IOSR Journal of VLSI and Signal Processing (IOSR-JVSP)
Volume 6, Issue 2, Ver. I (Mar. -Apr. 2016), PP 30-33
e-ISSN: 2319 – 4200, p-ISSN No. : 2319 – 4197
www.iosrjournals.org

A Comparative Study of Various Methods for Underwater Image Enhancement and Restoration

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Abstract : *Images taken underwater usually do not possess visual quality because of degradation in visibility. The propagated light from object to the camera undergoes attenuation and scattering before reaching the camera. Hence the images suffer from blurriness and lack of contrast. These effects which degrades the visibility of underwater images can be called as haze. The haze formation in images taken underwater is mainly due to water turbidity and the differential scattering of light by suspended particles in the water. Also due to the selective absorption of color components of light by the medium, images suffer from color imbalance which causes one particular color to dominate among others. In the past few years, many approaches were put forwarded to improve the visibility of underwater images by removing haze and some color correction techniques are introduced to enhance the perception of underwater images. This paper is a review on various approaches for underwater image enhancement over the last few years.*
Keywords: *color correction, enhancement, haze, transmission map, underwater image*

I. Introduction

In Ocean studies, underwater imaging plays a vital role in exploring the life under water. Underwater images are taken to conduct underwater surveys and to study about aquatic life and characteristics. But it is difficult to get clear images of objects under water due to poor visibility. As the light enters the water medium, it gets scattered by the suspended particles and also a portion of the light is absorbed by the medium. This can be explained by Beer - Lambert law which states that "the water layers having equal thickness will absorb equal fraction of light as it passes through the medium." Due to the characteristics of water medium, the light components having longer wavelengths are absorbed easily at the surface and those with shorter wavelengths manage to travel deep. This is why most of the underwater images possess greenish or bluish color cast.
The water surface effects are shown in Fig.1

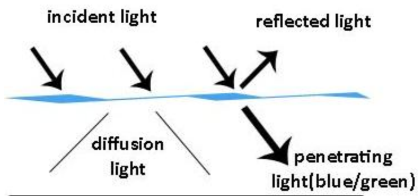

Fig.1 Water surface effects

Some part of the incident light passes through the water and the remaining light gets reflected at the surface. Due to selective absorption characteristics, the red color component of the light suffers severe attenuation from the surface itself. So the light penetrating deep to the water mainly consists of blue and green color components. The diffusion light represents the light which spreads throughout the water medium by scattering.

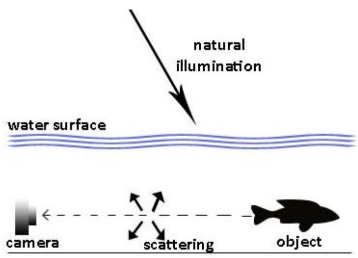

Fig.2 Underwater image acquisition

The amount of sunlight reduces as it goes deeper under water. As a result, underwater images appears to be dark. Also only a portion of light from the objects reaches the camera and the remaining light gets scattered while traversing the path through the water medium. Thus underwater images taken by a camera suffer from degradation in visibility, uneven illumination, blurring, color imbalance etc. The haze is one which hinders the visibility in underwater images. Most of the algorithms concentrate on removing haze from underwater images and to attain natural colors by color correction techniques.

Many computer vision methods are proposed to enhance underwater images for variety of applications such as underwater telecommunication systems, pipeline detection, mine detection. Underwater image enhancement and image restoration are two terms in which most of the research works are conducted. Image enhancement deals with the color manipulations with underwater images whereas image restoration is based on some optical models and is also termed as deconvolution where the scene radiance is derived from the model.

II. Image Enhancement Methods

In 2005, Yoav Y. Schechner and Nir Karpel [1], proposed a method to enhance underwater images through a set of images taken at different polarization using polarizers. The light undergoes partial polarization in underwater which causes the degradation. The method considered only the veiling light as the dominant degradation component. Veiling light is the ambient light scattered by the particles of the turbid water medium which hinders the visibility of image taken by the camera. The method was based on the fact that natural veiling is partially polarized. A pair of images were acquired using the polarizing filters, one with ‘best state’ of the polarizer which has minimum veiling light and the other with ‘worst state’ of the polarizer which has maximum degradation due to veiling light. Then an estimate of veiling light was obtained from these two images by taking an assumption to the water background and direction of propagation of light. Using the estimated veiling light and water transmittance, unveiled object radiance is obtained. After that, contrast stretching was done for color compensation. The method effectively inverts the effects that cause visibility degradation but the experimental setup requires time and cost.

