Single Image Dehazing via Multi-Scale Convolutional Neural Networks

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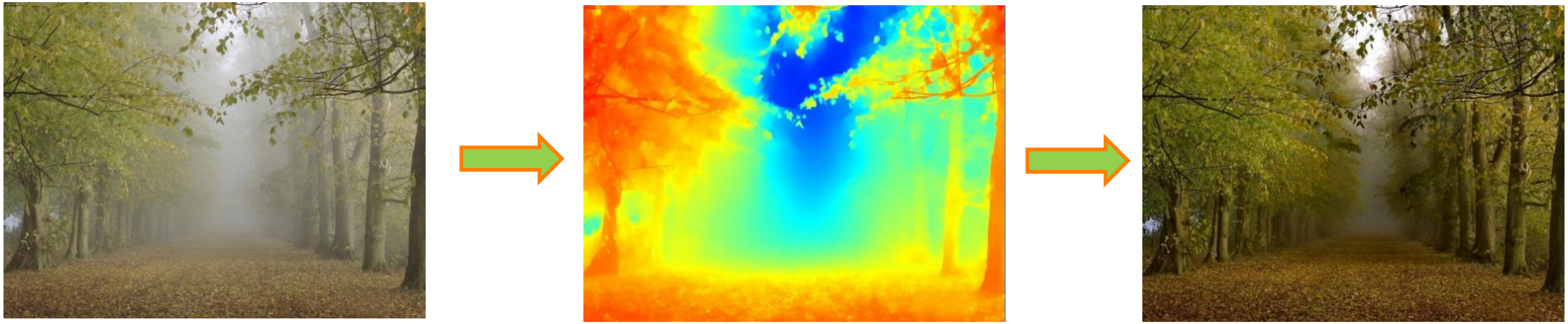
Introduction

- Hazy images
  - Low visibility: distance between an object and the observer increases
  - Faint colors: atmosphere color replaces the color of the object

Introduction

- Goals of image dehazing
  - Transmission estimation
  - Scene recovering



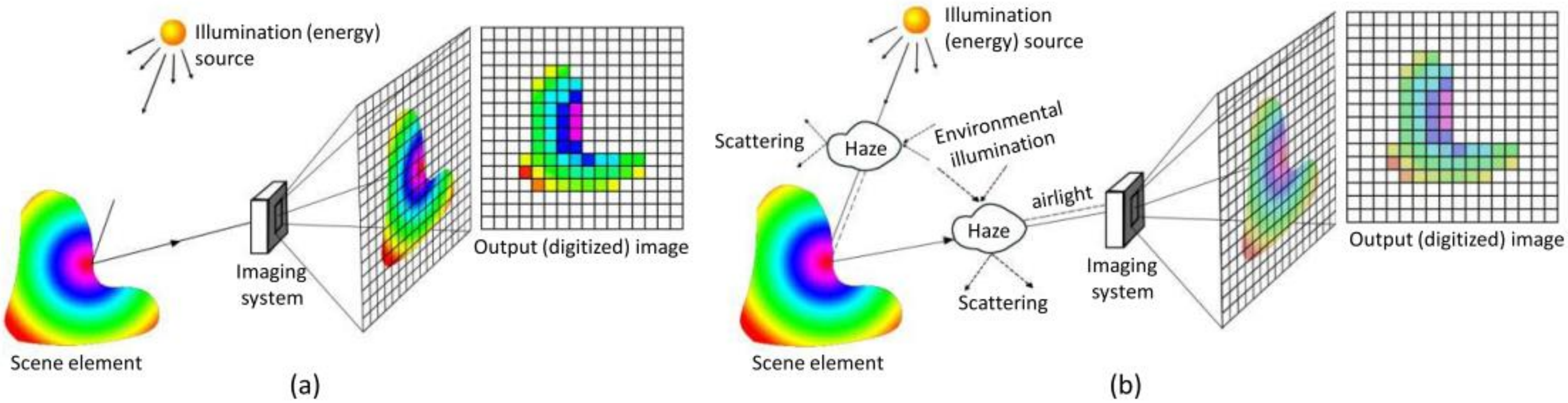
Hazy image   Transmission   Scene

Introduction

- Applications
  - CCTV surveillance (car plate or face)
  - Airborne surveillance
  - Unmanned drive

Introduction

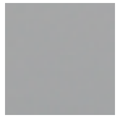
- Hazy imaging model



[1] A fast single image haze removal algorithm using color attenuation prior (Zhu et al. TIP 2015)

Introduction

- Hazy imaging model

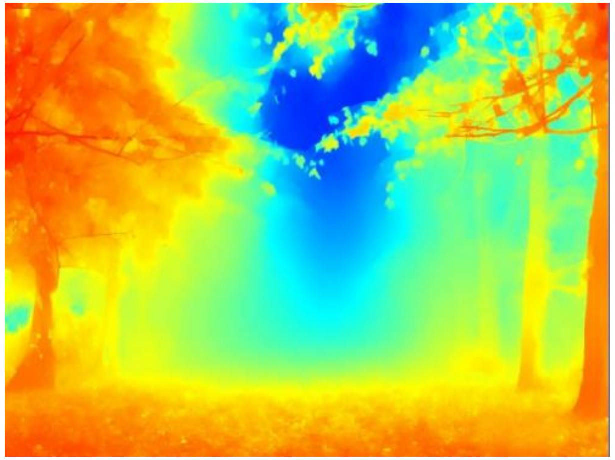


Atmospheric light

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

Hazy image

Scene



Transmission

Introduction

- Hazy imaging model

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

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

t(x): Transmission
d(x): Scene depth
β: medium extinction coefficient

Introduction

❑ Hazy imaging model

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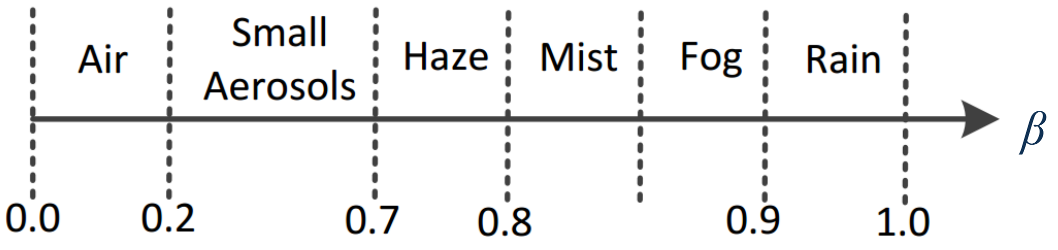


