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Haze Removal and Color Compensation of Underwater Image and Denoising

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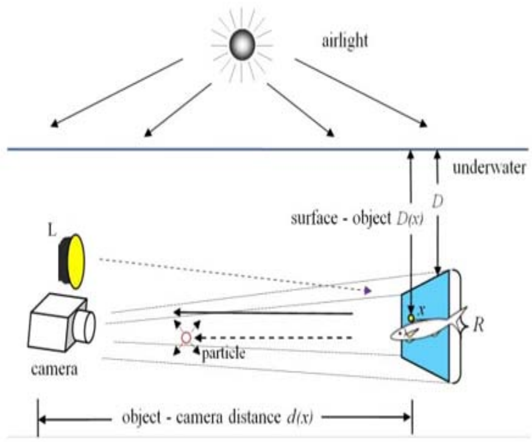
Abstract- Capturing image in underwater is challenging due to haze caused by light that is reflected from surface and is deflected and scattered by water particles. Color changes due to light attenuated for different wavelength .This paper proposes a novel systematic approach to enhance underwater images by a dehazing algorithm, to compensate the attenuation discrepancy along the propagation path, and to take the influence of the possible presence of an artificial light source into consideration. Once the depth map, i.e., distances between the objects and the camera, is estimated ,the foreground and background within a scene are segmented .The light intensities of foreground and background are compared to determine whether an artificial light source is employed during the image capturing process. After compensating the effect of artificial light, the haze phenomenon and discrepancy in wavelength attenuation along the underwater propagation path to camera are corrected. Next, the water depth in the image scene is estimated according to the residual energy ratios of different color channels existing in the background light. Based on the amount of attenuation corresponding to each light wavelength, color change compensation is conducted to restore color balance .Effect of noise is also reduced by using the frequency filter. Using this technique the visibility and color of the image can be enhanced.

Keywords– Color change, image dehazing, light scattering, under water image, wave-length compensation.

1. INTRODUCTION

Underwater photography is a more important for ocean engineering [1]. It is used to scientific research such as census of population, assessing geological environments, monitoring the sea life. In underwater environment various hazy images occur, caused by light that is reflected from a surface and is scattered by water particles. Underwater images are dominated by blue color, because of varying degrees of attenuation for different wavelengths i.e. red, green and blue [2] [3].This lowers the visibility and contrast. 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 [4], the multiscattering process along the course of propagation further disperses the beam into homogeneous background light.



The algorithm for wavelength compensation and image dehazing (WCID) existing work combines techniques of WCID to remove distortions caused by light scattering and color change.[5] Dark-channel prior [6], 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) Colorful objects or surfaces, e.g. green plants, red or yellow sands, and colorful rocks/minerals, deficient in certain color channels.
3) Dark objects or surfaces, e.g. dark creatures and stone

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 [5]

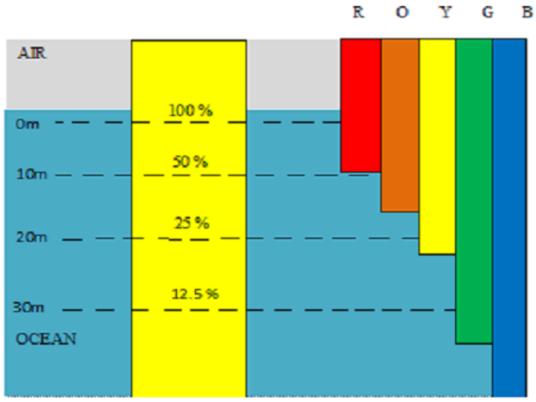


Fig 2 attenuation of different wavelength in water

The problem of image de-noising is to recover an image that is cleaner than its noisy observation.
Thus, noise reduction is an important technology in underwater image analysis and the first step to be taken before images are analyzed [7]. The previous work uses Spatial Filter to remove noise [8]. The proposed algorithm is used to remove distortion caused by light scattering and light
Attenuation and uses Frequency filter to remove noise. By using this algorithm, there are no requirements of expensive optical instruments or stereo image pairs.

