Close

Web of Science
Page 1 (Records 1 -- 1)
[1]

Print

Record 1 of 1

Title: Underwater Image Enhancement by Dehazing With Minimum Information Loss and Histogram Distribution Prior

Author(s): Li, CY (Li, Chong-Yi); Guo, JC (Guo, Ji-Chang); Cong, RM (Cong, Run-Min); Pang, YW (Pang, Yan-Wei); Wang, B (Wang, Bo)

Source: IEEE TRANSACTIONS ON IMAGE PROCESSING **Volume:** 26 **Issue:** 12 **Pages:** 5664-5677 **DOI:** 10.1109/TIP.2016.2612882 **Published:** DEC 2016

Abstract: Images captured under water are usually degraded due to the effects of absorption and scattering. Degraded underwater images show some limitations when they are used for display and analysis. For example, underwater images with low contrast and color cast decrease the accuracy rate of underwater object detection and marine biology recognition. To overcome those limitations, a systematic underwater image enhancement method, which includes an underwater image dehazing algorithm and a contrast enhancement algorithm, is proposed. Built on a minimum information loss principle, an effective underwater image dehazing algorithm is proposed to restore the visibility, color, and natural appearance of underwater images. A simple yet effective contrast enhancement algorithm is proposed based on a kind of histogram distribution prior, which increases the contrast and brightness of underwater images. The proposed method can yield two versions of enhanced output. One version with relatively genuine color and natural appearance is suitable for display. The other version with high contrast and brightness can be used for extracting more valuable information and unveiling more details. Simulation experiment, qualitative and quantitative comparisons, as well as color accuracy and application tests are conducted to evaluate the performance of the proposed method. Extensive experiments demonstrate that the proposed method achieves better visual quality, more valuable information, and more accurate color restoration than several state-of-the-art methods, even for underwater images taken under several challenging scenes.

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Close

Web of Science
Page 1 (Records 1 -- 1)
[1]

Print

Close

Web of Science
Page 1 (Records 1 -- 1)
[1]

Print

Record 1 of 1

Title: Underwater scene prior inspired deep underwater image and video enhancement

Author(s): Li, CY (Li, Chongyi); Anwar, S (Anwar, Saeed); Porikli, F (Porikli, Fatih)

Source: PATTERN RECOGNITION **Volume:** 98 **Article Number:** 107038 **DOI:** 10.1016/j.patcog.2019.107038 **Published:** FEB 2020

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Abstract: In underwater scenes, wavelength-dependent light absorption and scattering degrade the visibility of images and videos. The degraded underwater images and videos affect the accuracy of pattern recognition, visual understanding, and key feature extraction in underwater scenes. In this paper, we propose an underwater image enhancement convolutional neural network (CNN) model based on underwater scene prior, called UWCNN. Instead of estimating the parameters of underwater imaging model, the proposed UWCNN model directly reconstructs the clear latent underwater image, which benefits from the underwater scene prior which can be used to synthesize underwater image training data. Besides, based on the light-weight network structure and effective training data, our UWCNN model can be easily extended to underwater videos for frame-by-frame enhancement. Specifically, combining an underwater imaging physical model with optical properties of underwater scenes, we first synthesize underwater image degradation datasets which cover a diverse set of water types and degradation levels. Then, a light-weight CNN model is designed for enhancing each underwater scene type, which is trained by the corresponding training data. At last, this UWCNN model is directly extended to underwater video enhancement. Experiments on real-world and synthetic underwater images and videos demonstrate that our method generalizes well to different underwater scenes. (C) 2019 Elsevier Ltd. All rights reserved.

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Author Keywords: Underwater image and video enhancement and restoration; Underwater image synthesis; Pattern recognition; Deep leaming

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Close

Web of Science
Page 1 (Records 1 -- 1)
[1]

Print

Close

Web of Science
Page 1 (Records 1 -- 1)
[1]

Print

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Title: An Underwater Image Enhancement Benchmark Dataset and Beyond

Author(s): Li, CY (Li, Chongyi); Guo, CL (Guo, Chunle); Ren, WQ (Ren, Wenqi); Cong, RM (Cong, Runmin); Hou, JH (Hou, Junhui); Kwong, S (Kwong, Sam); Tao, DC (Tao, Dacheng)

Source: IEEE TRANSACTIONS ON IMAGE PROCESSING **Volume:** 29 **Pages:** 4376-4389 **DOI:** 10.1109/TIP.2019.2955241 **Published:** 2020

Abstract: Underwater image enhancement has been attracting much attention due to its significance in marine engineering and aquatic robotics. Numerous underwater image enhancement algorithms have been proposed in the last few years. However, these algorithms are mainly evaluated using either synthetic datasets or few selected real-world images. It is thus unclear how these algorithms would perform on images acquired in the wild and how we could gauge the progress in the field. To bridge this gap, we present the first comprehensive perceptual study and analysis of underwater image enhancement using large-scale real-world images. In this paper, we construct an Underwater Image Enhancement Benchmark (UIEB) including 950 real-world underwater images, 890 of which have the corresponding reference images. We treat the rest 60 underwater images which cannot obtain satisfactory reference images as challenging data. Using this dataset, we conduct a comprehensive study of the state-of-the-art underwater image enhancement algorithms qualitatively and quantitatively. In addition, we propose an underwater image enhancement network (called Water-Net) trained on this benchmark as a baseline, which indicates the generalization of the proposed UIEB for training Convolutional Neural Networks (CNNs). The benchmark evaluations and the proposed Water-Net demonstrate the performance and limitations of state-of-the-art algorithms, which shed light on future research in underwater image enhancement. The dataset and code are available at https://li-chongyi.github.io/proj_benchmark.html.

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