Non-Local Image Dehazing

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Single Image Dehazing

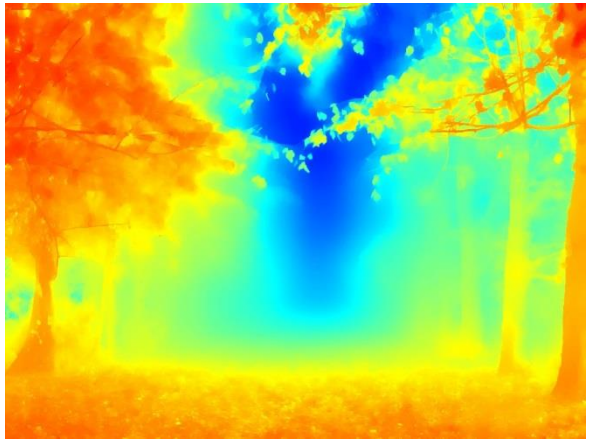
Input

$\boldsymbol{I}$

Output

Dehazed $\boldsymbol{J}$

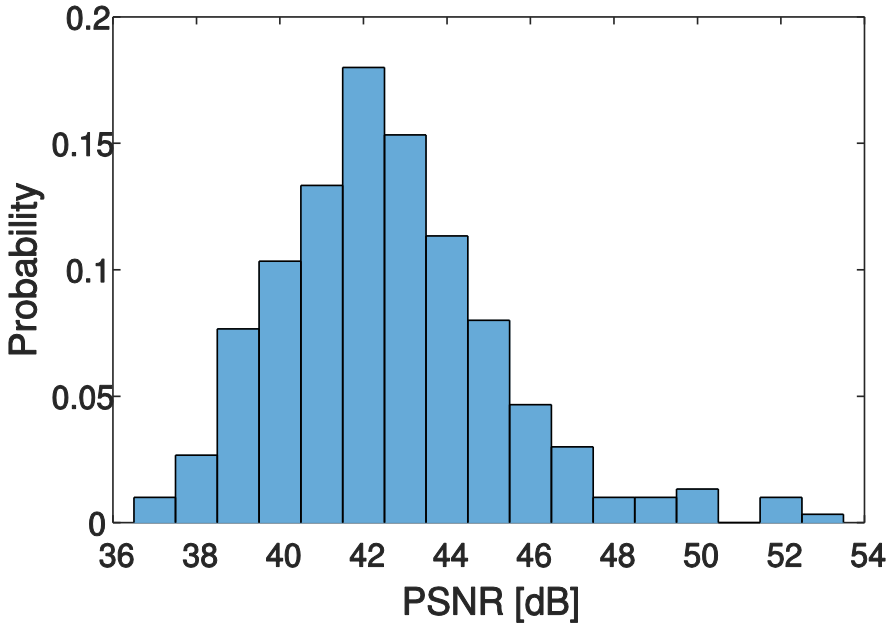
Transmission Map t



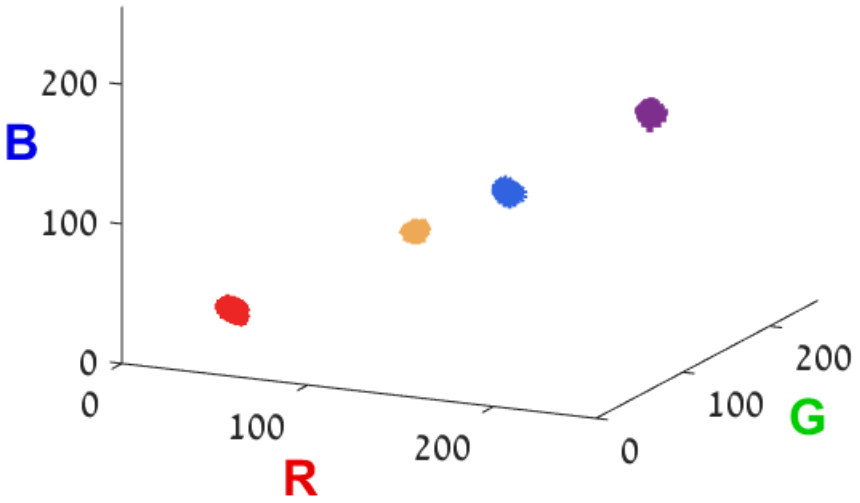
$$\boldsymbol{I}(\boldsymbol{x}) = t(\boldsymbol{x}) \cdot \boldsymbol{J}(\boldsymbol{x}) + [1 - t(\boldsymbol{x})] \cdot \boldsymbol{A}$$