2. UNDERWATER MODEL:

Underwater image formation model is shown in figure 1. Here natural light enters from air to an underwater scene point x and light reflected from the object and propagates distance d(x) to the camera. The light reached to the camera is the sum of the background light formed by multi-scattering and the direct transmission of reflected light. The background light in an underwater image can be used to approximate the true in scattering term in the full radiative transport equation to achieve the following simplified hazy Image formation model [9] [10].

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

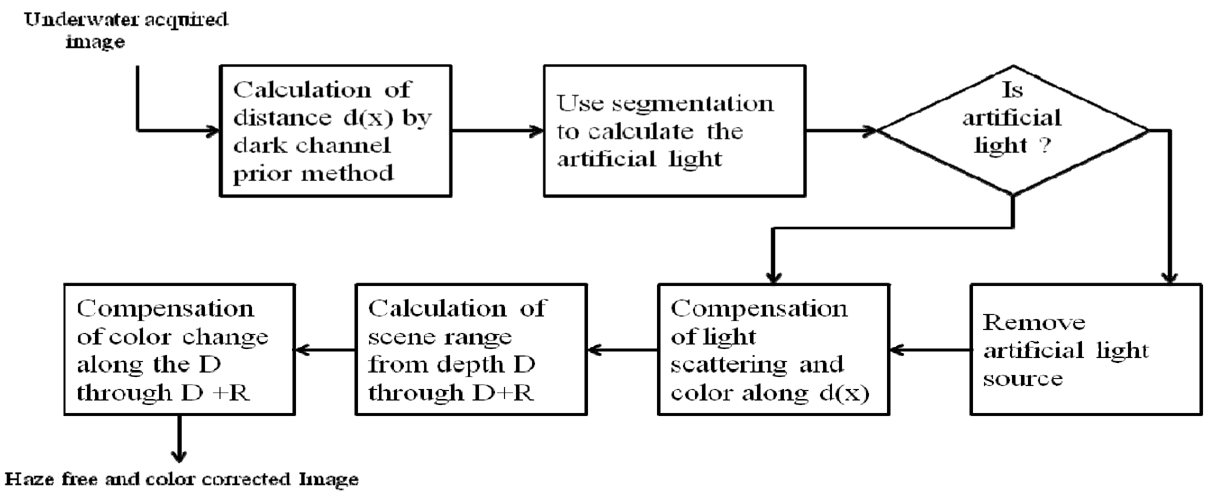
Where x = Point in the underwater scene, $I_\lambda(x)$ = Image captured by the camera,
$J_\lambda(x)$ =Scene radiance,
t_λ = residual energy ratio of $J_\lambda(x)$ after reflecting from point x in the underwater scene and reaching the camera,
A_λ = homogenous background light, λ = is the light wavelength
$J_\lambda(x).t_\lambda(x)$ = Decay of scene radiance in the water [11]
The residual energy ratio $t_\lambda(x)$ can be represented alternatively as the energy of a light beam with wavelength λ before and after traveling distance d(x) with in the water $E_\lambda^{initial}(x)$ and $E_\lambda^{residual}(x)$ respectively as follows

$$t_\lambda(x)=\frac{E_\lambda^{residual}(x)}{E_\lambda^{initial}(x)}=10^{-\beta(x).d(x)}=Nrer(\lambda)^{d(x)} \quad (2)$$

