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A hybrid method for underwater image correction

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ABSTRACT

Underwater images surfer from serious color deviation and blurring due to the effects of light absorption and scattering. In this letter, a hybrid method, which includes color correction and underwater image dehazing, is proposed to improve the visual quality of degraded underwater images. Firstly, an efficient color correction algorithm is applied to remove color casts of underwater images. Then, underwater image dehazing method is proposed to improve the visibility of underwater images, which includes a global background light estimation algorithm specialized for underwater images and a medium transmission estimation algorithm based on the combination a regression model with the characteristics of light traveling in water medium. Since there is no available dataset in this relatively new research area, a dataset which includes 45 underwater images with a wide variety of contents is collected. Subjective and objective performance evaluations demonstrate that the proposed method significantly improves both color and visibility of degraded underwater images, and is comparable to and even outperforms several state-of-the-art methods.

1. Introduction

The visual quality of underwater images plays a crucial role in many ocean engineering applications and scientific researches, such as marine ecological research [28] and ocean rescue [20]. However, underwater images are characterized by low contrast, limited visibility, and diminished color due to the effects of light absorption and scattering. For underwater scenario, light with different wavelengths is absorbed at different rates, which leads to the serious color casts. Moreover, light scattering blurs image features and decreases contrast. Thus, underwater image correction techniques are desired in both scientific researches and computer applications.

In this letter, a hybrid underwater image correction method, which includes color correction and underwater image dehazing, is proposed. Our contributions are four-fold: (1) to our best knowledge, it is the first method that estimates medium transmission of underwater image by combining learning-based strategy with the characteristics of light traveling in water medium; (2) a global background light estimation algorithm specialized for underwater images is proposed based on background light region detection and underwater optical property; (3) an underwater image dataset which includes 45 underwater images with a wide variety of contents collected from the Internet is presented; and (4) the proposed method does not require complex information about the underwater scenes and user interaction.

In the rest of the letter, we give a brief overview of the related work in Section 2. In Section 3, we introduce the color correction method used in this letter. Section 4 describes the proposed underwater image dehazing method. Section 5 presents the experimental results, and Section 6 concludes this letter.

2. Related work

A variety of methods have been proposed to improve the visual quality of degraded underwater images, and can be roughly classified from two aspects: restoration method and enhancement method.

Restoration method regards the recovery of underwater image as an inverse problem, which restores underwater images by estimating parameters of underwater image formation model. Trucco and Olmos-Antillon devised a self-tuning image restoration filter based on a simplified version of underwater image formation model. [30]. Optimal filter parameters are estimated based on a global contrast measure. Carlevaris-Bianco et al. proposed a prior that exploits the strong difference in attenuation among the three color channels of an underwater image to estimate the depth of scene [6]. Chiang and Chen combined a dehazing algorithm with wavelength compensation to restore underwater images [7]. Galdran et al. restored red channel to recover the lost contrast of un-

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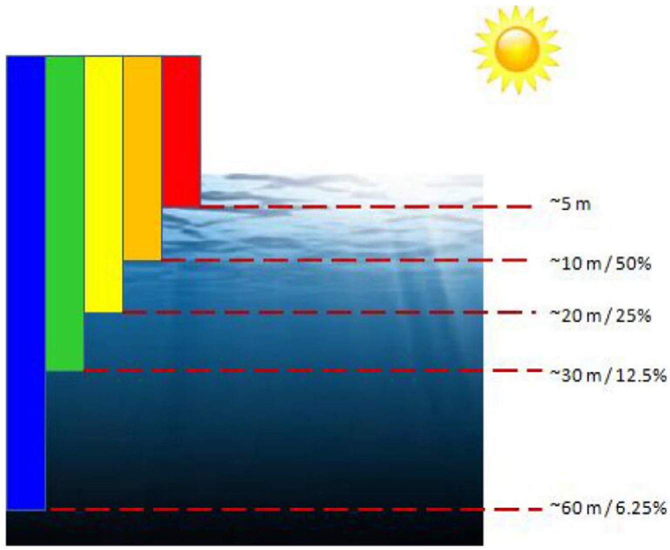

Fig. 1. Different light is attenuated at different rates in water.

derwater images [11]. Peng et al. adopted image blurriness with the image formation model to estimate the distance between the scene point and the camera, and thereby recovered underwater images [25]. Drews et al. extended the classical dark channel prior algorithm [14] to underwater image restoration [9].

Enhancement method does not rely on any image formation model, and enhances underwater images by modifying image pixel values. Iqbal et al. proposed an integrated color model and an unsupervised color correction method to enhance the visual quality of underwater images [17,18]. Ancuti et al. proposed a fusion-based method to increase the contrast of underwater images and videos [1]. Chani and Isa improved contrast and reduced noise of underwater images through modifying the integrated color model [12]. Li and Guo proposed an underwater image enhancement method based on dehazing and color correction [22]. Fu et al. proposed a simple yet effective underwater image color correction algorithm [10]. Bianco et al. proposed a new color correction method for underwater imaging. This method demonstrated the effectiveness of color correction in $L\alpha\beta$ color space [3]. Liu and Chau corrected color cast of underwater images based on surface reflectance statistics [23]. Despite the remarkable progress on underwater image correction methods, it is still an open problem.

