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Underwater Image Enhancement: A Review of Modern Utilized Concepts

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***Abstract* - The revolution in current technology imposes on most systems of daily life in processing a wide range of applications through digital image processing techniques that have produced practical answers to many challenges such as image optimization, analysis, reconstruction, recovery, compression, processing, and so forth. One application of interest in underwater image enhancement has attracted the attention of experts in recent years due to its importance. In this work, a review of modern processing concepts for underwater images is given to get the basic knowledge on what are the used methodologies, what are the processed degradations, and what processing concepts have been used in the past years. Hence, different methods are reviewed and implemented on underwater images to know their advantages and disadvantages. The results of each method are demonstrated, the processing concept is summarized, and a synopsis that includes the main notion, complexity, pros, and cons is given to get a generalized idea about this topic.**

Keywords: Underwater, image enhancement, utilized concepts, image processing, color images.

I. INTRODUCTION

In a wide range of applications, digital image processing (DIP) techniques have produced workable answers to various challenges such as image enhancement, analysis, reconstruction, restoration, compression, manipulation, and so forth. These challenges exist in different image-related applications, and one such application is underwater imaging. The processing of underwater images has caught the attention of experts in recent years, as DIP has been applied extensively in this field [1-3]. In scientific endeavors like observing marine life, counting populations, and analyzing geological or biological conditions, the quality of underwater photos is crucial. The difficulty of taking pictures underwater is primarily due to the murkiness that results from light that is reflected from a surface, deflected, and scattered by water particles, as well as color changes brought on by the differing levels of light attenuation for different wavelengths [4-6].

Images taken underwater suffer from contrast loss and color divergence due to light scattering and color alteration. Sand, minerals, and plankton, which are present in lakes, oceans, and rivers, are among the suspended particles that contribute to murkiness. A fraction of the light that is reflected off objects and traveling in the direction of the camera collides with these suspended particles. As shown in Figure 1, this then absorbs and scatters the light beam [7]. In (Figure 1) At point x, natural light enters an underwater scene from the air. The reflected light travels a distance D(x) to the camera. The radiance perceived by the camera is the sum of two components: the background light formed by multi-scattering and the direct transmission of reflected light [7].

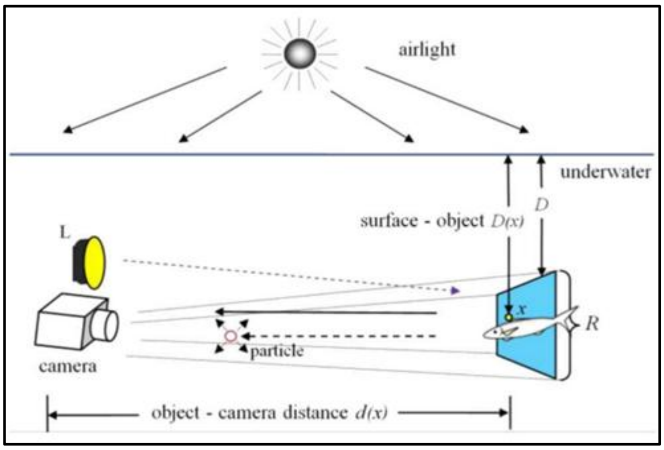

Figure 1: the underwater scene from the air [7]

Light of various wavelengths is attenuated in the water body in various ratios, as depicted in Figure 2. Underwater photos frequently exhibit color bias due to this unequal attenuation. Underwater image deterioration can also be brought on by suspended particles in the water. Figure 2 shows how particles close to the path that incident light takes to reach the camera create small-angle scattering (forward scattering) of that light, while particles in the surrounding environment cause large-angle scattering of ambient light to enter the camera lens (backscattering). Underwater photos become fuzzy and blurry due to these light refractions. Figure 2 shows how artificial lighting systems are installed as underwater expeditions progress deeper to provide the necessary illumination for the dark deep-sea environment. Given the constrained scope and in homogeneity of [8].