Non-Local Prior: Small Color Palette

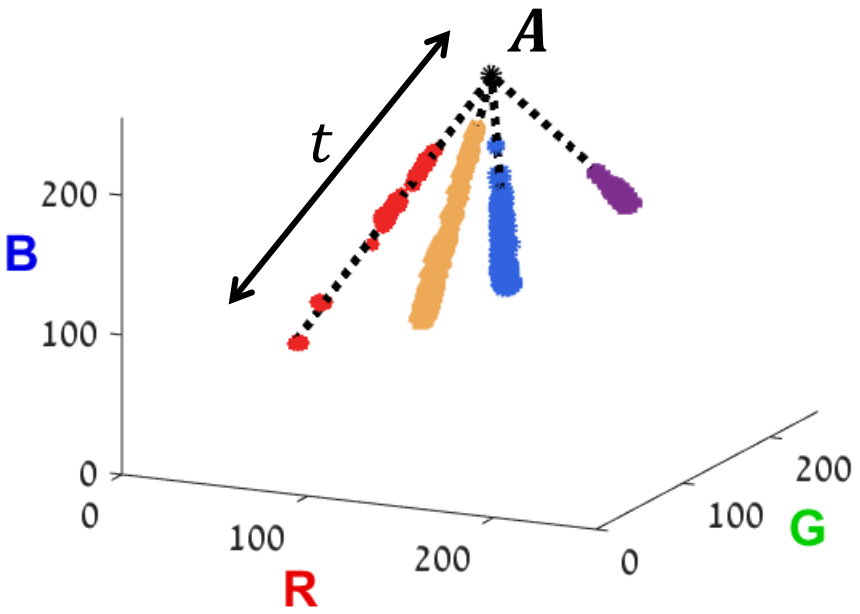
- Haze-free images can be well approximated by several hundred distinct colors
- Validation:
  - K-means clustering in RGB space (K=500)
  - Generate color-quantized images
  - Measure PSNR



Non-Local Prior



Non-Local Prior - Haze-Lines



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

Haze Lines

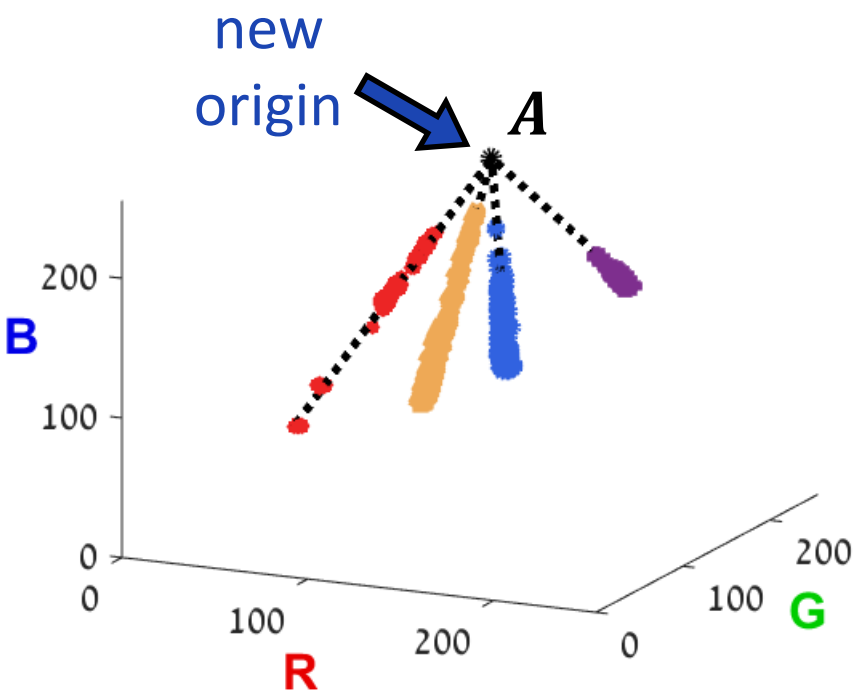
- Define airlight-centric coordinate system:

$$\boldsymbol{I}_{\boldsymbol{A}}(\boldsymbol{x}) \triangleq \boldsymbol{I}(\boldsymbol{x}) - \boldsymbol{A}$$

