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Image contrast enhancement using an integration of recursive-overlapped contrast limited adaptive histogram specification and dual-image wavelet fusion for the high visibility of deep underwater image

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A B S T R A C T

Deep underwater images suffer from several problems, such as low contrast and visibility, which reduce the extraction rate of valuable information from the image. In this paper, we proposed an approach which integrates the three main steps of homomorphic filtering, recursive-overlapped CLAHS and dual-image wavelet fusion and thus increases the visibility of deep underwater images and the extraction rate of important data. Additionally, this approach implements homomorphic filtering to provide homogeneity in the illumination of the entire image which will be used for subsequent processes. Recursive-overlapped CLAHS refers to the recursive process of overlapped tiles of divided image channel, where half of a tile is processed twice with an adjacent tile. Half of the tile is overlapped with its next adjacent tile. Dual-image wavelet fusion merging two images obtained from the integration of upper- and lower-stretched histograms are applied with discrete wavelet transformation before the main process of wavelet fusion is implemented. Qualitative and quantitative results reveal that the proposed method outperforms the current state-of-the-art methods. The highest value of average quantitative evaluations in terms of entropy, average gradient, measure of enhancement (EME) and EME by entropy are 7.835, 12.802, 8.343 and 27.616, respectively, in the proposed method.

1. Introduction

Most previous research works (Hitam et al., 2013; Dwivedi et al., 2015; Li et al., 2015) focused on shallow image where the improvement of the underwater quality is concentrated on images that are captured near the water surface. Shallow images exhibit a considerably high percentage of red colour channel compared with deep underwater image. Consequently, the low visibility of captured image is obtained because objects in the image are hardly seen. These phenomena decreases the amount of data extracted and sometimes results in useless images.

Deep underwater image normally suffers from a high concentration of blue-green illumination. This phenomenon occurs as the light spectrum that travels in water medium is absorbed according to its wavelength (Hitam et al., 2013). The shortest wavelength, that is, blue, is absorbed last, causing deep underwater image to appear bluish. Some applications, such as unmanned underwater robot and ocean floor mapping, are required to capture and analyse deep underwater images. Nevertheless, these applications suffer from extremely low visibility as the captured images are dark and affected by blue-green illumination. In an image processing area, no clear border exists to differentiate between shallow and deep underwater images, and no clear information is available for determining deep and shallow underwater images. In this paper, deep and shallow underwater images are assumed to determine the percentage of colour channels. In a red-green-blue (RGB) colour model, red is the first colour channel attenuated and lost during the propagation of light in water medium. The loss in the percentage of red colour channel increases the percentages of blue and green colour channels. Deep underwater images refer to images with $< 10\%$ red colour percentage compared with that of green and blue colour channels. Normally, deep image contains a high percentage of blue-green illumination as the image turns bluish or greenish. In deep underwater image, the objects are hardly seen, and no clear border exists between objects and background. Thus, objects in deep underwater images turn bluish or greenish.

This paper explains in detail a proposed method that enhances the visibility of deep underwater images and increases overall image quality. It integrates the two main methods of recursive-overlapped contrast limited adaptive histogram specification (RO-CLAHS) and dual-image wavelet fusion (DIWF). RO-CLAHS involves tiles histogram

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processing, clip-limit process, Rayleigh distribution mapping and grey-level mapping. DIWF implements the discrete wavelet transform of resultant images produced by RO-CLAHS. After applying wavelet fusion, we applied the resultant image with inverse discrete wavelet transform to produce the final output image.

The paper is organised as follows: Section 2 describes literature reviews that are related to the proposed method. Section 3 explains the proposed method in detail. Results and discussions are elaborated in Section 4. The paper ends with the conclusion, which is explained in Section 5.

2. Related works

Substantial research has been conducted for the enhancement of underwater image. Most studies focus on images captured near water surfaces, where objects are visible. These images are normally clearer than images captured in deep water, where images are nearly invisible because of the high concentration of blue-green illumination and limited light sources.

Chen et al. (2017) proposed entropy–preserving-mapping for contrast enhancement, which focuses on producing fine textures in an image to indicate the improvement of image contrast. Yelmanova and Romanyshyn (2017) proposed the adaptive enhancement of monochrome image with low-contrast objects. As they focus on monochrome image, the proposed methodology is not properly applicable for coloured images. For security purposes, Erat et al. (2017) addressed the colour cast problem in underwater images through implementation in border security. Eliminating this problem is the first priority of the proposed steps before contrast enhancement is implemented. The method proceeds with contrast stretching and white balance processing to improve the captured overall image quality.

