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A Survey on Underwater Image Processing Techniques

Arya Ravindran[1]
krarya106@gmail.com

Anand Lokapure[2]
anand.nio.goa@gmail.com

Dr. Aisha Fernandes[3]
aisha@gec.ac.in

[1]Student, Department of Information Technology and Engineering, Goa College of Engineering, Ponda, Goa, India.

[2]Scientist, Marine Instrumentation, National Institute of Oceanography, Dona Paula, Goa, India.

[3]Associate Professor, Department of Information Technology and Engineering, Goa College of Engineering, Ponda, Goa, India

***Abstract*—Images taken underwater generally suffer from various forms of degradation due to the effects of absorption, light scattering due to suspended particles, presence of background light, low light, et cetera. Over the years, researchers have put forth various underwater image enhancement and image restoration techniques to improve the conditions of these images to assist in the examination and analysis of marine lifeforms and underwater objects. This paper aims to provide a summary and analysis of a few recent existing underwater image enhancement and image restoration techniques that were put forth in the past six years. Also, the performance of a few of the methods was evaluated both subjectively and objectively.**

***Keywords*—**underwater image enhancement, underwater image restoration, scattering, noise, contrast.

I. Introduction

About 71% of the Earth's surface comprises the ocean and 80% of it continues to be terra incognita. Underwater imaging plays a crucial role when it comes to capturing and inspecting submerged infrastructure, detecting man-made objects as well as, and researching the impact of pollution, temperature, and weather on innumerable species of organisms. Apart from marine engineering, underwater military operations rely on underwater imaging for navigational purposes. However, images taken in underwater environment scenes generally lack the desired visual quality. This is because these environments are known to have a considerable number of suspended particles in the medium which makes the images captured look hazy, called turbidity. When light rays spread through the underwater environment, it tends to interact with these suspended particles thereby leading to being scattered and absorbed. Such phenomena diminish the amount of image information and culminate in a degraded rendition of the scene having distortions, low contrast, and noise. As a result, the images procured can't be used straightway for their intended practical applications. Underwater image processing algorithms are therefore employed to improve the quality of the degraded underwater images altogether.

Aside from this, quite often, underwater images exhibit color distortion because of the exponential decay that light sustains as it traverses through a much denser medium i.e., water, as per Figure 1. Color distortions mainly occur due to various wavelengths attenuating at dissimilar degrees in water at dissimilar depths. Furthermore, colors having dissimilar wavelengths have dissimilar attenuation rates i.e., red attenuates the first being the longest wavelength, which is then accompanied by the yellow wavelength and then the orange wavelength. Blue and green colors have the shortest wavelengths, hence underwater images that are taken at substantial depth exhibit a blue or green tone also called a

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blue-green color cast. In order to intercept this issue, researchers have proposed different color correction methods that examine the color channels of the degraded images and equalize the color values to ameliorate the overall quality and saturation of the images.

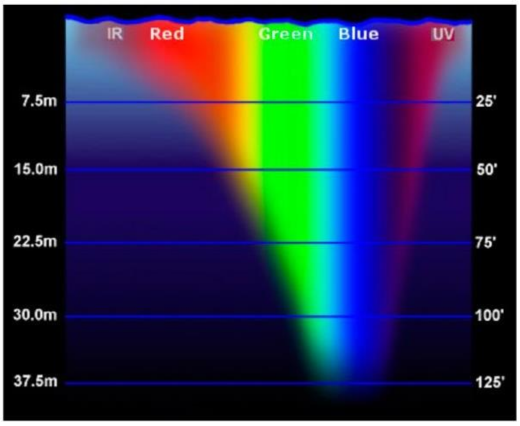

Figure 1. Effect of absorption of light in water [1]

Owing to all the above-mentioned complexities, researchers have conducted notable amounts of research for the restoration and enhancement of underwater images in recent years. Some of the techniques focus on straightforward pixel manipulation, whilst others try to estimate the underwater imaging properties like the background light and the depth at which the particular image was captured in order to cancel the noise, and improve contrast, brightness, and saturation. This paper provides a summary of recent image enhancement as well as restoration methods.

