Abstract - Underwater images are usually degraded due to the effects of absorption and scattering. Underwater imaging is very important in present technology for detecting object like fishes, algae, minor particles etc. Light scattering and color change are two dominant sources of distortion for underwater imaging that lowers the visibility and contrast of the captured images, affects ambient underwater environment dominated by a bluish tone. Hence, the presented system demonstrates a novel approach to enhance underwater images by distance factor estimation along with a dehazing algorithm and histogram equalization. The noise particles are removed before dehazing by implementing distance factor based on intensities of different color channels with gamma correction improving the brightness of dimmed images. The dark channel prior removes haze and noise effect, providing better visual quality with adaptive exposure map estimation for adjusting too dark and too bright regions of underwater image. At the final stage, the contrast and brightness of dehazed image is recovered by using contrast limited adaptive histogram equalization. The enhanced haze-free, natural appealing output can be used for display and analysis purpose.

Keywords - Underwater image dehazing, distance factor, gamma correction, dark channel prior, histogram equalization.

I. INTRODUCTION

Images captured under water are distorted due to the absorption and scattering effects. The light received by the camera is generated by three components [3]: a direct component reflecting light from the objects, forward scattering component randomly deviating light on the camera and back scattering component reflects light towards camera before it reaches the objects. This causes effects such as blurring, masking details of the image and may lead to produce noise.

When the light wave propagates through the water medium, different frequency components of light wave produces different absorption profile [1]. The absorption of light wave depends upon different factors such as amount of suspended particle in water, turbidity and salinity of water etc. It is seen that, light wave becomes weaker after traveling few distance in water. Fig.1 shows the comparison between absorption of light wave of different colors. Red wave travel very low distance and can propagate only one to two meter in pure water, green light travels nearly about 26 meters while blue light travels the highest distance and can propagate more than 30 meters in pure water. So any object lying more than 10 meters may lost its original color and the color of the objects seems to be blue.

K. He et.al [7] proposed a dark channel prior for dehazing the natural images. Dark channel having minimum intensity value on image patch among three (R, G, B) color components. Y. Chiang et.al [4] derived wavelength compensation and image dehazing (WCID) method for restoration of underwater images based on residual energy ratios of different color channels present in background light. Depending on the amount of attenuation related to each light wavelength, color change compensation is carried out to restore color balance. P. Dwivedi et.al [1] described a distance factor estimation with scattering loss reduction and high frequency emphasizing filtering to reduce blur and transparent layer of water. Degraded underwater images shows some limitations when being used for display and extracting valuable information for further processing, such as marine biology and archaeology, marine ecological research, and aquatic robot inspection. Gamma correction improves the brightness of underwater image. The distance between the objects and the camera is calculated that provides the estimation of each color channel by scene depth based on intensity level of three different color components. Implementation of the dark channel prior is a novel approach to dehaze the underwater image. The dehazed image value is adjusted to lie between specified pixel values eliminating too dark and too bright regions using exposure map. The contrast of dehazed image is enhanced by using adaptive histogram equalization which also reduces the transparent layer of water medium.

II. RELATED WORK

As an underwater image enhancement becomes important for display and analysis based applications,
A. Dark Channel Prior:
According to He et al. [7], the local regions that are present in background of the image have some pixel values with very low intensity in one of the color channel (R/G/B). This value is represented by Z in dark channel at x.

\[ Z_{\text{dark}}(x) = \min_{z \in \{R,G,B\}}(\min_{y \in \Omega(x)} Z^c(y)) \]  

(2)

In (2), \( Z^c \) represents one of the R, G, B channel of Z, and \( \Omega(x) \) is a square patch with center x. Normally, \( H(x) \) is brighter than \( Z(x) \) because \( H(x) \) represents intensity of image mixed with atmospheric or background light. So, dark channel of hazed image \( H(x) \) has high value compared to \( Z(x) \) and that is alterity to remove distortion. Medium transmission \( t(x) \) can be calculated by dividing (1) by global atmospheric light \( A \) as,

\[ \min_{z \in \{R,G,B\}} \left( \frac{H^c(y)}{A^c} \right) = \tilde{t}(x) * \min_{z \in \{R,G,B\}} \left( \frac{Z^c(y)}{A^c} \right) + [1 - \tilde{t}(x)] \]  

