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# Underwater Image Enhancement based on Histogram Manipulation and Multiscale Fusion

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**Abstract**

The underwater images are a good source of information which explores idea about sea creatures, to study about seafloor hydrothermal vents. Low contrast, color distortion and poor visual appearance are the major issues that an underwater image has to undergo. Such problems were caused by dispersion and refraction of light as they penetrate from rarer to denser media. The scattering of light reduces color contrast. The influence of water in underwater images is not only due to scattering but also due to the presence of underwater organisms. Here we introduce an improved method for underwater image enhancement based on the fusion method that is capable to restore accurately underwater images. The proposed work takes a single image as the input and a sequence of operations such as white balancing, gamma correction, sharpening, manipulating weight maps are performed on the input image. Finally multiscale image fusion of the inputs is done to obtain the resultant output. In the initial stage, color distorted input image is white balanced to remove the color casts maintaining a realistic subsea image. In the second stage, CLAHE is performed on the gamma corrected image. CLAHE plays a significant role in luminance enhancement of underwater images. At the same time, histogram equalization is performed on the sharpened image. The weight maps analyze image characteristics that properly specify the spatial pixel relationship. Finally in the last stage, multiscale pyramidal fusion of the inputs and weight maps are performed. The fusion performed here is the Pyramidal fusion. Result analysis depict the improvement of the underwater images using proposed method.



*Keywords:* Image Enhancement; CLAHE; Histogram Equalization; Luminance; Sharpening

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## 1. Introduction

The Underwater research is a good area since it escavates shipwreks, which blow light to an ancient period of time, the use of submarines, marine biology research etc. The underwater images have poor visibility due to the absorption and scattering effect of light. This causes contrast degradation and the images to be foggy, making distant objects misty. Due to the fact that the fading of colors increase with increase in water depth, the objects at a distance of more than 10 meters from the water surface are harder to distinguish .

Many attempts have been made to restore and enhance the quality of such degraded images. Usually limitations of underwater scene is due to the result of multiplicative and additive techniques[1]. Therefore the different enhancement techniques such as luminance enhancement, gamma correction, histogram equalization have limitations for such a task. In the literature work, these challenges are addressed by strategies using multiple images[2], specialized hardware or polarization filters [3]. Despite of their research works, these strategies still suffer from a number of issues that reduce their practical applicability. This paper introduces a method to improve the images taken deep in water. The work flow is depicted as follows. Initially the input image undergoes a white balancing operation. This white balanced image is gamma corrected and converted into a LAB color space. In the image enhancement process, CLAHE is performed and Luminance component of image is enhanced.This image is reconstructed to RGB color space. The same white balanced image is sharpened using unsharp masking and histogram equalization is applied to the enhanced image. Weight maps are calculated for the processed images. The input images and weight maps are fused using multiscale fusion.

The rest of the paper is structured as follows. Section 2 outline about the works in underwater image enhancement. Section 3 deals with background and theory. Section 4 illustrates the detailed working of proposed method. Underwater Image Enhancement based on Multiscale Fusion, Section 5 gives results and assessment metrics of the proposed method, Section 6 deals with the conclusion and the summarizes the contributions.

The contribution of our work lies in the application of CLAHE in the luminance component and also the application of histogram linearization after sharpening the image. Both of these histogram manipulation techniques have guided underwater images to obtain a better result.

## 2. Literature Review

Inorder to solve the problem of distortion and degradation in underwater images, several techniques are discussed in literature. There are different techniques such as polarization based, spatial and modulation based techniques that reject the back scattered light to improve the quality and contrast of images. The methods using specialized hardware make use of Lidar imaging. It uses laser technology to capture underwater images in turbid water.[4] The polarization of the light in the field of view is associated only with the backscatter. In these methods, the images of same scene, is captured with different degrees of polarization as is captured by a polarizing filter fitted on the camera. An adaptive filtering approach[3] is introduced to regulate the noise amplification of pixels. This works as an automatic method for finding the medium transmittance and the regularization does not blur close objects. The limitation of polarisation filters is that they are not applicable for video acquisition, so they cannot be used when dynamic scenes are considered. In the method proposed by Narasimhan and Nayar[2], a monochrome atmospheric scattering model, that explains how scene intensities are influenced by homogeneous weather condition is described. For different range of weather conditions such as fog , hist and haze, this model is valid.

