Image and Video Haze Removal

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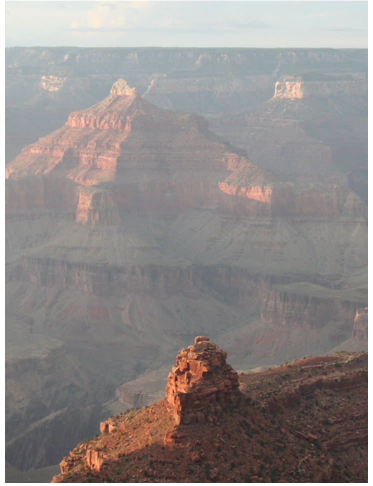
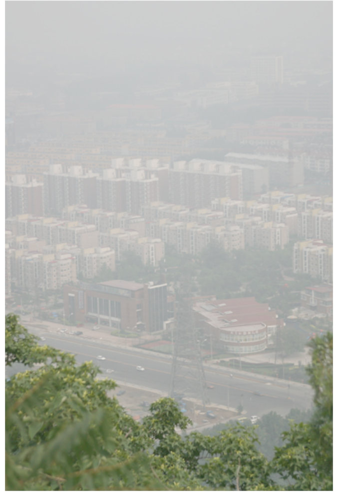
Motivation

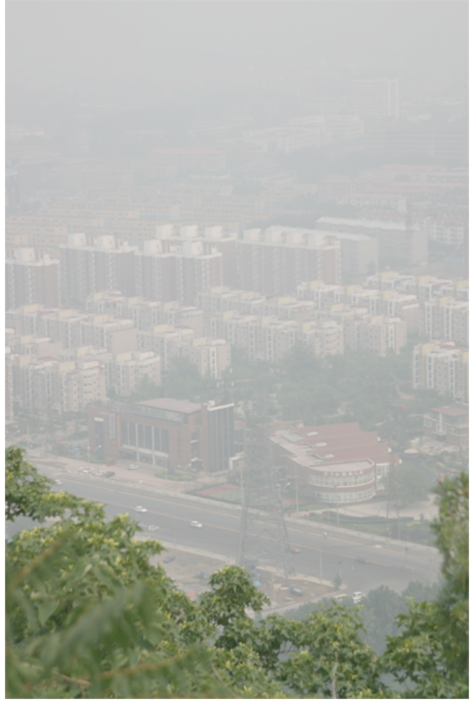
- low contrast
- poor visibility



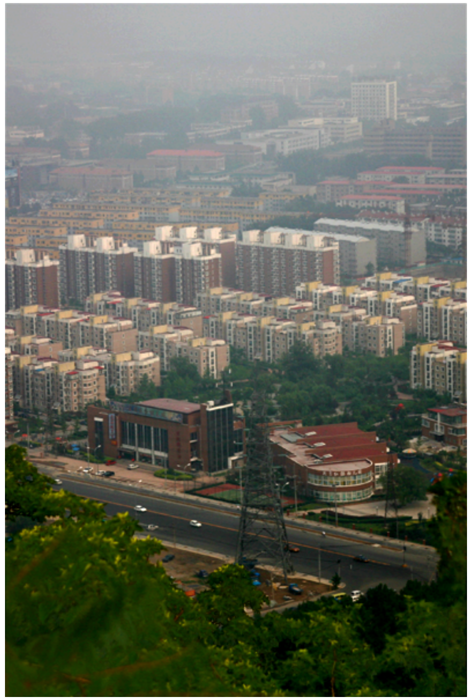



Goals of Haze Removal

- haze-free image
- depth map (by-product)



