UNDERWATER IMAGE ENHANCEMENT: A REVIEW

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***Abstract* —** This paper has been written with the objective of studying and understanding the most recent developments in the field of enhancement of underwater imaging. Enhancement of underwater images is essential for inspection of underwater infrastructure and detection of many man-made objects. The need for enhancement is also to understand marine biology, and for environmental evaluation. It also finds application in the research of monuments submerged in water. Underwater navigational monitoring in submarines largely depends on the quality of underwater images. This article recapitulates major points of the different methods used for the enhancement of images clicked underwater. These images suffer from severe degradation in the form of low resolution, color cast, color scatter, crinkle pattern, uneven light distribution. The techniques reviewed include integrated color model, Modeled PSF's, GWAC, WCID, color balance and fusion, White balancing and Rayleigh stretching.

***Keywords*—Underwater image enhancement, PSF, GW, ACE**

I. INTRODUCTION

Significant amounts of research have been conducted for enhancement of underwater images recently. Underwater imaging is not only an important aspect of Marine engineering, it also finds use in many military operations under water and can be vital for navigational purposes. Aquatic biodiversity research completely depends on imaging underwater. Thus, in such a scenario, it becomes vital to overcome any issues related to underwater images.

Images captured underwater typically suffer from problems of color cast (bluish tinge) due to the color scattering effect shown by water (as a medium), crinkle pattern due to random deflection of light rays, haze due to suspended particles, attenuation of the light reaching the depths of the ocean from the surface of water. Absorption of light reduces light energy whereas scattering of light changes direction of light propagation.

Several methods have been proposed for enhancing the underwater images. These techniques were proposed at different times of the century, all with different applications, as well as certain limitations.

II. EVOLUTION OF ENHANCEMENT TECHNIQUES FOR UNDERWATER IMAGES

Evolution in the field of underwater imaging occurred due to necessity of clearer photos for analysis of underwater architecture and construction. Higher resolution underwater images are very important to study underwater coral formations. These images are also used to study marine biology and effects of environmental changes on the same.

TABLE I. TECHNIQUES DEVELOPED IN THE RECENT YEARS TO ENHANCE UNDERWATER IMAGING

Problems encountered in underwater imaging	**Enhancement techniques**	**Year**
Problems of Color Cast	Gray world automatic color equalization[10]	2004
Problems of weak image signal and blurry end results due to scattering effects of water	Modeled PSFs [1]	2007
Problem of lighting and color Brightness	Integrated color model [3]	2010
Lighting problems and energy loss due to Attenuation	Wavelength compensation and image dehazing [9]	2012
Problem of uneven scattering of light and extensive absorption in Medium	CLAHE with Rayleigh scattering[23]	2013
Problems of color cast and scattering of light	Color balance and fusion[22]	2018
Problems of color cast due to presence of illuminant Underwater	White balancing and Rayleigh stretching [21]	2018

III. APPLICATIONS

Under water image enhancement finds a lot of application in multiple number of diversified fields. It finds use in inspection of underwater infrastructure and detection of any man-made objects.it is also used to understand marine biology research, for environmental evaluation, for the research of monuments submerged in water and for underwater navigational monitoring in submarines.

Underwater image enhancement is also crucial in the control system of underwater vehicles and to determine the cultural heritage of archaeological sites submerged under water. Also, study of underwater formations like coral reefs depends heavily on underwater image enhancement.

IV. TECHNIQUES USED IN ENHANCEMENT OF UNDERWATER IMAGING

A. Modeled PSF's (Point Spread Function)

In the framework [1], the authors incorporate all the effects of the medium as well as imaging system into a single system response function (Modelled PSFs), which is then used to perform further calculations. Any 2-D image that has been obtained as an output from the imaging system, (denoted by p(x,y)) can be treated as a convolution of the original image signal (t(x,y)) and the system response (f(x,y)) to that signal. This convolution becomes a simple multiplication (in frequency domain) when Fourier transform is applied.

This response of the imaging system (denoted by F(u,v)) (Point Spread Functions - PSFs) can be thought as being a combined effect of the imaging system, the effects of the medium as well as other factors. The response function becomes a simple multiplication (in the frequency domain)due to its cascading nature. All of this can be summed up in the following equations:

$$p(x,y) = \iint t(x_1,y_1) f(x-x_1.y-y_1) dx_1 dy_1 \quad (1)$$

$$P(u,v) = T(u,v)\ F(u,v) \quad (2)$$

$$F(u,v) = F_{system}(u,v)\ F_{medium}(u,v) \quad (3)$$

The individuality that the system and medium possess from one another in this framework is vital for accurate functioning of the method. [1] Determining the system response (and hence its Fourier transform) and taking inverse Fourier transform of equation (1), one can theoretically obtain the original image signal (without any effects of the medium) and hence a clearer underwater image.