[1] Srinivasa G. et al. Shedding Light on the Weather. CVPR 2003

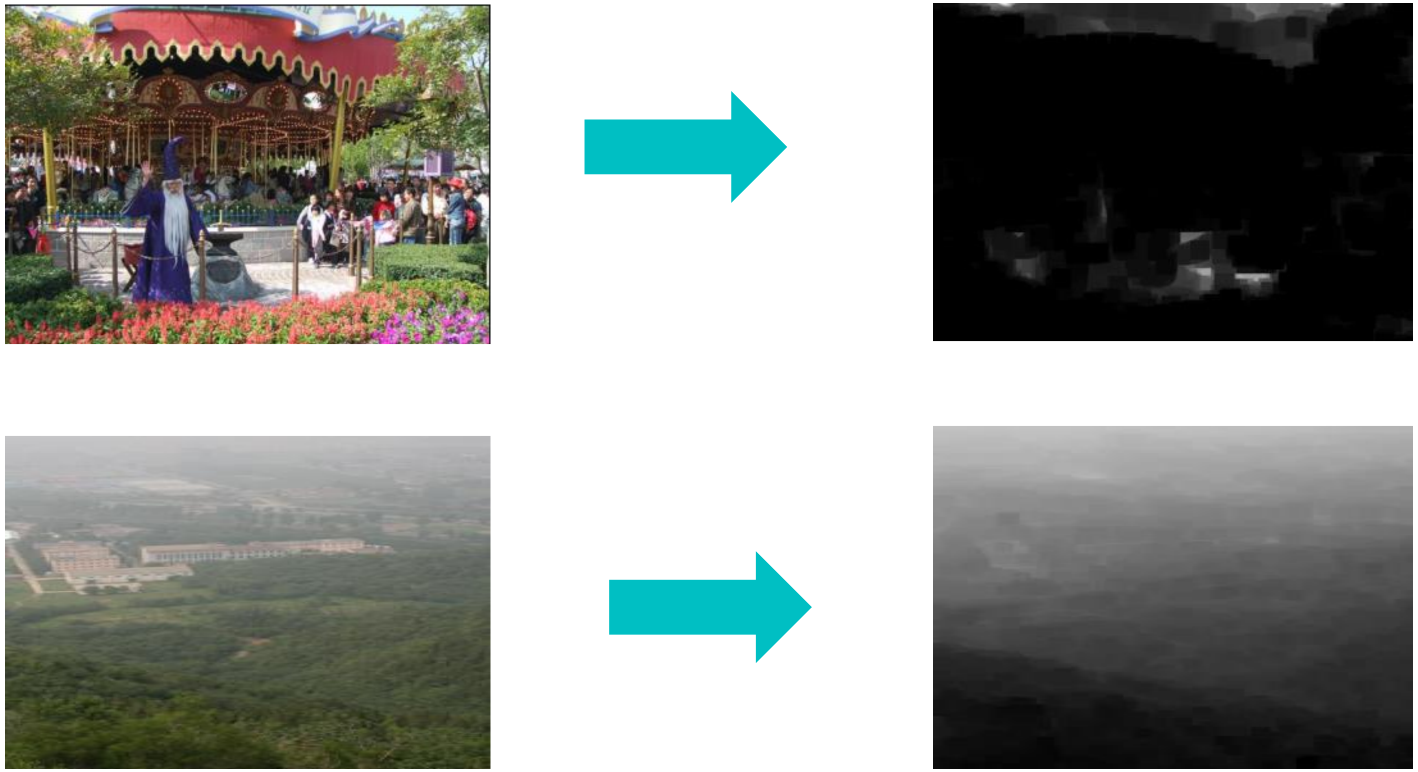
Related work

- Maximize local contrast

- Visibility in bad weather from a single image. Tan, CVPR 2008

Related work

- Dark channel prior



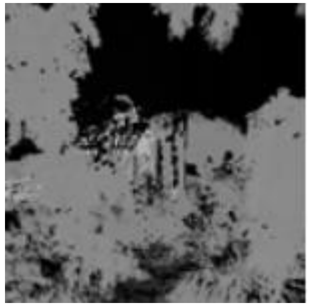
- Single Image Haze Removal Using Dark Channel Prior (He et al. CVPR 2009)

