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De-scattering and edge-enhancement algorithms for underwater image restoration

Key words: Image de-scattering; Edge enhancement; Convolutional neural network; Non-subsampled contourlet transform

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Motivation

- Enhancement algorithms do not depend on the reasons of image quality degradation. Pixels are operated in spatial or frequency domains to directly improve the brightness and color characteristics. However, enhancement algorithms have poor robustness under changing underwater environments.
- Algorithms based on degradation models give consideration to the cause of image degradation. Considering that the underwater image degradation model is similar to an atmospheric scattering model, many researchers use the haze removal algorithm for underwater images.

Main idea

- Restoration can be divided into two stages: de-scattering and edge enhancement. We introduce a multi-scale iterative framework for underwater image de-scattering, where a convolutional neural network is used to estimate the transmission map and is followed by an adaptive bilateral filter to refine the estimation results.
- A strategy based on white balance is proposed to remove color casts of underwater images. Images are converted to a special transform domain for denoising and enhancing the edge using the non-subsampled contourlet transform.

Method

1. De-scattering algorithm

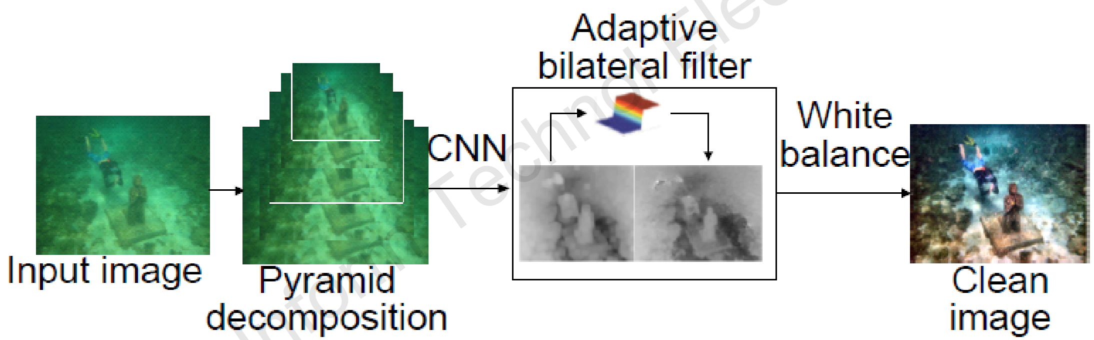

Fig. 2 Flow diagram of the de-scattering algorithm

2. Designs of the de-scattering network

2.1 Network architecture

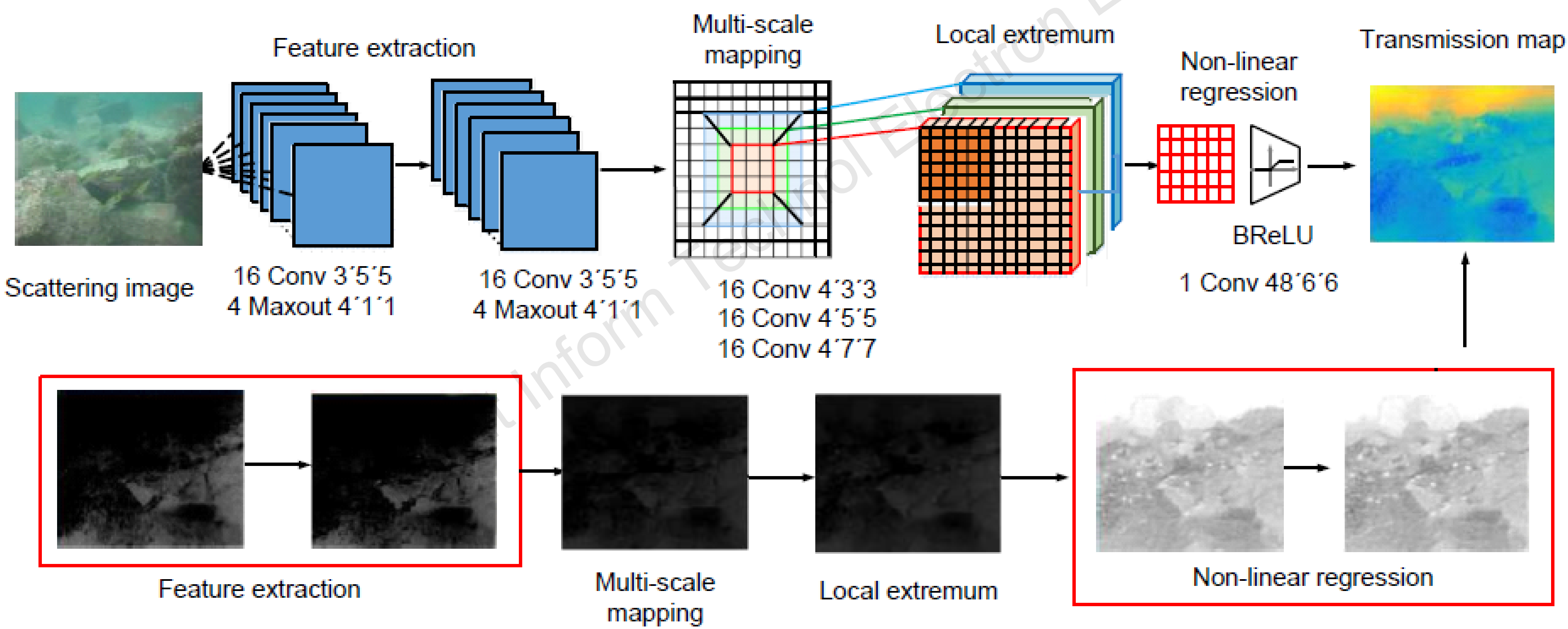

Fig. 3 Schematic of the de-scattering network

2. Designs of the de-scattering network

2.2 Loss function

Denote the input hazy image and real transmission map as X and Y, respectively. The goal of this study is to directly train a deep CNN architecture $h(X)$ on multiple images to minimize the loss function, expressed as

$$L = \frac{1}{N}\sum_{i=1}^{N}\left\| h(X_i) - Y_i \right\|^2, \tag{5}$$

2. Designs of the de-scattering network
2.3 Training

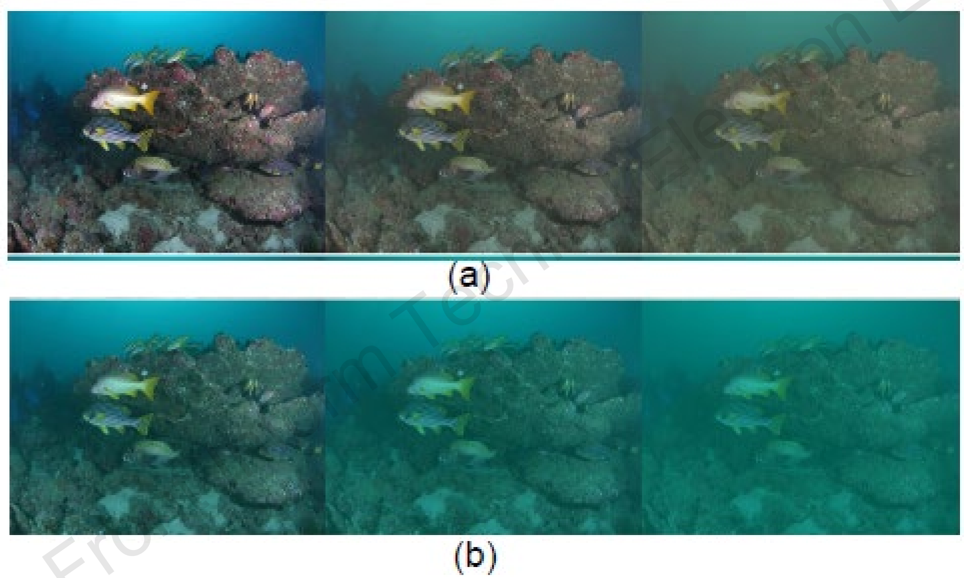

Fig. 4 Underwater color images (a) and synthesized images (b)

