Deep Fully Convolutional Regression Networks for Single Image Haze Removal

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Contribution

We propose an effective deep fully convolutional regression network (DFCRN) for more accurate transmission estimation. Our contributions are mainly in three-fold.

- We develop an end-to-end deep regression network endowed with novel UpConv units, which can automatically learn diverse haze-relevant features and then accurately predict the transmission map for an input hazy image of arbitrary size.
- We apply a outdoor synthetic dataset for network training and build a new benchmark to evaluate the performance of the various haze removal algorithms.
- We fully evaluate the proposed method against the existing CNN-based haze removal methods as well as some state-of-the-art traditional dehazing methods on a number of datasets including synthetic and real-world hazy images.

Introduction

Haze removal for a single image is known to be a challenging ill-posed problem in computer vision. The performance of existing prior-based image dehazing methods is limited by the effectiveness of hand-designed features. In order to improve the dehazed images, we aim to develop an effective deep fully convolutional regression network for more accurate transmission estimation.

Image Dehazing Background

The formulation of a hazy image can be modeled by the following atmospheric scattering model:

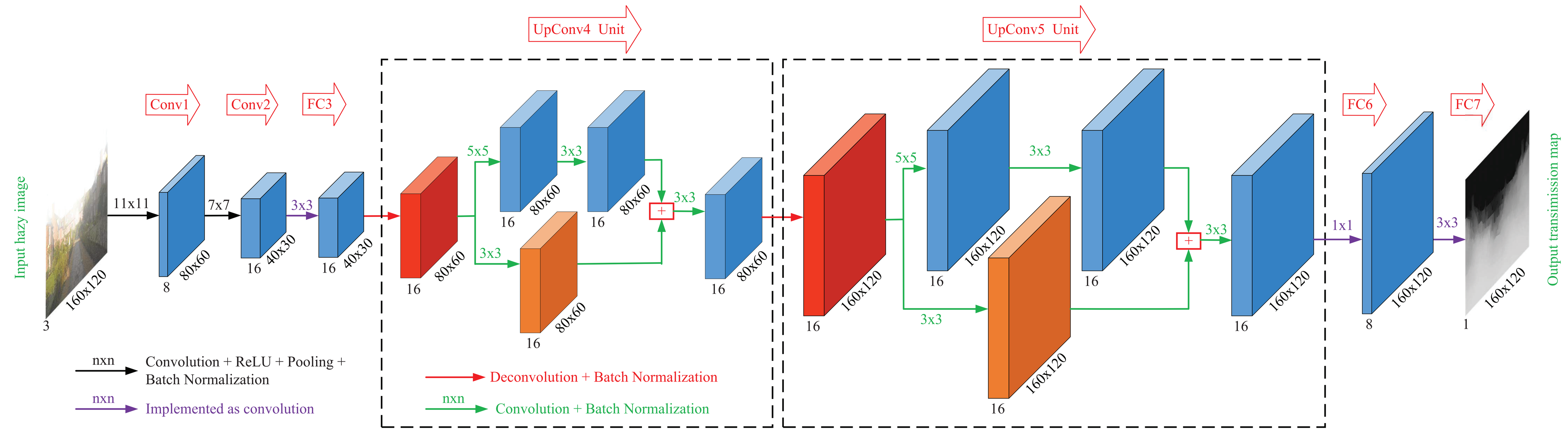
$$I(x) = J(x)t(x) + A(1 - t(x))\,, \tag{1}$$

$$t(x) = e^{-\beta d(x)}\,, \tag{2}$$

The key issue in haze removal is to estimate an accurate transmission map from an input hazy image. Once given the estimated transmission, the latent haze-free image can be easily restored via a simple pixel-wise operation.