Related work

- Maximize local contrast


Hazy input


dark channel feature


hue disparity feature


local max contrast feature

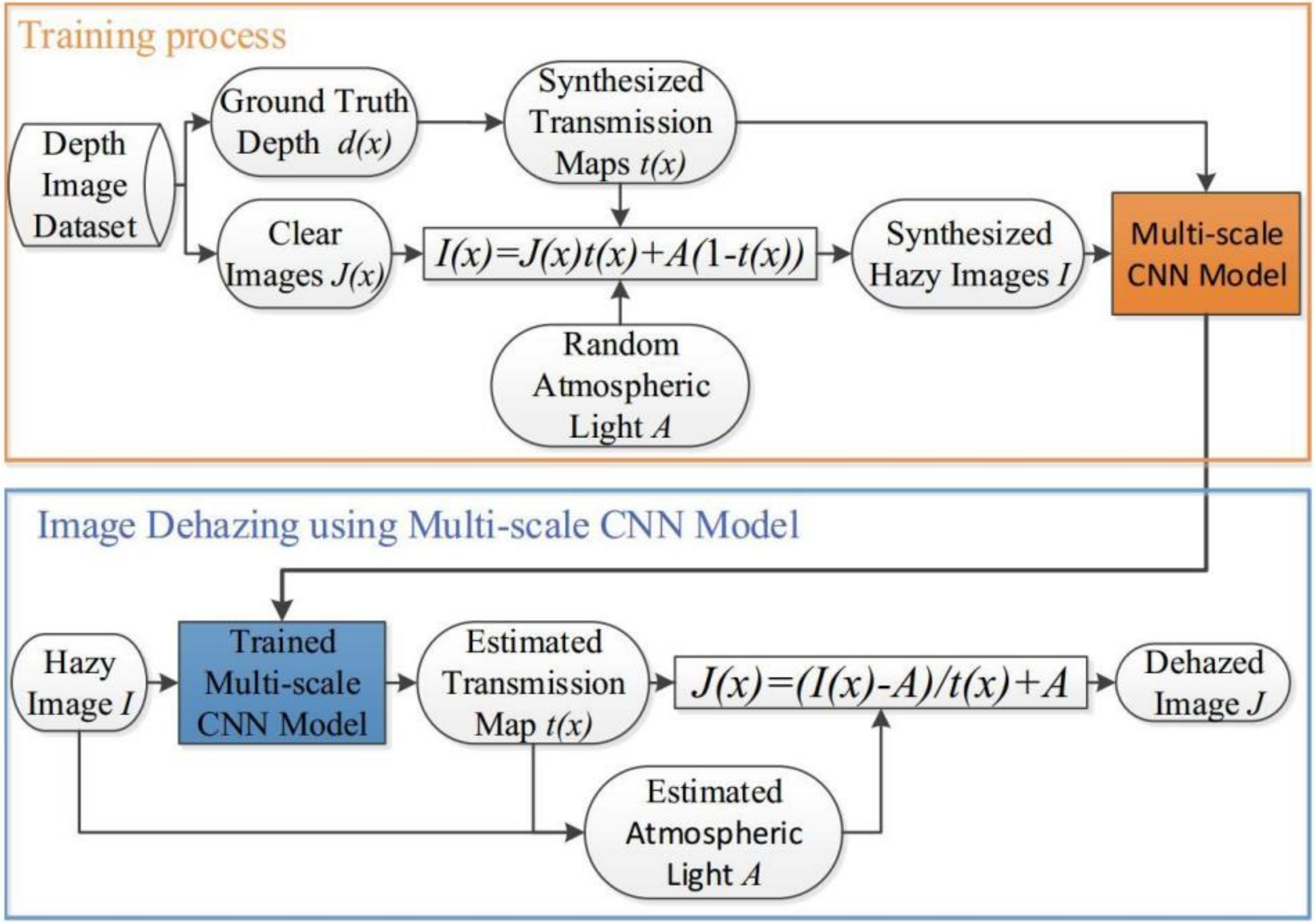

local max saturation feature

- Investigating Haze-relevant Features in A Learning Framework for Image Dehazing (Tang et al. CVPR 2014)

Contributions

- A multi-scale convolutional neural network for transmission estimation
- Analyze the differences between traditional hand-crafted features and the features learned by the CNN
- Real-time on QVGA (320×240) images

Algorithmic Overview



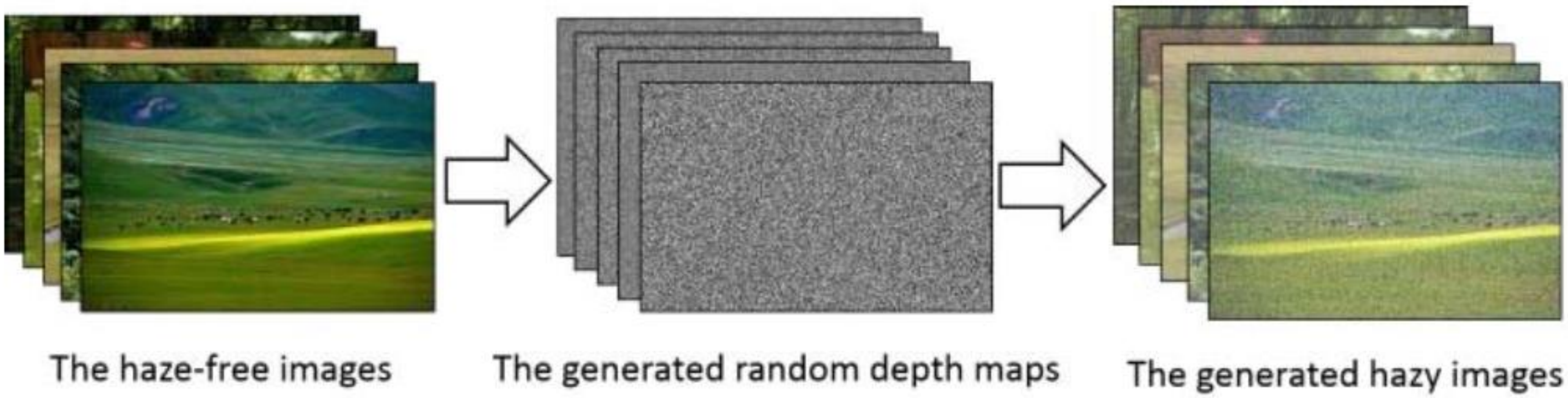
We first train the multi-scale CNN based on synthesized dataset

Then predict transmission based on the trained network

Training Data Synthesis

- Generate synthesized hazy images and transmission

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



[1] A fast single image haze removal algorithm using color attenuation prior (Zhu et al. TIP 2015)

Training Data Synthesis

- Generate synthesized hazy images and transmission
  - NYU depth dataset: $J(x)$ and $d(x)$
  - Hazy imaging model

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

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

t(x): Transmission
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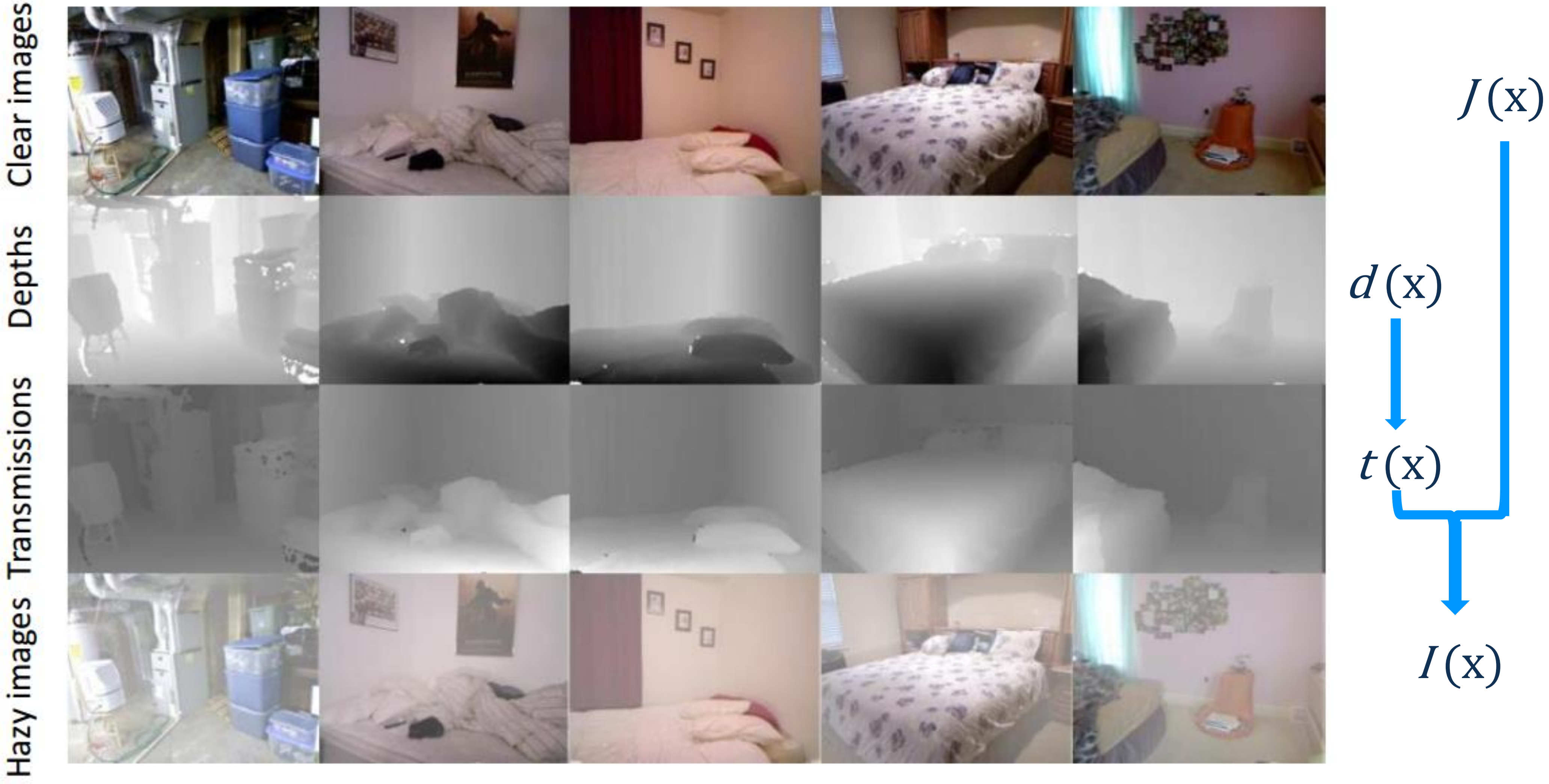
Training Data Synthesis