Dwivedi et al. (2015) proposed an enhancement method based on distance factor estimation. In the proposed method, an underwater image is assumed to be nearly identical to a haze image in free space where the image can be modelled as a combination of direct attenuation and scattering parts. As a consequence of motion in water medium, noise term due to motion of water medium is included in the equation of underwater image. Rayleigh scattering, which is the dominant scattering effect, leads to noise, which is non-additive in nature and can be minimised by statistics-based filtering techniques. Nevertheless, this technique produces numerous parameters that must be determined before running the method. The output images suffer from the effect of blue-green illumination and produce over-enhanced areas where images become extremely bright. These areas reduce image details, and the output image loses its important information.

Underwater image enhancement using inherent optical properties has been proposed by Li et al. (2015) to enhance shallow ocean optical images and videos through fast dark channel prior descattering. The proposed method begins by the estimation of the depth map through dark channels before considering the positions of lighting lamp, camera and imaging plane. Through the implementation of weighted guided median filtering, the proposed method can remove the scattering effect. Finally, colour correction is applied through spectral properties. The proposed method reduces the effect of blue-green illumination, but the visibility of the object is inadequately increased. The background objects are still hardly seen. Identical results have also been obtained using adaptive dehazing framework, which is proposed by Qing et al. (2015), as the proposed method inadequately increases the visibility of the background areas.

In 2012, pixel distribution shifting colour correction (PDSCC) was proposed by Naim and Isa. The method corrects the white reference point of the image and ensures that the white reference point is achromatic by the implementation of shifting process on the pixel distribution of a colour image. Although the method can reduce the effect of blue-green illumination, the overall image contrast remains low.

Hitam et al. (2013) proposed the mixture contrast limited adaptive histogram equalization (CLAHE-mix) to increase image visibility and reduce the noise and artefact of the image. The output image becomes clear by integrating the CLAHE-RGB and CLAHE-hue-saturation value (HSV)-implemented images by using Euclidean norm. However, the images become increasingly green in some cases and produce high noise level by exhibiting low peak signal to noise ratio.

Two famous methods normally used for comparing underwater images are integrated colour model (ICM) (2007) and unsupervised colour correction method (UCM) (2010), which were proposed by Iqbal et al. (2007, 2010). ICM can improve image contrast, but produces the effects of over- and under-enhancement as the output images produce dark and extremely bright areas. The proposed method of UCM sometimes produces brownish image that deviates from the nature of the original image. Abu Hassan et al. (2017) enhanced under-exposed underwater images through enhanced homomorphic filtering and mean histogram matching for object tracking. The method successfully increased the contrast and enhanced dark areas in the image. Consequently, the overall visibility of images increased and non-uniform illumination improved. The next section discusses the proposed method in detail.

3. Methodology: Integration RO-CLAHS and DIWF

3.1. Motivation

Most underwater images are captured without constant illumination, and images are captured with bright areas at the foreground and dark areas at the background. Precisely, the areas near the light source are brighter than the areas that are located far away from the light source. This nature of images must be determined before further processing. Combining bright and dark areas into a tile produces enhanced output distribution because the balanced improvement between both areas is considered in the enhancement process. To determine the nature of the capture image, we utilised entropy to determine its image detail. The high detail of an area indicates that the objects in the image are distinguished well, that is, with high visibility, from the background, whereas the low visibility of objects in an area indicates that the area is low in detail. This phenomenon reflects the value of entropy. When an entropy value is high, the visibility level of a particular area is high, whereas a low entropy value indicates a low visibility area. Thus, high and low entropy values correspond to bright and dark areas of image, respectively.

Therefore, as the first stage of the pre-processing of the image, the entropy at the borders of the image is determined. We used entropy to measure the richness of the image details. Entropy represents an abundance of image information, where the higher the value is, the more information is present in the image (Wu et al., 2005). Entropy is given by

$$H(X) = \sum_{x=1}^{k} p(x)\log_2\frac{1}{p(x)}$$

$$H(X) = -\sum_{x=1}^{k} p(x)\log_2 p(x) = -sum(p(x).*log2(p(x))) \quad (1)$$

where *p(x)* is the probability distribution function (PDF) of the image. The detail of the proposed method is explained in the next subsections.

In some cases, conventional CLAHE process produces improper pixel distribution especially when an object is on the border between tile regions. When two tiles containing objects are independently