ADVANCED IMAGE ENHANCEMENT METHODOLOGY FOR UNDERWATER IMAGING

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Abstract : Underwater images possess a poor contrast and are often color distorted due to low illumination of light and haziness. This haziness in the captured images makes identification of underwater world difficult and tedious. This drawback can be rectified by our proposed new approach of combining the underwater dehazing and enhancement algorithm. This paper reviews the existing enhancement methods available at present to compare the efficiency of the proposed method.Experimental results of the proposed method clearly exhibit that it restores the original color and nourishes the finest details of each and every pixel of an image. Quantitative and qualitative comparison of various state of the art methods (eight methods) with our proposed algorithm, proves that the proposed method is best suitable for enhancing underwater images.

I Introduction

Underwater imaging set forth a huge challenge and infact provides exciting facts to the investigators. These optical images obtained have a tremendous impact in the fields of underwater archaeology, marine geology, seafloor hydrothermal vents, marine military applications etc. The exploration of degraded ocean resources captured by underwater surveillance have become the essential work undertaken by researchers in recent years. The visual quality of objects and resources captured from underwater faces the issues of low clarity due to suspended particles like sand, minerals and attenuation of light. Due to the water currents, fluctuating temperatures and weather conditions, images taken from underwater suffer severe degradation when compared to the outdoor images.

In recent years, clear images are needed for the numerous underwater imaging applications. Therefore there is a need for dehazing and enhancing the images. Image enhancement is the technique of improving the quality and information content of original data before processing. Common practices of image enhancement technique include contrast enhancement, spatial filtering, density slicing, and False Color Composite (FCC). Fig 1(a) shows the schematic representation of underwater lighting model and luminance distributions due to scattering and absorption of light. This haze is caused by the suspended particles that are present inside the water bodies. As light reflected from objects proceeds towards the camera, a portion of the light meets these suspended particles, which gets absorbed and scattered by the light[1]. Forward scattering causes blur in the image and backscattering reduces the contrast and visibility of images captured by the camera. In addition to this, marine snow causes unwanted noise and increases the effect of scattering.

It is also a known fact that water absorbs and scatters certain radiations more than the way the air does. That is why different wavelengths of visible light i.e. VIBGYOR (Violet, Indigo, Blue, Green, Yellow, Orange and Red) will penetrate water to a varying degree which is illustrated in Fig 1(b) [2].

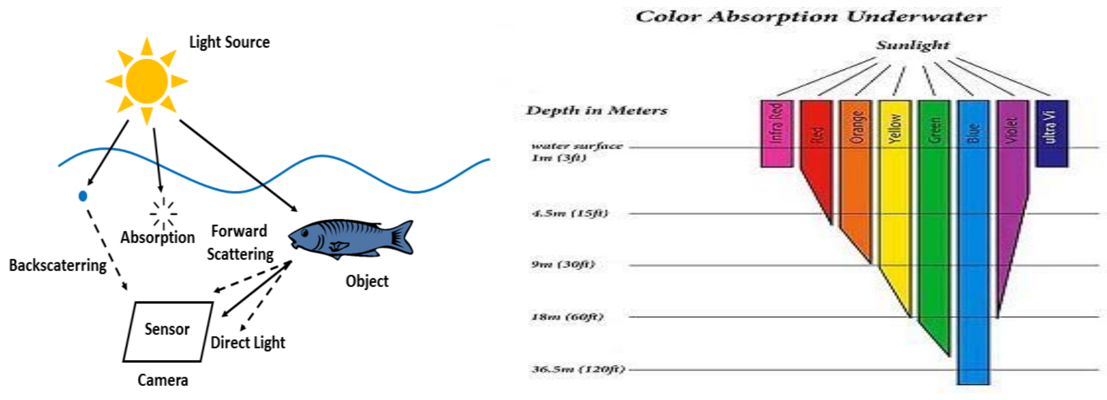

Fig 1(a) Schematic diagram of Underwater Lighting Model Fig 1(b) Illustration of different color absorption in underwater

In recent development of science & technology there is always an expectation to obtain clear images from underwater. Step to attain this expectation is the image enhancement. For example even a movie taken in an open air environment undergoes digital intermediate (DI) for fixing colour & other characteristics. In such a case there is an absolute necessity for the underwater images to go through image enhancement. The above facts led the researchers to take it as an essential work to explore the ocean resources.

Initially image enhancement method was classified into two broad categories i.e. spatial domain methods and frequency domain methods. In spatial domain techniques, the pixels of a distorted image can be directly manipulated whereas in frequency domain techniques, the images can be processed by computing the Fourier transform. Apart from the classification, the image enhancement techniques are also based on different grey level transformation functions. Basic grey level transformations include linear transformation (identity transformation and negative transformation), logarithmic transformation (log and inverse log transformation) and power law transformation (nth power and nth root transformation). Later different emerging algorithms were developed to enhance the low quality degraded images. Now the method of image enhancement progressed towards the techniques such as Convolutional Neural Networks, generative adversarial networks and deep learning techniques.The major contribution of this paper are,

1. To achieve the target of producing the realistic images, an effective dehazing algorithm is proposed. It is accomplished by considering the adjusted saturation level of an image and by calculating the depth transmission map. This resolves the problem of attenuation by acquiring the details of optical properties of images.