II. Underwater Image Processing Techniques

In general, underwater image processing techniques can be classified into image enhancement and image restoration wherein the former ignores the properties of the image model while the latter uses the prior knowledge of the image model to recover an enhanced version from the degraded image.

A. Underwater Image Enhancement

Underwater image enhancement techniques are considered to be simple and effective because they don't consider information regarding the environment wherein the image was captured at all. It deals with the sharpening of image features, contrasts, and reducing the scattering effect caused by suspended particles. Normally, any image or video taken in the underwater environment exhibits degradation due to absorption and scattering of light and suffers due to noise, low contrast, and poor visibility. The usage of artificial lighting also generates additional problems like vignetting. Hence, underwater image enhancement plays an important role in improving the overall quality of images so it can be beneficial in various applications such as underwater archaeology, geological exploration, autonomous underwater vehicles (AUV), marine biology, and so on. Table 1 summarizes numerous image enhancement techniques that will be discussed below.

Over the past few years, researchers have suggested various techniques to enhance underwater images. These techniques range from histogram equalization (HE), contrast stretching, and contrast-limited adaptive histogram equalization (CLAHE) to the latest CNN-based methods. Before applying any processing, generally, the images are first transformed from RBG to HSV model or other color spaces subject to the methods put forth by the authors. Deperlioglu et al. [2] have utilized the techniques of expanding the V element of HSV model, Histogram equalization, as well as Gaussian low-pass to enhance the visual quality of the underwater images. Performance of the method was then compared with AbuNaser et al. [3] by using four underwater images and has been able to deliver better results with respect to entropy and mean.

Although Histogram Equalization helps to improve the contrast of the image, CLAHE is regarded to be a major improvement over Histogram Equalization since it minimizes the over-amplification of noise that is generally visible in, HE. This is accomplished by applying HE to every block of an image and then setting a defined clip limit to avert the over-amplification of noise. To drop the haze and noise effect introduced by the bluish- greenish underwater environment, Malathi V et al. [4] utilized the Dark channel prior (DCP) and CLAHE respectively. DCP is a popular dehazing technique that was initially utilized for outdoor images but then was later remodeled for underwater images. But, the method has a serious drawback – the images produced tend to have lower contrast. Therefore, the authors merged this algorithm with CLAHE and assembled a test tank containing pebbles, rocks, shells, and so on in order to capture images under different depths and scattering effects. The resulting final enhanced images were free from haze and there was significant intensity and contrast improvement.

Since images captured at a depth are significantly affected by color, many researchers have developed color correction techniques to accomplish a balanced color distribution. Underwater color correction method based on the color filter array (CFA) and McCann Retinex-based enhancement (MR) technique as well as adaptive linear histogram transform for chromatic-depleted underwater images have been developed and suggested by Li et al. [5]. This method has been tested with 100 images taken at random and provides better detail, contrast and color than the mentioned reference methods of the authors.

Along with contrast and color correction, image sharpening also can be performed on the edges to emphasize details in an underwater image. Gao et al. [11] have put forth a revised local contrast correction technique and a guided filter for the purpose of edge preservation. Then the images were merged using the method of multi-scale fusion. The comparison results show that multi-scale fusion is better than single-weighted fusion because of the nonappearance of artifacts in resulting images. Feature points matching on the images was performed in order to demonstrate the effectiveness of improved results.

The color correction technique put forth by Zhang et al. [17] remunerates the middle and the lower color channels on the basis of fractions calculated by taking a ratio of the difference between upper and the lower color channels to those lower color channel. Then, an adaptive contrast-enhancement algorithm is utilized to enhance the contrast of final images. Images with different resolutions were considered to analogize the performance of the method, giving good results. Even though the proposed algorithm is better than existing methods, the method seems to over-enhance underwater images taken in artificial light.