Tarel and Hautiere explained about the contrast degradation of outdoor images[5]. Here visibility restoration is performed from a single image. Their proposed method consists of atmospheric veil estimation, image smoothing,tone mapping and image restoration. The advantage of the algorithm is that,it can deal with color images as well as grey scale images.

Dark Channel Prior (DCP)[6], has been proposed initially for outdoor scenes dehazing and later it was used for enhancing underwater images.

G.Padmavathi et al. 2010[7]have compared and evaluated three filters performance. They have used different filtering techniques for underwater enhancement such as homomorphic filter, averaging filter, and anisotropic diffuision filtering. The pre-processing of underwater images is done with the help of these filters. These filters help to improve the quality of image ,edge preservation, noise suppression and image smoothening. The Wavelet denoising by average filter gives accurate results in terms of Peak Signal to Noise Ratio(PSNR) and Mean Square Error(MSE).

In Ancuti et al.[8]an enhancement method is presented where, a single input image undergoes gamma correction and sharpening. Different weight maps are estimated. Finally multiscale fusion is applied on the weight maps and input images to obtain a enhanced underwater image.

## 3. Background and Theory

The absorption and scattering process [9]is leads to the attenuation of light. The light particles are considered several hundreds of times denser in sea water than in normal atmosphere. As a consequence,the sub-sea water absorbs gradually different wavelength of light. The absorption capability of colors can be expressed in terms of the longest wavelength color red, orange and yellow. The corresponding wavelengths are mentioned as (10 - 15 ft), (20 -25 ft), and (35 - 45 ft) respectively. The works of authors McGlamery[10]and Jaffe [11] proved that the illumination of light when falls on the image scene splits into three main components ie, direct component, forward scattering and back scattering in underwater medium. The direct component is the component of light reflected directly by the target object onto the image plane. The direct component at each image coordinate x, is expressed as:

$$E_D(x) = J(x)e^{-\eta d(x)} = J(x)t(x) \tag{1}$$

where, J(x) is considered as object radiance, d(x) is the observer-object, distance $\eta$ is the attenuation coefficient.

Scattering of the light is due to the presence of particles in underwater medium. Scattering consists of forward scattering and back scattering. Random deviation of the light ray from the camera lens is termed as forward scattering. The artificial light hits the particles present in water and is reflected back to the sensor camera. This process is called back scattering.

The forward scattering component $E_{BS}$ is a part of deflection of light. It has only a little part in image degradation process and so it can be ignored. The back scattering component is the main reason for loss of color contrast. The back scattering component is expressed as:

$$E_{BS}(x) = B_\infty(x)(1 - e^{-\eta d(x)}) \tag{2}$$

where $B_\infty(x)$ is a color vector known as the back-scattered light. Thus the simplified underwater optical model is formed by the combination of direct component and back scattering component; ignoring the forward scattering component as,

$$\mathcal{I}(x) = J(x)e^{-\eta d(x)} + B_\infty(x)(1 - e^{-\eta d(x)}) \tag{3}$$

The attenuation coefficient strongly depends on the wavelength of light and also the color in underwater environment. This is not reflected in the light model. Therefore the explicit inversion of the light model does not produce the required results and it is not used.

## 4. Underwater Image Enhancement based on Multiscale Image Fusion and Histogram based techniques-Proposed Method

In this work, we propose a method for the contrast enhancement of the underwater images. The contribution of work lies in the contrast enhancement part. The contrast enhancement is performed based on histogram techniques. CLAHE is used for luminance improvement and histogram linearzation is applied to sharpened image. This enhancement takes the input image, enhance the contrast of the image. More finer details can be visualized from the proposed method. The results are compared with Ancuti et al.[8]

The framework of proposed method is shown in Fig:1. In the framework, input image is white balanced using Grey World algorithm. The white balanced image is subjected to Gamma correction as well as sharpening. Both the images are directed to an enhancement module. The weight maps of input images are calculated. In Multiscale fusion, the inputs and weight maps are fused to obtain the final output.