2. A simple and single step is introduced to recover the radiance of the image that is Radiance recovery to obtain an enhanced image. The algorithm is very straightforward and time saving. The results obtained are the best compared to the other existing approaches.

3. To the best of our knowledge, this algorithm tops in almost all the different quantitative parameters.

4. This algorithm is developed using empirical method. It was applied to more than 200 open source images as well as real time images taken from Bay of Bengal to find its effectiveness and accuracy.

From the traditional methods to denoising the blurred images there are many algorithms introduced to restore the saturation, intensity which increases the visual quality, brightness and illumination of the processing images. The different prominent methods used are Unsupervised Color Correction Method (UCC)[1], Contrast Limited Adaptive Histogram Equalization (CLAHE)[2], Color Correction method (CC)[3],

Screened Poisson equation (SP) [5], Bright Channel Prior (BCP) [6], L*A*B based color model method [7], Dark Channel Prior (DCP) [8], Fusion [10]. In comparison with all the existing methodologies, our proposed method is developed with the aim to achieve the target of enhancing the images under any challenging environment. In addition to this, a single raw image is sufficient to bring out the desired output.
This paper categorizes the assorted modules involved and our proposed algorithm elucidates the novel approach of enhancing the distorted underwater images and to restore the natural appearance with better optimisation in section II. Qualitative and quantitative measurements of our proposed algorithm demonstrated in section III .

II Proposed work

After examining the existing algorithms available, we have designed an algorithm and tested for almost 200 hazy underwater images from different underwater environment. The flowchart of our proposed algorithm is demonstrated in Fig (2). The work presented in this paper explains about the proposed algorithm to enhance the image consisting of scattered particles, haziness and preserve the image without any loss of information of each pixel. This algorithm consists of various sections such as a) Contrast stretching b) Determination of adjusted saturation level output $A_s(x)$ c) Calculation of distance factor and transmission map d) Radiance recovery. The hazy underwater image model can be given as,

$$f_c(x) = J(x)t(x) + A\,(1 - t(x)) \qquad (1)$$

$f_c(x)$ represents hazy image, $J(x)$ is the radiance recovered image, $t(x)$ is the transmission map and A is atmospheric light [6].

a) Contrast stretching $I_c(x)$

Consider m x n raw degraded underwater RGB input image $f_c(x)$ undergoes the process of contrast stretching as its first step. Contrast of an image clearly distinguishes about the objects present in the distorted image. In order to improve the contrast to a better level, contrast stretching technique is used [10]. Contrast stretching is a basic image enhancement method which stretches the input range of intensity values to fill the full range from 0 to 255.

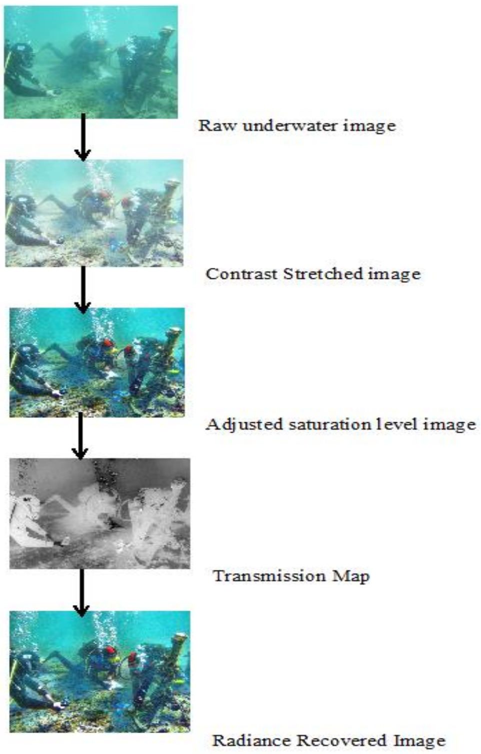

Fig 2 Flowchart of our proposed algorithm

This is used to highlight the dynamic range of grey levels in the original image which spreads over a lesser intensity range. It is important to note that minimum intensity value and maximum intensity value of input image should not be equal. The output image remains same as input image if the minimum and maximum intensity values are equal. In the contrast stretched image the light tone areas appear lighter and the dark tone areas appear darker thereby increasing the clarity of an image. The variation in the input data is now being very prominent and thus becomes easily differentiable. The resultant output of contrast stretching shows the variation of increased range of RGB intensities of an original image.

b) Determination of Adjusted saturation level output $A_s(x)$

Algorithm 1 : To estimate the adjusted saturation level image $A_s(x)$

Input : Contrast stretched image $I_c(x)$
Output : Adjusted saturation level image $A_s(x)$

