Literature Review on Underwater Image Restoration Techniques

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Abstract— Underwater image restoration is a complex task due to lack of reference image and varying underwater environment. These images are degraded by absorption and scattering effect of light propagation. In water light undergoes wavelength dependent attenuation thus red light (longer wavelength) attenuates faster than blue light. As depth increase, light drops most of the red content and image appears in bluish-green color tone. These images also suffer from low contrast, color cast and hazy appearance. Existing methods may require specialized hardware or it may be based on multiple images of same scene. Thus they cannot be used in real time or video acquisition task. Therefore it is desirable to develop an effective method to restore color and enhance contrast of these images. As goes deeper into water the blurriness in the image increases and this prior is used to obtain depth map. The backlight is obtained based on image blurriness and variance. These factors are substituted in the image formation model (IFM) to restore the image.

Keywords: Image Formation Model (IFM), Image Restoration Techniques, EMD

I. INTRODUCTION

In oceanic engineering underwater imaging place a vital role. Underwater images are used to study marine species, an inspection of underwater cables and pipelines, underwater scene analysis and scientific research. Nowadays several technologies are available to record underwater images and videos like waterproof cameras. But underwater images suffer from several drawbacks such as poor visibility, uneven illumination, contrast degradation and bluish appearance. This is because light on its path from the object to camera gets reflected by the organic particles suspended in water. The major problem in underwater image restoration is the lack of reference image and complex underwater environment. In underwater light propagation suffers from two degradation effects namely absorption and scattering. Scattering is due to collision with suspended particles and causes light rays to reflect in different directions, this may add a hazy layer to the image. Absorption causes energy loss of light rays and it depends upon the water medium properties such as density and turbidity. In more turbid water the absorption rate is higher compared to normal water.

As the light goes deeper into water it drops colors one by one depending upon the wavelength. Red light with longer wavelength attenuates rapidly than shorter wavelength blue light. Thus blue and green light reaches farther depth compared to red and orange. That is why underwater images appear in bluish-greenish color. The methods used to improve the visual quality of the underwater image falls into two categories restoration and enhancement. Enhancement involves un-sharp masking, histogram equalization etc., to provide a visually pleasing result. Enhanced image is not necessarily to be same as the original image. But restoration aims to improve the image as same as original image by modeling degradation. A physical model based on propagation of light and some prior knowledge about the scene was used to restore underwater image properly. It restores image by estimating the parameters of underwater image formation model. Underwater image can be modeled as a linear combination of direct component and backscattered component. Direct component is the amount of light reflected from the object surface, only a portion of it reaches the camera and remaining gets scattered or absorbed. Scattering is of two types: forward and backward scattering. Backward scattering is mainly responsible for low contrast thus it is included in image formation model and forward scattering component is neglected.

With every 10m increase in depth the brightness of sunlight is going to reduce by half. Almost all red colored light is decreased to 50% from the surface but blue continues to go deep in the ocean because of shorter wavelength of blue color and so it travels more distance in the water. That is why most of the underwater images appears to be blue and green color.

$$I(x) = S(x).t(x) + B(1-t(x)) \qquad (1.1)$$

I(x) is observed intensity at pixel x. J(x) is scene radiance, fraction of light reflected from the scene into camera. t(x) is medium transmission map, portion of the scene radiance that is not scattered or absorbed. B is backlight, portion of ambient light scattered into camera by the particles, it may add a hazy layer to image. The image is recovered by inversion action of image formation model that is scene radiance is obtained by using other parameters.

II. LITERATURE SURVEY

Several approaches are carried out to recover high quality underwater images.

Some method utilizes specialized hardware techniques such as polarization filters to capture the image. YoavY.Schechner and Nir Karpel proposed Recovery of underwater visibility and structure by polarization analysis [1]. In this method several images of same scene with different degree of polarization is captured using a polarization filter fixed to the camera. In underwater, light undergoes partial polarization which causes degradation. This method considers only veiling light (backlight) as the major source of degradation. A pair of images one with maximum veiling light and other with minimum veiling light is used to obtain an estimate of veiling light. Then using estimated veiling light and water transmittance unveiled object radiance is obtained. After that contrast stretching is done for color correction. This method achieves an enhancement in underwater visibility range and contrast. But the experimental setup requires additional time and cost. Also it is not suitable for automatic acquisition task such as video acquisition due to moving parts in polarization filters.

Duo Min He, Gerald G L Seet presented Divergent beam lidar imaging in turbid water [2]. It uses an optical or laser sensing technique to capture turbid underwater images. Water turbidity may increases absorption effects in underwater. The method involves very short, high energy pulses in divergent beam for illumination. The receiver gated width and illumination pulse width should match and the delay between them should be correspondent to the round trip time to the target. This allows gated camera to collect only the image containing light pulse reflected by the target and thereby reducing scattering related noise. The above mentioned two methods require multiple images of the same scene, thus are inadequate for real-time applications.