Training Data Synthesis

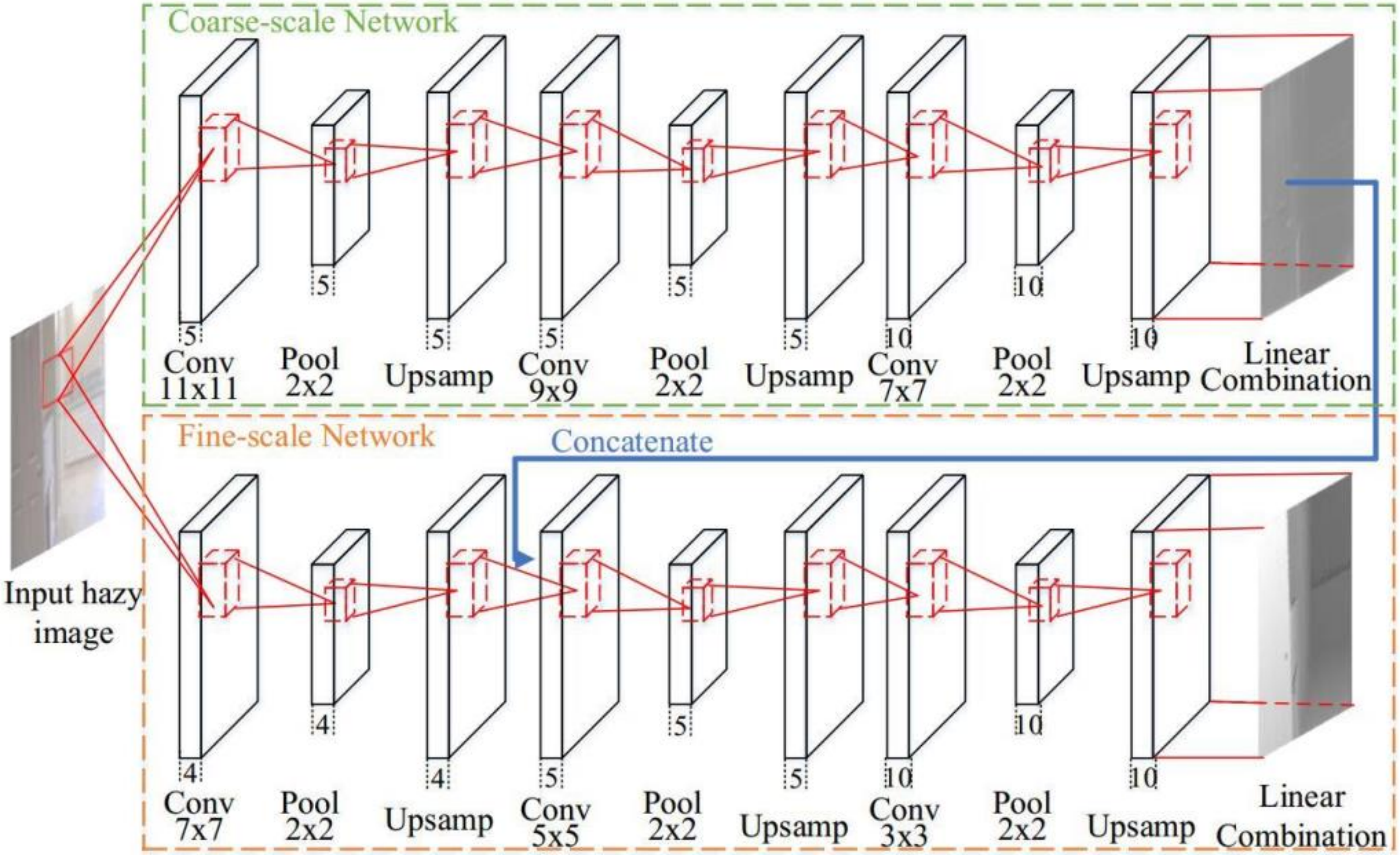
Clear image

Depth image

Hazy images with different β

Network Architecture

- The scene transmission map is first estimated by a coarse-scale network and then refined by a fine-scale network.



Network Architecture (Transmission Estimation)