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1. Initializing S_1 and S_2 where $S_1, S_2 \epsilon$ [0,1]
2. Estimating N ($S_1 + S_2$) and find $Q_c(x) = s_c * f_c(x)$
3. Compute the product of N and squared value of $Q_c(x)$
4. Adding the $I_c(x)$ and the result of step (3)
5. Compute the square root for output of step (4) to find the resultant image of adjusted saturation level

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Algorithm 1 presents the summary of determination of adjusted saturation level output image $A_s(x)$. Sometimes contrast of an image can be reduced while recovering the blurred pixel information, therefore to avoid this scenario, we have introduced the proposed algorithm in which the intensity values can be adjusted according to the saturation level of an image. In unsaturated images, color of the image produces dull effect whereas the processed image looks vivid when we increase the saturation level and this can be done by increasing the appropriate level of RGB intensity values. Thereby reduces the dullness and greyish tone of the processed image.

In our proposed algorithm, to make image more vivid and clear, saturation factor has been controlled and the saturation level intensities are taken as S_1= 0.5 and $S_2 = 0.7$. The resultant matrix value of adjusted saturation level output depends on saturation level intensities (S_1 *and* S_2). This can be applied to the RGB color channels independently. This facilitates the processed image to be enhance in each and every pixel of an image. The following equation indicates the transformed array with adjusted saturation level representation.

$$A_s(x) = [I_c(x) + N(Q_c(x))^2]^{\frac{1}{2}}$$
where c ∈ R,G,B (2)

Now the image scaled to array of transformed pixels with respect to Equation (2). $Q_c(x)$ represents the product of saturation constant s_c and input image $f_c(x)$. Also, s_c be the saturation constant lies in the interval [0, 1]. N represents the sum of both saturation levels S_1 and S_2, $I_c(x)$ indicates the intensity values of contrast stretched image RGB component respectively.

c) Calculation of distance factor and depth transmission map

Color scatter is a result of light absorption and multiple scattering by suspended particles on the way to the camera [8]. Color cast is due to the distortion of light which varies according to the distance. To remove these suspended particles and to avoid the color scattering issues, dehazing algorithms like dark channel is being used. Also, the distance from the object to the camera is measured using the Dark Channel algorithm [8]. This is done by first removing color scatter and color cast of an image. Dark Channel works on the fact that atleast one pixel with a near zero brightness value in the patch size $\Omega(x)$ surrounding any point x [8]. A dark channel is the outcome of two minimum operators which can be mathematically indicated as,

$$D(x) = ((A_s(x))), \lambda \{R, G, B\} \quad (3)$$

Substituting equation (2) in (3),

$$D(x) = [(I_c(x) + N(Q_c(x))^2]^{\frac{1}{2}} \quad (4)$$

For an outdoor haze-free image D(x) ≈ 0.

It implies,

$\{(A_s(x))\} \approx 0, \lambda \in \{R, G, B\}$

The resultant image is the outcome of two minimum operators consisting RGB channel and local patch respectively. Due to this, the dark pixels of an image gets brightened when the airlight is added.

Dark channel is effective when the degraded image consists of shades of objects having low intensities, objects with bright colors having atleast one low intensity channel and pixels having low reflectance in any color channel [9]. In such images, the intensity of the dark pixels provides an accurate estimation of haze distribution.

After the computation of dark channel, the resulting image is manipulated to obtain the transmission map function t(x). To improve the quality of the resulting image, depth map $\tilde{t}(x)$ is used. The depth map estimation $\tilde{t}(x)$ for the dark channel processed image is used to make the foggy or hazy underwater image visible and it reduces the information loss. To estimate the transmission t, equation (1) can be normalised.

$$f_c(x) = J(x)t(x) + A\big(1 - t(x)\big)$$

Taking Min operators on both sides for the above equation , we get

$$\{(f_c(x)\} = \{\{J(x)t(x) + A(1 - t(x))\} \quad (5)$$

$$\left\{\frac{(f_c(x))}{A}\right\} \approx \left(\frac{J(x)}{A}t(x)\right) + \left(\left(\frac{A(1-t(x))}{A}\right)\right)$$

Assuming the first term on the right hand side as zero,

$\left(\frac{J(x)}{A}t(x)\right) \approx 0,$

$$\left\{\frac{f_c(x)}{A}\right\} = 0 + ((1 - t(x)))$$

$$\left\{\frac{f_c(x)}{A}\right\} = 1 - (t(x))) \quad (6)$$

Rearranging the above equation,

$$\{(t(x))\} = 1 - \left\{\frac{f_c(x)}{A}\right\} \quad (7)$$

$$\tilde{t}(x) = 1 - \left\{\frac{f_c(x)}{A}\right\} \quad (8)$$

$$\therefore \tilde{t}(x) = \{t(x)\}$$

The term $\left\{\frac{f_c(x)}{A}\right\}$ is the dark channel of the normalised hazy image and A is the atmospheric light [11]. Sometimes artificial light sources are added to avoid the insufficient lighting when the images captured in underwater photographic environment [8]. Thus the equation (8) can be simplified and rewritten as,

$$\therefore \tilde{t}(x) = 1 - J_{dark}(x) \quad (9)$$

In depth map, haze free regions indicate the intensity value as 1 and hazy regions as 0. Even in clear days, the atmosphere is not absolutely free of particle. So the haze still exists when we look at distant objects. Fig (3) illustrates the result of depth map for an adjusted saturation level input image. By these steps dehazed image is obtained without the use of expensive optical instruments.