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Samples of different underwater images are given in Figure 3.Backscattering and light attenuation cause low visibility, which negatively affects underwater photographs. The appearance of murkiness is brought on by random light attenuation. The contrast of recorded images is diminished by some of the light reflecting from the medium along the line of sight. Distinct undersea habitats have different primary causes of visual deterioration. Recently, numerous approaches to enhance the quality of underwater images have been suggested by researchers [9-11]. However, not all were successful in enhancing the underwater images.

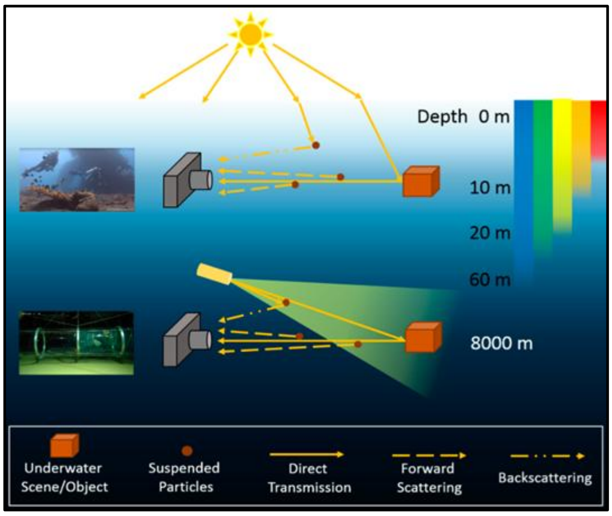

Figure 2: Underwater optical imaging in shallow water and deep sea [8]

Figure 3: Samples of different underwater images

As mentioned earlier, underwater images suffer from different types of degradation. The first is color distortions [12], as it is either assumed to be green or blue depending on the underwater region in which it is captured. For example, a greenish color cast will appear if the image was taken in an area where the water's algae content is high, and a blue color cast will appear if it was captured in deeper water. The second is poor contrast [13], which makes the image appear with a hazy look. The third is distorted sharpness [14], which makes the image details appear unclear and blurry. The fourth is incorrect illumination [15], which results in dark and unevenly illuminated images that hamper the observation of certain details in the image. Overcoming these degradations to produce improved-quality images is currently highly needed.

II. UTILIZED CONCEPTS

In the past years, researchers have approached the enhancement of underwater images in different ways. Moreover, not all the degradations have been addressed, as some research work focuses on one or two degradations only. In the upcoming sub-sections, different legacy methods will be reviewed, and their results will be demonstrated as well.

2.1 Wavelength Compensation and Dehazing (WCD)

In 2012, Chiang and Chen proposed the WCD algorithm, in that it initially uses the existing dark channel scene depth derivation method to estimate the distance between the object and the camera and generate the derived depth map (DDM). Using the DDM, the front, and back regions within the image are divided into two parts, and then the front light intensity is compared with the background light intensity to determine whether an artificial light source was used during the image acquisition process. If the light source is artificial, the illumination provided by the auxiliary lighting will be removed from the foreground area to avoid overcompensation in the advanced stages. A drying algorithm is then used for wavelength compensation to remove the effect of haze and color change from the object to the camera. The percentage of power remaining between the different color channels in the back is then used to estimate the depth of the water underwater. Finally, each color is compensated for each channel to adjust the blue tone to the natural color. Figure 4 shows sample results achieved by the WCD algorithm.

Figure 4: Some results of the WCD algorithm

2.2 Underwater Dark Channel Prior (UDCP)

In 2013, Drews-Jr et al. proposed a UDCP algorithm that utilizes the standard DCP in an exceptional way for underwater images, in that the DCP concept is only applied to

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the blue and green channels of the image as these two layers are vastly affected by the high absorption effect related to underwater conditions. In the UDCP, dark areas are detected using a specialized approach with is different from the one used by the standard DCP. In addition, it utilizes a spectral matting approach to enhance the approximation of transmission which is considered an important phase in the standard DCP. The outcome of these adaptions is an adapted DCP method that is more suitable for underwater images. Figure 5 shows sample results achieved by the UDCP algorithm.