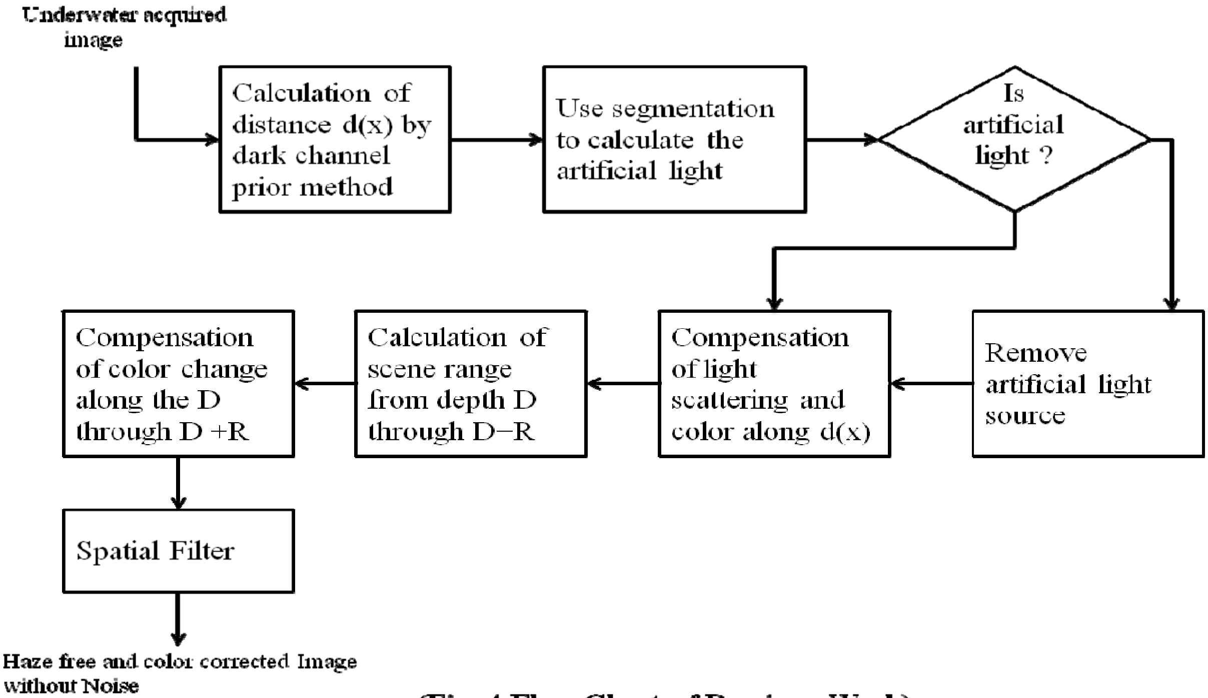
Where the normalized residual energy ratio Nrer(λ) corresponds to the ratio of residual to initial energy for every unit of distance propagated and β(x) is the medium extinction coefficient[10] The normalized residual energy ratio Nrer(λ) depends on the light wave length transmitted[12], as illustrated in Fig.2 where red light possesses longer wavelength and lower frequency and there by attenuates faster than the blue counter part. This results in the bluish tone prevalent in underwater images[13] Other than the wavelength of light transmitted ,the normalized residual energy ratio Nrer(λ) is also affected by water salinity and concentration of phytoplankton[12]. For every meter most clear ocean water the value of Nrer(λ) is 0.8 to 0.85 when λ is 650μm to 750μm, 0.93 to 0.97 when λ is 490μm to550μm and 0.95 to .99 when λ is 400μm to 490μm.