hazy image



after haze removal

depth

Haze Model

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

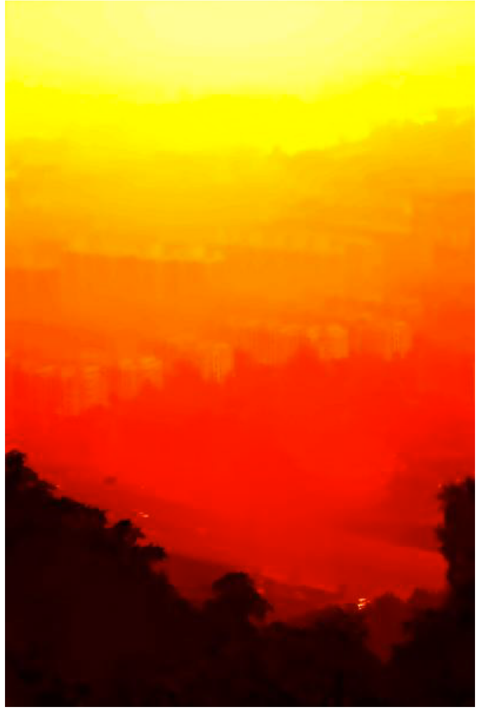
hazy image scene radiance transmission

$\boldsymbol{A}$: atmospheric light

x: pixel coordinates

Haze Model

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



depth d

$$d = -\ln t/\beta$$

transmission t

Haze Model

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

Goal: given hazy image I, estimate J with A and t as by-products

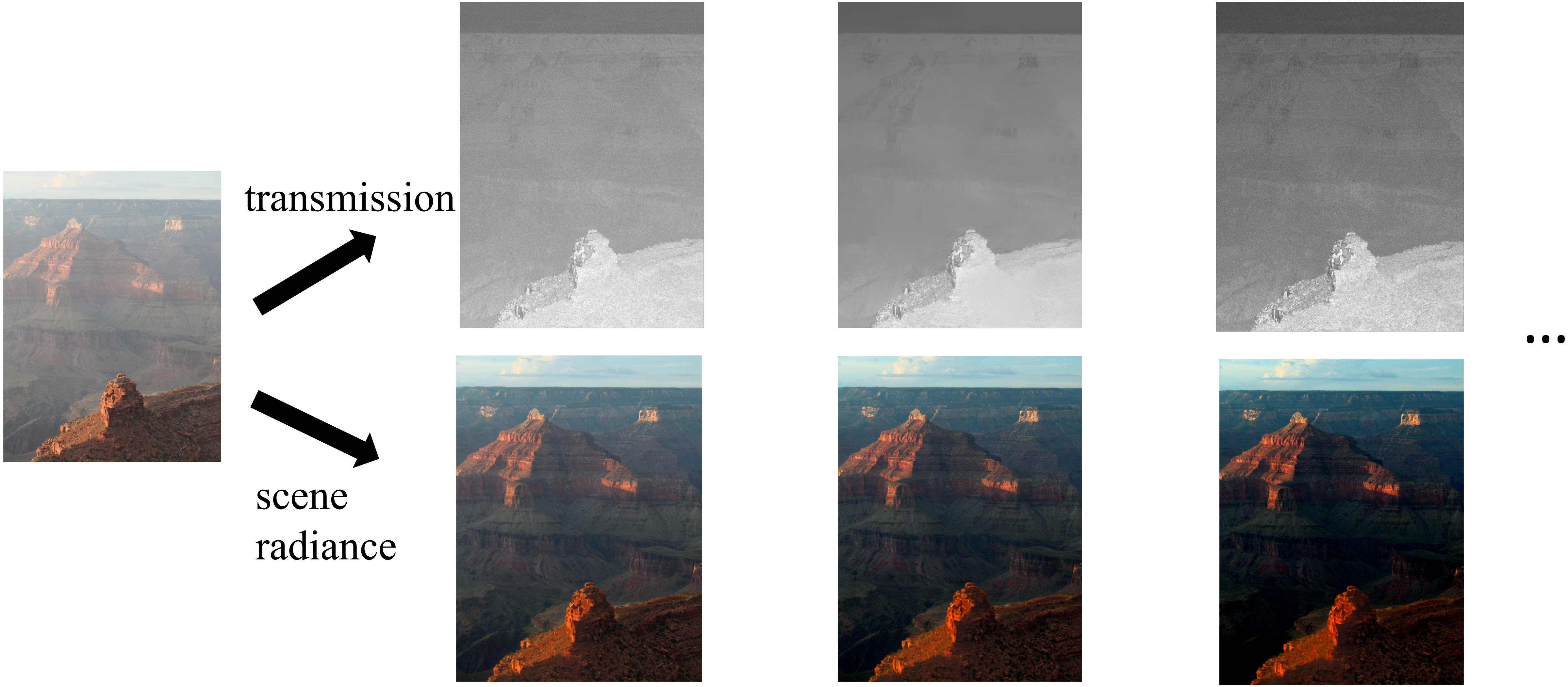
Challenge: ill-posed problems (under-determined system)

Airlight-albedo ambiguity:

Question: the faint red surface of the wall is:
A: a deep red surface through a thick white medium
B: a faint red surface through a clear medium

We can *not* answer this question for each pixel based on a *single* image.

