Underwater Image Enhancement by Wavelength Compensation and Dehazing

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Introduction

ACQUIRING clear images in underwater environments is an important issue in ocean engineering [1], [2]. The quality of underwater images plays a pivotal role in scientific missions such as monitoring sea life, taking census of populations, and assessing geological or biological environments. Capturing images underwater is challenging, mostly due to haze caused by light that is reflected from a surface and is deflected and scattered by water particles, and colour change due to varying degrees of light attenuation for different wavelengths [3]–[5]. Light scattering and colour change result in contrast loss and colour deviation in images acquired underwater. For example, in Fig. 1, the haze in the school of Carangid, the diver, and the reef at the back is attributed to light scattering, whereas colour change is the reason for the bluish tone appearing in the brown coral reef at the bottom and the yellow fish in the upper-right corner.

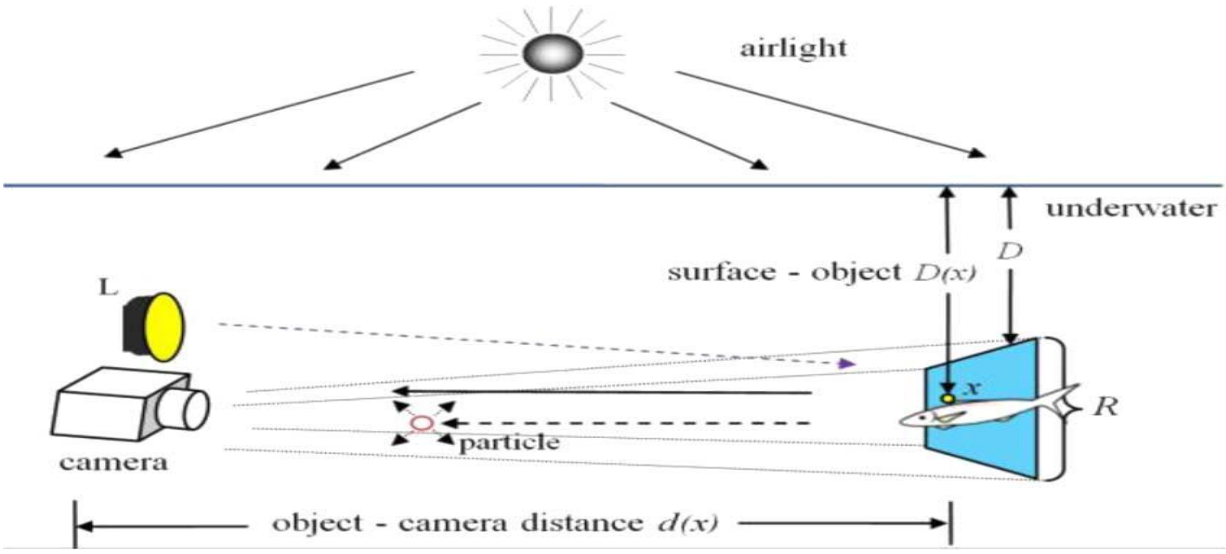


Fig. 1. Natural light enters from air to an underwater scene point . The light reflected propagates distance to the camera. The radiance perceived by the camera is the sum of two components: the background light formed by multiscattering and the direct transmission of reflected light.

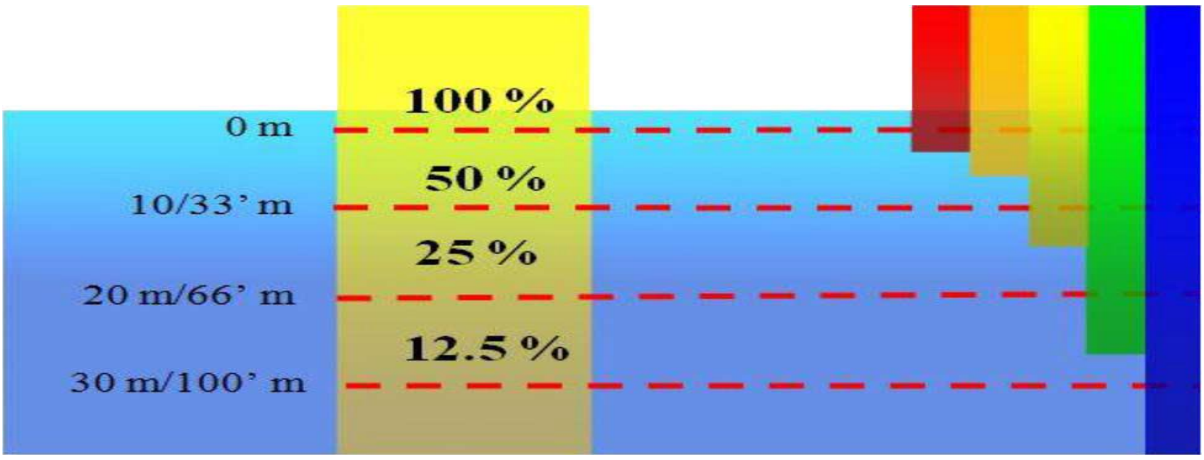


Fig. 3. Different wavelengths of light are attenuated at different rates in water. The blue color travels the longest in the water due to its shortest wavelength. This is the reason that underwater images are dominated by blue color.

