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Enhancement of low quality underwater image through integrated global and local contrast correction

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A B S T R A C T

The attenuation of the light that travels through a water medium subjects underwater images to several problems. As a result of low contrast and color performance, images are unclear and lose important information. Therefore, the objects in these images can hardly be differentiated from the background. This study proposes a new method called dual-image Rayleigh-stretched contrast-limited adaptive histogram specification, which integrates global and local contrast correction. The aims of the proposed method are to increase image details and to improve the visibility of underwater images while enhancing image contrasts. The two main steps of the proposed method are contrast and color corrections; an underwater image undergoes the former before the latter. Global contrast correction generates dual-intensity images, which are then integrated to produce contrast-enhanced resultant images. Subsequently, such images are processed locally to enhance details. The color of the images is also corrected to improve saturation and brightness. Qualitative and quantitative results show that the contrast of the resultant image improves significantly. Moreover, image detail and color are adequately enhanced; thus, the proposed approach outperforms current state-of-the-art methods.

1. Introduction

The physical properties of an underwater medium prevent the degradation of normal images taken in the air [1]. As light travels in water, light intensity is exponentially lost depending on the wavelength of the color spectrum. The attenuation of light limits the visibility distance to approximately 20 m in clear water and to 5 m or less in turbid water [2]. Light that travels in air is partially reflected back upon entering water; the direction and effect vary based on the structure of the water surface [3]. In addition, water motion produces waves that diffuse the light entering the water to create crinkle patterns [4]. Light is attenuated exponentially with distance and depth mainly as a result of absorption and scattering effects [5].

In summary, the low quality of underwater images is mainly caused by the following factors: low contrast, blurring, the diminished true color of objects, bright artifacts, floating particles, and nonuniform lighting. These factors lead to unbalanced illumination. Consequently, various underwater imaging techniques and methods have been introduced into the field of underwater image processing.

2. Related works and of state-of-the-art problems in techniques for underwater image contrast enhancement

Underwater image processing can be categorized into two procedures: (i) image restoration and (ii) image enhancement [1]. The former focuses on recovering a degraded image by constructing a model of the degradation in the original image formation. Image restoration methods are exhaustive and require a few model parameters that characterize water turbidity. The latter uses qualitative and subjective criteria to produce a visually pleasing image without depending on a physical model for image formation.

The initial values of the darkest and brightest points play an important role in image color. Shamsudin et al. [3] and Rizzi et al. [6] proved that a black point takes an initial brightness value of 5% and that a white point has a value of 95%. Furthermore, Shamsudin et al. [3] identified a considerable difference in the correction techniques of auto-enhanced techniques and depth at a significance level of 5%. Manually enhanced techniques and depth also vary

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remarkably at a significance level of 1%. The significance level of 5% is discussed in subsequent sections; this level is applied by the proposed dual-image Rayleigh-stretched contrast-limited adaptive histogram specification (DIRS-CLAHS) method in the processing step.

Eustice et al. [7] proposed an extension method for the MATLAB image processing toolbox. In the current study, however, we focus on the first extension, to which Eustice et al. applied contrast-limited adaptive histogram specification (CLAHS) as a preprocessing step. In their study, these researchers confirmed that the Rayleigh distribution is ideal for representing underwater images [7]. Nevertheless, CLAHS has a drawback in that underwater images cannot be enhanced automatically because a few parameters should be set based on the image characteristics. Even though CLAHS enhances the underwater image effectively, this method diminishes the color of the output image. Moreover, much noise is produced in this image.

Hitam et al. [8] proposed a method called mixture contrast-limited adaptive histogram equalization (CLAHE-Mix) to reduce the significant noise introduced into underwater images by CLAHE. CLAHE-Mix enhances the contrast in underwater images and limits the induced artifacts generated with CLAHE [8]. Hitam et al. [8] also applied CLAHE to images in red–green–blue (RGB) and hue–saturation–value (HSV) color models separately. Then, the individual images are integrated through Euclidean distance to produce low-noise, contrast-enhanced images. In several cases, however, this method produces output images with more noise than the conventional CLAHE does. As such, the output image is greenish.

Pixel distribution shifting color correction (PDSCC) was proposed for digital color images by Naim and Isa [9]. This method corrects the white reference point of images to ensure that this point is achromatic. In the experiment conducted by these researchers, the resultant images exhibited better contrast and brightness than those produced with the gray world and white patch methods did. Nonetheless, PDSCC does not significantly enhance image contrast, unlike methods such as CLAHS and CLAHE-Mix.