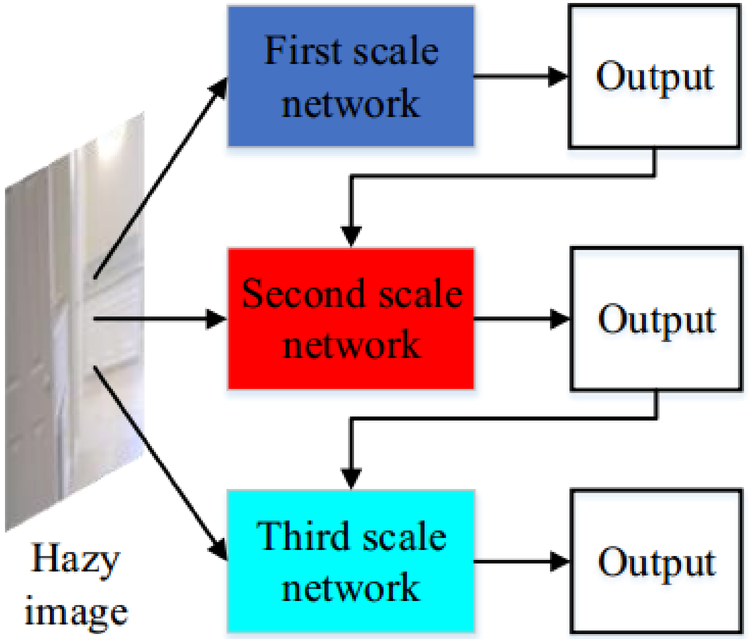
- Training loss

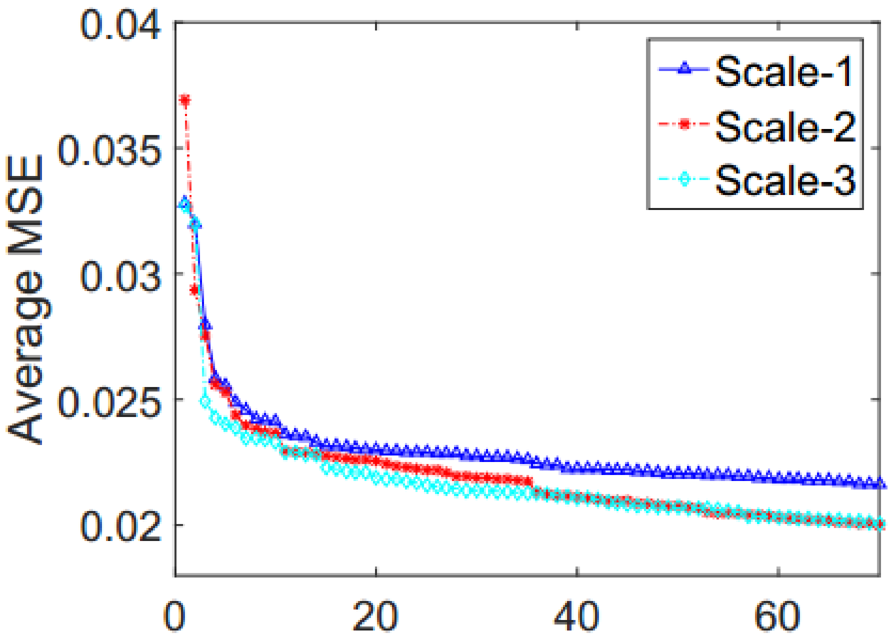
$$L(t_i(x), t_i^*(x)) = \frac{1}{q}\sum_{i=1}^{q} ||t_i(x) - t_i^*(x)||^2$$