(a)

(b)

(c)

Fig (3) Illustration of transmission maps (a) Raw underwater image (b) Adjusted Saturation level input image (c) Depth Map

But the output obtained from this step is grey scale image. Therefore, there is a need to proceed to the next step i.e. Radiance recovery.

d) Radiance recovery

The scene radiance is highly important to be evaluated since the recovered image shows the exact color restoration of underwater images. The restoration of color cast and transmission map can be modelled together to recover the radiance of the image using the equation.

$$J_\lambda(x) = \frac{D(x)-b_\lambda}{\tilde{t}(x)} + b_\lambda \qquad (10)$$

Thus, the above mentioned underwater image model effectively restore the image color with reduced blurriness. b_λ is the homogeneous background light depends on λ (wavelength of the RGB channels)

Algorithm 2 : To estimation the distance factor, depth map and scene recovery

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Input : Adjusted saturation level image $A_s(x)$

Output : Dehazed radiance recovered image.

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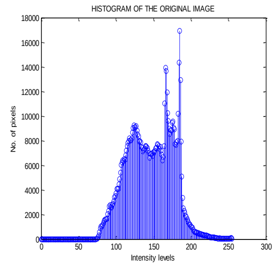
1. Compute D(x) from $A_s(x)$ with minimum operators
2. Compute the transmission map function t(x)
3. Obtain the depth map function $\tilde{t}(x)$.
4. Calculate the term $(D(x) - b_\lambda)/\,\tilde{t}(x)$.
5. Estimate the enhanced final output image $J_\lambda(x)$ by adding b_λ to step (4)

Algorithm 2 shows the steps involved to find the distance factor, depth map and radiance recovery from $A_s(x)$. To prove the efficiency of the proposed algorithm the simple histogram plot is done for randomly selected hazy underwater images.Fig 4(a) represents the sample image 1. Fig 4(b) represents the recovered image 1 by using our proposed algorithm. The Histogram plot in Fig (4) is shown for comparing the sample input image before and after enhancement in Fig 4(c) and Fig 4(d) respectively. The brightness of an image depends upon the spatial distribution of the values. An image is said to be darker if the histogram values are concentrated on left of the plot and vice-versa is lighter. A histogram with a prominent spike at the highest possible pixel indicates that the image's pixel intensities have experienced saturation effects.

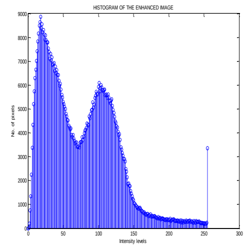
But incase of our proposed algorithm, spike is introduced in all histograms of enhanced image as clearly seen in Fig 4(d) due to the adjusted saturation level S_1 and S_2.

(a)Sample image 1

(b)Recovered image 1



(c) Histogram plot for sample image 1



(d) Histogram plot for recovered image 1

Fig (4) Results of Histogram equalization

A histogram in which the pixel counts evenly cover a broad range of grayscale levels indicates an image with good contrast. Therefore undoubtedly this demonstrates the actuality of the proposed algorithm. The rest of the paper describes about the experimental results of proposed algorithm, numerical metrics and the comparison with different existing dehazing algorithms.

III Results and Discussion

To estimate the performance of our proposed algorithm we have carried out comparison of both qualitative and quantitative methods respectively. The methods used for comparisons are Unsupervised Color Correction (UCC) , CLAHE, Color Correction (CC), Screened Poisson Equation (SP), Bright Channel Prior (BCP), L*A*B , Dark Channel Prior , Fusion. We compared our proposed algorithm results with the above mentioned 8 methods in order to prove our algorithm is better than those state of the art enhancement methods.