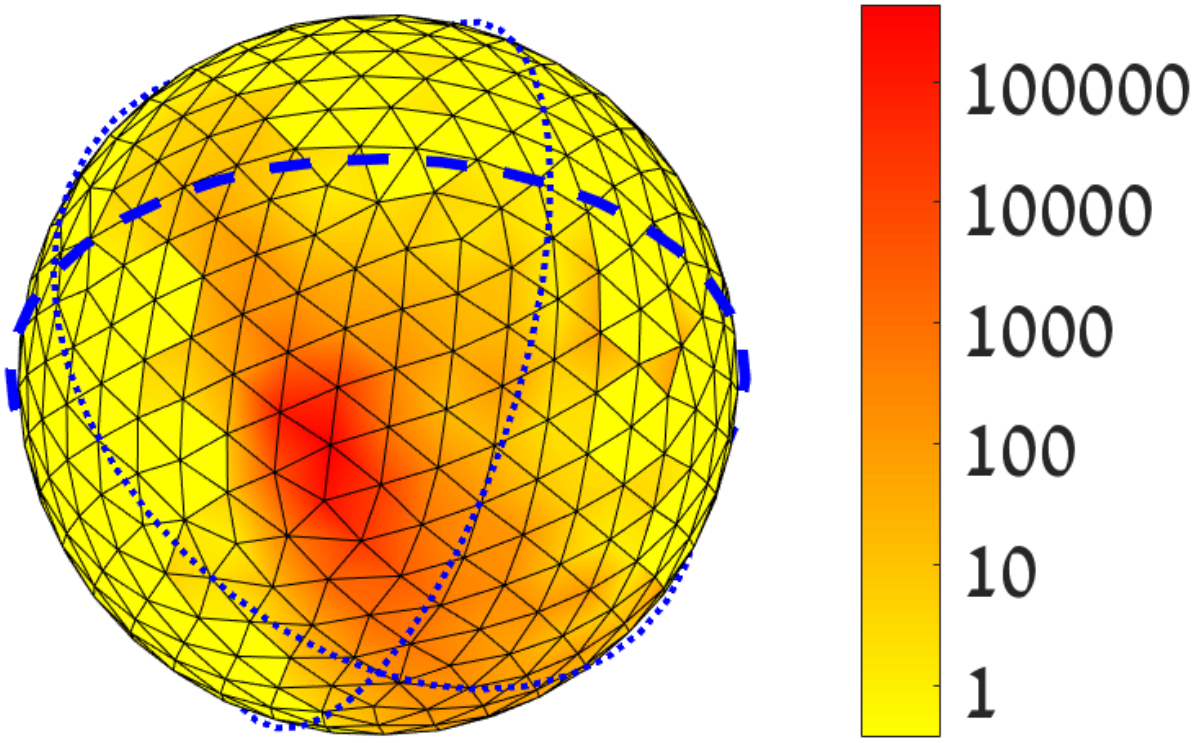
- Express $\boldsymbol{I}_{\boldsymbol{A}}(\boldsymbol{x})$ in spherical coordinates:

$$\boldsymbol{I}_{\boldsymbol{A}}(\boldsymbol{x}) = [r(\boldsymbol{x}), \theta(\boldsymbol{x}), \phi(\boldsymbol{x})]$$

- Bin pixels according to: $[\theta(\boldsymbol{x}), \phi(\boldsymbol{x})]$
- Each bin is a **haze-line**