Haze is caused by suspended particles such as sand, minerals, and plankton that exist in lakes, oceans, and rivers. As light reflected from objects propagates toward the camera, a portion of the light meets these suspended particles. This in turn absorbs and scatters the light beam, as illustrated in Fig. 1. In the absence of blackbody radiation [6], the multiscattering process along the course of propagation further disperses the beam into homogeneous background light. Conventionally, the processing of underwater images focuses solely on compensating either light scattering or color change distortion. Techniques targeting on removal of light scattering distortion include exploiting the polarization effects to compensate for visibility degradation [7], using image dehazing to restore the clarity of the underwater images [8], and combining point spread functions and a modulation transfer function to reduce the blurring effect [9]. Although the aforementioned approaches can enhance scene contrast and increase visibility, distortion caused by the disparity in wavelength attenuation, i.e., color change, remains intact. On the other hand, colour-change correction techniques estimate underwater environmental parametersby performing color registration with consideration of light attenuation [10], employing histogram equalization in both RGB and HSI color spaces to balance the luminance distributions of color [11], and dynamically mixing the illumination of an object in a distance-dependent way by using a controllable multicolour light source to compensate color loss [12]. Despite the improved color balance, these methods are ineffective in removing the image blurriness caused by light scattering. A systematic Approach is needed to take all the factors concerning light scattering, color change, and possible presence of artificial light source into consideration.

The algorithm for wavelength compensation and image dehazing (WCID) proposed in this paper combines techniques of WCID to remove distortions caused by light scattering and color change. Dark-channel prior [13], an existing scene-depth derivation method, is used first to estimate the distances of the scene objects to the camera. The low intensities in the dark channel are mainly due to three factors: 1) shadows, e.g., the shadows of creatures, plankton, plants, or rocks in seabed images; 2) colourful objects or surfaces, e.g., green plants, red or yellow sands, and colourful rocks/minerals, deficient in certain color channels; and 3) dark objects or surfaces, e.g., dark creatures and stone [8]. Based on the depth map derived, the foreground and background areas within the image are segmented. The light intensities of foreground and background are then compared to determine whether an artificial light source is employed during the image acquiring process. If an artificial light source is detected, the luminance introduced by the auxiliary Lighting is removed from the foreground area to avoid overcompensation in the stages followed. Next, the dehazing algorithm and wavelength compensation are utilized to remove the haze effect and color change along the underwater propagation path to the camera. The residual energy ratio among different color channels in the background light is employed to estimate the water depth within an underwater scene. Energy compensation for each color channel is carried out subsequently to adjust the bluish tone to a natural color. With WCID, expensive optical instruments or stereo image pairs are no longer required. WCID can effectively enhance visibility and restore the color balance of underwater images, rendering high visual clarity and color fidelity.

Underwater Model

The proposed WCID algorithm proceeds in a direction in- verse to the underwater image formation path discussed above, as depicted in Fig. 3. First, consider the possible presence and influen e$_L$ of the artificial light source. Next, remove the light scattering and color change that occurred along the course of propagation $d(x)$ from the object to the camera. Finally, compensate the disparities of wavelength attenuation for traversing the water depth to the top of the image and fine-tune the energy loss by deriving a more precise depth value for every point within an image.

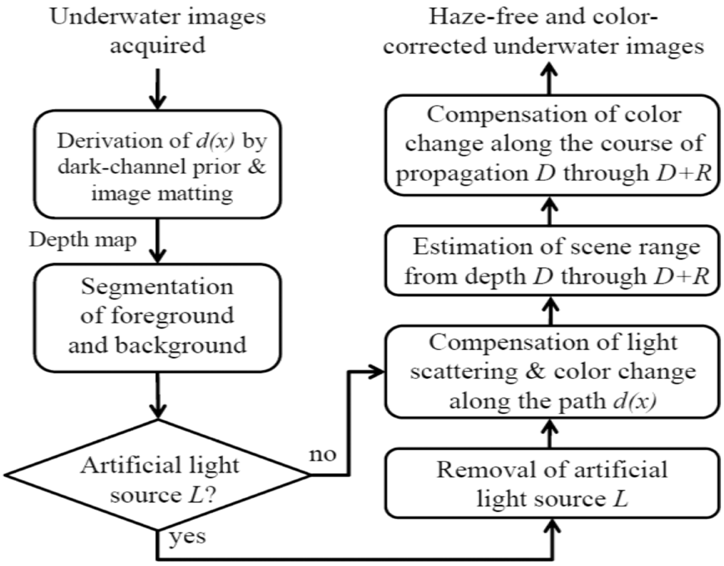


Fig. 3. Flowchart of the WCID algorithm proposed.