B. Underwater image restoration

The objective of underwater restoration methods is to resolve the problem of distance- dependent degradation. Contrary to underwater image enhancement, the depth and degradation caused by the scene are taken into account to remove haziness from the image. Over the years, many researchers proposed hardware-based approaches to restoration using polarizers, and software-based approaches such as DCP which are prior-based, and their variants which are not only cost-effective but also perform better compared to the former methods. Table 2 provides a summary of the recent advances in underwater image restoration methods.

The main disadvantage of DCP is that it takes into account the background of images, which can be mixed with haze and thus produces a low contrast image. Therefore, Galdran et al. [14] put forth an image restoration method to restore the lost contrast by employing the red channel technique, which is a version of the dark channel method. First is the method of estimating the water light of the red channel, which then aids to determine the estimate for the transmission map. To evaluate, calculation of the coefficient of underwater image restoration and enhancement e and r [27] were obtained and performed on four dissimilar test images showing different water quality, depth, illumination, etc., and collated with five dissimilar algorithms. This method managed to provide good quality images and restored natural colors better than the existing techniques.

Due to the fact that the red channel attenuation happens faster than other color channels under underwater condition, P.Drews et al. [18] stated that it can’t be utilized to approximate the depth of field. Therefore, the authors proposed UDCP, which used the minimum of blue and green channels to compute the dark channel of the image. Then, the highest value of dark channel was used to assess the background light.

Color restoration and contrast enhancement are usually achieved by transmission map estimation and background light estimation. The latter determines how much light gets to the camera without being absorbed and scattered by the particles. Peng et al. [8] achieved accurate estimation of background light (BL), transmission maps, as well as depth of scene by considering light absorption and image blurriness, rather than DCP. These techniques perform well for real and synthetic underwater images with different lighting conditions and tones while overcoming the disadvantages of DCP. The authors accurately estimated the BL and the depth of the scene and could improve underwater images taken in various types of underwater scenes.

With the emergence of deep learning (DL) making huge strides in video and image applications, researchers have shifted their attention from traditional techniques to deep neural networks. Lu et al. [36] put forth CycleGAN with Multiscale Structural Similarity Index Measure loss for restoration of underwater images. Here, dark channel prior of turbid images was used to obtain the transmission maps. Gray values of transmission maps were analyzed in order to obtain three filters and two thresholds. MultiScale SSIM loss made both structural similarity and content between input and output, improving the performance of image restoration.

TABLE I

OVERVIEW OF UNDERWATER IMAGE ENHANCEMENT METHODS

Author & year	Method	Quality metrics	Reference methods
Deperlioglu et al.[2], 2018	Expansion of V element of HSV, HE, and Gaussian low-pass	Entropy and mean	AbuNaser et al. [2], 2014
Malathi V et al.[4], 2019	DCP and CLAHE	MAE, PSNR, and MSE	Nil
Li et al. [5], 2020	Modified MR, adaptive histogram transformation	ENTROPY, NIQE, IL-NIQE,UIQM, UCIQE	GHS [6], UIED [7], UBL, UIRL [9], GLN [10]
Gao et al [11],2021	Local contrast correctionand multi-scale fusion	UCIQUE, UIQM, SIFT, UICM	He [12], Galdran [13], Galdran [14], Ancuti [15], Ancuti [16]
Zhang et al.[17],2021	Adaptive contrast enhancement, unsharp mask	EI, PCQI, UIQM, UCIQE, SIFT	ADCP [14], UDCP [18], UIC [19], IBLA [8], GDCP [20], GVF [21], UIVF [22], RBEA [23], TS [24], MCCM [25], and CCBE [26]