2. Designs of the de-scattering network
2.4 White balance

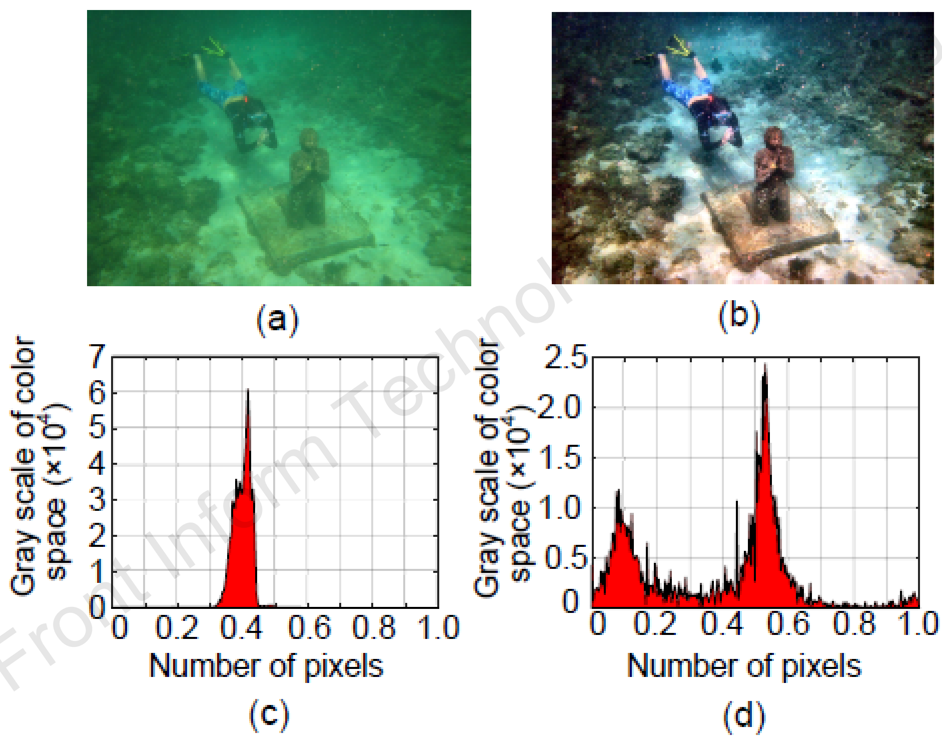

Fig. 7 Original image (a), color corrected image (b), hue histogram of the original image (c), and hue histogram of the color corrected image (d)

3. Edge-enhancement algorithm

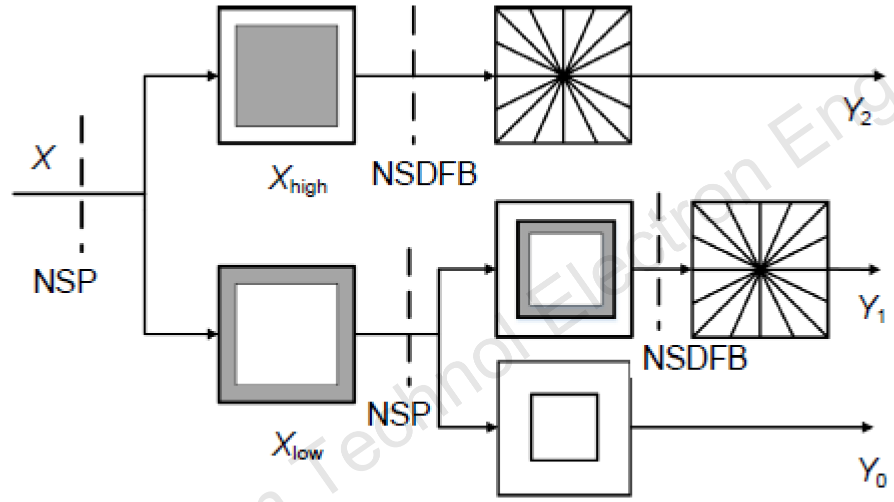

Fig. 8 Diagram of non-subsampled contourlet transform (NSCT)

NSP: non-subsampled pyramid; NSDFB: non-subsampled directional filter banks

Major results (de-scattering)