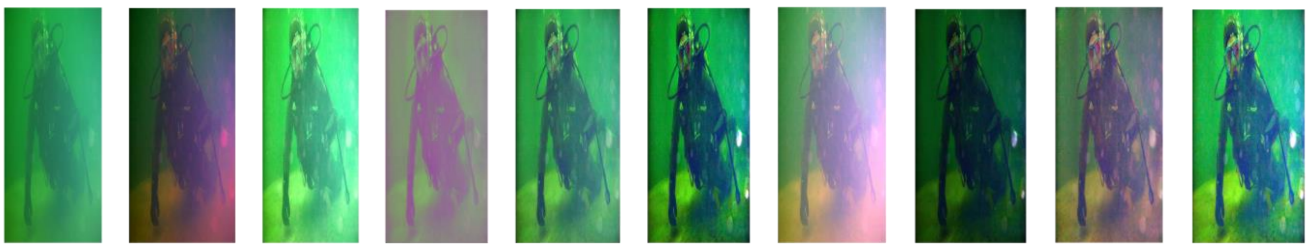
Since our algorithm is an underwater image dehazing and enhancement method, we attempted to test both open source and real world underwater images obtained using

Remotely operated vehicle (ROV) for our project. The results were clearly demonstrated and our proposed algorithm is good enough to enhance the hazy underwater images taken from various depth. In our simulation experiment, it is clear to be shown that color accuracy and effectiveness of proposed algorithm is better than other image dehazing methods. The simulated results for some of the open source and real world underwater images are demonstrated in Fig (5). The first six rows shows the simulation results of open source hazy underwater images and the next four shows the results of real time images captured from the coral reef at 5 – 10 meters depth at the Bay of Bengal. According to the simulation, the numerical parameter results were presented in the Table 1-7.

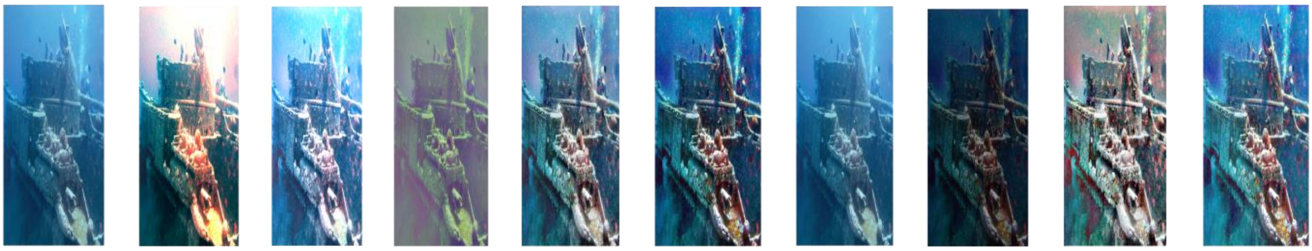
In addition to the qualitative results, it is important to measure the parameters such as Entropy Error, AMBE, PSNR, MSE, SNR, SSIM, UICM and PCQI to quantify the image brightness and color accuracy of an image. The below tables demonstrates the comparison of above mentioned numerical parameters for the 8 algorithms along with our proposed work. The table 1 represents the average calculation of Entropy Error, AMBE, MSE, PSNR, SNR, SSIM, PCQI, UCIM and UCIQE for 1-6 open source underwater images of Figure 5. Based on the analysis of numerical metrics indicated in Table 1, all the parameters of our proposed algorithm for an underwater distorted images yields better results. This shows the robustness of our algorithm against all other algorithms and therefore provides better enhancement and exact color restoration of the original image. Table 2,3,4,5 represents the different parameters of the above mentioned real time images 7,8,9,10 respectively shown in Figure 5. As shown in the below tables 2 ,3,4, 5, our dehazing method produces best results for the numerical parameter in terms of PSNR, MSE, SNR, SSIM, UCIM and PCQI.