- The training loss is used in both coarse and fine-scale networks

Network Architecture

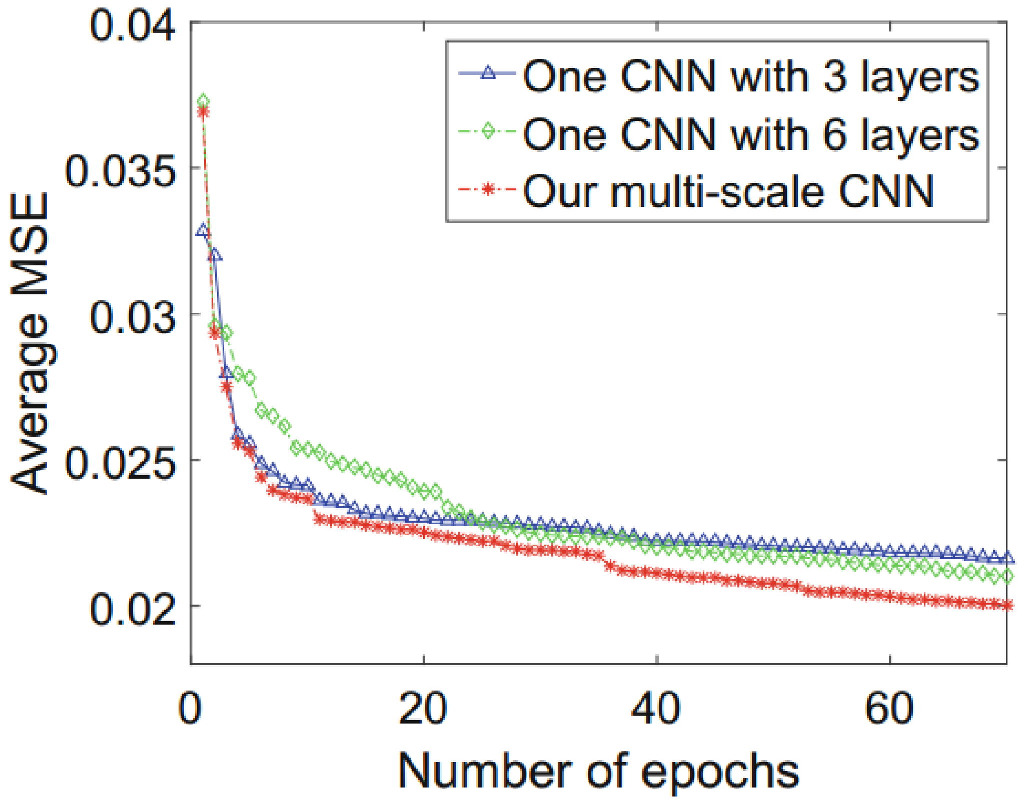
- Two-scale network is enough





Network Architecture

- Depth vs Scale



Atmospheric Light Estimation

- Compute atmospheric light from the estimated transmission map

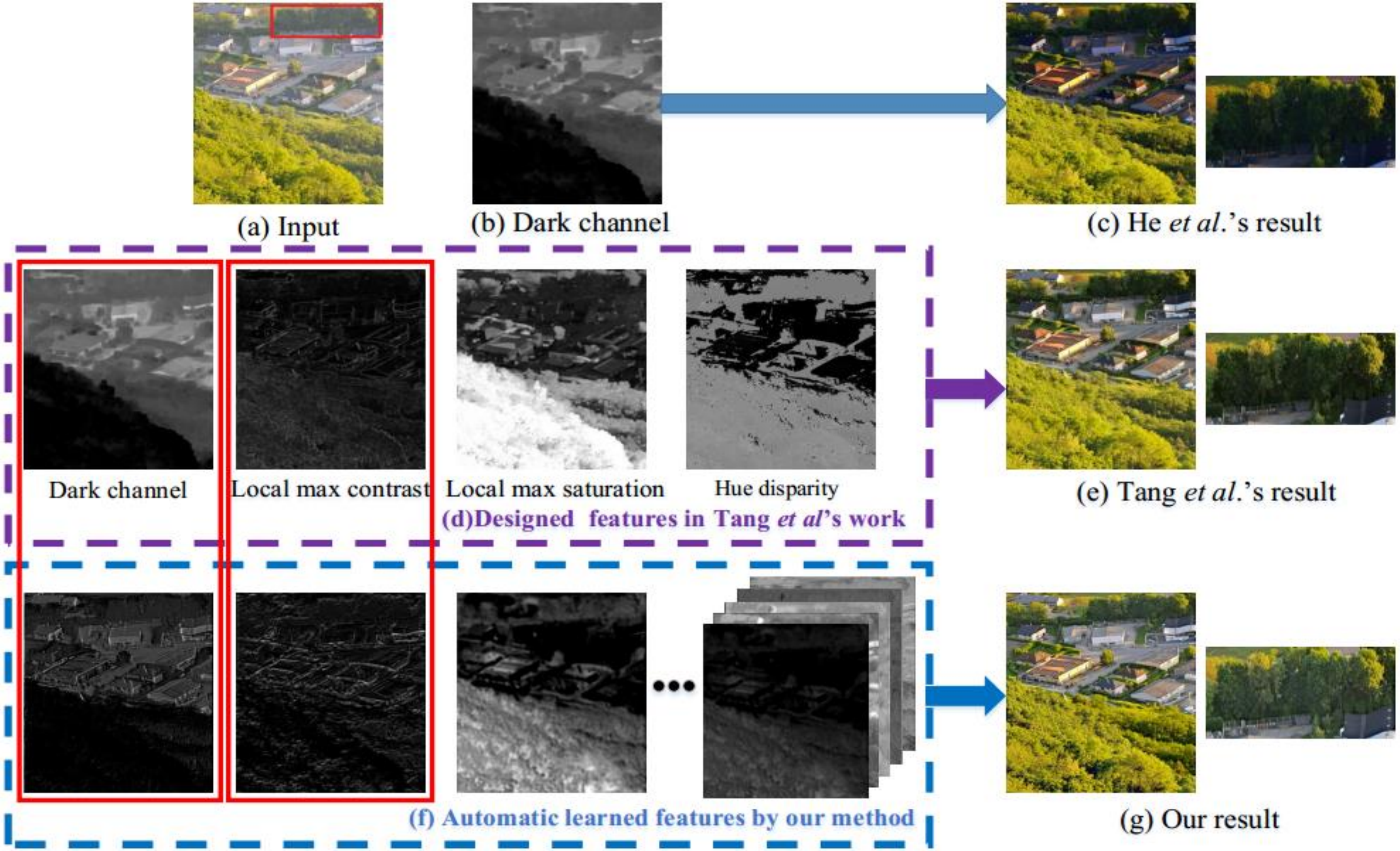
Haze Removal

- Recover haze-free images After atmospheric light and transmission are estimated

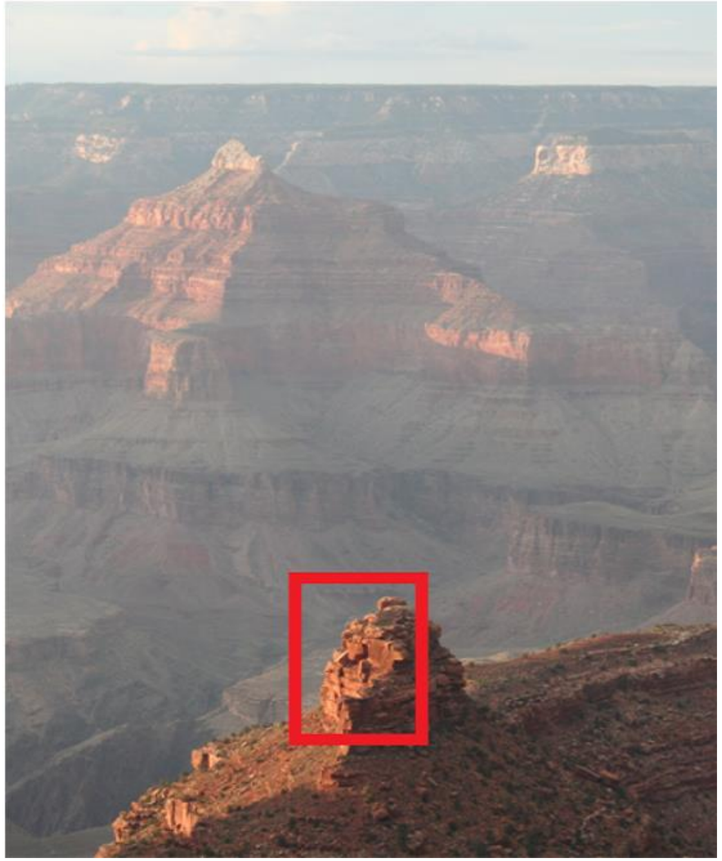
$$\boldsymbol{I}(x) = \boldsymbol{J}(x)t(x) + \boldsymbol{A}(1 - t(x))$$

$$\boldsymbol{J}(x) = \frac{\boldsymbol{I}(x) - \boldsymbol{A}}{t(x)} + \boldsymbol{A}. \longrightarrow \boldsymbol{J}(x) = \frac{\boldsymbol{I}(x) - \boldsymbol{A}}{\max\{0.1, t(x)\}} + \boldsymbol{A}.$$