In 2006, Stephane Bazeille et al. [2] put forwarded a set of operations for pre-processing of underwater images. The pre-processing steps included homomorphic filtering, wavelet denoising, anisotropic filtering, contrast stretching and color correction. The processing was done in YCbCr space rather than RGB color space in order to reduce the computation time. The advantage was instead of processing each color channel separately, one color channel from YCbCr can be processed in no time. The method can enhance the underwater image without prior knowledge of the surrounding environment. They succeeded in reducing the average blur present in underwater images.

In 2007, Kashif Iqbal et al. [3] created a method based on slide stretching. The method incorporates contrast stretching in RGB color space and saturation and intensity stretching in HSI color space. RGB stretching equalizes the overall color contrast of the image and solve the problem of uneven illumination. Saturation and intensity stretching in HSI color space was done to increase the true color. The results obtained were visually pleasing but the method fails to remove haze from the images.

In 2009, Frederic Petit et al. [4] developed a method which inverts the light attenuation in underwater images by a color dynamic compression using quaternions. Each pixel in the image in RGB space was represented by a pure quaternion which has real part zero and three imaginary parts to represent each color channels. By geometrical transformations, the vectors of the images were contracted towards the hue axis. The hue axis was determined from the Principal Component Analysis method. After the transformation, water pixels were moved close to the hue axis near the gray axis while colors of the objects were preserved and remains distant from the water pixels. The light attenuation inversion was achieved by normalizing pixel co-ordinates with the hue vector co-ordinates. The method achieved significant amount of color balance in restoration.

In 2010, Kashif Iqbal et al. [5] modified their own method mentioned in [3] to enhance low quality underwater images by unsupervised color correction technique. The method removes bluish color cast in underwater images by equalization of RGB color space and restores natural colors of underwater images. Underwater images possess average color maximum in the blue channel. So a high gain was used to multiply other two channels with respect to the average blue light intensity. The color channels were balanced by this process. After equalization, contrast correction in RGB and HSI color space is performed to improve the overall contrast of the image.

In the 2011, H.Y. Yang et al. [6] proposed a low complexity underwater image enhancement using the dark channel prior. In this method, the depth map of the image was computed directly from the observed image using median filter. Using the optical model for degraded images, the object scene radiance was recovered. To improve the contrast of images, a color correction technique was also employed. The method requires only less computing time and was suitable for real time underwater surveillance. In the same year, C.J. Prabhakar et al. [7] proposed some preprocessing steps for enhancing the degraded underwater images which was a modification of method mentioned in [2]. Homomorphic filtering was applied first to correct the non-uniform illumination and enhance the color contrast. Then wavelet based denoising was applied to the resultant image. Instead of using anisotropic filtering, a bilateral filter was used to smooth the image while preserving the edges. Finally contrast stretching was done to improve the contrast and the color correction was done by equalizing the color means. J. W. Kaeli et al. [8] in the same year designed a color correction technique for underwater imaging using the information from sensor modules. Overlapped sequences of underwater color images and Doppler Velocity Logs were used to estimate the attenuation co-efficient and strobe beam pattern. The obtained values are used to remove color artifacts from underwater images.

In 2012, John Y. Chiang and Ying-Ching Chen [9] invented a method which compensates for the attenuation effects along the propagation path and removes the influence of artificial light source from underwater images. A depth map was first estimated and then the foreground and background within a scene were segmented. The light intensities of foreground and background are compared to determine the presence of artificial light source and was compensated. The residual energy ratios of different color channels existing in the background light was exploited to estimate the water depth. Color balance was achieved by color change compensation based on the differential attenuation of each wavelength light. This way, the effect of light scattering and color change was compensated by the algorithm. Due to varying parameters, measurement of rate of light energy loss was not accurate and also calibration was required before processing. In the same year, T. C. Aysun and E. Sarp, [10] proposed a method for visual enhancement of underwater images using Empirical Mode Decomposition. In this method, the image was decomposed into several intrinsic mode functions and a residue. Each color channel in RGB color space was decomposed separately. The enhanced image is obtained by summing up individually weighted IMF's. The weight factor was determined by using a genetic algorithm. Finally, a color correction was applied to suppress prominent blue and green color.