3. METHODOLOGY

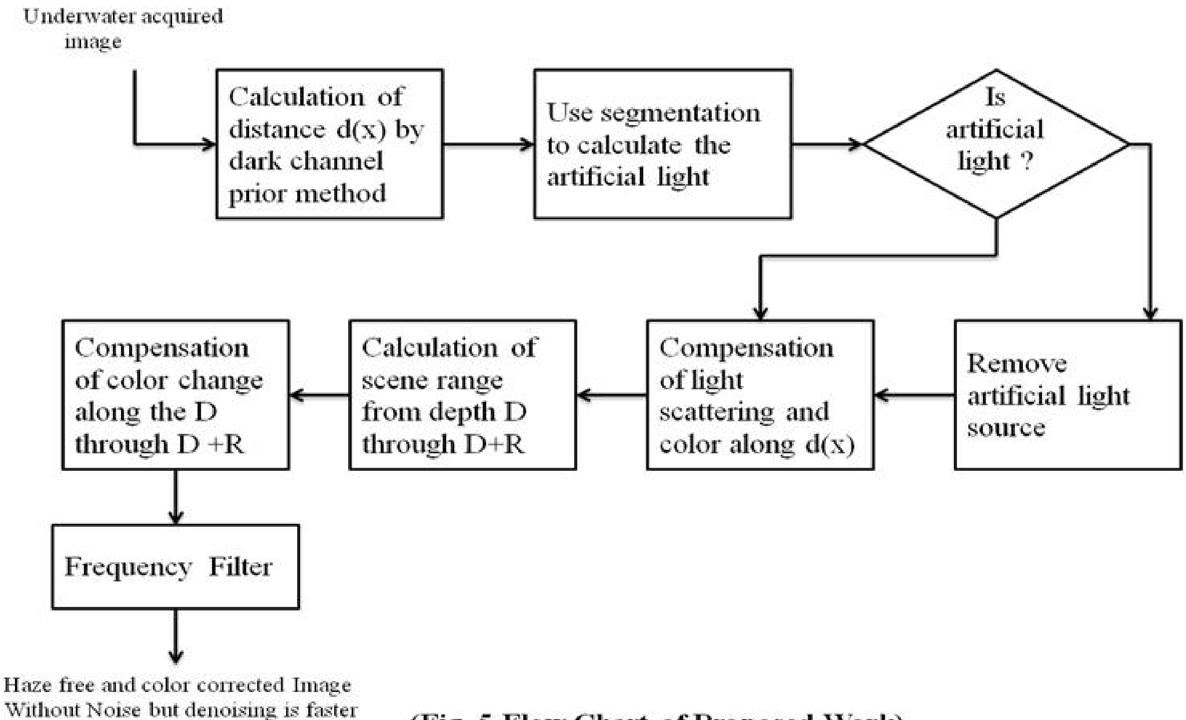
The Proposed algorithm represented in fig 3



(Fig. 3 Flow chart of WCID Algo.)



(Fig. 4 Flow Chart of Previous Work)



(Fig. 5 Flow Chart of Proposed Work)

First, consider the possible presence and influence of the artificial light source L. 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 D to the top of the image and fine-tune the energy loss by deriving a more precise depth value for every point with in an image. Incident light traverses from the surface of water reaching the image scene ,covering a range from depth D through D+R ,where corresponds to the image depth range. During the course of propagation ,light with different wavelengths is subjected to varying degrees of attenuation.

The amount of residual light W(x) formed after wavelength attenuation can be formulated according to the energy attenuation model in (2) as follows:

$$E_{\lambda}^{W}(x) = E_{\lambda}^{A}(x).Nrer(\lambda)^{D(x)}, \lambda \in \{red, green, blue\} \quad (3)$$

Note that color change occurs not only along the surface–

object propagation path but also along the object camera route. Light $J_\lambda(x)$. emanated from point x is equal to the amount of illuminating ambient light $E_\lambda^w(x)$ reflected, i.e. $E_\lambda^w(x).\rho_\lambda(x) = E_\lambda^A(x).Nrer(\lambda)^{D(x)}.\rho_\lambda(x)$
where $\rho_\lambda(x)$ is the reflectivity of point x for light with wave length λ .The surface object distance 'D(x)' is calculated by comparing the residual energy ratio of different color channels .By following the image formation model in a hazy environment in(1),the image $I_\lambda(x)$ formed at the camera can be formulated as follows

$$I_\lambda(x) = \left(E_\lambda^A(x).Nrer(\lambda)^{D(x)}.\rho_\lambda(x)\right).t_\lambda(x) + (1 - t_\lambda(x)).A_\lambda \qquad \lambda \in \{red, green, blue\} \qquad (4)$$