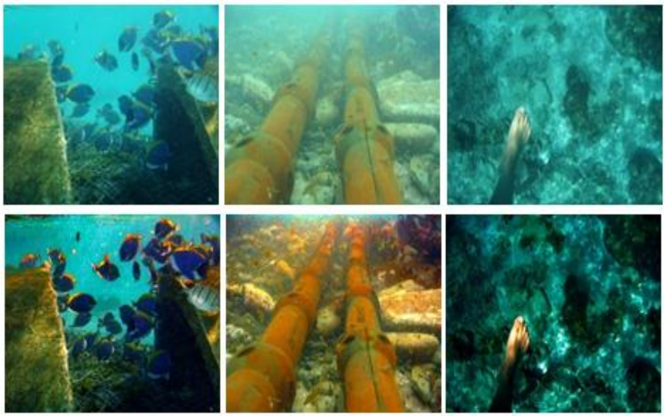

Figure 5: Some results of the UDCP algorithm

2.3 Blurriness and Light Absorption (BLA)

In 2017, Peng and Cosman introduced BLA, in that it generates the enhanced image using three steps. The first step involves computing the noise map and then processing it with a Gaussian filter. Next, the max filter is used to approximate the blur map followed by determining the blurriness (B) using the guided filter. The second step involves determining the light absorption amount by selecting background light from the hazy image regions to be used next in obtaining the transmission map (TM). The third step involves creating the out image using TM, B, and the original image. Figure 6 shows sample results achieved by the BLA algorithm.

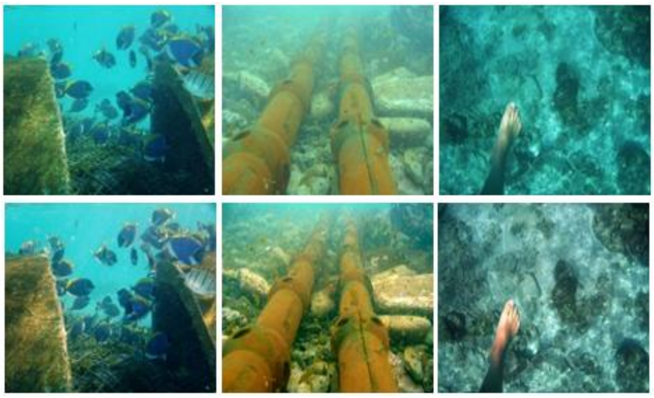

Figure 6: Some results of the BLA algorithm

2.4 Two-Step Approach (TSA)

In 2017, Fu et al. proposed TSA, which utilizes two basic principles of color correction and contrast enhancement. For the first step, it utilizes a piecewise linear approach on the saturation channel of the input image for color correction. Next, the image is transformed to the LAB domain and adaptive histogram equalization is applied to improve contrast. Finally, the final image is obtained by converting the filtered image back to the RGB domain. Figure 7 displays sample results achieved by TSA.

Figure 7: Some results of TSA

2.5 Dehaze Net with Hybrid Wavelets (DHW)

In 2018, Pan et al. introduced a DHW algorithm, in that it first uses an end-to-end convolutional neural network to estimate the transmission map (TM). At the same time, it utilizes the bilateral adaptive filter to improve the TM. Moreover, a color aberration removal strategy based on white balance is utilized for color enhancement. Next, the Laplace hierarchy is applied to obtain a sharper image. Finally, the hybrid wavelets concept is used to generate the output image. Figure 8 illustrates sample results achieved by the DHW algorithm.

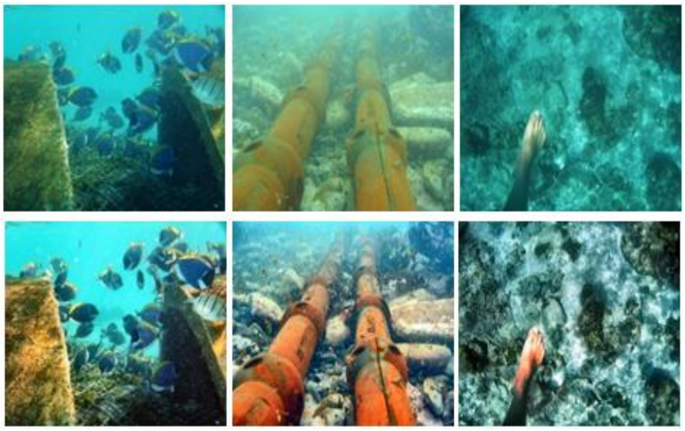

Figure 8: Some results of the DHW algorithm

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2.6 Guided image fusion (GIF)