The various phases in the proposed method are discussed as follows,

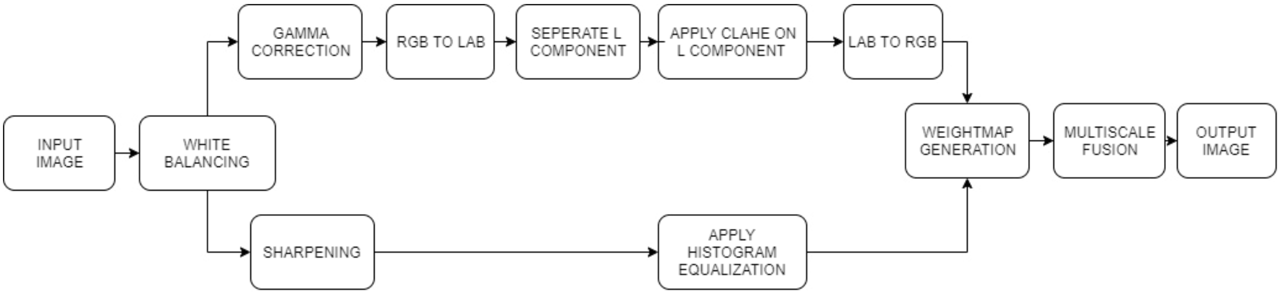


Fig. 1. Work Flow Diagram of Proposed method

### 4.1. Estimating White Balance

The process of removing the color cast in images is termed as white balancing. The color cast or color distortion in images is the overpresence of a particular color in the scene while capturing the image. The different color balancing algorithms are Simplest color balance[12], Grey world [13], Robust Auto White balance[14] and Sensor Correlation[15]. The impact of color identification and recognition in underwater is related to the depth. The crucial issue of the underwater image is the green-bluish color in underwater images that need to be rectified.

The white balancing is done to compensate the color cast caused by the selective absorption of colors with depth. A colour cast is an over presence of a specific unwanted colour which have a sufficient impact on the whole photographic image evenly.

Grey World algorithm [13], [8]is selected in our work which better remove the bluish tone present in underwater images. It is assumed that the light reflectance from the an image is colorless or achromatic. The defect of Grey world algorithm is that it suffers from severe red artifacts. Those artifacts are due to a very small mean value for the red channel, leading to an overcompensation of this channel in locations where red is present. The Gray world divides each channel by its mean value. To circumvent this issue, following the conclusions from previous underwater works[16], [17], the first aim is to compensate for the loss of red channel. In a second step, the Grey World algorithm is used to calculate the white balanced image. are followed inorder to implement compensation of the red channel:

The compensated red channel [8] $I_{rc}$ at every pixel location (x) is denoted as follows:

$$I_{rc}(x) = I_r(x) + \alpha.(\bar{I}_g - \bar{I}_r).(1 - I_r(x)).I_g(x), \tag{4}$$

where $I_r$ , $I_g$ represent the red and green color channels of image I, each channel being in the interval [0, 1], after normalization by the upper limit of their dynamic range, while $\bar{I}_r$ and $\bar{I}_g$ denote the mean value of $I_r$ and $I_g$. The blue channel may be greatly attenuated in turbid waters or in places with high plankton density due to its absorption by organic matter . Here the red channel compensation is found to be insufficient and the compensation of blue channel have to be done to reduce its attenuation.[18] This is followed by the white balancing process using Grey World algorithm.

### 4.2. Gamma Correction

After white balancing process, an output is obtained, which is subjected to color compensation. Since white balancing is not enough to recover the absorbed color in underwater images, we apply gamma correction to the white balanced image. Gamma correction is meant to correct global contrast and it is important due to the fact that the white balanced images appear to be too bright in general. But in the under/over exposed regions, gamma correction have a tendency to lose the image details. This loss of details is recovered to an extent by applying a sharpening operation.