The artificial light source L is provided to compensate insufficient lighting under the water. The luminance contributed by the artificial light source has to be removed before the dehazing and color compensation.When the artificial light source L is detected, the light emitted E_λ^L has first to travel distance d(x) before reaching Point x .The residual energy after the course of propagation is $E_\lambda^L.Nrer(\lambda)^{d(x)}$.
The total amount of light impinges on point x is therefore the summation of ambient lighting $E_\lambda^W(x)$and the attenuated artificial light $E_\lambda^L.Nrer(\lambda)^{d(x)}$.The total amount of incident light

$$E_\lambda^A(x).Nrer(\lambda)^{D(x)} + E_\lambda^L.Nrer(\lambda)^{d(x)} \qquad (5)$$

is reflected with reflectivity $\rho_\lambda(x)$ and bounces back distance d(x) before reaching the camera .During both forward and backward courses of propagation pertinent to d(x) , color change occurs. Accordingly (6) can be further modified as the hazy image formation equation-

$$I_\lambda(x) = ((E_\lambda^A(x).Nrer(\lambda)^{D(x)} + E_\lambda^L.Nrer(\lambda)^{d(x)})) .\rho_\lambda(x)\ Nrer(\lambda)^{d(x)} + (1 - Nrer(\lambda)^{d(x)})\,A_\lambda \quad ,\lambda \in \{red, green, blue\}$$

(6) Above model shows the hazing effect, wavelength attenuation and artificial light effect. Now the given steps used to calculate the distance d(x), D(x), presence of artificial light, depth range 'R' and the corresponding procedure for dehazing color compensation and denoising.

3.1 Distance Between the Camera and the Object using dark channel prior method:

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[14] The dark channel prior [14],which is an existing scene-depth derivation method, is based on the observation that, in most of then on background light patches Ω(x) ,where x∈ Ω(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. We further assume that the transmission in a localpatch Ω(x) is constant.We denote the patch's transmission as t*(x). Note that the low intensity observed through the dark channel is a consequence of low reflectivity $\rho_\lambda(x)$ existing in certain color channels.No pixels with a very low value can be found in the local patch Ω(x) ,which implies the existence of haze.The concentration of haze in a local patch can then be quantified by dark-channel prior. This inturn provides the object–camera distance d(x) [15]. So-

$$J^{dark}(x) = \min_{\lambda\epsilon\{R,G,B\}}\left(\min_{y\epsilon\Omega(x)} J_\lambda(y)\right) \qquad (7)$$

From equation(1)-

$$I_\lambda(x) = J_\lambda(x).t_\lambda(x) + (1 - t_\lambda(x).A_\lambda \ \lambda \in \{r,g,b\}$$

Taking the min operation in the local patch on the haze imaging Equation -

$$\min_{y\epsilon\Omega(x)} I_\lambda(y) = t^*(x) \min_{\lambda\in\{r,g,b\}} J_\lambda(x).+(1 - t^*(x).A_\lambda \quad \lambda \in \{r,g,b\} \qquad (8)$$

$$\frac{\min_{y\epsilon\Omega(x)} I_\lambda(y)}{A_\lambda} = t^*(x) \min_{\lambda\in\{r,g,b\}}\left(\frac{J_\lambda(x)}{A_\lambda}\right) + (1 - t^*(x)) \qquad (9)$$

Then,we take the min operation among three color channels on the above equation and obtain:

$$\min_\lambda \frac{\min_{y\epsilon\Omega(x)} I_\lambda(y)}{A_\lambda} = t^*(x)\min_\lambda \min_{\lambda\in\{r,g,b\}}\left(\frac{J_\lambda(x)}{A_\lambda}\right) + \left(1 - t^*(x)\right) \ (10)$$

According to the dark channel prior, the dark channel Of the haze-free radiance J tend to be zero:

$$J^{dark}(x) = \min_{\lambda\epsilon\{R,G,B\}}\left(\min_{y\epsilon\Omega(x)} J_\lambda(y)\right) = 0 \qquad (11)$$