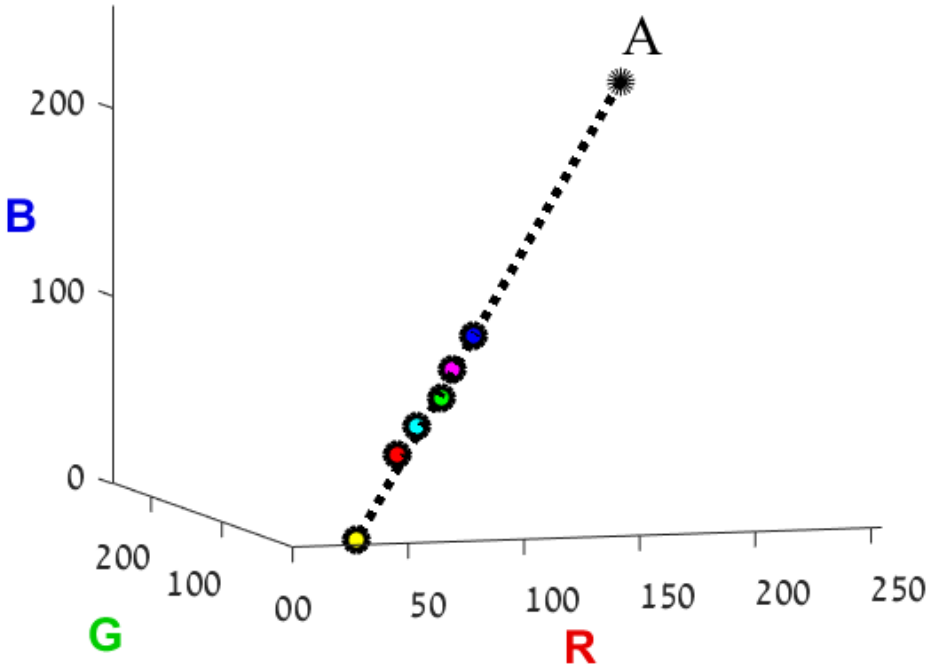


Haze-Lines



A histogram of angles projected onto a sphere

Haze-Lines



Transmission Estimation

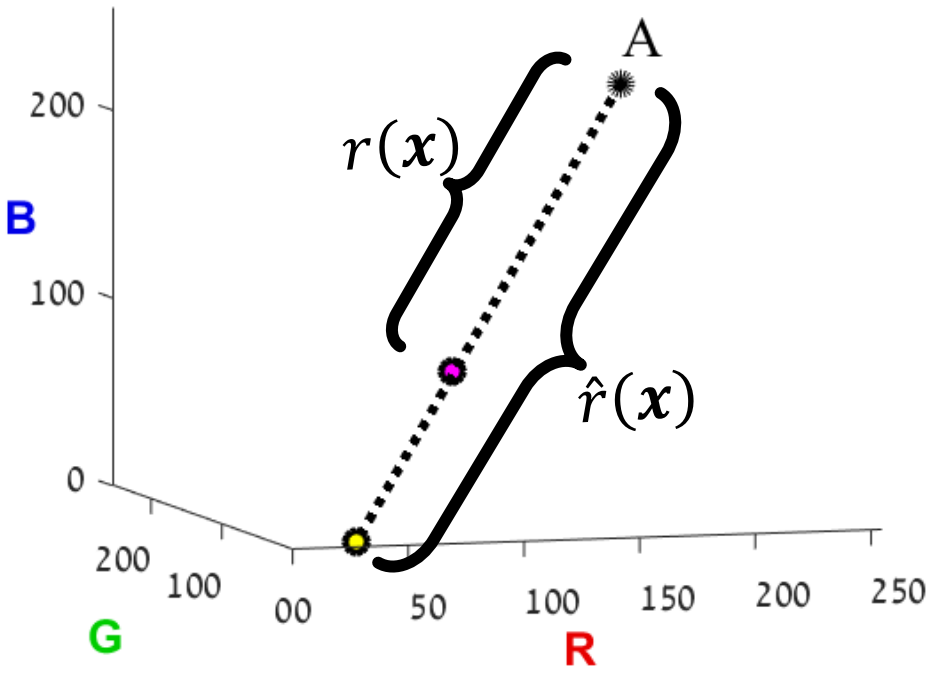
- $r(\boldsymbol{x}) = \| \boldsymbol{I}(\boldsymbol{x}) - \boldsymbol{A} \|$