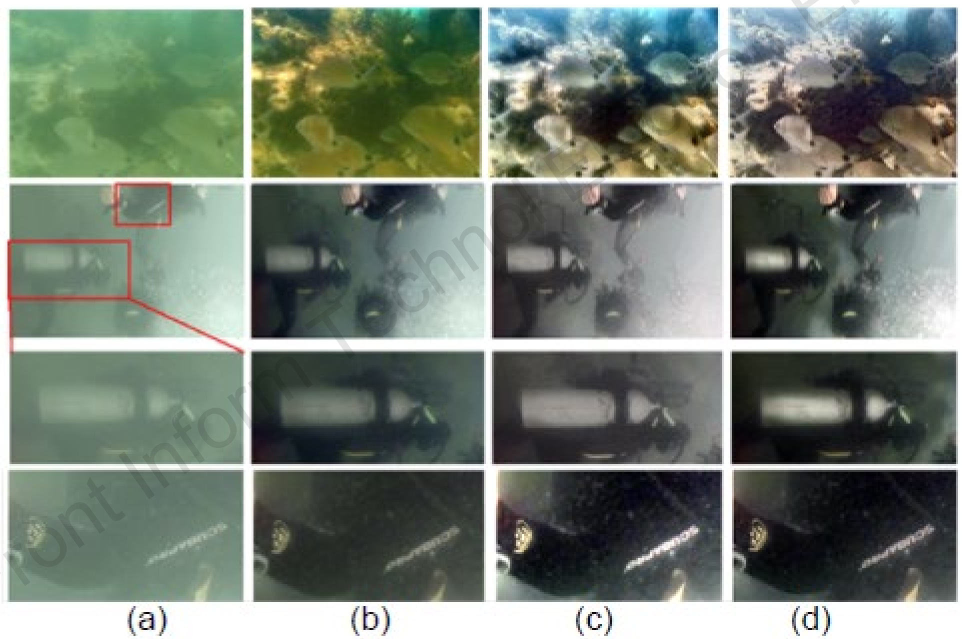

Fig. 10 Original images (a), images restored by He et al. (2011)'s method (b), images restored by Ancuti et al. (2012)'s method (c), and images restored by the proposed method (d)

Major results (edge enhancement)

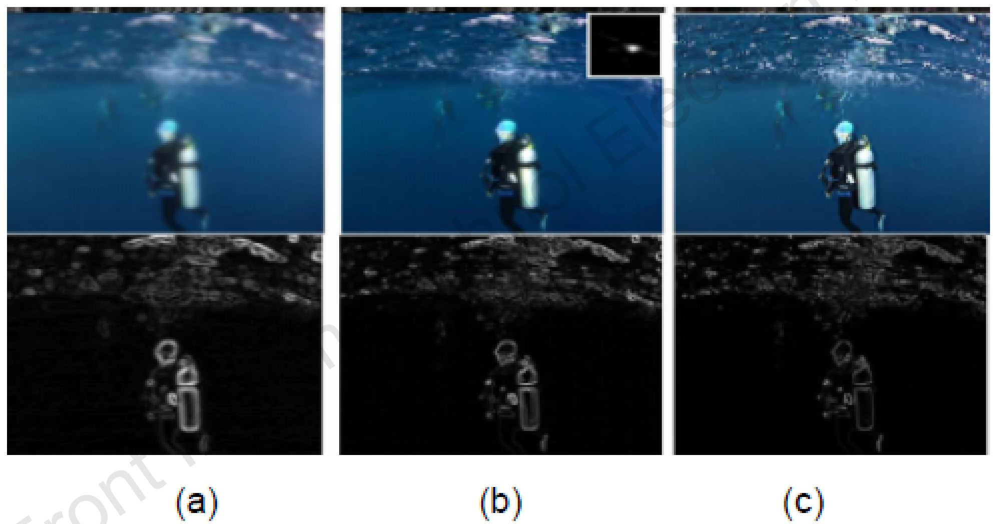

Fig. 11 Observed images (a), images enhanced and blur kernel estimated by Pan et al. (2016)'s method (b), and images enhanced by the proposed method (c)

Major results (performance comparison)