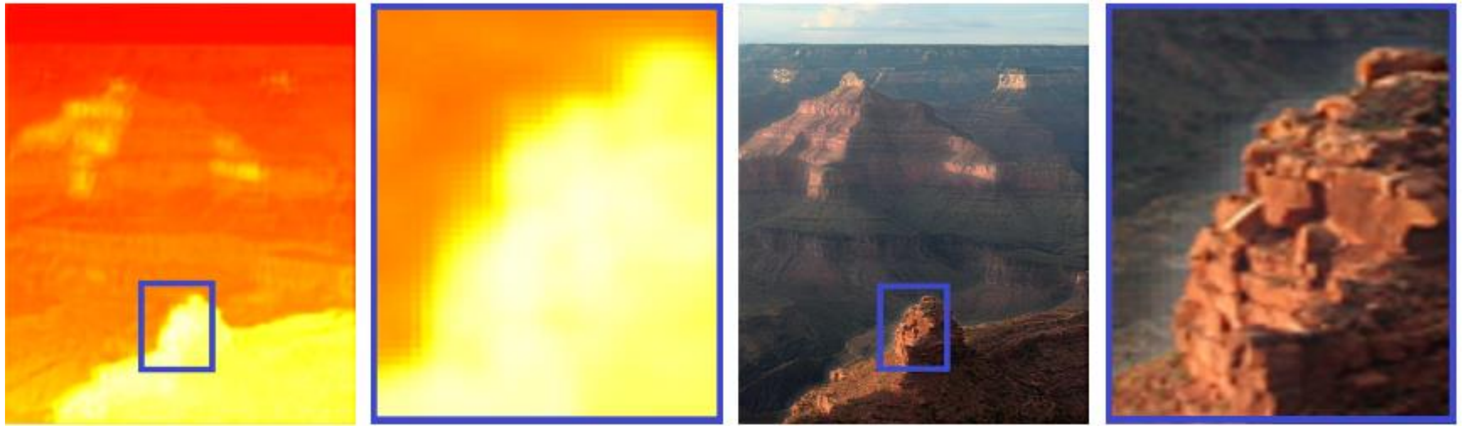
Feature Analysis



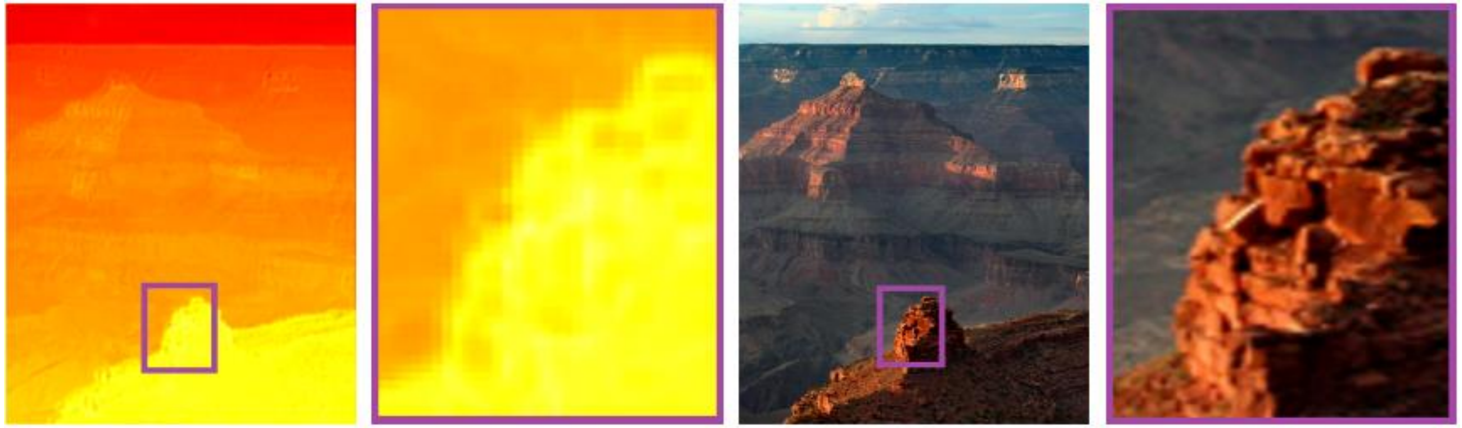
Effectiveness of Fine-scale Network



Hazy image



Without the fine-scale network



With the fine-scale network

Generalization Capability

- Our synthesized transmission maps cover the range of values in real transmission maps