Distance between the Camera and the Object:

The common approach for estimating the depth of objects within a scene, i.e., depth map, often requires two images for parallax [20]. In a hazy environment, haze increases with distance; therefore, haze itself can be a useful depth clue for scene understanding. Consequently, evaluating the concentration of haze in a single image is sufficient to predict the distance $d(x)$ between the object in the scene and the camera [21]. The dark- channel prior [8], which is an existing scene-depth derivation method, is based on the observation that, in most of the non- background light patches $\Omega(x)$, where $\Omega(x)$, on a haze-free underwater image, at least one color channel has a very low intensity at some pixels. In other words, the minimum intensity in such a patch should have a very low value, i.e., a dark channel. Note that the low intensity observed through the dark channel is a consequence of low reflectivity existing in certain color channels. No pixels with a very low value can be found in the local patch $\Omega(x)$, which implies the existence of haze. The concentration of haze in a local patch can then be quantified by dark-channel prior. This in turn provides the object–camera distance $d(x)$ [13].

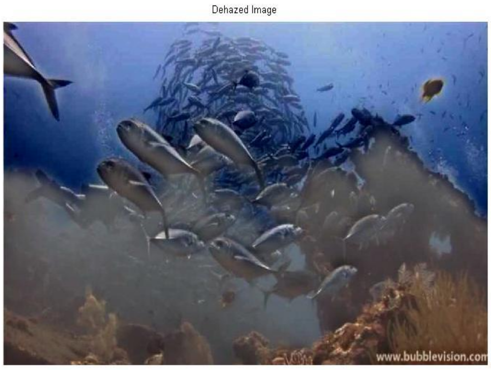
$$I_\lambda(x) = J_\lambda(x)t_\lambda(x) + B_\lambda(1 - t_\lambda(x)), \lambda \in \{R, G, B\}$$

$$t_\lambda(x) = \frac{Eo(\lambda, d(x))}{E_I(\lambda, 0)} = 10^{-\beta(\lambda)d(x)} = \left(Rer(\lambda)\right)^{d(x)}$$

$$E_B(\lambda, D) = E_A(\lambda, 0) \times \left(Rer(\lambda)\right)^D, \lambda \in \{R, G, B\},$$

To get the estimate of distance we get the estimate of Scattering Concentration and Color Cast by using Dark Channel Prior and calibrate the distance. Dark channel prior is an algorithm by which we can estimate hazing concentration and We Calculate distance from Camera to Object. After getting the estimate of depth we get the estimate of depth by same process and we remove the haze effect by subtracting the interpolated model of haze from original image.

Results of dehazing by this algorithms:



Hazed Image 1

Dehazed Image 1

Hazed Image 2

Dehazed Image 2

Hazed Image 3

Dehazed Image 3

Figure 4.

Conclusion:

The WCID algorithm proposed in this paper can effectively restore image color balance and remove haze. To the best of our knowledge, no existing techniques can handle light scattering and color change distortions suffered by underwater images simultaneously. The experimental results demonstrate superior haze removing and color balancing capabilities of the proposed WCID over traditional dehazing and histogram equalization methods. However, the salinity and the amount of suspended particles in ocean water vary with time, location, and season, making accurate measurement of the rate of light energy loss (λ) difficult. Errors in the rate of light energy loss will affect the precision of both the water depth and the underwater propagation distance $d(x)$ derived. Constant monitoring and long-term tabulation of the rate of light energy loss according to time, location, and season might provide a reasonable estimate of the actual value. In addition, a calibration procedure might be performed first by drivers before an image-capturing session by taking a test picture at known water depth and underwater propagation distance to fine-tune the rate of light energy loss. In addition, the artificial lighting is assumed to be a point source emitting uniform omnidirectional light beams across all wavelength spectrums. This is different from the linear or surface light source with a strong beam directionality and nonuniform color characteristic commonly encountered in underwater photography. The precise estimation of the luminance distribution of the light source is also demanding. If the geographic location in taking the underwater footage and the characteristics of the light source employed are known *a priori*, even better results in haze removal and color balance can be reached. Another source for causing compensation errors is the estimation of the scene depth $d(x)$ by the dark-channel prior, as commonly encountered in depth derivation by utilizing a single image. Relatively large white shiny regions of a foreground object might be misjudged as far away ones.

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