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Underwater image quality enhancement through integrated color model with Rayleigh distribution

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ABSTRACT

The physical properties of water cause light-induced degradation of underwater images. Light rapidly loses intensity as it travels in water, depending on the color spectrum wavelength. Visible light is absorbed at the longest wavelength first. Red and blue are the most and least absorbed, respectively. Underwater images with low contrast are captured due to the degradation effects of light spectrum. Therefore, the valuable information from these images cannot be fully extracted for further processing. The current study proposes a new method to improve the contrast and reduce the noise of underwater images. The proposed method integrates the modification of image histogram into two main color models, Red–Green–Blue (RGB) and Hue-Saturation-Value (HSV). In the RGB color model, the histogram of the dominant color channel (i.e., blue channel) is stretched toward the lower level, with a maximum limit of 95%, whereas the inferior color channel (i.e., red channel) is stretched toward the upper level, with a minimum limit of 5%. The color channel between the dominant and inferior color channels (i.e., green channel) is stretched to both directions within the whole dynamic range. All stretching processes in the RGB color model are shaped to follow the Rayleigh distribution. The image is converted into the HSV color model, wherein the S and V components are modified within the limit of 1% from the minimum and maximum values. Qualitative analysis reveals that the proposed method significantly enhances the image contrast, reduces the blue-green effect, and minimizes under- and over-enhanced areas in the output image. For quantitative analysis, the test with 300 underwater images shows that the proposed method produces average mean square error (MSE) and peak signal to noise ratio (PSNR) of 76.76 and 31.13, respectively, which outperform six state-of-the-art methods.

1. Introduction

Underwater image processing is a challenging field because of the physical properties of such an environment. Scientists engaging in underwater research face the challenges of light absorption and diffusion effects on underwater imaging [1–3]. For instance, images captured deeper into the ocean turn greenish or bluish.

Generally, the quality of underwater images is affected by different factors, such as limited range of visibility, low contrast, non-uniform lighting, bright artifacts, noise, blurring, and diminishing color [1]. As light travels in water, it rapidly loses intensity, depending on the color spectrum wavelength. In clear open water, visible light is absorbed at the longest wavelengths first [4]. Red, the most absorbed light color, is reduced to 1/3 of its intensity after a depth of 1 m and is essentially lost after 4 m to 5 m underwater [5]. Meanwhile, the blue and violet lights are least absorbed compared with other wavelengths. As such, open ocean water appears deep blue to the naked eye.

Fig. 1 shows an illustration of underwater color diminishing. As can be seen, the red color is the first color component absorbed by water at a depth of 5 m, followed by orange, yellow, green, and blue. Underwater images appear blue-green because these color components are least absorbed. Such color absorption results in low color and contrast in the captured underwater images. Important information from the image is also lost. The application of computer vision and image processing are becoming important considerations in restoring the contrast, color, and lost information from the images.

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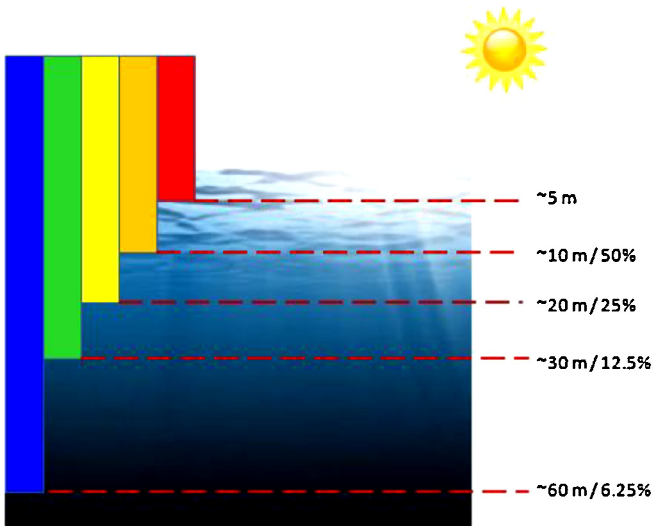

Fig. 1. Illustration of underwater color diminishing [5].

Contrast enhancement technique is a widely used technique for underwater image processing, which improves contrast performance and achieves greater dynamic range. The development of the contrast enhancement technique has attracted considerable research attention in recent years, although it remains a new area compared with techniques in processing normal images. Many researchers have used various algorithms to improve the quality of underwater images and extract as much valuable information as possible from the images. Numerous works have been published based on the models of subjective human color vision [4,5], which are presented in the next section.