One major advantage of the method is that, it can be very medium and condition specific [1] i.e. system response will vary depending upon the type of water (saline of fresh water) and also on other external factors such as thermal conditions (temperature of water), presence of foreign particles, etc. This would help produce better results in every kind of medium environments and conditions as the response function will change accordingly incorporating any changes in the medium characteristics.

To estimate the effectiveness of the restoration procedure, a quality metric is designed incorporating the environmental properties. [3] This metric utilises wavelet decomposition and denoising algorithms constrained by a power-spectrum ratio. [4]

Limitations to this procedure would occur mainly in the form of errors in the edge detection algorithms, deficit in noise reducing procedures and also in the level of wavelet deposition for quality metric. [4]

B. Integrated color model

Initially contrast stretching is applied in RGB platform which helps in equalization of the contrast in the images.[3] Next in the HSI platform saturation and intensity stretching is performed which enhances the colour and helps solve the low lighting issue.[3]

HSI-Represents every color with three parameters Hue Saturation and intensity.[14] A wider colour range is available in the HSI platform since various colour elements can be varied in this stage of enhancement.[3] These parameters solve color brightness and lighting problem in underwater images. [3]

Contrast stretching - By 'stretching' the range of intensity values that an image contains, to a desired range of values, the method revamps the contrast of that image.[15]

C. Gray World Automatic Colour Equalization

Color constancy enhancement based on GWACE. They have used combined algorithm of GW, ACE, WP for underwater image recognition.[10] Gray world - Lightness constancy adaptation (it acts similar to how an exposure control works in a camera). White patch - Color constancy (the lightest coloured patch is selected to be used as a reference, it's working is similar to human visual system) [16]

A new approach ACE was hence derived by merging both the algorithms mentioned above. [10] The background was subtracted in order to recognize the images. The fishes were remotely selected from the tank and fish on screen are chosen to recognise images in real time. [10]

D. Wavelength compensation and image dehazing

An artificial light source is used to take care of the lighting problem underwater since the light from the surface does not reach the depth completely.[9] While compensating the energy loss the luminance of the light must be taken care of to prevent overcompensation.[9] This algorithm follows a process of reverse compensation to take care of the color cast and image scatter and from the artificial light source and then reinstituting the color cast for the depth at which image was captured.[9]

E. White balancing and Rayleigh stretching

The white balanced image is integrated with gamma correction and rayleigh contrast stretching. Rayleigh Stretching (Histogram stretching) removes noise from underwater image. Output histogram is stretched depending upon strong/weak color channel.

White balancing - The unwanted colour cast is balanced and reduces the interruption caused by the diverse illuminants present at the depth.[21] First WPR (White Patch Retinex) is used for illuminant estimation which is followed by CCT (Correlated Color Temperature)

F. Colour balance and fusion

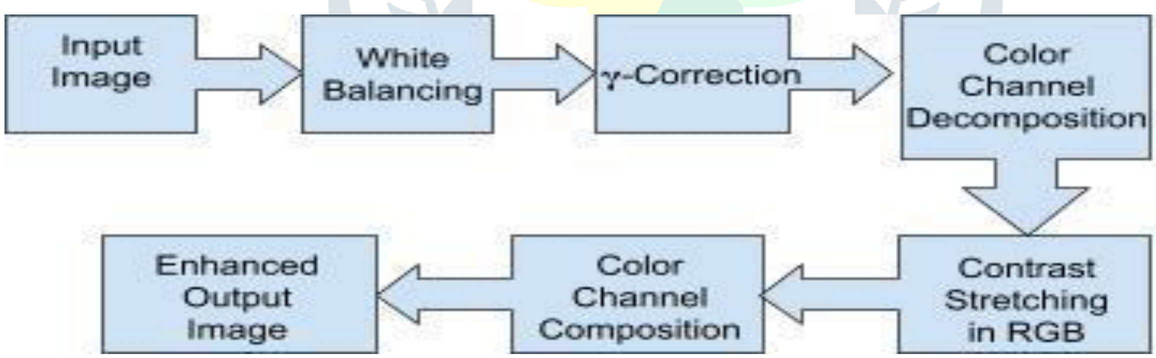
Blending of two images- color compensated of the original and the white balance of the degraded original image[22] This method mainly finds applications in inspection of underwater infrastructure, detection of man-made objects marine biology and archeological research

Original image is sent through a white balance corrector and then the output is passed through an Image-sharpening System and a Gamma-Correction system in parallel. More details in [22]. The output from the two systems acts as an input for a multi-scale fusion system which produces the end result. Underwater white balance aims at improving image aspects by removing the color casting due to illumination and attenuation.[22] Attenuation depends on wavelength methods such as Gray world algorithm, etc.