OS image 1

OS image 2

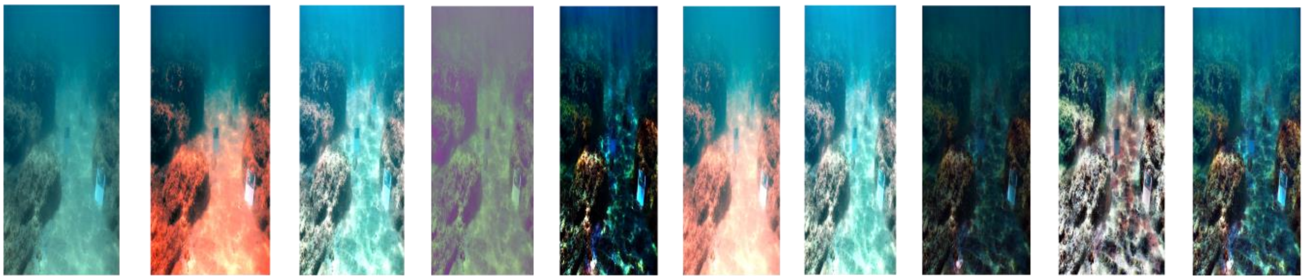


OS image 3

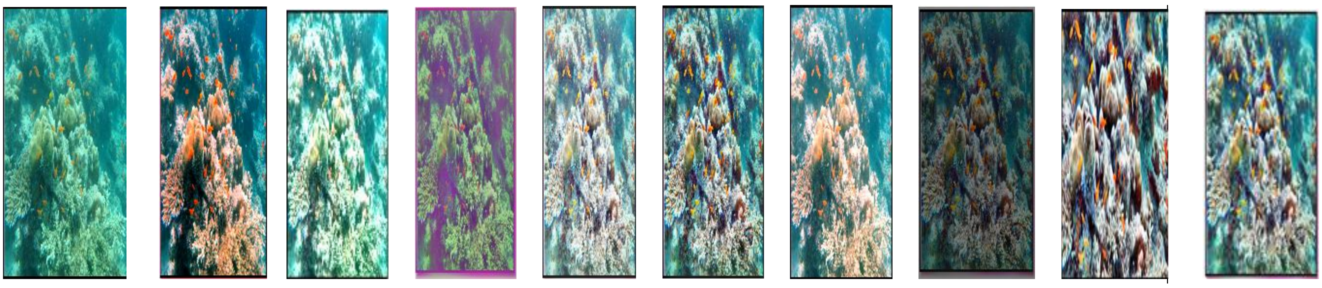


OS image 4

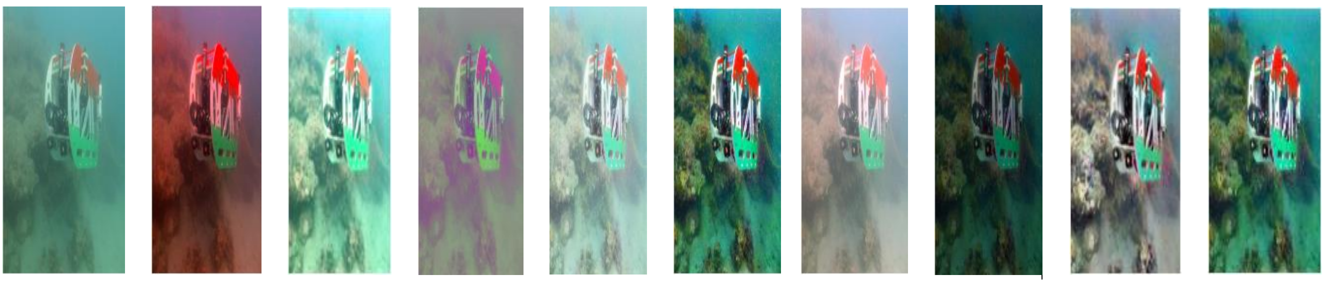
OS image 5



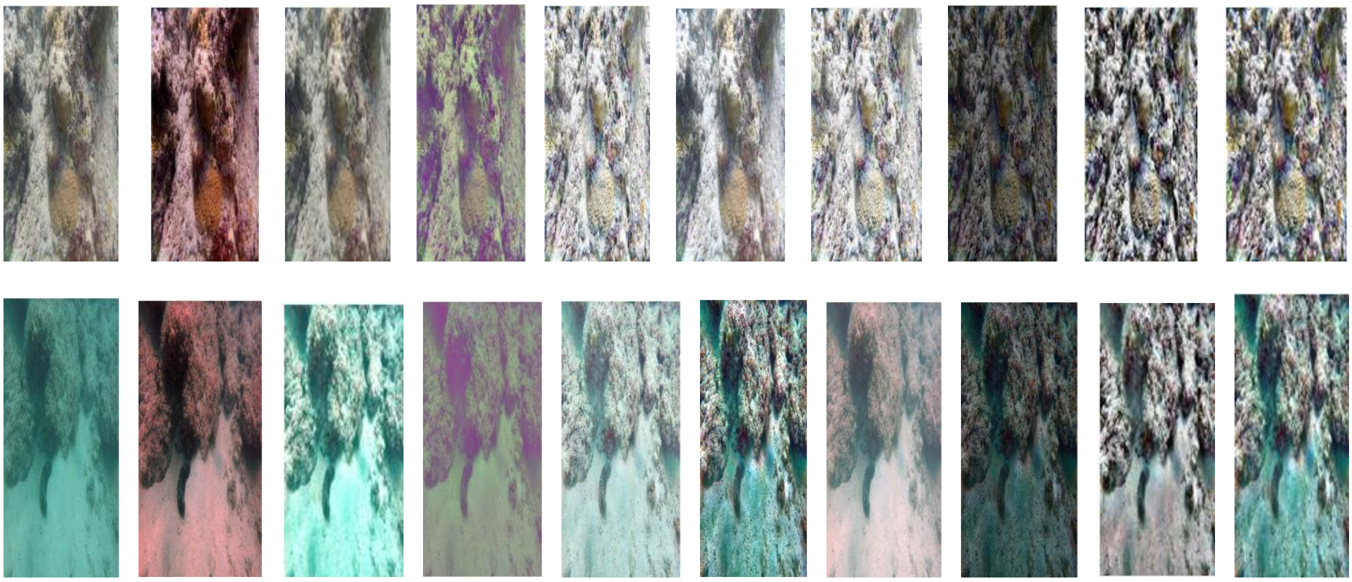
OS image 6



RT image 1



RT image 2



RT image 3

RT image 4

(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)

Fig (5) : Qualitative Comparison (a) Open source underwater hazy images captured from various challenging scenes (column1 to 6) and OS represents Open Source , Real time images captured at 5 - 10 metres depth (column 7 to 10) and RT represents Real Time (b) UCC method (c) CLAHE method (e) SP method (f) BCP method (g) L*A*B method (h) DCP method (i) Fusion method (j) Output of our proposed algorithm.