Iqbal et al. presented the integrated color model (ICM) [10] and the unsupervised color correction method (UCM) [11]. When ICM is used, the input image in the RGB color model is decomposed into its respective channels before these channels are stretched over the entire dynamic range. Then, the image is converted into the hue–saturation–intensity (HSI) color model, where the S and I components are applied with contrast stretching throughout the entire dynamic range. These researchers also modified two color channels, namely, red and green, to reduce the color cast based on the von Kries hypothesis [11]. The overall observation indicates that the images are under-enhanced in several areas. The primary drawback of these reviewed techniques is that they produce resultant images corrupted with high noise.

In addition, Rizzi et al. [12] proposed an unsupervised digital image color equalization method simultaneous global and local effects. Schechner and Karpel [13,14] developed an image recovery algorithm based on a couple of images taken through a polarizer at different orientations by analyzing the physical effect of visibility degradation. Furthermore, Trucco and Olmos-Antillon [15] devised a self-tuning image restoration filter that simplified the well-known underwater image formation model proposed by Jaffe [16] and McGlamery [17]. However, the main disadvantages of these physics-based methods are that they require much computing resources and have a long execution time.

On the basis of previous research, two main problems have been identified in relation to the current underwater image contrast enhancement technique. First, the contrast of the output image remains low in the under-enhanced and over-enhanced areas. Second, several of these methods still generate noise/unwanted artifacts in the resultant image. Computational consumption is still high; as a result, processing time increases. The method proposed in the present study reduces the first two problems to produce underwater images with high contrast and little noise effect.

Underwater images normally exhibit a high percentage of blue, followed by green and red. Therefore, most underwater images appear bluish or greenish, as shown in Figs. 1 and 2, given that blue and green are the dominant color channels forming the overall image color. Red is the inferior color channel, and its percentage is generally lower than those of the other two color channels. This phenomenon can be observed in Fig. 1(b) and (c), where the pixels of the red channel are distributed on the left side (low intensity value) of the intensity diagram. The pixels of the blue and green color channels are positioned at high intensity level (on the right side of the intensity diagram), as per Fig. 1(b), (d), and (e).

Another underwater image sample, branch, is presented in Fig. 2 to explain the phenomenon further. In Fig. 2(b), the 3D RGB color model of this image clearly indicates that the pixels are distributed around the blue-green plane. Thus, a solution for improving the contrast of this underwater image involves modifying pixel concentration to ensure that the pixels are significantly distributed to appropriate color channels and are not concentrated only in certain channels or planes.

On the basis of the previously presented argument and hypothesis, this study emphasizes the image contrast enhancement technique that modifies image histograms without forming physical images.

Several state-of-the-art methods have successfully reduced the problem of underwater images. The results obtained for the image *branch* (Fig. 3) are analyzed to determine the advantages and disadvantages of these methods. The CLAHE-Mix method does not enhance image contrast adequately because the blue-green illumination effect is retained in the resultant image. In addition, the objects in the image are hardly distinguishable from the background, and the appearance of the image details is thus diminished. PDSCC generates a reddish image because pixel distribution shifts toward the red plane. The resultant image fails to improve image contrast given that the objects cannot be observed clearly.

The UCM and ICM approaches increase image contrast more effectively than the CLAHE-Mix and PDSCC methods do. Objects are effectively differentiated from the background; nevertheless, the UCM produces excessive red color. Therefore, the resultant image is reddish and yellowish. In addition, the blue-green illumination effect is retained in the image produced through ICM. Both of these methods over-enhance areas because excessively bright regions are spotted in the resultant images.

CLAHS is commonly integrated with other techniques, such as the CLAHE-Mix method. CLAHS is utilized because of its promising results in enhancing image contrasts locally; nonetheless, certain parameters in this method, such as clip limit, distribution parameter, and number of tiles, should be set accordingly to enhance the resultant image contrast. The sample image depicted in Fig. 3 applies the default parameter setting for CLAHS [7] and CLAHE-Mix [8] as suggested by the authors. The image processed by CLAHS (Fig. 3) indicates that CLAHS improves the limited image contrast but does not reduce the blue-green illumination effect adequately.

The technique proposed in the present study is specifically designed for low-contrast underwater images that are normally dominated by green and blue color channels. As per previous research and the results presented in Fig. 3, enhancing image contrast typically results in an over-enhanced image that is reddish or excessively bright and is subject to the blue-green illumination effect. Furthermore, the output images appear unnatural.

These problems with underwater images cannot be solved by using only one general method. As per the previous explanation

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