Algorithms utilizing a single image of the scene also suffers from several problems. Shuai Fang, Rong Deng, Yang Cao introduced Effective single underwater image enhancement by fusion [3]. First white balancing is applied to the input image. It removes the unwanted color cast caused by light scattering and achieves natural appearance of underwater images. White balancing may lead to overcompensation of red channel where red content is present. As green channel is preserved in underwater a portion of green channel is added to red for avoiding overcompensation. The added portion should be a linear function of the difference between mean green and mean red values. First input is obtained by performing gamma correction of white balanced image. It corrects the global contrast since white balanced images appear to be bright. Second input image corresponds to the sharpened version of white balanced image. Sharpening may reduce degradation caused by scattering effects. Multi-scale fusion is used to combine gamma corrected and sharpened image. In multi-scale fusion each source input is decomposed into Laplacian pyramid while weight maps are decomposed using a Gaussian pyramid. Both pyramids have the same number of levels. Mixing of the laplacian inputs with the Gaussian normalized weight map is performed independently at each level. Then dehazed output is obtained by summing the fused contribution of all levels. This method requires less execution time and can be used for real time underwater surveillance. It enhances the image only if medium is homogeneous in most of the cases this assumption cannot be achieved.

Kaiming He, Jian Sun, and Xiaoou Tang developed image restoration using Dark channel prior (DCP)[4]. Natural image appears to be dark in one of the RGB channels. The dark channel was due to shadows in the image, colorful surface where atleast one channel has low intensity. Low intensity of one channel is due to wavelength dependency of attenuation. Points in the scene closer to the camera appear to be dark as it experiences less brightening from the object. This information is used to calculate transmission map and restore the image. The absorption rate in red channel is high thus for greater depth red channel appears to be dark and misregarded as point is closer to the camera. This may leads to erroneous transmission map estimation and poor restoration.

Adrian Galdran, David Pardo, Artzai Picon, Aitor Alvarez Gila proposed Automatic red channel underwater image restoration [5]. Colors associated with different wavelength have different attenuation rate among this red light undergoes greater attenuation. In DCP as larger the depth red channel values will be small thus scene points are falsely regarded as closer. To overcome this drawback of general DCP this paper is based on inverted red channel values. Here DCP is based on green, blue and inverted red channel, instead of directly using red channel values. For greater depth red channel values will be small whereas inverted red channel has larger values. Backlight is obtained from top 1 percentage of brightest red pixels and transmission map estimated using DCP information. Using image formation model scene radiance is restored. This method is simple and robust also recovers lost visibility range. Although this method suffers from several problems due to the wavelength dependency of light attenuation. Mainly DCP methods are suitable for terrestrial image restoration (in the case of fog) because absorption effects are absent in atmosphere.

N Carlevaris Bianco, A Mohan, and R Eustice presented Maximum intensity prior (MIP) to estimate transmission map[6]. Depth has a linear dependence on attenuation of color channels, as goes deeper into underwater the haze in image also increases. A measure of attenuation of different color channel can be used to obtain an estimate of haze thereby transmission map. MIP is calculated as the difference between maximum intensity of red channel and that of green and blue channels. A larger value of this prior indicates that red channel attenuates less therefore the point is closer to camera. A smaller value of this prior indicates that target is at a larger distance from camera. Scene radiance is modeled as Markov random field, then posterior probability is maximized to obtain maximum a posteriori estimate of scene radiance. It requires a single image of the scene and does not require any specialized hardware. This method also directly uses red channel values thus gives poor restoration results.

Kashif Iqbal, Michael Odetayo, Anne James introduced underwater image enhancement using an Integrated color model[7]. This method removes bluish color cast and improves the contrast of image. Bluish color cast removed by equalization of color space. For a good quality image all the 3 color channels have almost similar values but in underwater image blue channel has higher intensity values. Thus a high gain value is used to multiply red and green channel with respect to average blue channel intensity. After channel equalization contrast correction in RGB and HSI color space is performed to improve the overall contrast of the image. It involves contrast stretching in RGB color space and saturation and intensity stretching in HSI color space. RGB stretching compensates the color cast and eliminates uneven illumination. Saturation and intensity stretching is to increase true color of image. This method fails to remove haze from image.

Aysun Tas_yapı Celebi and Sarp Erturk have presented a new algorithm based on an Empirical Mode Decomposition (EMD) which is used to improve visibility of underwater images[8]. It is indicated that the proposed method provides finer results compared to regular methods such as contrast stretching, histogram equalization. In the given approach, initially EMD is used for decomposing every spectral part of an underwater image into Intrinsic Mode Functions (IMFs). Then by combining the IMFs of spectral channels, enhanced image is constructed with variables weights in order to attain an improved image with enhanced visual features.

Setiawan, Agung W., Tati R. Mengko, Oerip S. Santoso, and Andriyan B. Suksmono used Contrast Limited Adaptive Histogram Equalization (CLAHE) to enhance color retinal image [9]. Here, they introduced new enhancement method using CLAHE in G channel that improve the color retinal image quality. The enhancement process conduct in G channel is suitable to enhance the color retinal image quality. Visual observation is used to judge the enhanced images and compare them with the original images.

