An Underwater Image Dehazing Method using Dark Channel Prior

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Abstract: Haze is caused by suspended particles such as sand, minerals, and planktons that exist in lakes, oceans, and rivers. It visually disturbs underwater images resulting in low contrast, poor visibility conditions, absorption of natural light and little color variations. It is important to dehaze so as to improve the quality and visibility of underwater images. In this paper, the Dark Channel Prior (DCP) algorithm is put forth, based on the observation that most local patches in the outdoor haze-free images contain some pixels whose intensity is very low in at least one color channel. With DCP, significantly enhanced visibility and superior color fidelity of underwater images are obtained. It reduces the computational complexity and improves the efficiency in terms of dehazing effect.

***Keywords:**Dehazing, Dark Channel Prior, underwater images, color channel.*

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I. INTRODUCTION

Light dispersion and color effect are two major sources of distortionsin an underwater image. Light scattering lowers the visibility and contrast of the captured image. Also color change leads to the varying degrees of attenuation with particles such as sand, minerals, plankton 0and so on,such particles present in water along with the absorption of natural light, and scattering affects an image taken in underwater. As light reflected from theseobjects proceeds towards the camera, a portion of the light meets such suspended particles, thus absorbing and scattering the light. The applied method, Dark Channel Prior (DCP) method estimates the atmospheric light and the mathematical function to handle both sky and non-sky regions. Then it finds the affected patches on images, estimates the scene depth and dehazes the image. As block-based dark channel prior produces a less accurate depth map, image matting is applied along with the depth map to improve accuracy and to identify object contours more precisely. The application of image matting to the underwater depth map derived by the general dark-channel methodology is a novel approach. The next section lists out the existing works.

II. LITERATURE SURVEY

John Y. Chiang and Ying-Ching Chen [1]proposed the Wavelength Compensation and Image Dehazing (WCID) algorithm,to handle light scattering and color change distortions suffered by underwater images. They demonstrated superior haze removing and color balancing capabilities of theproposed WCID over traditional dehazing and histogram equalization.

XinweiZhao, TaoJin, and SongQu [2]first derived the inherent optical properties of underwater images. Using formation model and DCP algorithm they estimated the red color channels to improve the images.It showed good improvement on dehazing when compared with other existing methods.

Rubi Mandal andSitendra Tamrakar [3] restored the color and enhanced on underwater images affected by light scattering using the WCID algorithm. The proposed WCID method performed better than other dehazing and histogram equalization methods.

Bingquan Huo and Fengling [4]recovered a sing haze image by using the optical model and DCP model followed by estimation of transmission. The DCP and estimate transmission model approach enabled dehazing when the problem cannot be solved by optics alone.

R.Sathya and M.Bharathi [5]enhanced underwater images using hue alteration. Hazewas removed by DCP followed by hue alteration using wavelength compensation.

Guo, Xue, Tang and Guo Lingrui [6] restored the visibility, color, and natural appearance of underwater images.They achieved better visual quality, more valuable information and more accurate color restoration when compared with several state-of-the-art methods.

The proposed methodology is explained in the following section.

III. PROPOSED METHODOLOGY

The Dark Channel Prior (DCP) algorithm proposed by He, Sun and Tang [8] whichis an existing scene depth derivation method that dehazesan underwater image is used here.Based on the depth map,the foreground and background of the imageis segmented.Using this prior along with the haze imaging model, can directly estimate the transmission map and recover a high quality haze-free image.Fig.1. shows the flow chart of DCP.