Ambiguity in Haze Removal



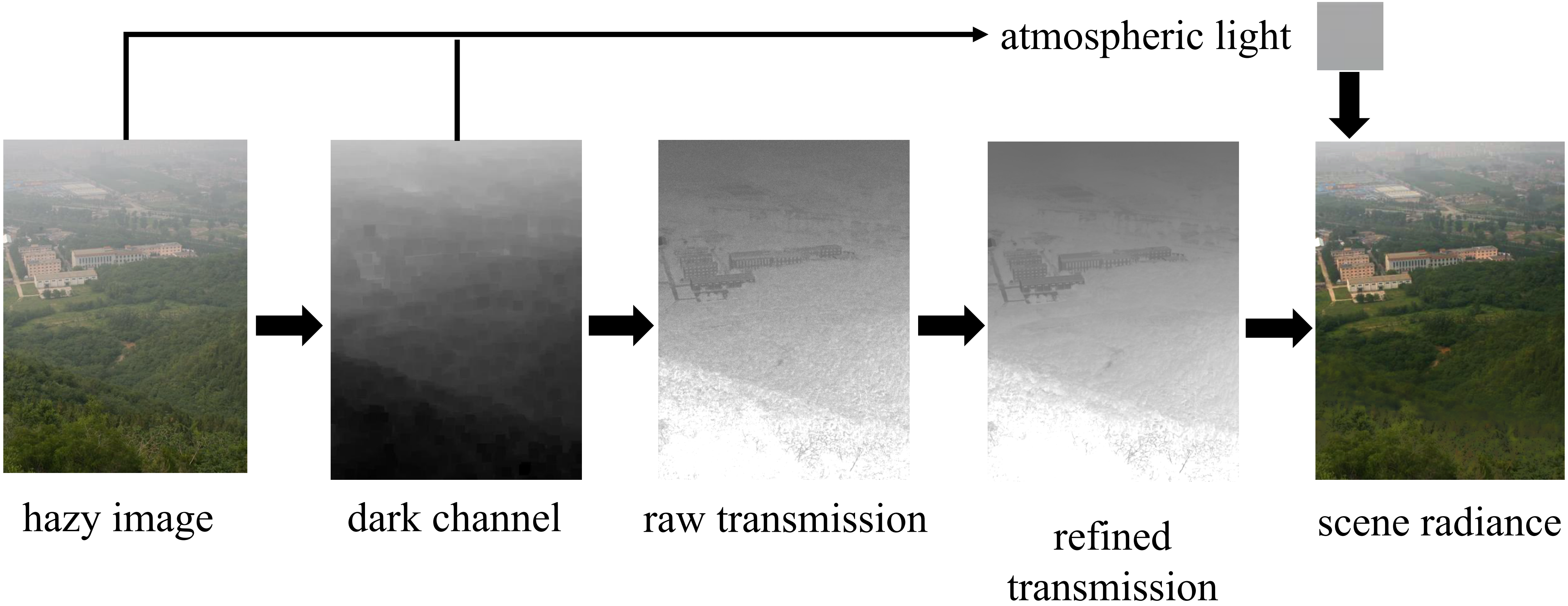
Previous Works

Introduce priors or assumptions:

- dark channel prior [He et al., 2010, 2011]
- contrast enhancement [J-H Kim et al., 2013; R. Tan, 2008]
- independent component analysis [Fattal, 2008]
- multiple images [Narasimhan & Nayar, 2000]
- color-line based dehaze [Dana Berman et al., 2016]
- …

$$\text{ill-posed problem} \xrightarrow{\text{prior}} \text{well-posed problem}$$

Dark Channel Prior



Dark Channel

$$\boxed{J^{dark}(x) = \min_{y \in \Omega(x)} \left(\min_{c \in \{r,g,b\}} J^c(y) \right)}$$

J^c: color channel of $\boldsymbol{J}$

J^{dark}: dark channel of $\boldsymbol{J}$

$\Omega(x)$: local patch contains pixel at x position

input image

$\xrightarrow{\min_c \boldsymbol{J}^c}$

$\xrightarrow{\min_\Omega \left(\min_c J^c \right)}$

dark channel

Dark Channel Observation

haze-free images

dark channel

Dark Channel Observation

For outdoor haze-free images:

$$\boxed{\min_{\Omega}\left(\min_{c} J^{c}\right) \to 0}$$

Based on 5,000 outdoor haze-free images, observe that 86% pixels of dark channels in [0,16].

Why dark?

- Shadow
- colorful object
- black object

Dark Channel Observation

The dark channel of hazy image is no longer dark.

hazy image

dark channel

Transmission Estimation

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

Normalize $$\frac{I^c}{A^c} = \frac{J^c}{A^c} t + 1 - t$$

Computer dark channel

$$\min_{\Omega}\left(\min_{c}\frac{I^c}{A^c}\right) = \boxed{\left\{\min_{\Omega}\left(\min_{c}\frac{J^c}{A^c}\right)\right\}} t + 1 - t$$

$$\longrightarrow 0$$

$$\longrightarrow \quad \min_{\Omega}\left(\min_{c}\frac{I^c}{A^c}\right) = 1 - t$$

Transmission Estimation

Estimate transmission

$$t = 1 - \min_{\Omega}\left(\min_{c} \frac{I^c}{A^c}\right)$$

input I

estimated transmission t

Transmission Refinement

Haze image model $$\boldsymbol{I} = \boldsymbol{J} \cdot t + \boldsymbol{A} \cdot (1 - t)$$

Matting model $$\boldsymbol{I} = \boldsymbol{F} \cdot \alpha + \boldsymbol{B} \cdot (1 - \alpha)$$

hazy image

+

raw transmission map

=

refined transmission

Transmission Refinement

$$\arg\min_t E(t) = \underbrace{\lambda \|t - \tilde{t}\|^2}_{\text{data term}} + \underbrace{t^T L t}_{\text{smoothness term}}$$

t: refined transmission map

$\tilde{t}$: transmission map before refinement

λ: weight of data term, set small so that t is softly constrained by $\tilde{t}$

L: matting Laplacian matrix [A. Levin et al., CVPR 2006]

Transmission Refinement

Get optimal t by solving the sparse linear system: [I. Omer & M. Werman CVPR ‘04]

$$(L + \lambda U)t = \lambda \tilde{t}$$

U: identity matrix of the same size as L.