G.Padmavathi, Dr.P.Subashini, Mr.M.Muthu Kumar and Suresh Kumar Thakur have compared and evaluated three filters performance [10]. The filters are homomorphic filter, anisotropic diffusion and wavelet de-noising by average filter. All the filters are helpful in preprocessing of underwater images. Image quality is improved, noise is suppressed, edges in an image are preserved and image is smoothen by the use of these filters. Among the three filters used wavelet de-noising by average filter gives required results in terms of Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR).

III. DIFFERENT TECHNIQUES

A. Contrast Stretching

Contrast stretching is an image enhancement method that is used to improve, enhance the image contrast by `stretching' the series of intensity values. A measure of image's dynamic range or the "broaden" of image's histogram is the contrast of an image. Whole range of intensity values present within the image, or in a easier way, the minimum pixel value subtracted from the maximum pixel value is called dynamic range of image. It differs from the complicated histogram equalization in a way that it can only concern a linear scaling function to the image pixel values.

B. Empirical Mode Decomposition

EMD is a versatile and based on the local moment period function of the figures[8]. So, it is suitable to help nonlinear along with non-stationary data so that it is an incredibly adept opportunity for real-life software. The EMD method is exceptionally direct, and the fundamental procedure is to carry out sifter operations on the new data arrangements until the final data series are stationary, and subsequently disintegrate the whole signal into many Intrinsic Mode Functions (IMFs) and a residue. EMD is connected to the Red, Green, Blue channels independently. The original image is break up into several intrinsic mode functions by EMD process and a final residue.

C. Homomorphic Filtering

The homomorphic filtering is used to fix non-uniform lighting to reinforce contrast from the impression. This is a frequency filtering technique. It is the most used system that it redresses non-uniform lighting and sharpens the picture.

$$F(x,y) = I(x,y)*r(x,y) \qquad (3.1)$$

Where $F(x, y)$ is the function of image detected by device, $I(x, y)$ the illumination function and $r(x, y)$ the reflectance function. By multiplying these components filter can reduce the non-uniform illumination present in the image.

D. Anisotropic Filtering

Anisotropic filtering disentangles picture components to enhance picture division. This channel smoothens the picture in homogeneous range whereas it conserve edges and upgrades them. It is used to smooth compositions and decreases relics by erasing little edges enhanced by homomorphic filtering.

E. Wavelet de-noising by Average Filter

Wavelet de-noising is used to lower the noise i.e., the Gaussian noise are generally present in the camera pictures and other kind of instrument pictures [10]. While moving the pictures Gaussian noise can be included. This wavelet denoising gives great results contrasted with other de-noising routines because, unlike other methods, it does not assume that the coefficients are independent. Undoubtedly wavelet coefficients in normal pictures have enormous conditions. Besides the reckoning time is short.

F. Red Channel Method

In this method, colors having short wavelengths are recovered, as expected for underwater images, leading to recovery of the lost contrast [5]. This method can estimate the color of the water. Pick a pixel that lies at maximum depth with respect to camera. It is assumed that degradation of image depend upon location of pixel. After estimating the water-light transmission of the scene is estimated. Thus, Color correction is done.

G. Histogram Equalization

Histogram equalization is a method for modifying image intensities and contrast of image in image processing using the image's histogram. Histogram equalization is helpful in pictures with backgrounds and frontal areas that are both bright or both dim. This is a simple and straightforward technique. But it has a disadvantage also that is it amplifies the background noise present in the image and lead to decrease in the useful signal. So it produces unrealistic effects in the output images. The basic idea lying behind this method is mapping the gray levels depending upon the probability distribution of the input gray levels.

H. Contrast Limited Adaptive Histogram Equalization (CLAHE)

It is generalization of adaptive histogram equalization. With this technique the image is broken up into tiles. The gray scale is calculated for each tiles, based upon its histogram and transform function, which is derived from the interpolation between the manipulated histograms of the neighboring sub-regions. The transformation function is relative to the cumulative distribution function (CDF) of pixel values in the area. CLAHE contrasts from AHE in contrast limiting. CLAHE [9] limits the noise enhancement by cut-out the histogram at a client characterized worth.

I. Integrated Color Model

The integrated color model is proposed on color harmonizing by contrast improvement is RGB color space and color adjustment in HSI model [1]. In integrated color model, first step is to diminish the color cast by the equalization of all the color values present. In the second step an improvement is applied to the contrast amendment to broaden the histogram values of the red color. Second step is done for green and blue colors again. In the last step, the saturation and intensity components of the HSI color model is applicable for contrast adjustment to enhance the true color and for the issue of uneven illumination.

IV. CONCLUSION

Different underwater image restoration techniques are reviewed and studied. All the reviewed methods enhance and restore the underwater images to great extent. Underwater images suffer from poor visibility due to color casts and light scattering that caused by physical properties existing in underwater environments. Degraded underwater images lead to a low accuracy rate of underwater object detection and recognition. The experimental results show that the above explained techniques improves the quality of underwater images efficiently and arrives at good results in underwater objects detection and recognition.