  $= t(\boldsymbol{x}) \cdot \| \boldsymbol{J}(\boldsymbol{x}) - \boldsymbol{A} \|,$

  $0 \leq t(\boldsymbol{x}) \leq 1$

- $\hat{r}(\boldsymbol{x}) = \max_{\boldsymbol{x},\boldsymbol{y} \in H} \{r(\boldsymbol{y})\}$

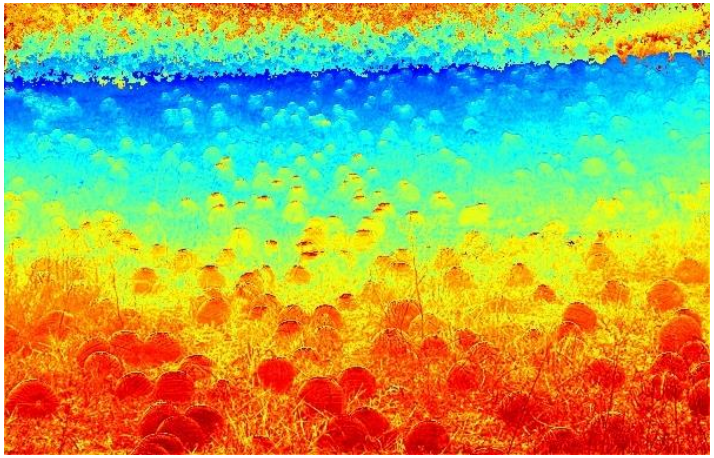
- $\tilde{t}(\boldsymbol{x}) = \frac{r(\boldsymbol{x})}{\hat{r}(\boldsymbol{x})}$



Transmission Estimation

Input Image

$\tilde{t}(\boldsymbol{x})$



Regularization

We seek $\hat{t}(\boldsymbol{x})$ which is the minimum of:

$$\sum_{\boldsymbol{x}} \frac{[\hat{t}(\boldsymbol{x}) - \tilde{t}(\boldsymbol{x})]^2}{\sigma^2(\boldsymbol{x})} + \lambda \sum_{\boldsymbol{x}} \sum_{\boldsymbol{y} \in N_{\boldsymbol{x}}} \frac{[\hat{t}(\boldsymbol{x}) - \hat{t}(\boldsymbol{y})]^2}{\| \boldsymbol{I}(\boldsymbol{x}) - \boldsymbol{I}(\boldsymbol{y}) \|^2}$$

$\boldsymbol{I}(\boldsymbol{x})$ - The hazy input image

$\tilde{t}(\boldsymbol{x})$ - Estimated per-pixel

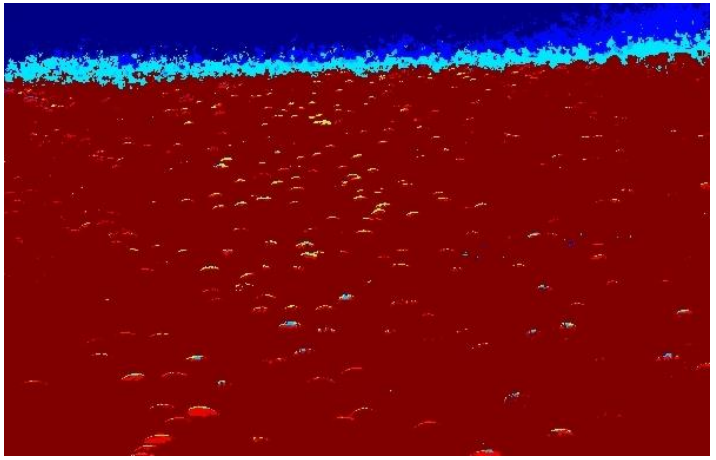
$\sigma(\boldsymbol{x})$ - Measure the certainty of $\tilde{t}(\boldsymbol{x})$