In 2019, Bavirisettiet al. developed the GIF method, in which white balancing is initially performed on the input image for initial image adjustment. Then, the adjusted image is obtained, and two images are generated from it, one having better sharpness and the other one owning a corrected gamma. Next, for both images, the weight map is generated after detecting the salient features using a directed filter. The final image is generated using the weight generated weight maps when merging the sharpened and the gamma-corrected images. Figure 9 expresses sample results achieved by the GIF algorithm.

Figure 9: Some results of the GIF algorithm

2.7 Hybrid Framework (HF)

In 2020, Li et al. introduced HF, in that the input image is initially processed by underwater white balance (UWB). UWB consists of for main steps: color compensation, histogram stretching, gray-world approach, and mapping. The output of UWB is then processed by a guided filter and sent to the variational contrast and saturation enhancement (VCSE) phase along with the input image. VCSE is an approach that improves the contrast and saturation of the image through multiple iterations to generate the final image. Figure 10 shows sample results achieved by the HF algorithm.

Figure 10: Some results of the HF algorithm

2.8 Hybrid Approach (HA)

In 2021, Sequeira et al. proposed a hybrid approach, in that the dark channel prior method is applied to the blue channel instead of the red channel due to the unstable density of the red channel in the aquatic environment. It involves splitting the image into patches, calculating the light amount for each patch, and smoothing the transmission map via a directed filter. The image is then converted to the HSV color model, and a linear stretching approach is applied to all the channels. Next, contrast stretching is applied to the saturation and value channels and the image is converted back to the RGB domain to generate the output image. Figure 11 demonstrates sample results achieved by HA.

Figure 11: Some results of the HA algorithm

2.9 Multi-weight and multi-granularity fusion (MWMGF)

In 2022, Wanget al. introduced the MWMGF approach, in that it first corrects the colors by using color weight balance and adaptive histogram equalization. From the previous step, different weights are determined which are Laplace contrast weights, local contrast weights, saliency weights, saturation weights, and exposure weights. Having the input and processed images with the computed weights, the output image is generated using a multigrain fusion procedure. Figure 12 demonstrates sample results achieved by the MWMGF algorithm.

Figure 12: Some results of the MWMGF algorithm

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Table 1: A synopsis of the studied algorithms

#	Method	Concept	Intricacy	Advantage	Disadvantage
1	WCD [7]	Wavelength compensation and dehazing	Moderate	Preserve the color of the image	Amplifies the brightness
2	UDCP [16]	Dark channel prior	low	Fast	Processing artifacts
3	BLA [17]	Blurriness and light absorption	Moderate	Increase the Contrast	Much complicated
4	TSA [18]	Color and contrast correction	low	Fast	Unnatural contrast
5	DHW [19]	DehazeNet and hybrid wavelets	High	Improves the visual details	Increases the color distortion
6	GIF [20]	White balancing, sharpening, and gamma correction	High	works well with blue images	Improper white balancing
7	HF [21]	White balance with variational contrast and saturation enhancement	Moderate	Improvements in contrast and saturation	Generates color artifacts
8	HA [22]	Dark channel prior with guided filter	Moderate	Good output image contrast and high-speed	Unclear background objects
9	MWMGF [23]	Multi-weight and multi-granularity fusion	High	Balanced Contrast	Noise amplification

III. CONCLUSION

Various research works have been introduced by many researchers related to underwater image enhancement. Underwater images suffer from different types of degradation such as color distortions, contrast imperfections, loss of sharpness, and improper illumination. Such degradations affect the quality of images and therefore, they should be processed properly to produce acceptable results in terms of visual quality. However, the introduced methods in the past years did not adequately process underwater images as they may not consider all the degradations, utilize complex computations, introduce artifacts, color distortions, and so forth. Therefore, this research field remains open for development and the need for developing high-end algorithms related to underwater image enhancement is still high.

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