As A_λ is always positive, this leads to

$$\min_\lambda\left(\min_{\lambda\in\{r,g,b\}}\left(\frac{J_\lambda(x)}{A_\lambda}\right)\right)=0 \qquad (12)$$

Putting Equation(12) into Equation (10),we can estimate the transmission $t^*(x)$ simply by:

$$t^*(x) = 1 - \min_\lambda \frac{\min_{y\epsilon\Omega(x)} I_\lambda(y)}{A_\lambda} \qquad (13)$$

From equation (2)-

$$\min_\lambda\left(Nrer(\lambda)^{d(x)}\right) = 1 - \min_\lambda\left(\frac{\min_{y\epsilon\Omega(x)} I_\lambda(y)}{A_\lambda}\right) \ (14)$$

Among all color channels, Nrer (red) possesses the lowest residual value.This indicates that $\min_\lambda\left(Nrer(\lambda)^{d(x)}\right)$ where $\lambda \in \{r,g,b\}$ is simply equal to Nrer(red). The background light is usually assumed to be the pixel intensity with the highest brightness value in an image [15] However, this simple assumption often renders erroneous results due to the presence of self-luminous organisms or an extremely smooth surface,e.g.,a white fish.In order to increase the detection robustness of background light,a min operation is first performed in every localpatch Ω(x) of all pixels x in a hazy image I . The brightest pixel value among all local minima corresponds to the background light A_λ as follows:

$$A_\lambda = \max_{x\epsilon I} \min_{y\epsilon\Omega(x)} I_\lambda(y), \ \lambda \in \{r,g,b\} \qquad (15)$$

Given the valuesof $I_\lambda(y)$, A_λ,and Nrer(red) ,distance d(x) between point x on an object and the camera can be determined. Block-based dark channel prior will inevitably introduce a Mosaic artifact and produce a less accurate depth map.By imposing a locally linear assumption for foreground and background colors and applying image matting to repartition the depthmap, the mosaic effect is reduced, and object contours can be identified more precisely [15][16][17].

3.2 Removal of the Artificial Light Source L –

The existence of an artificial light source can be determined by comparing the difference between the mean luminance of the foreground and the background. In an underwater image with out artificial lighting, the dominant source of light originates from the airlight above the water surface. The underwater background corresponds to light transmitted without being absorbed and reflected by objects and is therefore the brighter part of the image. Higher mean luminance in the foreground of an image than that in the background indicates the existence of a supplementary light source. The foreground and the background of an image can be segmented based on the depth map derived earlier as follows:

$$\text{area-type}(x)=\begin{cases} foreground & if\ d(x)>\sigma \\ background & if\ d(x)\le\sigma \end{cases} \quad (16)$$

d(x) where d(x) is the distance between the object and the camera whereas σ is a threshold . The amount of the luminance supplied is inversely proportional to the square of the distance between the object and the light source. The closer the object, the stronger the intensity of the artificial light source, and vice versa .We know that the light

$$J_\lambda(x) = ((E_\lambda^A(x).Nrer(\lambda)^{D(x)} + E_\lambda^L.Nrer(\lambda)^{d(x)})) .\rho_\lambda(x)$$

reflected from point x is equal to the product of reflectivity $\rho_\lambda(x)$ times the summation of the ambient lighting $E_\lambda^A(x).Nrer(\lambda)^{D(x)}$ and attenuated artificial light $E_\lambda^L.Nrer(\lambda)^{d(x)}$. For a fixed object–camera distance d(x) ,the intensity of an attenuated artificial lighting is a constant $E_\lambda^L.Nrer(\lambda)^{d(x)}$ is a constant. The difference in terms of brightness perceived by a camera for fixed d(x) can therefore be attributed to the reflectance of objects. Once presence of artificial light source is detected, then it has to be removed. Reflectivity of object can be calculated at all pixels for every wavelength i.e. R, G and B [5] is as shown below:

$$\rho_\lambda(x) = \frac{(I_\lambda(x) - (1 - Nrer(\lambda)^{d(x)})).\frac{A_\lambda}{Nrer(\lambda)^{d(x)}}}{E_\lambda^A(x)\cdot Nrer(\lambda)^{D(x)} + E_\lambda^L.Nrer(\lambda)^{d(x)}}, \lambda\in\{R,G,B\}$$