$N_{\boldsymbol{x}}$ - Four nearest neighbors of pixel $\boldsymbol{x}$

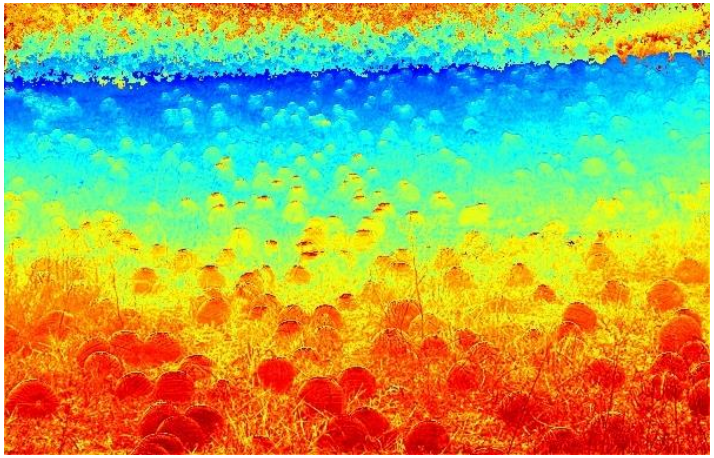
Regularization

Input Image

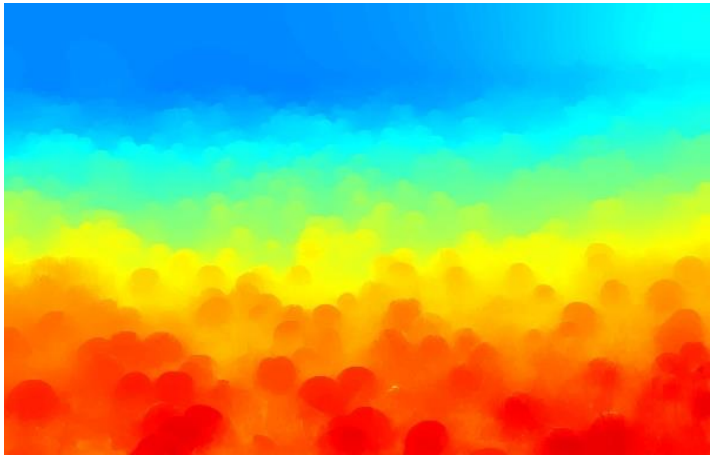
$1/\sigma^2(\boldsymbol{x})$



$\tilde{t}(\boldsymbol{x})$



$\hat{t}(\boldsymbol{x})$



Method Summary

- Calculate airlight
- Non-Local Image Dehazing:
  - Clustering the pixels into haze-lines, by binning
  - Transmission estimation
  - Regularization of the transmission
  - Dehazing

Related Work

- Additional Information
  - Polarization filter [Schechner et al., CVPR 2001]
  - Multiple images [Narasimhan & Nayar, TPAMI 2003]
  - Known 3D geometry [Kopf et al., SIGGRAPH Asia 2008]
- Single Image
  - Dark Channel Prior [He et al., CVPR 2009]
  - Color-Lines [Fattal, SIGGRAPH 2014]
  - Patch Recurrence [Bahat & Irani , ICCP 2016]
  - Haze-Lines [Berman et al. , CVPR 2016]

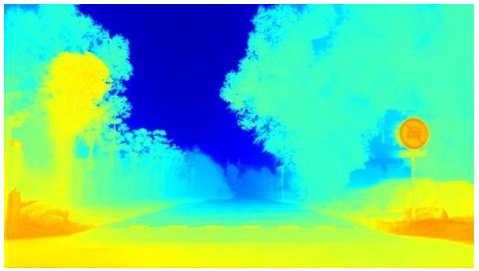
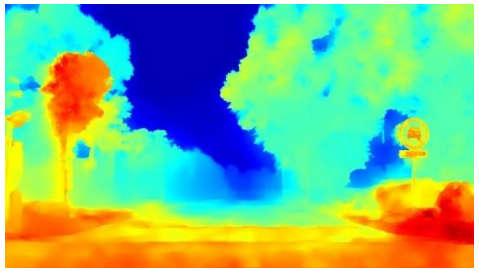
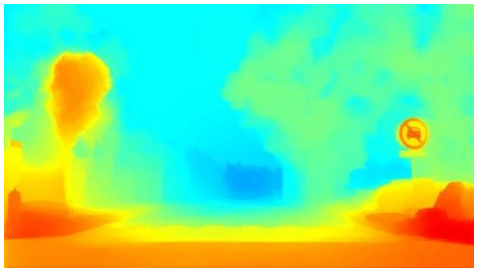
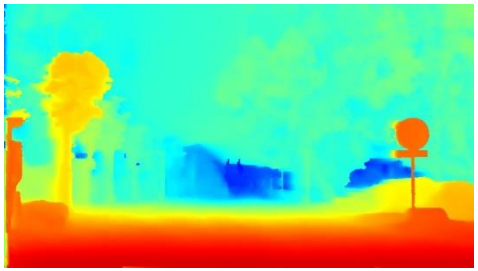
patch-based