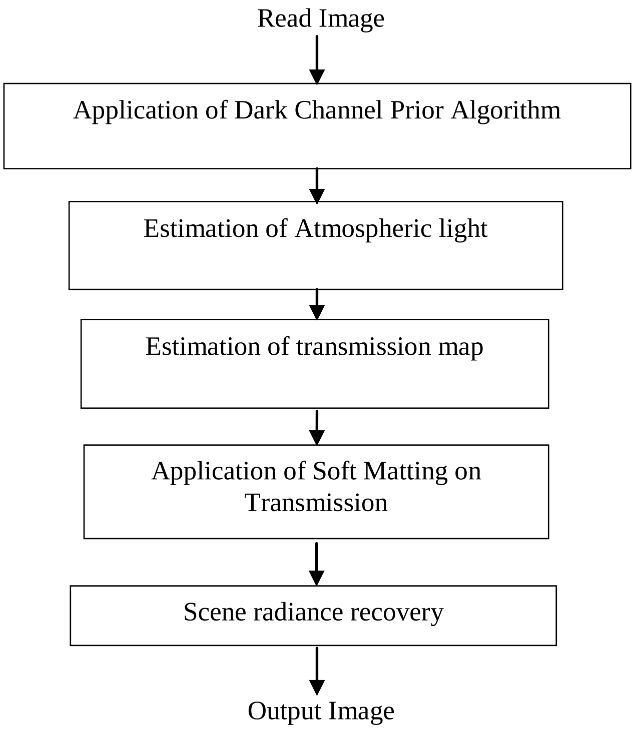


Fig.1. Flow chart of dark channel prior algorithm

The most widely used model to describe the formation of a haze image is given in Eqn. (1)

$$I(x) = J(x)\,t(x) + A\,(1 - t(x)) \qquad \text{Eqn. (1)}$$

where *I* is the observed image intensity, *J* is the scene radiance, *A* is the global atmospheric light and *t* is the medium transmission, describing the portion of light that reaches the camera. The goal of haze removal is to recover *A*, *J* and *t* from *I*. [7]

Thiswork computes the DCP, and then estimates the Atmospheric Light*A* based on it. Then,the estimated *A*is used to estimate transmission *t*. This transmission is then refined using soft matting and scene radiance *J* is recovered using the results. The improved DCP algorithm is explained in the next section.

IV. DARK CHANNEL PRIOR ALGORITHM

A. Computation of Dark Channel Prior

The basis of this work and the usage ofDCP is the observation that in most of the non-sky patches, at least one color channel has very low intensity at some pixels. Formally for an image *J*, Eqn. (2) is given below.

$$J^{dark}(x) = \min_{c\in\{r,g,b\}}\left(\min_{y\in\Omega(x)} \left(J^{c}(y)\right)\right), \qquad \text{Eqn. (2)}$$

J^c is a color channel of *J* and $\Omega(x)$ is a local patch centered at *x*. The computation of DCP is given in algorithm1

Algorithm1:Computation of DCP

1: Select an image
2: Resize the image to the maximum of width and height of 500px
3: Dark channels are computed using a patch size 15*15 pixels

In the dark channel image, white pixels have values close to 1 and black pixels have values close to 0.

B. Estimation of Atmospheric Light

To get the atmospheric light, the average of the pixels in the original image that correspond to the top lightest 0.01% in the dark channel is used. The estimation of atmosphere light is given in algorithm2 [8]

Algorithm2: Estimation of Atmospheric Light

1. Assume the atmospheric light as A
2. Let the patch's transmission be *t(x)*
3. Take the min operation in the local patch on the haze imaging using Eqn. (3)

$$\min_{y\epsilon\Omega(x)}(I^c(y)) = t(x)\min_{y\epsilon\Omega(x)}(J^c(y)) + (1-t(x))A^c \quad \text{Eqn. (3)}$$

The min operation is performed on three color channels independently using Eqn. (4),

$$\min_{y\epsilon\Omega(x)}(\frac{I^c(y)}{A^c}) = t(x)\min_{y\epsilon\Omega(x)}(\frac{J^c(y)}{A^c}) + (1-t(x))\text{Eqn. (4)}$$

Then the min operation among three color channels is taken on the above Eqn. (4)to obtain Eqn. (5)

$$\min_c(\min_{y\epsilon\Omega(x)}(\frac{I^c(y)}{A^c})) = \tilde{t}(x)\min_c(\min_{y\epsilon\Omega(x)}(\frac{J^c(y)}{A^c})) + (1-\tilde{t}(x))\text{Eqn. (5)}$$

According to DCP, the dark channel J^{dark} of the haze-free radiance J tend to be zero as given in Eqn. (6)

$$J^{dark}(x) = \min_c(\min_{y\epsilon\Omega(x)}(J^c(y))) = 0\text{Eqn. (6)}$$

As A^c is always positive, this leads to Eqn. (7)

$$\min_c(\min_{y\epsilon\Omega(x)}(\frac{J^c(y)}{A^c})) = 0 \qquad \text{Eqn. (7)}$$

Putting Eqn. (7) into Eqn. (5), the transmission *t*is estimated by Eqn. (8)

$$\tilde{t}(x) = 1 - \min_c(\min_{y\epsilon\Omega(x)}(\frac{I^c(y)}{A^c}))\ \text{Eqn. (8)}$$

