visual quality of underwater images more accurately, it is necessary to consider the color richness, sharpness and contrast of the image. In this paper, we use the comprehensive underwater image quality evaluation function UIQM[7] without reference. This function is a linear combination of the color evaluation function(UICM), sharpness evaluation function (UISM) and contrast evaluation function(UIConM) of the image:

$$UIQM = \alpha \times UICM + \beta \times UISM + \gamma \times UIConM$$  \hspace{1cm} (12)

In (13), $\alpha$, $\beta$ and $\gamma$ represents the weight factors about three evaluation functions.
For the recovered images shown above, Table 2 shows the objective evaluation statistics for these methods. It can be clearly seen that this method can make the underwater degradation image more clearly and achieve the better visual effect.

Beside the above methods, this paper also takes the image information entropy as an index to compare and analyze these algorithms. The larger of the entropy, the better of the enhanced image quality.

\[
E = -\sum_{i=0}^{255} p(i) \log p(i)
\]  

Where, \(p\) represents the probability of the pixel value \(i\) in the image. Table 3 shows the information entropy about the result image. As we can see, our method can get the higher entropy than other algorithms in most cases.

| Input     | Method[8] | Method[2] | Method[7] | Method[3] | Proposed |
|-----------|-----------|-----------|-----------|-----------|----------|
| Image1    | 2.6168    | 3.7964    | 4.1838    | 3.8946    | 4.3906   |
| Image2    | 1.0406    | 2.9543    | 3.1495    | 2.6747    | 3.5638   |
| Image3    | 0.1043    | 2.4688    | 2.9560    | 2.2511    | 4.9513   |
| Image4    | 1.0481    | 3.8971    | 3.2320    | 2.6747    | 4.4072   |
| Image5    | 0.7678    | 3.0829    | 1.8054    | 2.9560    | 3.1595   |

| Input     | Method[8] | Method[2] | Method[7] | Method[3] | Proposed |
|-----------|-----------|-----------|-----------|-----------|----------|
| Image1    | 7.3157    | 7.7243    | 7.8075    | 7.2296    | 7.7442   |
| Image2    | 6.9090    | 7.4541    | 7.3801    | 6.9797    | 7.6251   |
| Image3    | 7.4393    | 7.6505    | 7.6588    | 7.2644    | 7.124   |
| Image4    | 7.1721    | 6.8352    | 7.2375    | 7.2521    | 7.6818   |
| Image5    | 6.2143    | 5.4144    | 6.7873    | 6.3083    | 7.6332   |

6. Conclusion

About the problem of color distortion and low contrast in underwater image, this paper designs a single underwater image enhancement method based on UCIQE. Firstly, the background intensity is estimated by the quad-tree search method[1]; secondly, the objective function is constructed by the underwater color image quality evaluation function and the information loss function, then solved by optimization; finally, the guided filtering is applied to optimize the transmission image. The experimental results demonstrate that our method has the better effect on color correction and detail improvement of underwater images.

References

[1] Kim J H, Sim J Y, Kim C S. Single image dehazing based on contrast enhancement[C]/ IEEE International Conference on Acoustics, Speech and Signal Processing. IEEE, 2011:1273-1276.
[2] Carlevaris-Bianco N, Mohan A, Eustice R M. Initial results in underwater single image dehazing[C]/ Oceans. IEEE, 2010:1-8.
[3] Galdran A, Pardo D, Picón A, etc. Automatic Red-Channel underwater image restoration [J].Journal of Visual Communication & Image Representation, 2015, 26(C):132-145.
[4] Li C, Quo J, Pang Y, etc. Single underwater image restoration by blue-green channels dehazing and red channel correction[C]/ IEEE International Conference on Acoustics, Speech and Signal Processing. IEEE, 2016:1731-1735.
[5] Yang M, Sowmya A. An Underwater Color Image Quality Evaluation Metric[J]. IEEE Transactions on Image Processing, 2015, 24(12):6062-6071.
[6] Liu H, Chau L P. Underwater image restoration based on contrast enhancement[C]/ IEEE International Conference on Digital Signal Processing. IEEE, 2017:584-588.
[7] Bekaert P, Haber T, Ancuti C O, etc. Enhancing underwater images and videos by fusion[C]// IEEE Conference on Computer Vision and Pattern Recognition. IEEE, 2012:81-88.

[8] Reza A M . Realization of the Contrast Limited Adaptive Histogram Equalization (CLAHE) for Real-Time Image Enhancement[J]. Journal of VLSI Signal Processing Systems for Signal, Image, and, Video Technology, 2004, 38(1):35-44.