pixel-based

Results

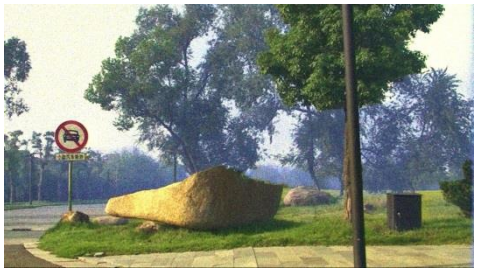
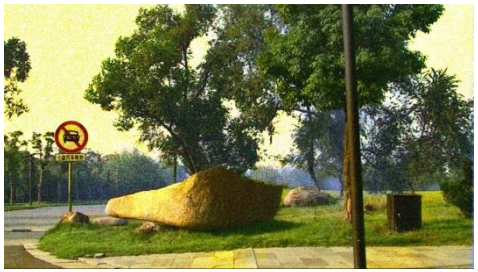
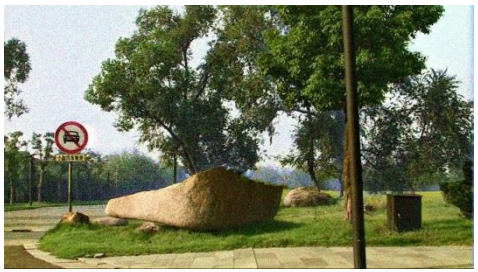
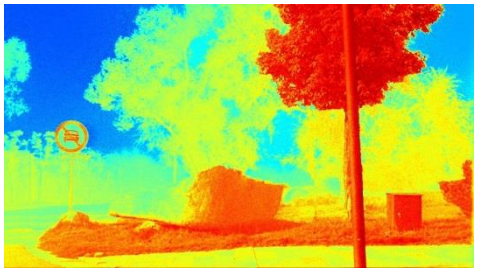
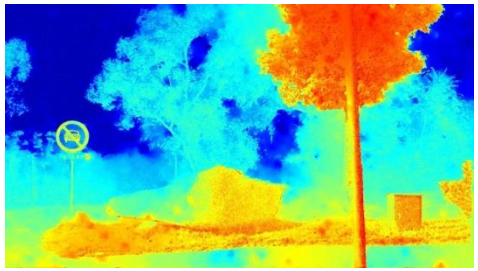
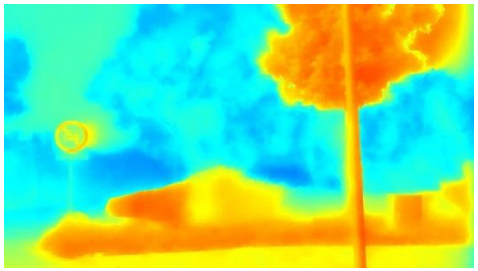
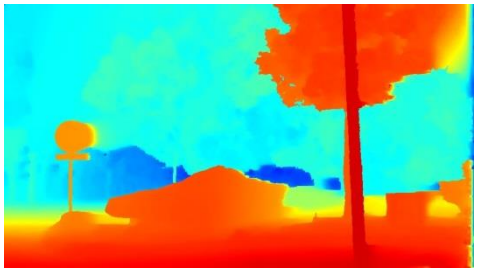
Results - Quantitative