(3)

Referring to dark channel prior, the dark channel of haze haze-free image shows zero value, so it is given as,

\[ \min_{z \in \{R,G,B\}} \left( \frac{Z^c(y)}{A^c} \right) = 0 \]  

(4)

From (3) and (4),

\[ \tilde{t}(x) = 1 - \min_{z \in \{R,G,B\}} \left( \frac{H^c(y)}{A^c} \right) \]  

(5)

Moreover, He [7] added a small parameter in last term to keep small value of haze in the image to obtain the scene depth. A soft matting algorithm filters the medium transmission \( \tilde{t} \) and to obtain the accurate medium transmission \( t \). Dark channel prior shows some limitations when scene object is inherently similar to the background light over a large patch.

B. Wavelength Compensation & Image Dehazing
John Y. Chiang and Ying-Ching Chen implemented a wavelength compensation and image dehazing (WCID) [8] algorithm to remove the distortions caused by light change and color change simultaneously. They also used the dark channel prior method to estimate the distance of the scene objects to the camera, called as depth map. Based on the derived depth map, the foreground and the background regions are compared to detect the existence of the artificial light source, if any. If an artificial light source is detected, then its luminance is removed form foreground region to prevent overcompensation. The WCID algorithm removes the haze effect and color change along the underwater propagation path to the camera. Energy compensation for each channel is carried out subsequently to adjust the bluish tone to a natural color. Scene depth estimation by dark channel prior may cause compensation errors where relatively large white shiny regions of a foreground object might be misjudged as far away ones.

C. Histogram Equalization
Histogram equalization is a technique for enhancing contrast by adjusting image intensities. Adaptive histogram equalization (AHE) is used to magnify the local contrast in images [5]. It computes several histograms, each corresponding to a different part of the image, and then used to redistribute the brightness values of the image. Adaptive histogram clip (AHC) adaptively clips level and moderates over-enhancement of background regions of images. Rayleigh distribution can be used as AHC, which produces a bell-shaped histogram given as:
Rayleigh, \( K = K_{\text{min}} + \left[ 2(\alpha^2)\ln\left(\frac{1}{1-p(0)}\right) \right]^{0.5} \) (6) 

where \( K_{\text{min}} \) is a minimum pixel value, \( p(f) \) is a cumulative probability distribution and \( \alpha \) is a non-negative distribution parameter. However, AHE tends to over amplify noise in relatively uniform regions of an image.

D. Adaptive Gamma Correction

Enhanced color images are acceptable to human vision by using the HSV color model, which can decouple the achromatic and chromatic information of the original image to maintain color distribution [9]. In the HSV color model, the hue (H) and the saturation (S) preserves the color content and value (V) representing the luminance intensity. The color image can be enhanced by preserving H and S while enhancing only V. Hence, the AGC method [6] applied to the V component for color contrast enhancement, increasing the low intensity and avoiding the significant decrement of the high intensity for dimmed underwater images.

III. SYSTEM OVERVIEW

For free space haze image, particles assumed to be steady but for underwater images steadiness of water medium is seldom, so the image suffer from multiple reflection. Due to this effect another term is added as a motion blur due to motion of water medium (particles). So underwater image mathematically can also be derived as,

\[
I_w(x) = I_0e^{-\beta d(x)} + \eta_s + \eta_m \tag{7}
\]

where, \( \beta \) is scattering coefficient, \( d(x) \) is the scene depth, \( \eta_s \) is the noise term and \( \eta_m \) is the noise term due to motion of water medium. The recommended block diagram for underwater image enhancement is shown in fig. 3.