C. *Estimation of transmission map*

The transmission map and atmospheric light have important roles in haze removal. Estimation of transmission map is given below in algorithm3 [8]

Algorithm3: Estimation of transmission map

1. Given A as calculated above
2. Assuming that the transmission in a local patch is constant, the transmission is estimated using Eqn. (9)

$$\min_c(\min_{y\epsilon\Omega(x)}(\frac{I^c(y)}{A^c})) \to 1, and\ \tilde{t}(x) \to 0, \text{Eqn. (9)}$$

Here, a value omega (=0.95) is used to decide how much haze to keep in the image so that the human ability to perceive depth is not removed, which is given in Eqn. (10)

$$\tilde{t}(x) = 1 - \omega\min_c(\min_{y\epsilon\Omega(x)}(\frac{J^c(y)}{A^c}))\ \text{Eqn. (10)}$$

The transmission value is defined as 1 – omega multiplied with the dark channel of the normalized haze image. The normalized haze image is computed as a channel-by-channel division of each element by the corresponding channel*A*followed by the darkchannel function on the output.

D. *Application of soft matting on transmission*

Let the refined transmission map be*t(x)*. Rewriting t(x) and $\tilde{t}(x)$in their vector form as *t* and $\tilde{t}$, minimize the following cost function. The application of soft matting on transmission is given in algorithm4 [8]

Algorithm4: Application of soft matting on transmission

1. Apply soft matting algorithm to refine the transmission using Eqn. (11) as

$$E(t) = t^T \mathrm{LT} + \lambda(t - \tilde{t})^T(t - \tilde{t})$$

Eqn. (11)

2. The optimal *t* can be obtained by solving the following sparse linear system using Eqn. (12) as

$$(\mathrm{L} + \lambda \mathrm{U})t = \lambda\tilde{t}$$

Eqn. (12)

Where *U* is an identity matrix of the same size as L. Here, a small value is set on $\lambda(10^{-4}$in experiments) so that t is softly constrained by$\tilde{t}$.

3. The (i,j) element of the matrix L is defined using Eqn. (13) as

$$\sum_{k|(i,j)\epsilon\omega_k} (\delta_{ij} - \frac{1}{|\omega_k|}(1 + (\mathrm{I}_2 - \mu_k)^T(\sum\nolimits_k + \frac{\in}{|\omega_k|}\mathrm{U}_3)^{-1}(\mathrm{I}_3 - \mu_k)))$$

Eqn. (13)

Where $I_2$and$I_3$are the colors of the image *I* at pixels *I* and *j*, δ_{ij} is the Kronecker delta, μ_k and $\sum_k$ are the mean and covariance matrix of the window ω_k, U_3 is a 3*3 identity matrix, ε is a regularizing parameter, and |*wk*| is the number of pixels in *wk*.

E. Scene radiance recovery

With the transmission map, recover the scene radiance using algorithm5[8]

Algorithm5: Scene radiance recovery

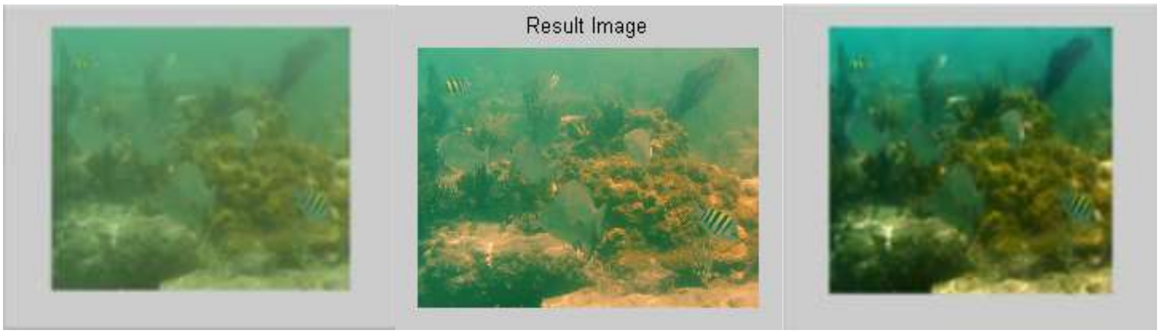
1. Recover the scene radiance *J*using Eqn.(1) with the transmission map*t* and the atmospheric light *A*
2. Restrict the transmission *t(x)* set to a lower bound, *t0* on *t* to avoid a noisy recovered scene radiance
3. The final scene radiance*J(x)* is recovered using Eqn. (14)

J(x) = A + (I(x) - A/max (t(x), t0)). Eqn. (14)

The next section is about experimental results and analysis.