### 4.3. Sharpening

The sharpening of the white balanced image is done in this module. Sharpening is performed using the unsharp masking[25]. In Unsharp masking, a low pass version of the image is subtracted from the image itself obtaining an image with more finer details such as edges,corners, boundaries etc. Thus a high pass filtered image is obtained. It is done by the formula S = I + $\beta$(I - ($G * I$)). where I is the image to sharpen, $G * I$ denotes the Gaussian filtered version of I, $\beta$ is a parameter whose small value is not enough to sharpen the image and high value give rise to oversaturated region[8]. Therefore the unsharp masking is done as follows:

$$S = (I + \mathcal{N}\{I - G * I\})/2, \tag{5}$$

where I is the image to sharpen, $\mathcal{N}$ is the normalization operator, $G * I$ denotes the Gaussian filtered version of I, $3 \times 3$ Gaussian filter is used in the unsharp masking.

### 4.4. Luminance Enhancement

In this work, enhancement is done parallelly as a two step process. In the first step, the gamma corrected output undergoes a luminance enhancement in LAB color space.In the second step, histogram linearization is applied to the sharpened image.

#### 4.4.1. Luminance Enhancement using CLAHE

One of the challenging factors in an underwater image is non-uniform illumination. In order to overcome this limitation, luminance enhancement of the image is performed. The gamma-corrected output of the white balanced image is subjected to luminance enhancement in L*a*b* color space. The L*a*b* is a device-independent Color space. Here L* denotes luminance and a* and b* denotes the chromaticity coordinates. The L* component is separated and CLAHE[19],[20] is applied on it.

#### 4.4.2. Contrast Enhancement using Histogram Linearization

The sharpened output obtained after applying unsharp masking is subjected to Histogram Linearization[26].As a result, an output image is obtained which has a higher contrast than the input image. These two histogram manipulation procedures paved way to obtain a more enhanced output during fusion.

### 4.5. Weight Map Generation

Since we need to explore the spatial relations of degraded regions, we have to generate a weight map. Here each pixel weight is generated based on the characteristics of the object such as hue, saturation, contrast. The different weight maps used here are Laplacian Contrast Weight, Saliency Weight, Saturation Weight[8]. The following section explains how each weight map is generated.

#### 4.5.1. Laplacian Contrast Weight

Laplacian Contrast Weight($W_L$) estimates the global contrast by computing the absolute value of a Laplacian filter applied on each input luminance channel. This map is used in different applications such as tone mapping [21] and extending depth of field since it assigns high values to edges and texture. For the underwater enhancement task, however, this weight is not sufficient to recover the contrast, mainly because it cannot distinguish much between a ramp and flat regions. To handle this problem, the Saliency Weight map is generated.

#### 4.5.2. Saliency Weight

Saliency Weight($W_s$)highlight the most noticeable objects that fail to show prominence in the underwater scene.We use Achantay et al.[23]method to measure the saliency. This is a computationally efficient algorithm that has been inspired by the biological concept of center-surround contrast. The property of saliency map is that it favor highlighted areas. To overcome this limitation, we introduce an additional weight map based on the observation that saturation decreases in the highlighted regions.

#### 4.5.3. Saturation weight

Saturation weight ($W_{Sat}$)enables the fusion process to gain chromatic information from highly saturated regions. It measures the intensity of color in an image. The saturated colors make the image look more vivid. This weight map estimation is based on the deviation for every pixel position between the color channels and luminance.

### 4.6. Multiscale Image Fusion

In Multi-scale image ,enhanced sharped image and enhanced gamma corrected image and weight maps are fused together. The defects of these inputs can be decreased and the image quality can be increased to some extend by the application of weight map. Then multiscale fusion of the inputs and weight maps are performed.

#### 4.6.1. The Fusion process

The Multiscale fusion performed here is on the basis of Laplacian Pyramid.[22].In the Multiscale Fusion, which is a pyramid representation, the input image is divided into a sum of band pass images. Here each level of the pyramid filter the input image with a low-pass Gaussian filter G, and decimates the filtered image by a factor of 2 in both directions. Then the upsampled version of the lowpass image is substracted from the input image. According to the traditional multi-scale fusion strategy[21], each source input $I_k$ is decomposed into a Laplacian pyramid while the normalized weight maps $\bar{W}_k(x)$ are decomposed using a Gaussian pyramid. The mixing of the Laplacian inputs with the Gaussian normalized weights is performed independently at each level l:

$$\mathcal{R}_l(x) = \sum_{k=1}^{K} G_l \left\{\bar{W}_k(x)\right\} L_l \left\{I_k(x)\right\} \tag{6}$$

where $l$ denotes the pyramid levels and $k$ refers to the number of input images.The enhanced output is obtained by summing the fused contribution of all levels, after appropriate upsampling. The Multiscale Fusion reduces the artifact occured due to the sharp transition of the weight map.