The current study proposes a method of contrast enhancement of underwater images to improve image contrast and noise reduction. The rest of the paper is organized as follows: Section 2 describes the existing techniques proposed by previous researchers; Section 3 details the proposed technique; Section 4 discusses qualitative and quantitative results; and Section 5 presents the conclusion.

2. Literature review

Underwater image processing can be described from two different perspectives: as an image restoration technique and as an image enhancement method [4]. Image restoration recovers a degraded image using a model of the original degraded image formation. These methods are rigorous and require varied model parameters that characterize water turbidity, such as attenuation and diffusion coefficients [4]. The image enhancement method uses qualitative and subjective criteria to produce a more visually pleasing image without depending on any physical model for image formation. The methods proposed by previous researchers mostly involve modifying image pixels values that improve image contrast and colors.

Schechner and Karpel [6,7] analyzed the physical effects of visibility degradation and proposed an image recovery algorithm based on a couple of images taken at different orientations with a polarizer. Rizzi et al. [8] proposed unsupervised digital image color equalization with simultaneous global and local effects. Trucco and Olmos-Antillon [9] devised a self-tuning image restoration filter, which simplified the well-known underwater image formation model proposed by Jaffe [10] and McGlamery [11]. These researchers suggested that underwater images can be represented as a linear superposition of three components, namely, the direct (light reflected directly by the object and has not been scattered in the water), forward-scattered (light reflected by the object and has been scattered at a small angle), and backscattered components (light reflected by the objects not on the target scene but enters the camera because of other reasons, such as floating particles). However, these physics-based methods require high-computing resource, thus consuming more execution time.

Naim and Isa [12] proposed a method called pixel distribution shifting color correction (PDSCC) for digital color images to correct the white reference point and ensure that it is achromatic. PDSCC is the latest contrast enhancement technique designed for underwater images. The technique extends the method of 3D rotational matrix (3DMAT) by modifying the 2D two-color channel plane. 3DMAT is the first 3D rotational method used because of its simplicity and rapid execution. The method employs the 3D pixel distribution rotational by rotating the pixels three times (yaw, pitch, and roll) using three different rotational angles. In PDSCC, two 3D rotational methods for color correction are specifically designed to shift the pixel distribution of an image, such that the surrounding insignificant illumination is suppressed or removed from the output image. The process is performed by moving the pixel distribution of the image to the diagonal plane of the 3D Red–Green–Blue (RGB) color model. The shifting process is then directly implemented on 2D two-color channel planes instead of the 3D RGB color model. These 2D color planes are constructed from the 3D RGB color model, namely red-green plane, red-blue plane, and green-blue plane [12]. This process ensures that the surrounding illumination pixel distribution is rendered achromatic. From the viewer side, the method corrects the image color to make it more natural and pleasant. The method also corrects image saturation; however, it does not significantly increase the image contrast.

Hitam et al. [5] proposed a method called mixture contrast limited adaptive histogram equalization (CLAHE-Mix) for underwater images. This method aims to reduce significant noise introduced by CLAHE to ease the subsequent processing of underwater images. Hitam et al. [5] applied CLAHE to the image in RGB and Hue-Saturation-Value (HSV) color models separately. CLAHE is first applied to the image in the RGB color model, wherein the image is decomposed into their respective channels (red, green, and blue). The method is individually applied to these color channels and then the color channels are composed to produce an output image. For the HSV color model, the identical source image in the RGB color model is first converted into the HSV color model, after which the image is decomposed into its respective channels. The S and V components of the image are applied with CLAHE, and these channels are then composed and converted back into RGB color model. Here, the pixel distribution is set according to the Rayleigh distribution for the CLAHE process in both color models. These processes of applying CLAHE in the RGB and HSV color models produce two independent images: the image processed using CLAHE in RGB color model, which is called CLAHE-RGB, and another image processed using CLAHE in HSV color model, which is called CLAHE-HSV. These images are integrated to produce a contrast-enhanced image with low noise using Euclidean norm. In some situations, this method produces output images with higher noise than those from the conventional CLAHE. Moreover, the output image sometimes becomes greenish.

Iqbal et al. proposed an integrated color model (ICM) [13] and unsupervised color correction method (UCM) [14]. In [13], the output image in the RGB color model is stretched over the entire dynamic range. The image is then converted to the Hue-Saturation-Intensity (HSI) color model. In this color model, the S and I components are applied with contrast stretching, after which the image in the HSI color model is converted back to RGB color model to produce an enhanced output image. In [14], Iqbal et al. modified two color channels (red and green) based on the von Kries hypothesis to reduce the color cast. Contrast correction is then applied in the RGB color model. The image histograms are