transmission map before refinement $\tilde{t}$

refined transmission map t

Transmission Refinement

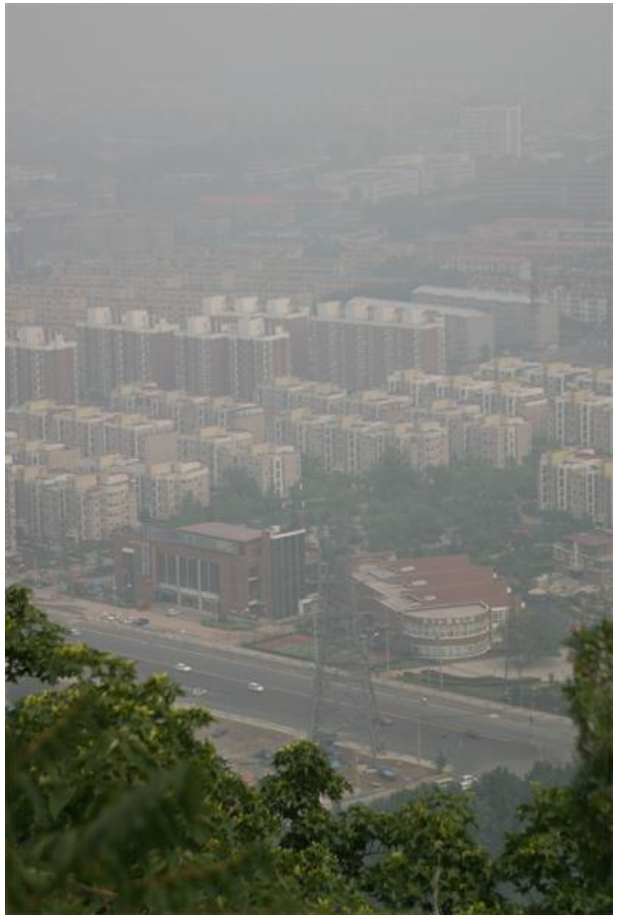
Another approach to refine transmission map:

- use the hazy image as *guided filter*

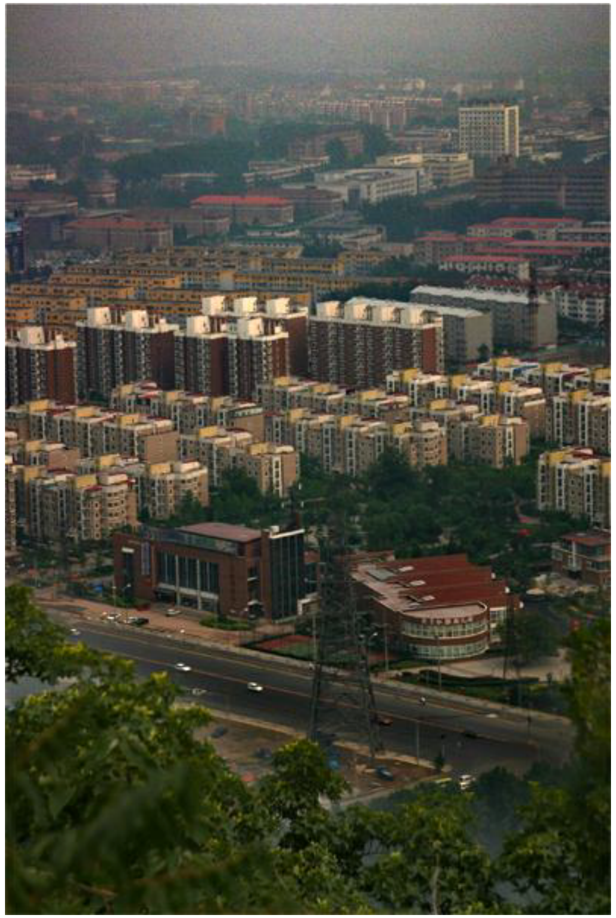
Advantages:

- much faster
- results are visually similar

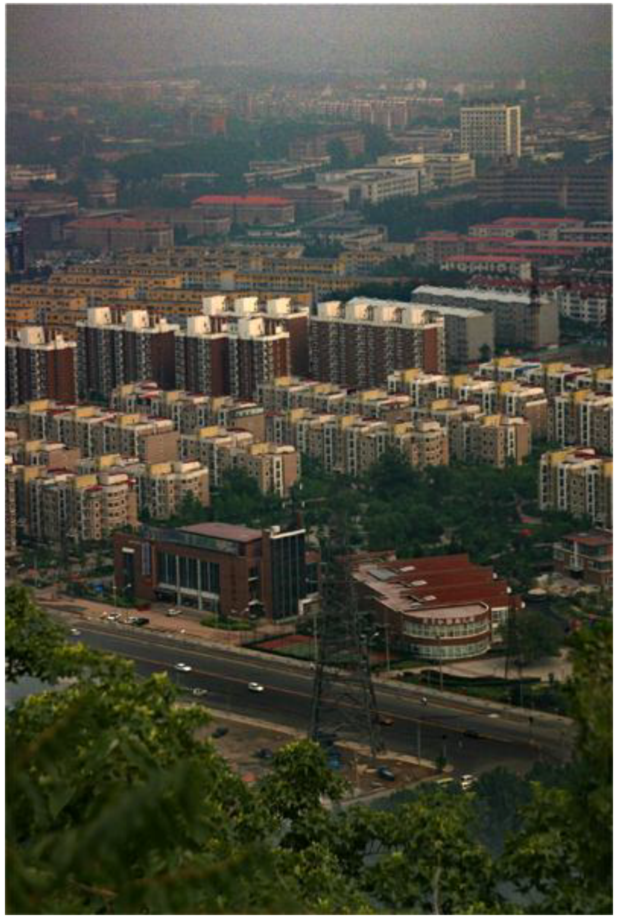
Example



input hazy image



guided filter
(< 0.1s, 600 ×400p)