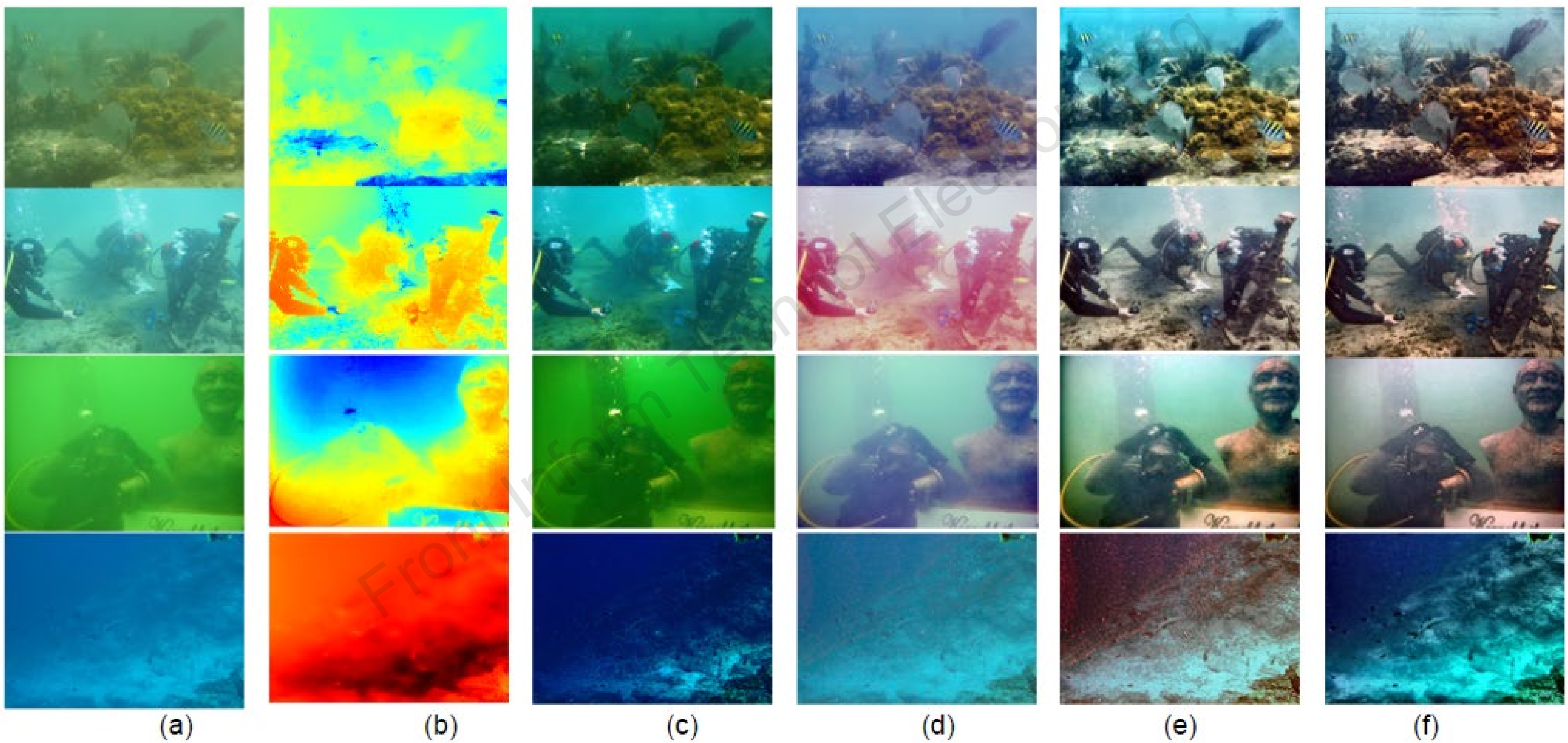

Fig. 12 Original images (a), transmission maps estimated by the proposed method (b), images enhanced by Chiang and Chen (2012)'s method (c), images enhanced by Zhang et al. (2012)'s method (d), images restored by Galdran et al. (2015)'s method (e), and images restored by the proposed method (f)

Major results
(image segmentation)

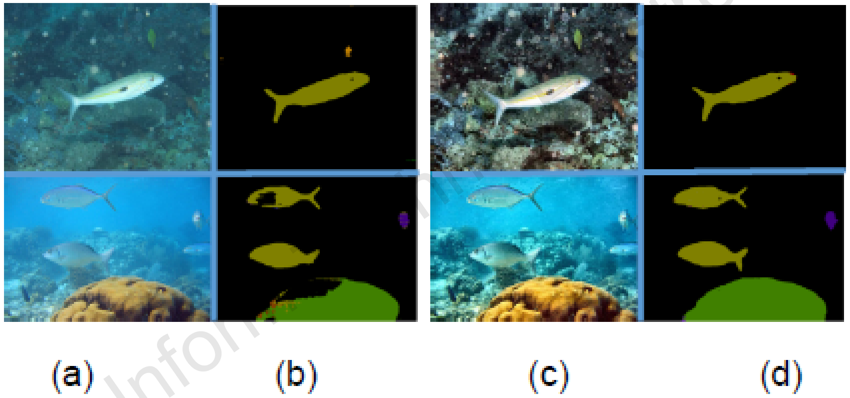

Fig. 15 Image segmentation results: (a) raw underwater images; (b) raw underwater images' segmentation results; (c) restored images; (d) restored images' segmentation results

Major results
(dust storm image)

Test results demonstrating that the proposed method is actually a general framework for image preprocessing tasks

Conclusions

1. In this paper, we have presented an end-to-end deep learning framework for transmission map estimation and single-image de-scattering.

2. We have synthesized clean/hazy image pairs for convolutional neural network training.

3. In the edge-enhancement stage, we have transformed underwater images into the NSCT domain to remove noise and for edge enhancement. Results showed that the proposed method noticeably outperforms state-of-the-art methods in terms of subjective and objective performances.

4. Our approach is suitable for atmospheric images and can be a general work for image preprocessing tasks.