PARAMETER	UCC	CLAHE	CC	SP	BCP	L*A*B	DCP	Fusion	Proposed
Entropy Error	0.6076	0.6934	1.1270	0.2159	0.4915	0.7214	0.4355	0.5442	**0.3397**
AMBE	136.5748	118.8912	11.2361	8.7482	5.5278	21.1160	0.1237	-0.0083	**-58.2442**
PSNR	26.7881	56.9147	37.8320	48.2204	39.7314	35.4137	57.2957	63.0640	**68.2463**
MSE	0.08645	56.9181	42.932	0.5814	0.1206	43.497	0.1165	0.0921	**0.0615**
SNR	16.6547	13.233	18.1679	13.8405	14.5460	16.0753	16.1962	14.622	**22.276**
SSIM	0.7026	0.8028	0.5262	0.4986	0.9238	0.7010	0.9195	0.9393	**0.9421**
UICM	0.4014	0.4677	0.4014	0.3438	0.5448	0.4496	0.5442	0.5706	**0.5728**
PCQI	0.7984	0.7984	0.8230	0.7194	0.9998	0.8851	1.0682	1.0761	**1.0777**

Table 1 : Quantitative Comparison in terms of average measurement of Entropy Error, AMBE, PSNR, MSE, SNR, SSIM, UCIM and PCQI for first 6 open source underwater images (1 to 6) in Figure 5 (Bold and underlined results presents the best among the values).

PARAMETER	UCC	CLAHE	CC	SP	BCP	L*A*B	DCP	FUSION	PROPOSED
Entropy Error	0.5733	0.7262	0.6836	0.4521	0.5547	0.5292	1.0245	2.5607	**0.1849**
AMBE	116.4988	116.2768	9.8916	15.6124	10.2354	30.9489	10.6570	0.2088	**0.0580**
PSNR	29.1450	29.1450	29.1450	89.2140	41.2890	29.1450	51.8524	58.4730	**58.4730**
MSE	79.1730	79.1730	79.1730	87.5689	15.6422	79.1730	0.1248	0.0924	**0.0924**
SNR	13.8994	11.8133	16.1068	9.2135	10.2536	11.2094	11.9547	10.3157	**15.8015**
SSIM	0.8847	0.8841	0.7164	0.7758	0.9647	0.8845	0.8842	0.9923	**0.9923**
UICM	0.0033	0.0033	0.0033	0.0024	0.0064	0.0042	0.0058	0.0113	**0.0189**
PCQI	0.0084	0.0084	0.0151	0.0262	1.0047	0.0362	1.0298	1.1022	**1.1096**

Table 2 : Quantitative comparison of numerical parameters of existing 8 algorithms with proposed method for underwater Real Time(RT) image 1

PARAMETERS	UCC	CLAHE	CC	SP	BCP	L*A*B	DCP	FUSION	PROPOSED
Entropy Error	**0.1375**	0.4655	1.2448	1.5641	1.0063	0.5292	0.9943	0.4470	0.5770
AMBE	115.3631	115.0390	1.2448	10.2365	9.3684	30.9489	1.2325	**0.0424**	0.0862
PSNR	28.8366	28.8366	28.8366	35.4122	56.8555	29.1450	57.5693	59.4045	**59.4045**
MSE	85	85	85	0.8894	0.7164	79.1730	0.6157	0.0746	**0.0746**
SNR	17.9292	15.8932	20.8349	10.5647	11.2123	11.2094	14.2587	15.2228	**17.1753**
SSIM	0.4512	0.4468	0.4589	0.4429	0.8457	0.4475	0.8835	0.8823	**0.8842**
UICM	0.0085	0.0085	0.0085	0.0049	0.0086	0.0054	0.0109	0.0162	**0.0188**
PCQI	0.9833	0.9900	0.9925	0.9490	1.0041	0.9924	1.0228	1.0323	**1.0541**

Table 3 :Quantitative comparison of numerical parameters of existing 8 algorithms with proposed method for underwater Real Time(RT) image 2