## 5. Result Analysis

### 5.1. Qualitative Analysis

We have done the experiments using MATLAB in a computer with a Windows 10 Operating System, 16 GB RAM and Intel Core i7-6700CPU . The test color images of size $1037 \times 778$ are obtained from the dataset in the paper by Zhang et al.[24]

#### 5.1.1. Result

Fig:2shows the intermediate stages of underwater image enhancement of the proposed work. In Fig:2Starting left to right in the top row, the first image shows the input underwater image, The input image is dominated by a green color. Prior to white balancing, compensation of the red and blue channel is done. Second image shows the compensated image after the red and blue channel compensation,This is done due to the fact that, Grey World algorithm used for white balancing has a severe red artifact. Second row from left to right shows the white balanced image, the gamma corrected image and sharpened image respectively. The white balanced image has a hazy nature. Inorder to overcome this, gamma correction and sharpening is done. The gamma corrected image is converted to LAB color space. Then Luminance component is extracted and CLAHE is applied. Bottom row from left to right shows the output of CLAHE, Histogram Equalized image and Multiscale fused output respectively.
The improved proposed method could reveal much more details and structures compared with the existing system. We can also notice that the color cast is removed and a clear and visually appealing result is obtained using the proposed method.

Fig:3shows the output images of Ancuti et al. and the proposed method. From the output figures it is clear that the proposed method shows better results than the method of Ancuti et al. .