![Block Diagram](image)

**Fig. 3: System Block Diagram**

A. Gamma Correction:

Probability density function (PDF) and cumulative distribution function (CDF) are used to enhance the pixel intensity, but the brightness may get distorted. However, traditional gamma correction method based on constant power function with exponent \( \gamma \) provides brightness enhancement. So, \( \gamma \) value based on PDF and CDF is determined by the probability and statistical inference [6]. The simple form of the transform-based gamma correction (TGC) is given as:

\[
T(l) = I_{\text{max}} \left( \frac{l}{I_{\text{max}}} \right)^{1-cdf(l)} \tag{8}
\]

\[
cdf(l) = \sum_{l=0}^{l_{\text{max}}} \text{pdf}(l) \tag{9}
\]

\[
\text{pdf}(l) = \frac{n_l}{\tau} \tag{10}
\]

\[
\gamma = 1 - cdf(l) \tag{11}
\]

where \( n_l \) is number of pixels with intensity \( l \) and \( \tau \) is total number of pixels in image. This system enhances the contrast of image with appropriate brightness without generation of additional artifacts and distortion.

B. Distance Factor Estimation:

The intensity of light depends on the distance travelled by the light wave. The main problem in present domain is that the absorption of the medium is different for different chromatic of light, so distance factor will be different for different color component.

Here some conditions about different channels are taken and subsequently all assumptions related to color and depth of object are considered [1]. Then distance ratio based on intensity of patch in the image is derived as,

\[
D_r = \left[ \sum_{r,m} (I_g + I_b)/2 \right] * I_r \tag{12}
\]

\[
D_g = \left[ \sum_{r,m} (I_r + I_b)/2 \right] * I_g \tag{13}
\]

\[
D_b = \left[ \sum_{r,m} (I_r + I_g)/2 \right] * I_b \tag{14}
\]

If \( D_r > (D_g + D_b) \),

\[
D_r = K_r [1 - \{(D_r - D_g) + (D_r - D_b)] \tag{15}
\]

If \( D_r < (D_g + D_b) \),

\[
D_r = K_r [1 + \{(D_r - D_g) + (D_r - D_b)] \tag{16}
\]

where, \( r \) is size of patch, \( c \in (r, g, b) \) and \( K \) is parameter for strengthening the distance factor, \( K_r > K_g > K_b \). The range of \( K \) is 0 < \( K < 1 \). The intensity of output image is given as,

\[
I_o = (I_w(x) - \eta_s - \eta_m)e^{-\beta d} \tag{17}
\]

Asin (17), the noise particles generated due motion of water and multiple scattering of light are eliminated from the underwater hazed image.

C. Dark Channel Dehazing:

A dark channel method is an effective method to restore original clarity of the underwater image. Using dark channel prior [7], the scene depth can be estimated by the assumption that most local patches in an image contains some pixels with very low
intensities in at least one color channel. From (2), \(Z_c\) is one of the RGB channel of \(Z\), and \(\Omega(x)\) is a square region with center \(x\). If \(x\) doesn’t belong to local regions, then \(Z_{\text{dark}}(x)\) shows a low value and may tends to zero, so it is named as dark channel. In underwater images, the intensity of these dark pixels is provided by background light.
\[
Z(x) = \frac{\max[1, \frac{1}{I(x)} I_0]}{\max[1, \frac{1}{I(x)} I_0]} + A \tag{18}
\]
Combining the dark channel prior and a soft matting interpolation method of transmission map [5] given in (5), we obtained enhanced haze-free image as derived in (18). The threshold value \(t_0\) prevents low value of denominator.

D. Adaptive Exposure Map Estimation:
Based on the observation that the dark and bright regions of underwater images become too dark or too bright after being restored by dark channel dehazing, so an adaptive exposure map is employed to adjust the illumination intensity for better visual quality [8]. The adaptive exposure map \(s(x)\) can be obtained by solving the following optimization problem:
\[
\min_{s} \sum_{x} \left\{ 1 - s(x) \left[ \frac{Y_1(x)}{Y_0(x)} \right] + \sigma[S(x) - 1]^2 + \Phi(s) \right\} \tag{19}
\]
where \(s(x)\) is the adaptive exposure map, \(Y_1\) and \(Y_0\) are the illumination intensities of the restored and the input image, \(\sigma = 0.3\) is a constant and \(\Phi(\cdot)\) is a smoothness regularization. This optimization problem solved using a two steps. First, \(s(x)\) is solved without the smoothness regularization that provide a closed form solution. Second, guided filter GFI is applied to smooth this solution. Thus, a fast approximate solution as:
\[
s(x) = \text{GFI}\left[ Y_1(x), Y_0(x) + \sigma Y_1(x), \frac{Y_1(x)}{Y_0(x)} + \sigma Y_1(x) \right] \tag{20}
\]
Output = \(Z^c(x) \ast s(x), c \in (r,g,b)\) \(\tag{21}\)