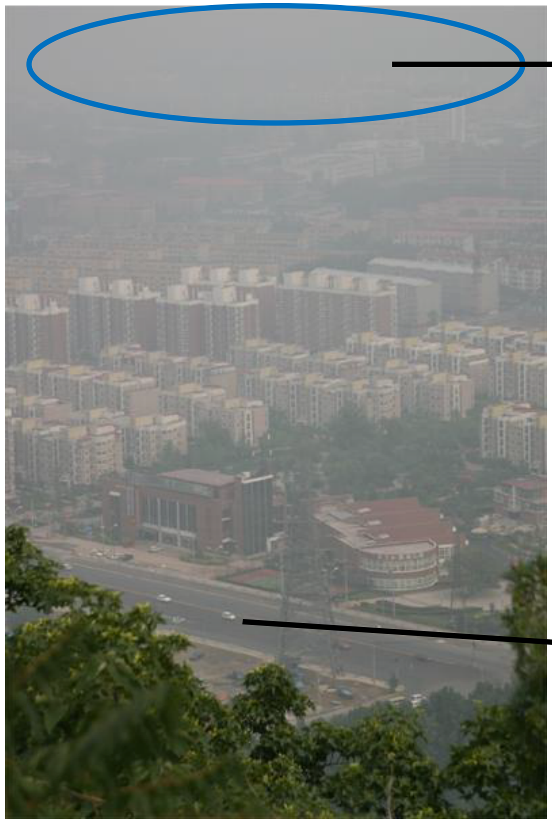


matting Laplacian
+ bilateral filter
(10s)