Gray World Algorithm - This method best removes the bluish tone but suffers for severe red artefacts. However green channel is well preserved and fraction of green channel is added to red. Compensation is directly proportional to difference in mean of green and red values

Multi-Scale Fusion process involves two inputs - one to enhance color contrast (through gamma correction) and the other to enhance edge sharpness of white balance. The weights of the fusion process include Laplacian contrast weight, Saliency weight and Saturation weights.

FIG I. Steps involved in white balancing and rayleigh stretching



G. CLAHE

Contrast limited adaptive histogram equalisation improves the contrast and equalises histogram efficiently. CLAHE with Rayleigh distribution more optimal quantity among (Rayleigh, uniform, exponential) histogram distribution. Unsupervised color correction method (UCM) eliminates bluish color cast and enhance low red color, low illumination and true colors of underwater images. Methods involved in this process include CLAHE, SIFT-based image matching and Contrast stretching.

CLAHE divides image into several non-overlapping regions, histogram is calculated for each region followed by clipping to a required limit for contrast expansion and for better quality the pixel distribution of the histogram is converted into Rayleigh. SIFT- based image matching involves the steps such as Scale-space extrema detection, Key-point localisation, Orientation assignment, as well as the use of Key-point descriptor. Finally, contrast stretching is done wherein the range of intensity values is stretched in order to escalate the contrast of image.

TABLE II. STEPWISE EFFECT OF VARIOUS PROCESSES INVOLVED IN UNDERWATER IMAGE ENHANCEMENT TECHNIQUES

Modeled PSFs	System Response Function	Incorporation of medium and environment effects
	Splitting System response into medium and Environmental effects	Individuality of medium and environmental effects emphasised
Integrated Color Model	Contrast stretching is applied in RGB platform	Balance the contrast in the images
	Saturation and Intensity stretching in the HSI platform	Enhances the colour of the image and solves low lighting issues
	Variation of color parameters in HSI platform	Provides solution to brightness problem in Underwater Images
Gray world automatic color equalization	Gray World Algorithm	Provides brightness consistency like exposure control in cameras
	White Patch Algorithm	Helps achieve color consistency like human visual system
	Automatic color equalization	Merges effect of gray world and white patch algorithm.
		Subtracts the effect of background from the image
Wavelength Compensation and Image Dehazing	Artificial light source	Take care of the lighting problem underwater
		Compensating energy loss avoiding over compensation
	WCID Algorithm - Process of reverse compensation	Take care of the image scatter and color cast
Colour Balance And Fusion	Color cast removal	Improves image aspects
	Gray World Algorithm	Removes Bluish tone, balances loss of red channel
	Multi-Scale Fusion	Enhances Color Contrast and Edge Sharpness
	Laplacian Contrast Weight	Tone Mapping, Extending Depth
CLAHE	Rayleigh Distribution	Provides for Optimum Histogram Distribution
	Unsupervised Color Correction Method	Eliminates Bluish Color Cast
		Enhances Low Red Colour, Low Illumination
	Stretching of Contrast Intensity Values	Enhances Contrast of Underwater Images
White balancing and Rayleigh stretching	White Balancing	Reduces interruption By Various Illuminants
	Integration of White-Balanced image with Rayleigh Stretching	Removes Noise from Underwater Images
	White Patch Retinex (WPR)	Estimation Of Illuminant

V. CONCLUSION

Clicking clear and high resolution photos underwater can prove to be a tough task given the intense absorption and scattering effects of the medium. Thus image enhancement techniques are applied to remove image noise and improve overall image clarity. Technique involving modelling of medium characteristics into a PSF can be used to determine very accurate images but that requires explicit and thorough knowledge of medium conditions in real time and hence this method increases equipment cost.

The typical problems of color cast can be dealt with using GWACE method as well as with the technique of color balance and fusion. WCID technique has been proven to be extremely effective in solving the problem of rapid signal degradation due to absorption in water. It finds applications in improving the range of photography underwater significantly. Thus, we can see that we have come a long way in improving underwater imaging standards and still there lies a lot of scope for improvement. With the increasing pace of technology and growing fields(like ocean thermal energy, tidal energy, marine biology, etc), procedure implementation time will reduce drastically and in future, these enhancement algorithms can find applications in underwater video enhancement too. The importance of underwater images becomes even more apparent and paves its way for future research and developments in this area.

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