Image Dehazing with DFCRN

0.1 DFCRN Architecture



0.2 Haze removal with the trained network

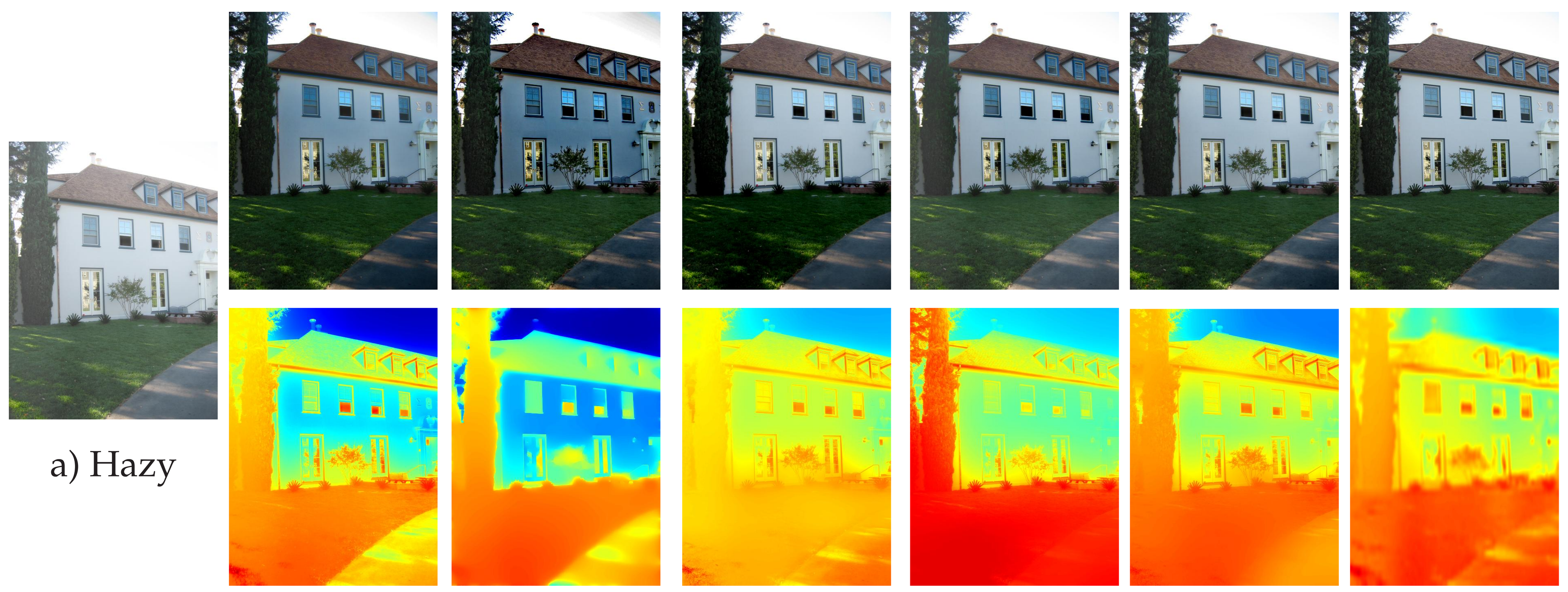
Given the estimated medium transmission $t(x)$ and atmospheric light A, the final scene radiance $J(x)$ is recovered easily by Eq.(1), which is rewritten as follows:

$$J(x) = \frac{I(x) - A}{[\max\{t(x), \gamma\}]^{\delta}} + A\,, \tag{3}$$

where γ is a constant with small value (typically 0.05) to avoid dividing by zero, and the exponent δ is a optional parameter used to adjust the estimated medium transmission.

Experiments

0.1 Quantitative comparison on synthetic images



a) Hazy b) He *et al.* c) Meng *et al.* d) DehazeNet e) Ren *et al.* f) Ours g) GT

Figure 1: Qualitative comparison of different methods on developed Make3D synthetic haze dataset.