Atmospheric Light Estimation

brightest pixels

dark channel



input hazy image

most hazy area

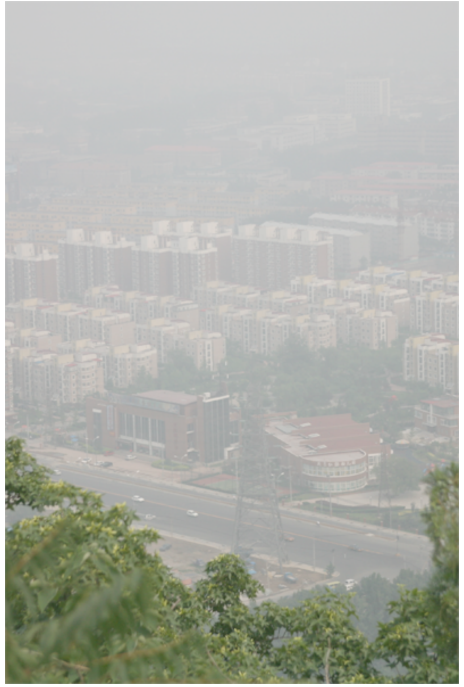
brightest pixel

Scene Radiance Restoration

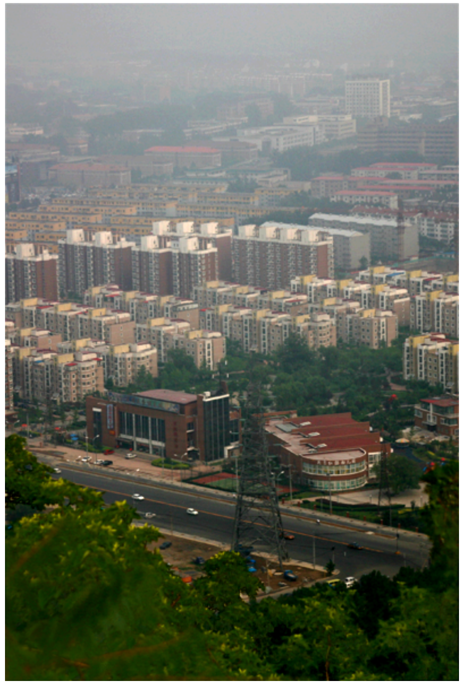
Haze image model

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

atmospheric light A



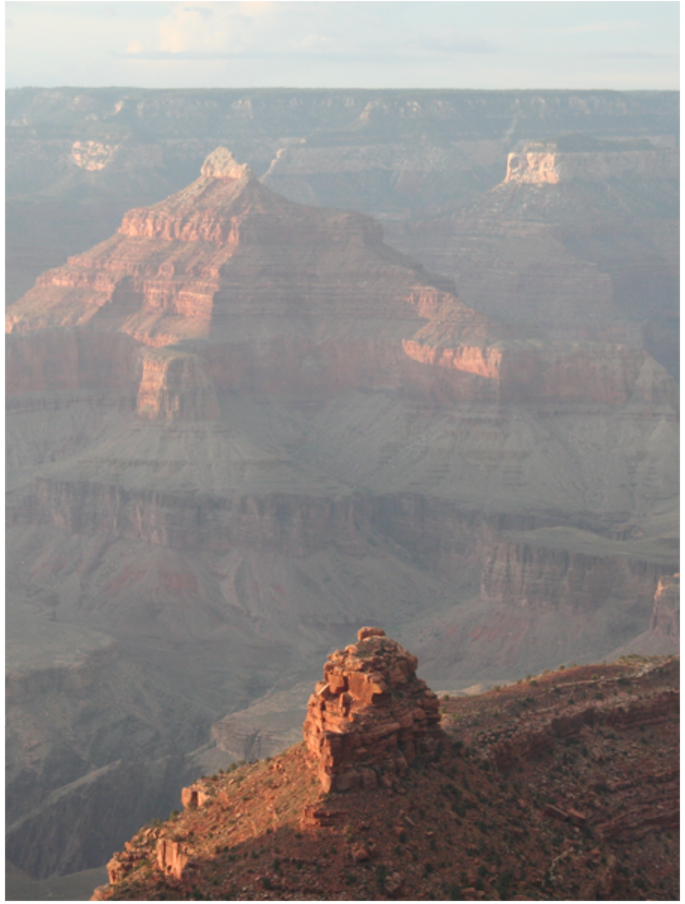
input hazy image $\boldsymbol{I}$



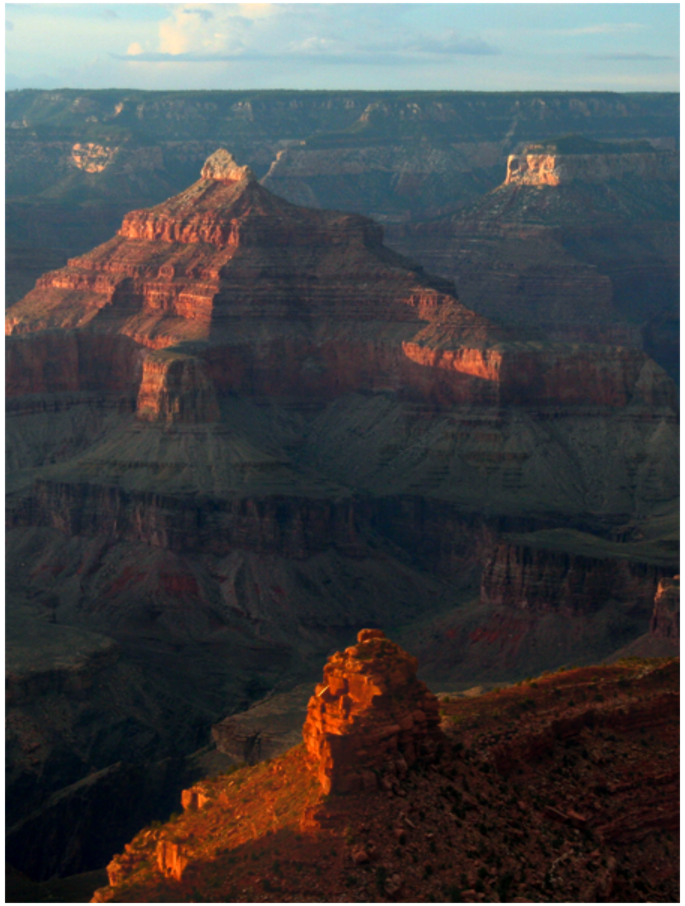
scene radiance $\boldsymbol{J}$

transmission map t

Results



input hazy image



result

transmission map

Results

input hazy image

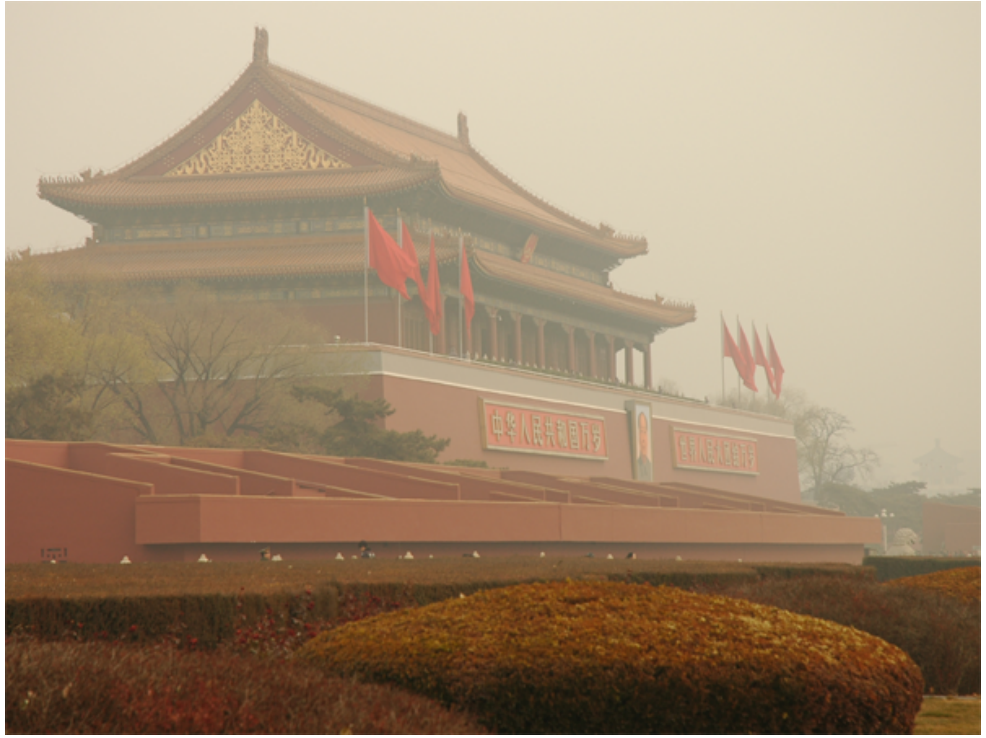