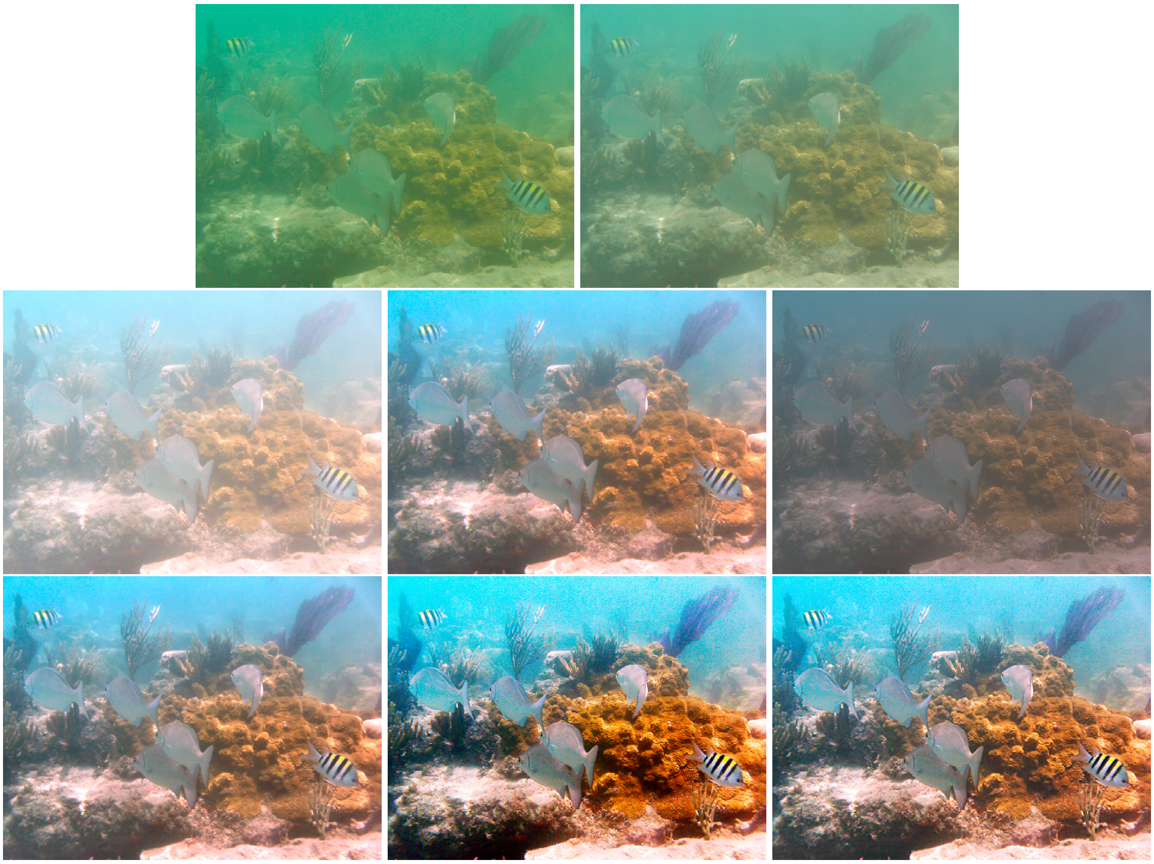

Fig. 2. Result images. Top row from left to right shows Input image and Color Compensated image. Second row from left to right shows the White balanced, Gamma corrected and Sharpened image respectively. Bottom row from left to right shows Clahe applied to gamma corrected image, Histogram equalization applied to sharpened image and Final fused output - Proposed method

### *5.2. Quantitative Analysis*

There are several evaluation measures used for assessing the quality of under water enhancement using UCIQE, BRISQUE and ENTROPY, NIQE, PCQI. Here we use UCIQE and ENTROPY as the performance matrices.

#### *5.2.1. UCIQE*

UCIQE(Underwater Color Image Quality Evaluation Metric)metric, is a linear combination of saturation, chroma and contrast. It is used to measure the non-uniform color cast, low contrast and blurring that characterize and monitor underwater images.

#### *5.2.2. ENTROPY*

The image information content is obtained on measuring the entropy. Entropy in an image can be defined as the corresponding states of intensity level which individual pixels can adapt. It is used in the quantitative analysis and evaluation image details. The entropy value provides better comparison of the image details.

Fig. 3. First column shows the output of Ancuti et al. [8] and Second column shows the output of proposed method

| Images | Ancuti et al. | | Proposed Method | |
|---|---|---|---|---|
| | UCIQE | ENTROPY | UCIQE | ENTROPY |
| ancuti5 | 2.3868 | 5.6481 | 3.5183 | 7.751 |
| ancuti1 | 2.5018 | 5.9667 | 3.1379 | 7.8752 |
| ancuti2 | 6.1733 | 5.893 | 6.9424 | 7.8531 |
| ancuti7 | 1.61 | 5.4112 | 2.5828 | 7.6691 |
| ancuti3 | 4.7776 | 5.7592 | 6.3631 | 7.8067 |
| galdran1 | 5.0161 | 5.874 | 6.1796 | 7.8609 |
| **AVERAGE** | **3.744267** | **5.7587** | **4.78735** | **7.802667** |

Table 1. Performance Analysis of Ancuti et al. and Proposed method

Table 1 shows the performance analysis of Ancuti et al.[8] and the proposed method, from the table it is clear that the average of UCIQE and ENTROPY shows a greater value for the proposed method.

## 6. Conclusion

The visibility of objects at a distance long or short in underwater scene is a big problem in image processing. Even though, many methods are available for image enhancement, they have so many limitations. The proposed method takes into consideration the advantages of multiscale fusion and contrast enhancement technique. This method does not require any additional information other than the single original image. This input image is white balanced and this is classified into two steps, first by performing the gamma correction and then sharpening. The output of this two methods are subjected to an enhancement procedure. The weight maps of these inputs are calculated. The process is followed by a Multi Scale fusion of the inputs and estimation of normalized weight maps to obtain the final enhanced output. The method is suitable for recovering the significant features and edges which have been faded. The experiments showed that the proposed method improves the visual quality of underwater images. To boost underwater image processing, a suitable database of test images for different imaging conditions is still required. More studies have to be done in order to overcome the issue of color restoration for the images taken from a greater distance in underwater.

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