PARAMETERS	UCC	CLAHE	CC	SP	BCP	L*A*B	DCP	FUSION	PROPOSED
Entropy Error	0.3316	0.1846	0.4327	0.7457	1.5264	**0.1247**	1.1249	0.6470	0.4774
AMBE	126.6708	126.3774	6.2237	11.5568	10.5684	42.3958	0.4578	0.0037	**0.0286**
PSNR	28.8366	28.8366	28.8366	28.8741	44.6214	28.8366	50.2144	58.4999	**58.4999**
MSE	85	85	85	84	0.6971	85	0.6658	0.0919	**0.0919**
SNR	14.6827	13.4319	14.6801	10.2391	11.0475	14.4888	10.5574	11.1586	**16.5488**
SSIM	0.6671	0.6459	0.6652	0.6573	0.7725	0.7698	0.7705	0.7781	**0.7794**
UICM	0.0036	0.0036	0.0036	0.0027	0.0092	0.0083	0.0094	0.0101	**0.0107**
PCQI	0.8545	0.9411	0.8545	0.8812	1.0163	0.9636	1.0246	1.0300	**1.0311**

Table 4 :Quantitative comparison of numerical parameters of existing 8 algorithms with proposed method for underwater Real Time(RT) image 3

PARAMETERS	UCC	CLAHE	CC	SP	BCP	L*A*B	DCP	FUSION	PROPOSED
Entropy Error	0.1603	0.1840	1.3256	1.2354	0.8542	**0.0739**	1.4414	0.5712	0.4986
AMBE	113.9599	113.7093	19.2655	20.4781	18.5694	44.1931	0.7128	0.0699	**0.0448**
PSNR	28.8366	28.8366	28.8366	11.2851	47.3654	28.8366	57.3696	59.3410	**59.3410**
MSE	85	85	85	85	0.4254	85	0.1547	0.0757	**0.0757**
SNR	15.0555	14.0031	**17.8643**	10.2147	10.2498	13.9904	11.5869	12.6455	16.7976
SSIM	0.7691	0.8442	0.8144	0.7756	0.7336	0.7756	0.8566	0.8842	**0.8889**
UICM	0.0084	0.0074	0.0031	0.0022	0.0087	0.0085	0.0106	0.0120	**0.0125**
PCQI	0.9456	0.9511	0.9425	0.9642	1.0538	0.9511	1.0313	1.1423	**1.1636**

Table 5: Quantitative comparison of numerical parameters of existing 8 algorithms with proposed method for underwater Real Time(RT) image 4

Image	He[9]	Galdran[21]	Galdran[22]	Ancuti[23]	Ancuti[24]	Farong[25]	Proposed
Open source Image 1	0.565	0.611	0.646	0.634	0.632	0.763	**1.7182**
Open source Image 2	0.593	0.613	0.529	0.643	0.659	0.734	**1.6819**
Open source Image 3	0.456	0.523	0.529	0.590	0.592	0.815	**2.0619**
Open source Image 4	0.485	0.531	0.641	0.588	0.594	0.706	**2.1110**

Table 6 – Quantitative Comparison of UCIQE parameter for first four open source underwater images in Fig 5.

Image Name & size	UCC	CLAHE	CC	SP	BCP	L*A*B	DCP	FUSION	PROPOSED
Open source image 2 512 X 384	103.45s	236.57s	76.58s	77.81s	68.56s	97.69s	55.83s	**51.25s**	**50.46s**
Open source image 3 640 X 480	71.56s	56.33s	41.22s	89.25s	75.33s	99.54s	34.81s	**33.15s**	**32.35s**
Open source image 6 960 X 720	120.35s	117.25s	120.87s	133.56s	68.23s	87.69s	55.64s	**50.89s**	57.12s

Table 7– Run time comparison between the proposed and existing algorithms

In these tables, the bold numbers represents the best results. Additionally we further tested the proposed method with numerical parameter UCIQE using some images that are commonly used in recent image dehazing and contrast enhancement methods like He [9], Galdran[21], Galdran [22], Ancuti[23], Ancuti [24], Farong [25]. The compared results can be seen in Table -6. The highest UCIQE score means that our dehazing method can effectively balance the chroma, saturation, and contrast of the restored underwater images, and then produce most visually appealing results. Furthermore the run time calculation of the randomly selected images is carried out to evaluate and reveal the performance of our proposed algorithm. The results are tabulated in Table – 7. Our algorithm ranks first for an image size 512 X 384 and 640 X 480. However it ranks second best for the size 960 X 720.

IV Conclusion and Future Work

Our proposed algorithm enhances and restores the original colour of the hazy image. This algorithm provides enhanced output by removing the effect of absorption and scattering components in hazy underwater images. This method suits all kinds of images like green hazy, clustered underwater images taken under various environmental conditions. Furthermore the image clarity of the 8 different existing methodologies is compared with this new algorithm and the quantitative results are tabulated. The results clearly manifests the natural color, better visibility and authentic appearance. In future we intend to combine convolutional neural networks (CNN) with our proposed algorithm for object recognition and image classification. This algorithm can be further modified to suite both underwater and outdoor images (Generic) to produce better clarity, genuine color, natural appearance And more effective quantitative results.

Acknowledgement

The authors were thankful to the Department of Science and Technology (DST), Government of India who sponsored this project named as DIGITAL POOMPUHAR.

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