3. Color correction

Unlike common images, underwater images usually suffer from more serious color casts (bluish or greenish) due to the special underwater imaging and lighting conditions. As shown in Fig. 1, different light is attenuated at different rates, which leads to color casts of underwater images. Generally, red light disappears at depth of 5 m in water, and then brown light and yellow light disappear, finally green light and blue light disappear at depths of 30 m and 60 m. This is the main reason why most underwater images are dominated by blue-green coloration. Color casts affects the visual quality of underwater images. Therefore, we first remove the color cast and restore underwater images to the relatively genuine color.

Fu et al. proposed a simple yet effective color correction algorithm [10]. In this letter, to remove the effects of color casts, we use this color correction algorithm as our pre-processing based on its effectiveness and low-complexity. Based on extensive statistics, Fu et al. found that the maximum $C(x)^c_{\max}$ and the minimum $C(x)^c_{\min}$ color deviation in each color channel (i.e., RGB) for under-

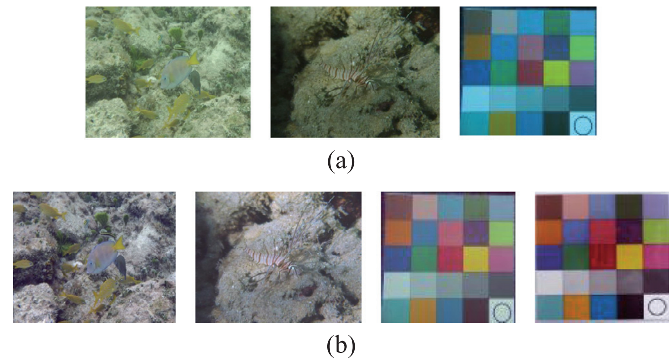

Fig. 2. Color corrected underwater images. (a) Raw underwater images. (b) Color corrected underwater images using the algorithm proposed by [10]. The last image in (b) is the ground truth of color checker image. The raw color checker image and ground truth are obtained from [16].

water image can be defined as:

$$C(x)^c_{max} = f(x)^c_m + \eta^c \cdot f(x)^c_v, c \in \{r, g, b\}, \tag{1}$$

$$C(x)^c_{min} = f(x)^c_m - \eta^c \cdot f(x)^c_v, c \in \{r, g, b\}, \tag{2}$$

where $f(x)^c_m$ is the mean value, $f(x)^c_v$ is the mean square error value, and η^c is a parameter, which tempers the saturation of result. Then, color corrected underwater image $f(x)^c_{CR}$ is obtained by:

$$f(x)^c_{CR} = \frac{f(x)^c - C(x)^c_{min}}{C(x)^c_{max} - C(x)^c_{min}} \times 255, c \in \{r, g, b\}, \tag{3}$$

where $f(x)^c$ is input image. Replacing $C(x)^c_{\max}$ and $C(x)^c_{\min}$ with (1) and (2), (3) is translated to:

$$f(x)^c_{CR} = \frac{f(x)^c - f(x)^c_m + \eta^c \cdot f(x)^c_v}{2\eta^c \cdot f(x)^c_v} \times 255. \tag{4}$$

In Fu et al.'s work [10], the saturation parameter η^c is a heuristic value and set to 3 for each color channel. Fig. 2 shows several examples of color corrected results.

In Fig. 2, the greenish tone in the raw underwater images (first two images) is removed by the algorithm [10]. For the underwater color checker image, more color details are unveiled in the color corrected image when compared with ground truth. We do not have enough underwater images with ground truth to verify the accuracy and robustness of this color correction algorithm. Nevertheless, after processing by this algorithm, the color of underwater images looks more pleasing and genuine than before, which is desired in our framework.

4. Underwater image dehazing

4.1. Problem formulation

Inspired by classical dark channel prior [14] and learning-based [29] image dehazing methods, our underwater image dehazing method estimates medium transmission of an underwater image based on learning-based strategy and the characteristics of light traveling in water medium. Follow previous work [26] and [7], simplified McGlamery–Jaffe underwater image formation model [24] and [19] is described as:

$$I^c(x) = J^c(x)t^c(x) + A^c(1 - t^c(x)), c \in \{r, g, b\}, \tag{5}$$

where $I^c(x)$ is the degraded underwater image, $J^c(x)$ is the clear underwater image, A^c is the global background light, and $t^c(x)$ is the medium transmission. Furthermore, the medium transmission is expressed as:

$$t^c(x) = \exp(-p^c d(x)), c \in \{r, g, b\}, \tag{6}$$