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Wavelet based perspective on variational enhancement technique for underwater imagery

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ABSTRACT

In deep sea environment, the quality of underwater imagery is primarily affected with low contrast, blur and color cast due to the absorption and scattering. In order to deal with these discrepancies a framework is proposed in this paper wherein a set of energy functionals is applied on the approximation and the detailed coefficients of the image. The approximation coefficients of RGB components are modified for adjusting the average intensity value of the image followed by the color correction of these coefficients at finer scales. Subsequently, the processing of detailed coefficients are done for improving local contrast of the image. The performance of the proposed method is evaluated qualitatively and quantitatively on three underwater datasets at varying depths. Qualitative analysis is carried out by comparing the hue histogram of input and output images, whereas quantitative analysis comprises of PSNR, Entropy and SSIM quality metrics. The results of the proposed method are compared with state-of-the-art methods. From the obtained outcomes, it is observed that the proposed method significantly removes the color cast by improving the contrast of underwater images in addition to preserving its detailed structural features.

1. Introduction

1.1. Background

Remotely operated vehicles (ROV's) and autonomous underwater vehicles (AUV's) are considered as important tools for submarine and military operations. These vehicles are typically equipped with sonar and vision sensors for acquiring underwater images. Sonar sensors are useful in detection and classification of long range objects, whereas the vision sensors are used in conclusive short range applications (Çelebi and Ertürk, 2012). The visual quality of underwater images useful for scientific areas such as taking a census of populations, monitoring sea life and assessing geological or biological environments (Chiang and Chen, 2012b). According to the Lambert–Beer empirical law (Gordon, 1989), light is exponentially attenuated as it travels in water. The exponential loss of intensity, called attenuation, is emerging from absorption which causes energy loss of light and the scattering that changes direction of the electromagnetic energy (Zhao et al., 2015). Underwater image model proposed by Jaffe-McGlamery (Matte et al., 2011) is represented as a linear combination of three components: (i) the direct component E_d (ii) the forward-scattered component E_f and (iii) the backscatter component E_b. Therefore, the total irradiance E_T is given as (Schettini and Corchs, 2010):

$$E_T = E_d + E_f + E_b \tag{1}$$

The direct component is the light reflected by the object and reaches camera without scattering. Forward scatter occurs when the reflected light from the object deviates its direction on the way to camera, resulting in blurring and contrast reduction of the image. Backscatter occurs when the light directly comeback to the camera before reaching the object to be illuminated. Contrast of the image is reduced due to backscattering. On going deeper in sea, not only the amount of sunlight is reduced but the colors are also dropped off one by one depending on their wavelength. Firstly, the red color disappears at a depth of 3 m, followed by the orange color. Most of the yellow color vanishes at a depth of 10 m. After 30 m only blue color will exist and travel further due to its shortest wavelength. Therefore, underwater images are mainly dominated by blue-green color cast (Iqbal et al., 2007).

1.2. Related work

The primary aim of image enhancement algorithms is to remove

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blue/green color cast and generate the good contrast images with minimal artifacts. Comprehensive literature survey on enhancing the color and texture of images is presented in (Cho and Yu, 2015; Galdran et al., 2015; Zhao et al., 2015). The techniques available for enhancement of underwater images can be combined in various groups on the basis of their center of attention. In this regard, the first set of techniques are intended towards the removal of haze or blurring effect. Fattal (2008) predicted the radiance of the scene followed by deriving the transmission image by a single image. Heavy haze images are not able to handle by this method. Nicholas et al. (Carlevaris-Bianco et al., 2010) proposed an algorithm to estimate the depth of a scene so as to dehaze the underwater images. This method does not require any prior knowledge of the scene towards assessment of true image from this depth information. Serikawa and Lu (2014) proposed a joint trigonometric filter for dehazing the underwater image. This filter was able to preserve edges and reduces the overly dark areas of the underwater image. The influence of the artificial light source is not considered during implementation of the algorithm.

The second group of techniques belong to correction of color in underwater image/video. Torres-Méndez and Dudek (2005) proposed a method wherein the multi-scale representation of color corrected and color diminished images is carried out for constructing a probabilistic algorithm to improve the emergence of underwater images. In Iqbal et al. (2010), tried to reduce the color cast by modifying three color channels based on the Von Kries hypothesis. Thereafter the image is converted to HSI color model, wherein the S and I components are stretched at both ends. Some regions in Iqbal's output image are under-enhanced and affected by high noise. Color correction of underwater images by using lαβ color space is proposed by Biancoa et al. (2015). This method requires just a single image and does not need any particular filters or prior knowledge of the scene. Moreover, due to its low computational cost it is suitable for real-time implementation.