In 2013, Haocheng Wen et al. [11] introduced a new optical model for underwater images considering the differences between light attenuation in atmosphere and water. A new underwater dark channel was derived from the optical model to estimate the patch transmission and scattering rate. The background light was estimated considering the severe attenuation of red channel in water. But the enhanced images appear to be dark which needs further processing. M S Hitam et al. [12] in the same year, formulated a method based on mixture Contrast Limited Adaptive Histogram Equalization. It aimed to overcome the noise amplification during processing of underwater images. CLAHE differs from normal histogram equalization in such a way that it operates on small regions on image called tiles thus obtaining several histograms corresponding to each region. The resultant sets of histograms were used to redistribute intensity of the image. The amplification is clipped at a user defined value called clip limit which represents the amount noise to be smoothed and the level of contrast enhancement. CLAHE was applied to individual channels in RGB color space and finally combined together whereas in HSV color space, it was applied to S and V only for easiness. The undesired artifacts were reduced by combining the results of above two operation using Euclidean norm.

Shuai Fang et al. [13] developed a fusion strategy based image enhancement method. The method first applies white balancing to reduce the significant difference between brightness values and restores natural light. Then a clear image was obtained by histogram stretching to increase global contrast of the images thereby enhancing the visibility of hazy portions. These two images were taken as inputs and are weighted by specific maps. The weighted sum of the two inputs were computed in a per pixel fashion to obtain the enhanced results. The algorithm requires only less execution time and can enhance the underwater image only if the medium is homogeneous. Since there are no deconvolution operations which costs extensive computation time, the method can be used for real time underwater surveillance. B. Zhang et al. [14] has proposed a method for optimization of underwater images. The method considers water itself an imaging object and the removal of water and attenuation compensation is done using Chroma transform. After that, visual quality is improved using optimization.

In 2014, S. Serikawa and H. Lu [15] have proposed a fast joint trigonometric filtering dehazing algorithm for underwater images based on dark channel prior. The depth map was obtained from red channel for underwater images. A fast joint trilateral filter was used to refine the transmission map to remove block artifacts. The computational complexity is less as compared to soft matting using laplacian and the noise level is reduced in the resultant images. But the recovered images appear to be dark and need contrast enhancement. In the same year, Pooja Sahu et al. [16] proposed a method for underwater image enhancement based on unsharp masking. Unsharp masking is subtracting an image from its blurred version which will emphasize the details in an image. The normalized color stretched image was sharpened by unsharp masking and again it was filtered to detect the presence of edges. The unsharp mask thus formed along with sharpened image and normalized image was used increase the contrast along edges thereby enhancing the image. Zhe Chen et al. [17] introduced a method based on region specialized underwater image restoration in inhomogeneous environment. The method was based on the statistics of hazy images. Like the dark channel, most local patches of a haze free image possess maximum intensity in atleast one color channel. This was the bright channel. The image was segmented into regions in such a way that the region influenced by ambient light was having dense haze thickness than the region where ambient light was low. Bright channel was used to segment the images into regions of different illumination. After that, the depth information and scattering light was estimated from the dark channel at particular regions and region based dehazing with color compensation was done.

In 2015, Adrian Galdren et al. [18] developed an automatic red channel underwater image restoration algorithm which was a variant of dark channel prior. The marine environments are characterized by absorption which is not present in the case of atmosphere. The red channel gets absorbed severely than the blue and green channels in underwater environments. The method recovers colors associated to shorter wavelengths. The recovered images attained a natural color correction and improved visibility. In the same year, Richa Gupta and Zuber Farooqui [19] formulated a dark channel based method with FFT enhancement. The method was a slight variation from the wavelength compensation based image dehazing [9]. With the prior knowledge, the transmission map was obtained from the residual energy ratios of each wavelength light and it was adjusted using morphological operations. The recovered scene radiance was enhanced for clear visibility using Fast Fourier Transform. Y. T. Peng et al. [20] in the same year proposed a method to estimate the depth map of underwater images from image blurriness rather than from dark channel prior. First, a difference between original image and a multi scale Gaussian filtered image was taken to estimate the pixel blurriness. Then a rough estimate of depth map was obtained by applying a maximum filter to the pixel blurriness map assuming depth was uniform among local patches. Then morphological operations along with guided filter was used to refine the depth map thus obtained. The refined map was finally utilized in the image formation model (IFM) to get the enhanced output. The method effectively enhances underwater images under different lighting conditions.

III. Conclusion

This paper presents a comparative study on various methods for underwater image enhancement and restoration for the last few years. Earlier, hardware elements such as polarizers, sensors etc. are used to take a set of images of the same scene and are processed to obtain a clear image. With the development of computer vision techniques, optical models are derived for image formation both in outdoor as well as underwater environments suffering from visibility degradation. A single image with visibility degradation can be used in these models to get an enhanced output image. Other than histogram equalization and contrast stretching, most commonly used method for image enhancement is based on the optical model for degraded image. Recently, underwater image enhancement using multiscale fusion technique is introduced which reduced the computational complexity to an extent.

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