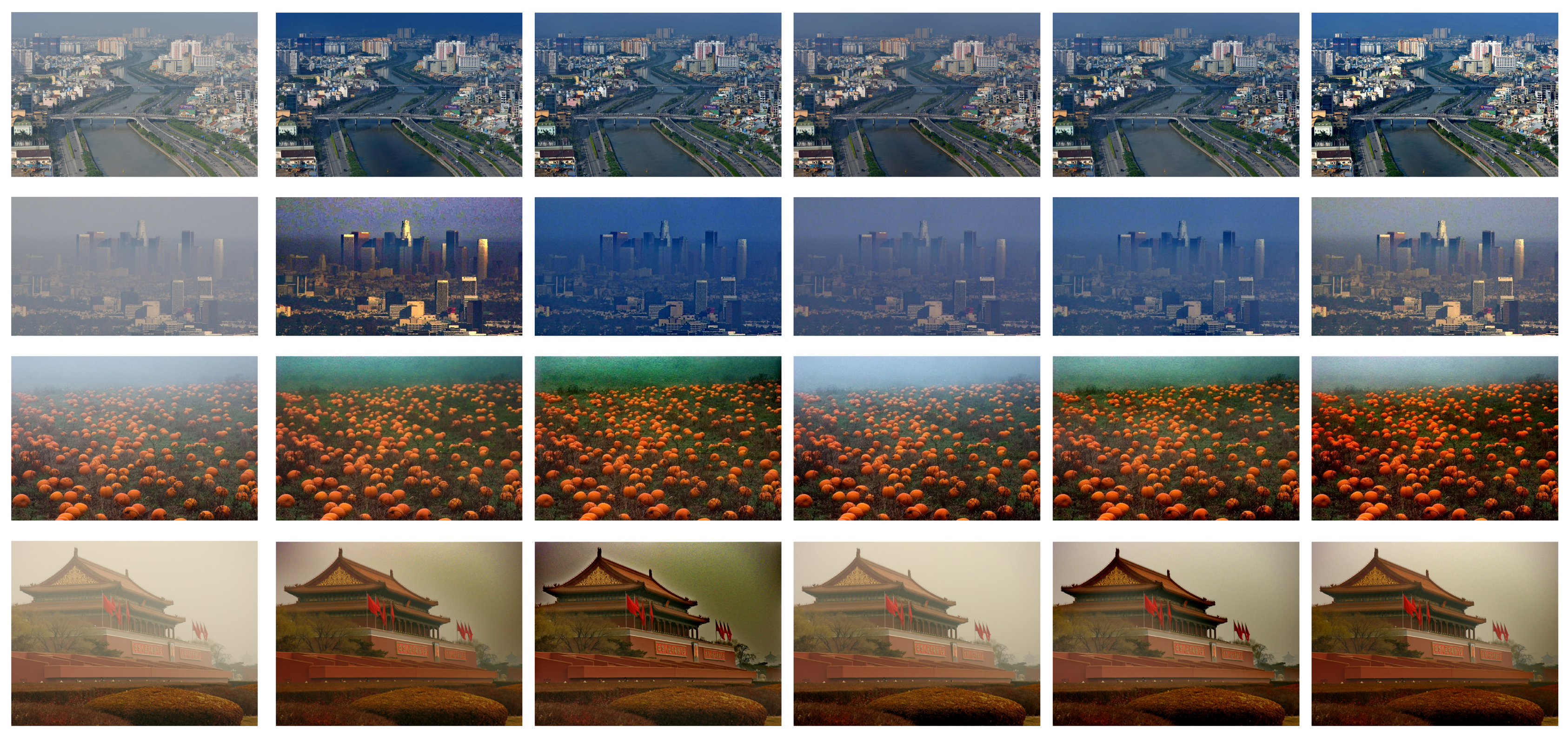
Dataset	Metrics	He *et al.*	Meng *et al.*	DehazeNet	Ren *et al.*	Ours
Make3D	PSNR	16.04	21.42	20.01	22.64	**23.43**
	SSIM	0.85	0.94	0.87	0.94	**0.96**
NYU	PSNR	17.50	19.78	19.03	19.05	**21.91**
	SSIM	0.85	0.88	0.86	0.86	**0.91**

Table 1: Average PSNR and SSIM of dehazed results on different synthetic dataset.

Dataset	Metrics	He *et al.*	Meng *et al.*	DehazeNet	Ren *et al.*	Ours
Make3D	PSNR	13.74	17.38	16.82	**19.55**	19.53
	SSIM	0.78	0.90	0.89	0.88	**0.92**
NYU	PSNR	17.59	18.80	19.95	19.02	**21.76**
	SSIM	0.83	0.90	**0.92**	0.90	**0.92**

Table 2: Average PSNR and SSIM for transmission map estimation on different synthetic dataset

0.2 Qualitative comparison on real-world images.



a) Hazy image b) He *et al.* c) Meng *et al.* d) DehazeNet e) Ren *et al.* f) Ours

Conclusion

We propose a deep fully convolutional regression network (DFCRN) combined with a novel UpConv unit for haze removal, and develop a new outdoor synthetic dataset based on the learned depth map from the single clear image to train and optimize the proposed network. The experimental results demonstrate that our trained regression model achieves superior dehazing performance than the current state-of-the-art methods.

Acknowledgment

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Dataset Reference

[1] Ashutosh Saxena *et al.*: *Make3d: Learning 3d scene structure from a single still image*, IEEE transactions on pattern analysis and machine intelligence, vol. 31, no. 5, pp.824-840,2009.