result

Results

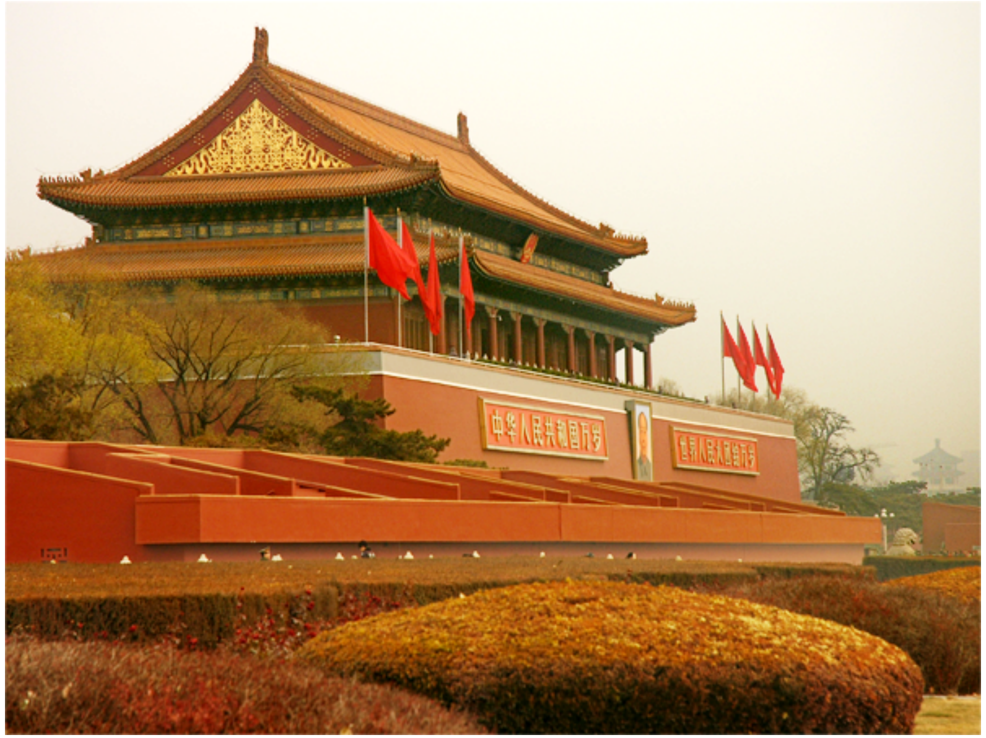
input hazy image

result

Results



input hazy image



result

Results

input hazy video

result video

Limitations

- Inherently white or grayish objects

input

result

Limitations

- non-constant atmospheric light

input

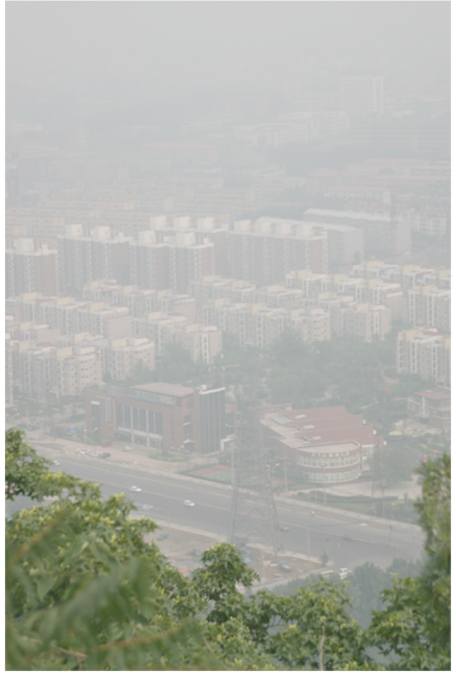
result

Summary

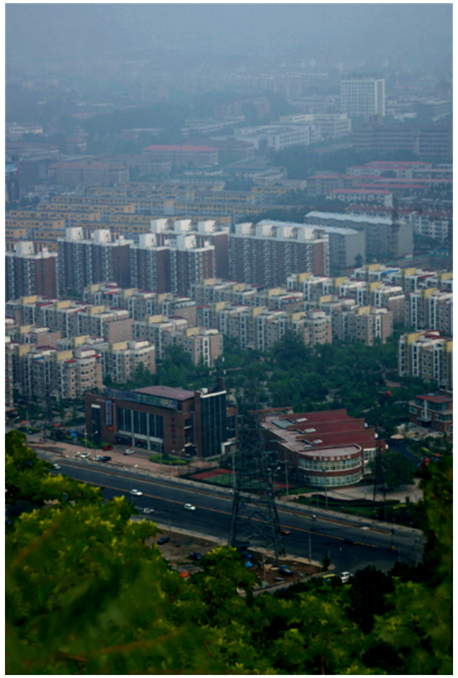
- Dark channel prior
  - ➢ simple but effective
  - ➢ make good use out of a bad image

Future Work

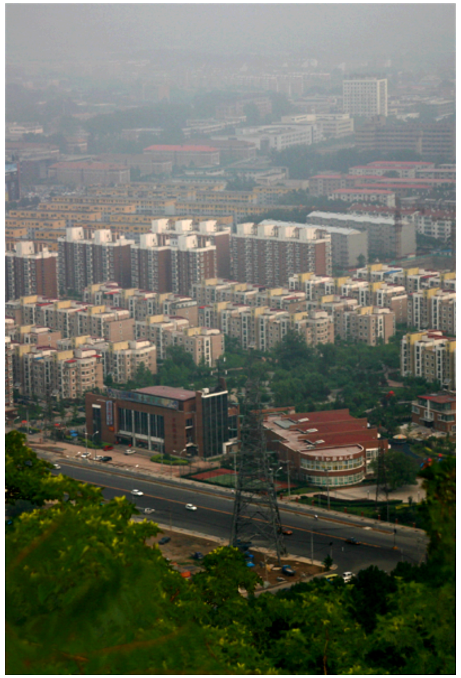
- more robust algorithm, e.g. dark prior patch size