Hazy images

Our results

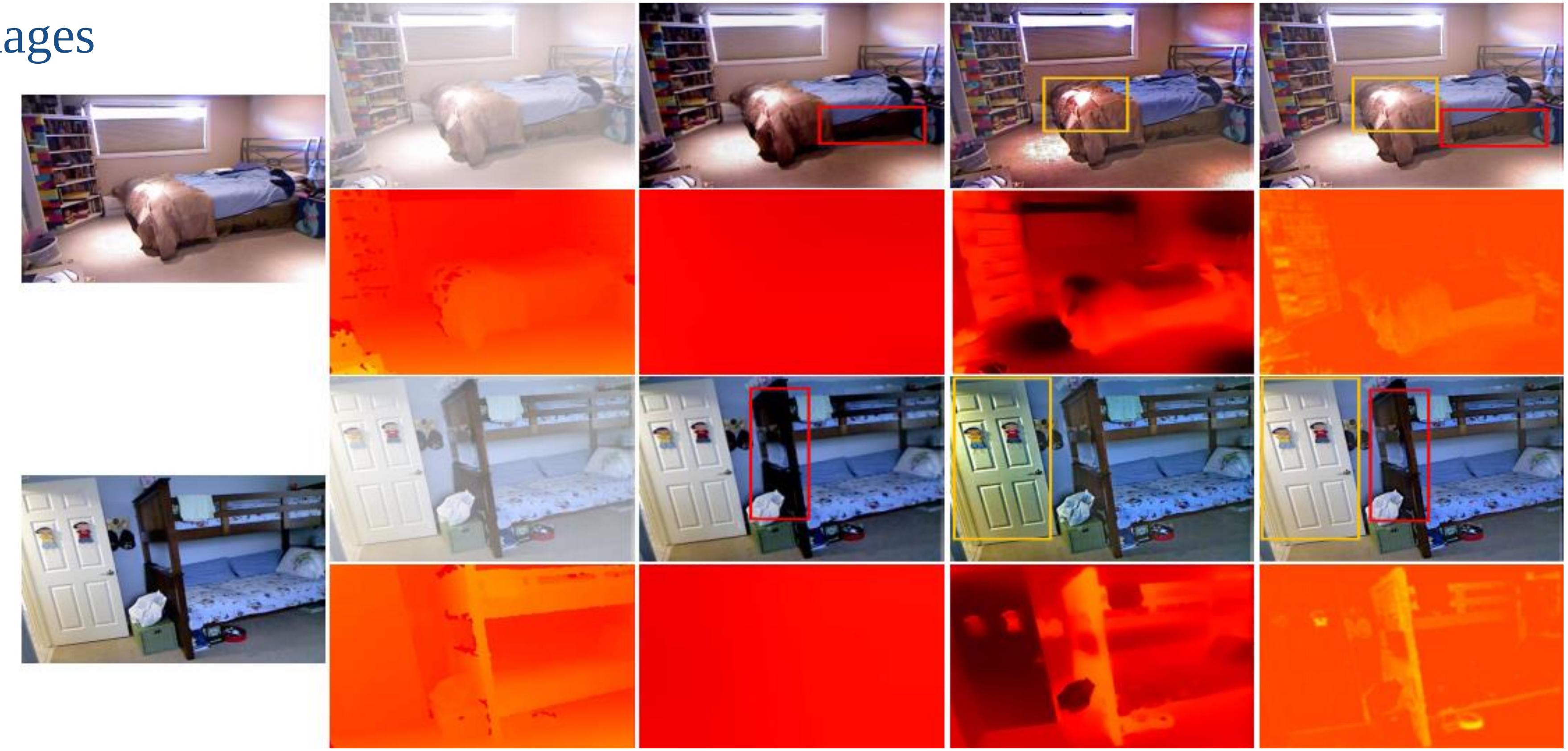
Close shot

Medium shot

Long shot

Experimental Results

- Synthesized images

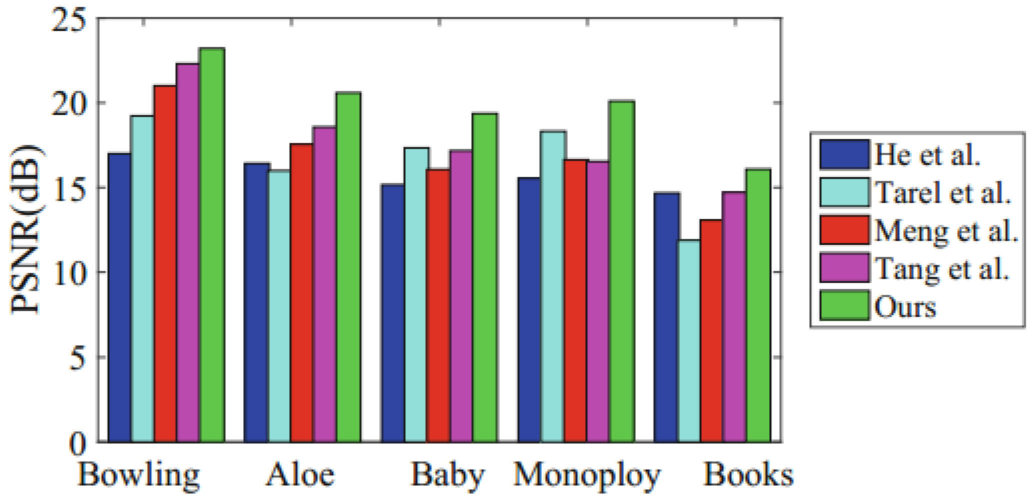


Ground truth | Hazy image and transmission | He et al. | Meng et al. | Proposed

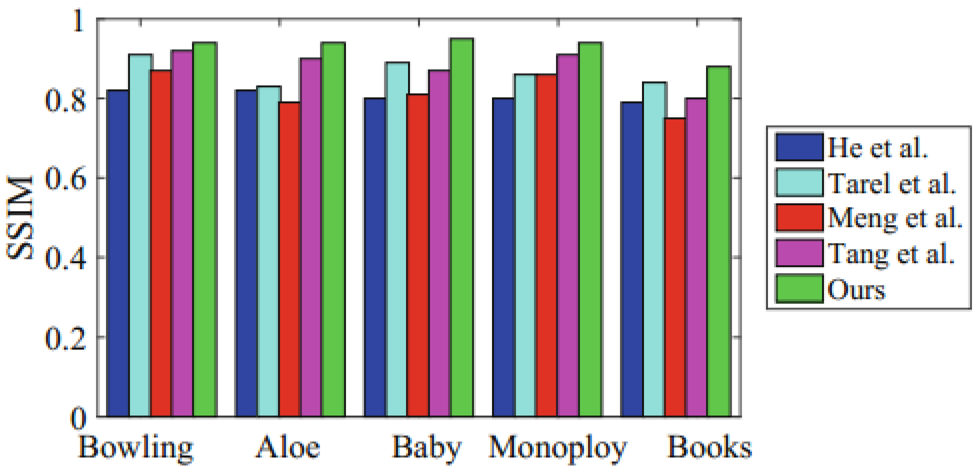
- Single Image Haze Removal Using Dark Channel Prior (He et al. CVPR 2009)
- Efficient Image Dehazing with Boundary Constraint and Contextual Regularization (Meng et al. ICCV 2013)

Experimental Results

- Synthesized images



(a) PSNR

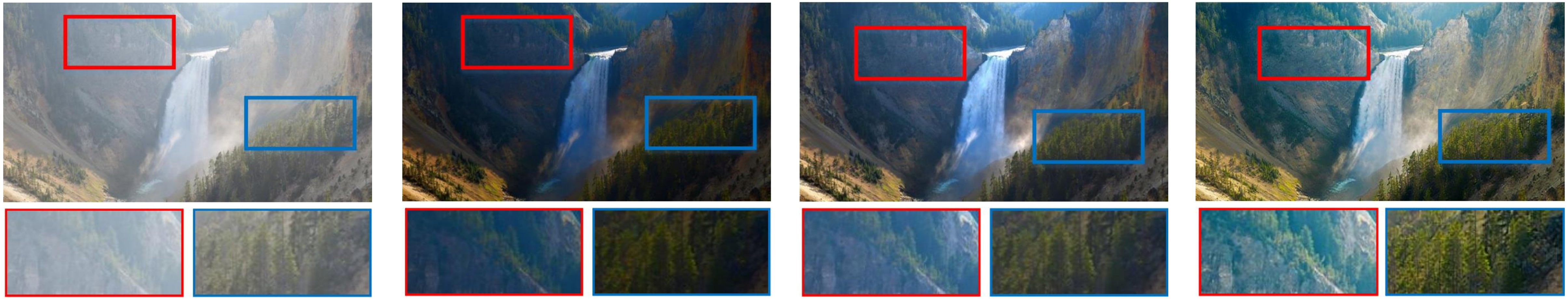


(b) SSIM

- Single Image Haze Removal Using Dark Channel Prior (He et al. CVPR 2009)
- Efficient Image Dehazing with Boundary Constraint and Contextual Regularization (Meng et al. ICCV 2013)
- Investigating Haze-relevant Features in A Learning Framework for Image Dehazing (Tang et al. CVPR 2014)

Experimental Results

- Real-world images



Input | He et al | Tang et al | Proposed

- Investigating Haze-relevant Features in A Learning Framework for Image Dehazing (Tang et al. CVPR 2014)

Experimental Results

- Real-world images


Input


He et al


Meng et al


Proposed

Experimental Results

- Real-world images


Input


He et al


Tang et al


Proposed

Run Time

- Faster than other dehazing methods

Seconds	Fattal	He	Tarel	Meng	Zhu	Ours
427×370	25.68	13.15	2.02	2.29	1.13	**0.36**
640×480	63.09	26.90	7.02	3.23	2.51	**0.61**

- Single Image Dehazing (Fattal. Siggraph 2008)
- Vision enhancement in homogeneous and heterogeneous fog (Tarel et al. ITSM 2012)
- A fast single image haze removal algorithm using color attenuation prior (Zhu et al. TIP 2015): Learning-based method

Failure Case

- Failure case for nighttime hazy images

Nighttime hazy image model [1]: $\mathbf{I}(\mathbf{x}) = \mathbf{R}(\mathbf{x})t(\mathbf{x}) + \mathbf{L}(\mathbf{x})(1 - t(\mathbf{x})) + \mathbf{L}_a(\mathbf{x}) * APSF,$

Input

Li et al

Proposed

- [1] Nighttime haze removal with glow and multiple light colors (Li et al. ICCV 2015)

Concluding Remarks

- Learning transmission map by a multi-scale neural network
  - Coarse-scale network predict holistic transmission
  - As an additional feature in Fine-scale network
- Achieve state-of-the-art dehazing results
  - Real time
  - Vivid color information

Code, model, and video dehazing example available at:
https://sites.google.com/site/renwenqi888/research/dehazing