(17)

$$\check{I}_\lambda(x) = I_\lambda(x) - (E_\lambda^L.Nrer(\lambda)^{d(x)}) .\rho_\lambda(x)).Nrer(\lambda)^{d(x)}) = ((E_\lambda^A(x).Nrer(\lambda)^{D(x)}..\rho_\lambda(x)).Nrer(\lambda)^{d(x)} + (1 - Nrer(\lambda)^{d(x)}).\ A_\lambda, \lambda\in\{r,g,b\} \quad (18)$$

3.3 Compensation of Light Scattering and Color Change Along the Object–Camera Path-

Haze occurs because of background , the haze can be removed by subtracting the in-scattering term $(1 - t_\lambda(x).A_\lambda$.Now compensation of light scattering term and color compensation as

$$I'_\lambda(x) = I_\lambda(x) - (1 - Nrer(\lambda)^{d(x)}).A_\lambda = ((E_\lambda^A(x).Nrer(\lambda)^{D(x)}..\rho_\lambda(x)) .Nrer(\lambda)^{d(x)}). \quad (19)$$

thus

$$J'_\lambda(x) = ((E_\lambda^A(x).Nrer(\lambda)^{D(x)}..\rho_\lambda(x)) = \frac{I'(x)}{Nrer(\lambda)^{d(x)}} \quad (20)$$

This result gives the image after compensation of light scattering and bluish tone along the path, object camera distance. Here aim is to calculate the value of

$$((E_\lambda^A(x)..\rho_\lambda(x))$$

3.4 Underwater Depth D-

After penetrating the water depth D,the energy of each color channel after attenuation, becomes E_{red}^w, E_{green}^w ,E_{blue}^w respectively . To estimate the underwater depth D ,the corresponding intensity of the ambient lighting shall be detected first. Therefore ,the water depth D is the least squares solution that makes the difference between the attenuated version of the incident light ,E_{red}^w, E_{green}^w ,E_{blue}^w after propagation ,and the detected ambient lightingE_λ^w λ ∈ {red,green,blue} in depth D, with energyE_{red}^w, E_{green}^w ,E_{blue}^w at a minimum as follows-

$$\min_D \sum \left\| E_\lambda^w - E_\lambda^A \cdot Nrer(\lambda)^k \right\|^2 = 0, \lambda\in\{R,G,B\}.$$

After the calculation of D the restored energy of the underwater image after haze removal and calibration of color change will be-

$$J_\lambda^+(x) = \frac{J'_\lambda(x)}{Nrer(\lambda)^{D(x)}} \ (E_\lambda^A(x)..\rho_\lambda(x) = \lambda\in\{r,g,b\} \quad (22)$$

3.5 Image Depth Range R-

The underwater depth of pixel can be derived point wise by linear interpolation as follows

$$D(x)=D+R.\frac{l1-l2}{l3-l2} \qquad l2\le l1\le l3 \quad (23)$$

where Suppose that pixel x and top and bottom background pixels are located on scan line l1,l2 and l3 respectively.

3.6 Image denoising-

Here frequency filter is applied for denoising. The frequency transformation method preserves most of the characteristics of the one-dimensional filter, particularly the transition bandwidth an dripple characteristics. . The shape of the one-dimensional frequency response is clearly evident in the two-dimensional response. The transform of the Image is multiplied with a filter that attenuate certain frequencies. The filter can either be created directly in the frequency domain or be the transform of a filter created in the spatial domain.In this case the Fourier transform of the image is multiplied with the fourier transform of the impulse the transfer function.

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