TABLE II

OVERVIEW OF UNDERWATER IMAGE RESTORATION METHODS

Author & year	Method	Quality metrics	Reference methods
Galdran et al. [14], 2015	Automatic Red-channel	e and r [27], μ_{diff}, σ_{diff}, and λ [29]	[28],[29],[30],[31],[32]
Peng et al. [8],2017	Estimation of depth basedon image blurriness and light absorption (IBLA)	BRISQUE, UIQM, UCIQE, depth map, BL, PSNR, SSIM	[30], [33], [14],[34]
Lu et al. [36],2018	Combination of DCP and CycleGAN, SSIM loss	UICM, UISM, UIConM, UIQM	CLAHE, Retinex , White balance,DCP , CAP [37], NON[38], DehazeNet [39], CycleGAN [40], and Li's method [41]
Drews et al [18],2016	UDCP	Empirical restoration score	MDCP, DCP, BP

III. Metrics For Evaluation

The images obtained from the restoration and enhancement methods should be analyzed to compare the subjective and objective performance of the algorithms. Subjective assessment is made on the basis of the human visual system (HVS); while the latter deals with the calculation of image quality metrics andcan be either no reference or full reference evaluation. Mean square error (MSE), mean absolute error (MAE), peak signal to noise ratio (PSNR), structural similarity index (SSIM), Entropy, etc are some of the widely used full-reference metrics. These metrics require high quality reference images which may not be achievable due to the complex and diverse underwater environment.

On the other hand, no-reference image quality metrics do not require a base or a reference image to assessimage quality. It just considers the information of the degraded image whose quality is being evaluated. For instance, Underwater color image quality evaluation (UCIQE) considers chroma, saturation, and contrast, whereas underwater image quality measure (UIQM) consists of chroma (UICM- underwater image colorfulness measure), sharpness (UISM – underwater image sharpness measure) and contrast (underwater image contrast measure (UIConM)). BRISQUE (Blind/referenceless image spatial quality evaluator**)** is another metric that uses the image pixels to compute features and it depends on the spatial Natural Scene Statistics. Patch-based contrast quality index (PCQI) is also a popular method for the analysis of contrast in underwater images.

IV. Underwater Image Evaluation Results

This section aims to present the visual results of different image enhancement and restoration methods such as HE, CLAHE, Ancuti[15], Deperlioglu[2], Gao[11], DCP, UDCP, and IBLA. The images were obtained from the EUVP dataset and were implemented on Windows 11 with Core i5 8.00GB RAM, Python 3.8. Figures. 2 and 3 show the results of different underwater image enhancement and restoration techniques.

For quantitative evaluation purposes, two metrics i.e., UCIQE and UIQM were taken under consideration. Underwater Image Quality Measure (UIQM) [42] is a combination of three underwater image attribute measures: the colorfulness (UICM), sharpness (UISM), and contrast (UIConM) measures, where

$$UIQM = c1\times UICM + c2\times UISM + c3\times UIConM \quad (1)$$

A greater value of the UIQM represents higher image quality and has better human visual effects. A higher UCIQE implies that the images have better contrast, saturation, and chroma. Table 3 indicates the mean value obtained for the methods. Ancuti [15] and Gao [11] provide better results when it comes to removing the color cast and enhancing the images when compared to, HE and CLAHE. IBLA works well for images with blue color cast and has higher UCIQE and UIQM values compared to DCP, UDCP, and IBLA.

Figure 2. Results of underwater image enhancement methods

Figure 3. Results of underwater image restoration methods

TABLE III

QUANTITATIVE RESULTS

	HE	CLAHE	Ancuti[15]	Gao [11]
UCIQE	0.5318	0.640	0.651	0.828
UIQM	2.033	2.0644	4.213	4.520

	DCP	UDCP	IBLA
UCIQE	0.5645	0.5817	0.582
UIQM	4.026	3.580	3.585

V. CONCLUSION

In this survey paper, a few traditional and recent research advances in underwater image enhancement and image restoration techniques were summarized. The paper also discusses the main reasons for the degradation of underwater images i.e., low contrast, scattering, absorption, poor visibility, and so on, and the implementation, significance, and classification of existing methods. Although traditional methods try to solve these issues, the resulting image still may have remnants of degradation in terms of noise after dehazing, unevenness, and over-illumination in certain regions of the images.

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