Contrast enhancement techniques are employed in the third group of underwater image enhancement techniques. Arnold-Bos et al. (2005) proposed complete pre-processing framework for underwater images. A combination of deconvolution and enhancement methods are used for considering all types of noises present in underwater domain. Results on simulated and real dataset are presented. Çelebi and Ertürk, (2012) proposed an Empirical Mode Decomposition (EMD) based enhancement method for underwater images. The enhanced image is constructed by summing the Intrinsic Mode Functions (IMF) of R, G and B channels by an optimum weight set obtained using genetic algorithm. The problem of low contrast in underwater images is addressed.

The fourth group is a combination of the above mentioned techniques named as hybrid techniques. In hybrid techniques, any two methods from each group are combined for underwater image enhancement. Chiang and Chen (2012a) proposed image enhancement technique using wavelength compensation and dehazing. This method tries to address both light scattering and color cast problems. Using this technique, expensive optical instruments or stereo image pairs are no longer required. Two step process has been followed by Li and Guo (2015). First, the haze caused by light scattering is removed to get dehaze image. Second, a color correction technique is employed on dehazed image for removing color cast. Above mentioned methods are combinations of haze removal and color correction techniques. The second category in hybrid techniques is a combination of haze removal and contrast enhancement techniques. Ancuti et al., (2012) technique was based on fusion concept. In their method, the degraded image is white balanced in order to remove the color cast of the sub-sea images followed by suppressing some of the undesired noise. This is the first method of underwater enhancement technique for several applications such as segmentation and image matching. This method is not able to enhance images acquired at longer depths using artificial illumination source.

The third category in hybrid techniques is a combination of color correction and contrast enhancement techniques. Bazeille et al. (2006) proposed a method able to correct non uniform illumination, suppress noise, adjust colors and enhance edges. This method requires no priori-knowledge and no parameter adjustment. Quantitative comparison of the method is not done using quality index parameter. In Hitam et al. (2013), contrast limited adaptive histogram equalization (CLAHE) is applied to RGB and HSI components. Using euclidean norm, these images are combined to produce a enhanced contrast image with low noise. Output images of this method has higher noise than those from the conventional CLAHE in some situations. Shuai Fang et al. (2013) applied the white balance and global contrast enhancement technologies to the original image respectively, followed by these two adapted versions of the original image as inputs that are weighted by specific maps. This method is not applicable to images having non-homogeneous medium in the water. Lu et al. (2015) proposed enhancement technique for shallow water applications. They developed a robust colorline-based ambient light estimator for estimate the ambient light. A weighted guided domain filter has been proposed to compensate for the transmission followed by a color correction method for removing color cast. This method is effective in removing haze-like scatter and not with large particles scatter. Modification of the histogram of the combined RGB and HSV color models is proposed by Ghani and Isa (2015). This method improves image contrast in addition to noise reduction. This technique is the modification and extension of ICM and UCM proposed by Iqbal et al. (2010). The effect of under and over enhanced areas in the output images are reduced by this technique. The blue-green color cast of the image is also reduced by the above mentioned method.

Existing underwater image enhancement techniques, using discrete wavelet transform, utilizes either approximation or detailed coefficients. Preserving structural details of the objects and color cast removal of an image cannot be achieved simultaneously by applying the extensive operations on particular coefficients of the image. However, the proposed method processes the approximation and detailed coefficients separately so as to address the variations of underwater images. In this manner the main contribution of the proposed method is its ability to improve the visual quality besides to retaining the structural details of the underwater images.

The organization of the paper is as follows: In Section 1, a brief introduction about underwater imaging and the related work of various underwater image enhancement techniques are given. Section 3 describes the proposed approach. The experimental results and discussions are given in Section 4. Based on the above work conclusions are derived in Section 5.

2. Proposed wavelet based perspective on variational enhancement technique

In general, for better visual quality of natural images/video, the intensity distribution of pixels in respective RGB components should be uniform. But, in underwater images, intensity distribution of an image should not stretch in the entire range of the histogram due to the particular color spectrum is absorbed by water medium. So in order to improve the low contrast and removing the effect of color loss of underwater images without changing structural details of the objects in an image, Wavelet based perspective on variational enhancement technique (WPVET) has been proposed.

2.1. The scheme of the discrete wavelet transform (DWT)

A 2-D discrete wavelet transform coefficients are calculated efficiently in discrete space by applying the associated 1-D filter bank to each column of the image, and then applying the filter bank to each row of the resulting coefficients. In the first level of decomposition, one approximation coefficients sub-image (LL_1) and three detail coefficients sub-images (LH_1, HL_1 and HH_1) are created. In second level of