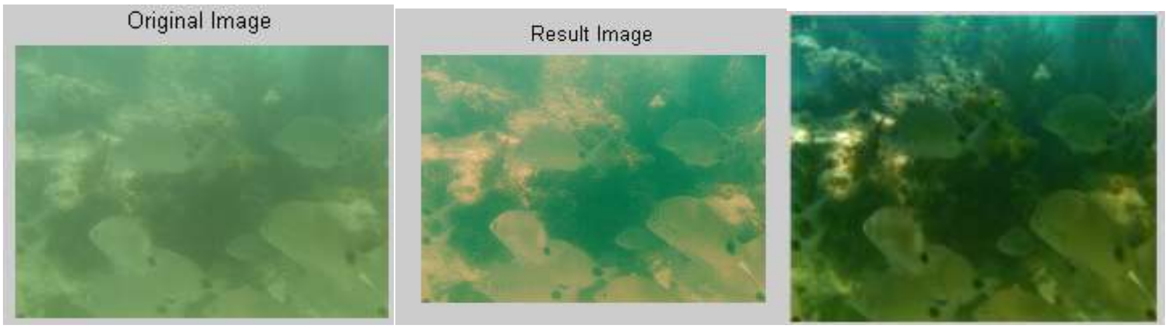
V. EXPERIMENTAL RESULTS AND ANALYSIS

The local patch size is a very important parameter for dark channel construction. Color textures are transferred to the dark channel when a small local patch is used, whereas blurry dark channels are obtained when a large local patch is used. The methods used for comparisons include dark channel prior method and histogram equalization method. Fig. 2. (a) And Fig. 3. (a) Are an imageswith haze, losing its brightness,that is, its original color.



(a) (b) (c)

Fig.2. Underwater sea plants and fish (a) Original image (b) Image obtained by histogram equalization and (c)Dehazed image by dark channel prior



(a) (b) (c)

Fig.3. Degraded underwater Fish image (a) Original image (b) Image obtained by Histogram Equalization and (c) Image obtained by DCP

Fig.2 (c) and Fig.3 (c)showthe outputs of DCP haze removal. Both haze images results show superior haze removing and color balancing capabilities over traditional histogram equalization method, as shown in Fig.2 (b) and Fig.3 (b). In the next section performance analysis is discussed.

VI. PERFORMANCE ANALYSIS

The performance measures for image dehazing are determined by measuring its Peak Signal to Noise Ratio (PSNR) and Mean Square Error (MSE). They are error metrics used to compare the image compress on quality.

A. *Mean Square Error (MSE):*

The MSE represents the cumulative squared error between the compressed and the original image, as given in Eqn. (15)

$$MSE = \frac{1}{m\,n}\sum_{i=0}^{m-1}\sum_{j=0}^{n-1}[I(i,j) - k(i,j)]^2$$

Eq. (15)

Here, M and N are the number of rows and columns in the input images, respectively.

B. *Peak Signal to Noise Ratio (PSNR):*

The PSNR represents the measure of peak error. To compute the PSNR, the block first calculates the mean-squared error using Eqn. (16)

$$PSNR = 20.log_{10}(MAX^2 I)$$ Eq. (16)

Table.1. The comparison of MSE and PSNR valuesfor different Haze images

Images	Method	MSE	PSNR
Underwater sea plants and fish	Histogram equalization	8.60	8.08
Degraded underwater Fish image	DCP method	8.96	8.98

VII. CONCLUSION

In this paper, the DCP algorithm is applied for underwater environment. By estimating the atmospheric light, and refining the transmittance image, underwater images are eventually restored. The experiment results shows that the DCP method enhances the quality of underwater images effectively compared to histogram equalization.Though the DCP algorithm performs better than the histogram equalization method, the obtained performance metrics values show that the existing DCP algorithm can be further enhanced for better image dehazing. Also, a fusion process can be introduced to increase the scene contrast and color appearance of the underwater image to improve the existing work.

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