Input

Dark Channel Prior	Color-Lines	Haze-Lines (ours)	Ground-truth
			
L1 = 0.06	0.04	0.04	
			
L1 = 0.09	0.06	0.06	

Results – with noise

Input, $\sigma = 0.05$

Dark Channel Prior	Color-Lines	Haze-Lines (ours)	Ground-truth
			
L1 = 0.11	0.11	0.10	
			
L1 = 0.14	0.12	0.09	

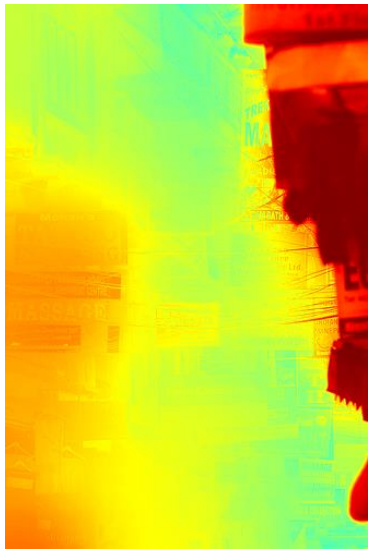
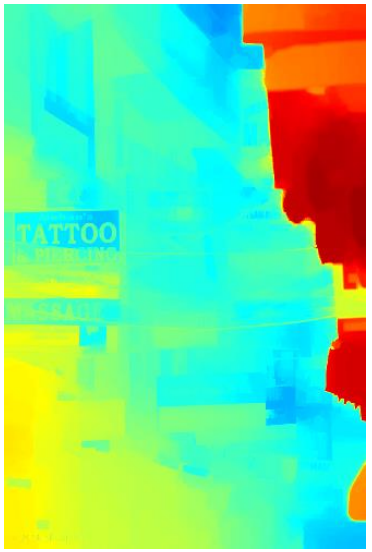
Results - Qualitative

Input	Dark Channel Prior	Color-Lines	Patch Recurrence	Haze-Lines (ours)

Results - Qualitative

Input	Dark Channel Prior	Color-Lines	Patch Recurrence	Haze-Lines (ours)

Results - Qualitative

Input	Dark Channel Prior	Color-Lines	Patch Recurrence	Haze-Lines (ours)
				

Results - Qualitative

Input

Dark Channel Prior

Color-Lines

Patch Recurrence

Haze-Lines (ours)

Results - Qualitative

Input

Input - Zoom

Dark Channel Prior

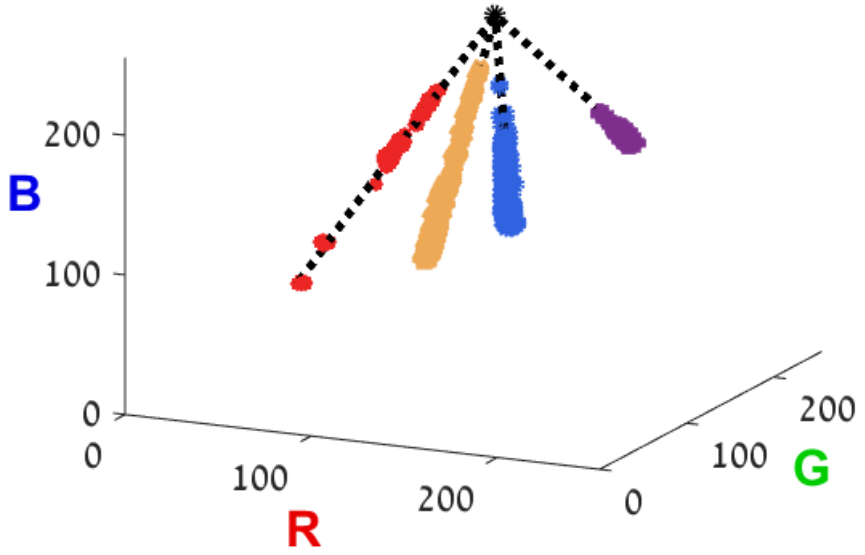
Color-Lines

Patch Recurrence

Haze-Lines (ours)

Summary

- Non-local method
- Pixel-based
- Deterministic
- Fast – *O(#pixels)*



More results are available on the website:

http://www.eng.tau.ac.il/~berman/NonLocalDehazing