E. Contrast Limited Adaptive Histogram Equalization:
The output have very low contrast, so it is applied to modified adaptive histogram equalization called contrast limited adaptive histogram equalization (CLAHE), that avoids the noise problem of AHE by limiting the amplification [5]. CLAHE model enhances the contrast of each tile. The induced artificial boundaries are eliminated by combining the neighboring tiles using bilinear interpolation. CLAHE restricts the amplification by clipping the histogram at a user-defined value called clip limit to avoid amplifying any noise especially in homogeneous areas in the image using uniform histogram distribution. Here, the clip limit is set at different level for images having different mean intensity values. And finally input image is matched with output of CLAHE to get the smoothed enhanced output.

IV. RESULTS

The results obtained by this method are shown in fig. 4. The experiment performed in MATLAB R2014a on a database available on YouTube [10]. The video first converted into series of images and then these images (a) are processed through derived algorithm. Gamma correction provides sufficient brightness for dimmed images (b). Distance factor estimation provides accurate distance between foreground object and the background. The dark channel prior efficiently removes the effect of haze and noise in the image (c) using distance factor but output contains too dark or too bright regions. This problem is avoided by adaptive exposure map estimation. This low contrast dehazed image is processed by CLAHE to enhance contrast and intensity. The contrast enhanced output is matched with input image to obtain smooth output (d). The quantitative results in table 1 shows that the proposed system provides best results compared with traditional methods. The derived system gives least mean square error of 508, and also provide maximum peak signal to noise ratio of 21.02 dB for the first fish image. The enhanced haze free output image shows every details of an image which can be further used for display and analysis purpose.

<table>
<thead>
<tr>
<th>Method</th>
<th>MSE</th>
<th>PSNR (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SID</td>
<td>1690.7</td>
<td>15.851</td>
</tr>
<tr>
<td>DCP</td>
<td>638.06</td>
<td>20.082</td>
</tr>
<tr>
<td>WCID</td>
<td>1013.3</td>
<td>18.073</td>
</tr>
</tbody>
</table>
Underwater Image Enhancement using Dark Channel Prior and Gamma Correction

Table 1: Quantitative Results

<table>
<thead>
<tr>
<th>HE</th>
<th>1556.3</th>
<th>16.209</th>
</tr>
</thead>
<tbody>
<tr>
<td>Proposed Method</td>
<td>508.26</td>
<td>21.069</td>
</tr>
</tbody>
</table>

CONCLUSION

Underwater image enhancement techniques provide a way to improve the property or object detection in underwater environment. There is lot of research initiated for improving the quality of underwater images, but very few enhancement techniques derived. This paper proposes a novel approach for underwater image enhancement based on dark channel dehazing method along with gamma correction that improves the brightness of the dimmed images. Dehazing algorithm based on dark channel prior provides enhanced output by removing the effect of absorption and scattering components, avoiding too dark and too bright regions by using adaptive exposure map. The contrast of an image is regained using CLAHE which avoids the over amplification of noise by setting clip limit. The overall system provides noise free enhanced image, maintaining natural appearance with improved visibility that unveils more details and valuable information.

ACKNOWLEDGEMENT

The authors gratefully acknowledge the support of Smt. Kashibai Navale College of Engineering, Pune. The author would like to express his sincere thanks to Dr. S.K. Shah, Head of Department, for her valuable reference, support throughout the work and Prof. N. M. Wagdarikar, for his complete support, cooperation, timely suggestions and valuable guidance.

REFERENCES


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