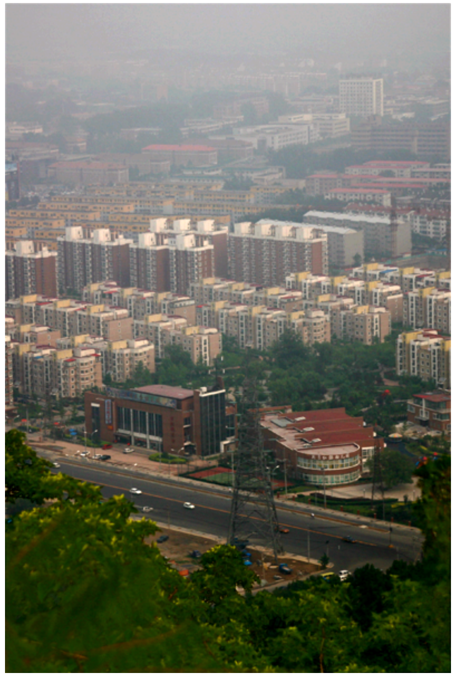
input hazy image



3×3 patches



15×15 patches

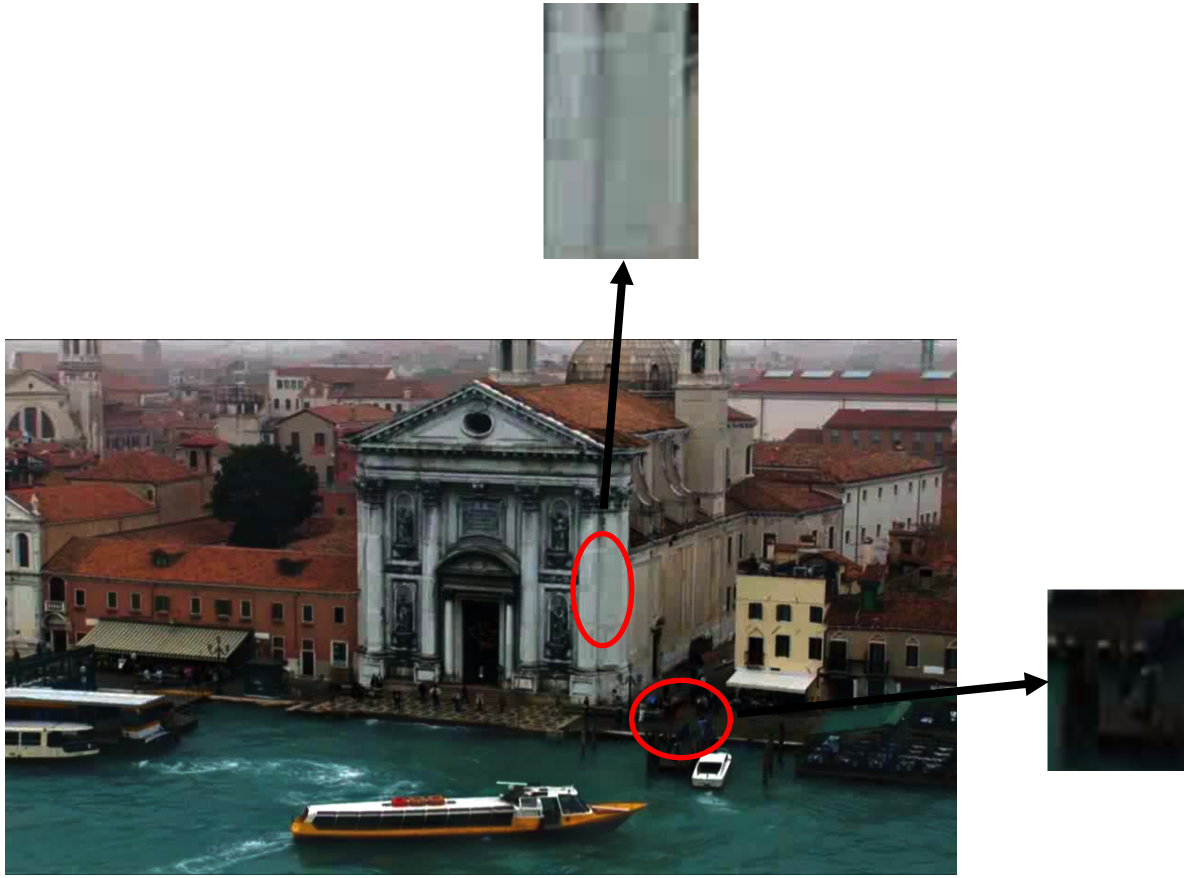


30×30 patches

Future Work

- suppress visual artifact

input



result

References

1. He, Kaiming and Sun, Jian and Tang, Xiaoou. Guided image filtering. CVPR, 2013.

2. He, Kaiming and Sun, Jian and Tang, Xiaoou. Single image haze removal using dark channel prior. CVPR, 2011.

Thank you