Digital Image Processing - Project

Haze Removal using Dark Channel Prior

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Introduction

Outdoor scenes, in bad weather are usually degraded due to the presence of particles or droplets in the atmosphere. The amount of scattering depends on the distances of the scene points from the camera.

Single Image dehazing is non-trivial because it is highly constrained as the local transmission which depend on the scene depth has to be estimated. To solve this, we use Dark Channel Prior which gives us an effective method to estimate the local transmissions for hazy images.

THE IDEA...

The basic observation is that on haze-free outdoor images, most of the non-sky patches, at least one color channel has very low intensity at some pixels. The low intensities in the dark channel are mainly due to:

- Dark objects, shadows of trees and rocks.
- Colorful objects Ex- green, red, yellow, blue

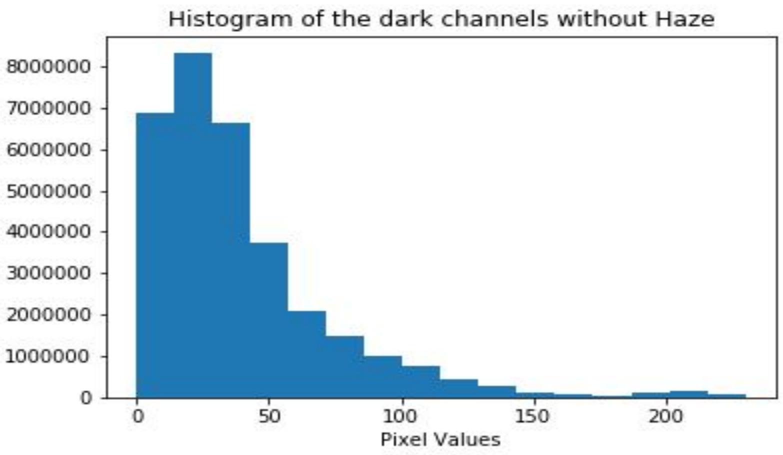
Since the natural outdoor images are usually colorful and full of shadows, it is reasonable to generalize the observation.

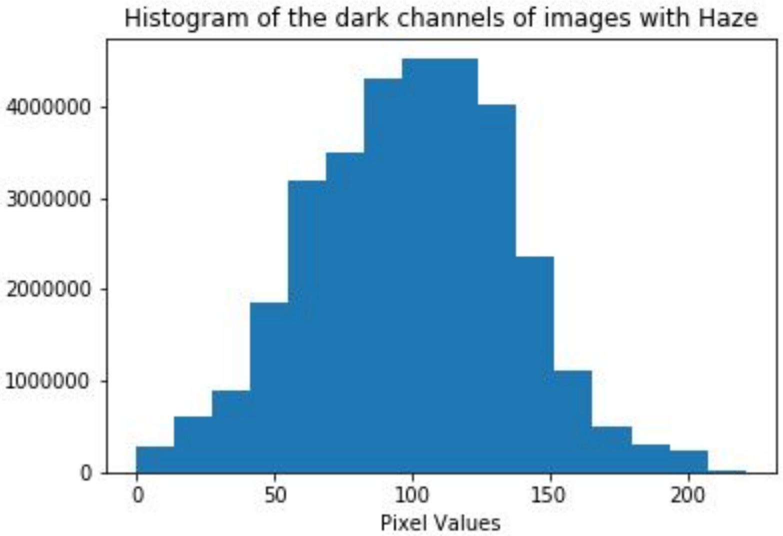
HISTOGRAM

We found the histogram for the dark channels on a collection of outdoor images with and without haze.

The values above 200 are due to the presence of sky in the image.

In contrast, the dark channel of the haze image will have higher intensity in regions with dense haze. Visually, the intensity of the dark channel is a rough approximation of the thickness of the haze.





Original Image

Dark Channel

Estimating Atmospheric Light

The dark channel of a haze image approximates the haze denseness. We can use it to estimate the atmospheric light.

We pick the top 0.1% brightest pixels in the dark channel. These pixels are the most haze opaque. Among these pixels the pixel with the highest intensity in the Image is selected as the atmospheric light.

This method is better than picking the brightest pixel. Since, in images, the brightest pixel could be on white objects.

Estimating the Transmission

Taking min operation in the local patch on the haze imaging equation

$$\min_{\mathbf{y}\in\Omega(\mathbf{x})}(I^c(\mathbf{y})) = \tilde{t}(\mathbf{x})\min_{\mathbf{y}\in\Omega(\mathbf{x})}(J^c(\mathbf{y})) + (1-\tilde{t}(\mathbf{x}))A^c$$

I is the observed intensity. J is the scene radiance. A is the atmospheric light. t is the transmission map describing the portion of the light that is not scattered and reaches the camera

$$\min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\frac{I^c(\mathbf{y})}{A^c}\right) = \tilde{t}(\mathbf{x})\min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\frac{J^c(\mathbf{y})}{A^c}\right) + (1-\tilde{t}(\mathbf{x}))$$

According to dark channel prior, the dark channel of the haze-free J tends to 0

$$J^{dark}(\mathbf{x}) = \min_c\left(\min_{\mathbf{y}\in\Omega(\mathbf{x})}(J^c(\mathbf{y}))\right) = 0$$

Estimating the Transmission

Substituting J to be 0, we get

$$\tilde{t}(\mathbf{x}) = 1 - \min_c\left(\min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\frac{I^c(\mathbf{y})}{A^c}\right)\right)$$

In general, the atmosphere has particles and there seems to be little haze when we look at far off objects. Presence of haze helps to perceive some depth. Hence, we can keep a small amount of haze for distant objects

$$\tilde{t}(\mathbf{x}) = 1 - \omega \min_c\left(\min_{\mathbf{y}\in\Omega(\mathbf{x})}\left(\frac{I^c(\mathbf{y})}{A^c}\right)\right)$$

ω ($0<\omega<1$) is a parameter. It is kept to 0.85

Dark Channel

Estimated Transmission Map

Guided Filter

There are some block effects since the transmission is not always constant in a patch. We refine the transmission map using guided filter. Guided filter is a type of edge-preserving smoothing operator, which filters the input image (Estimated transmission map) under the guidance of another image(Original image).

The filtered output q, as a function of the input image p and guidance image I is calculated as:

$$a_k = \frac{\frac{1}{|w|}\sum_{i \in w_k} I_i p_i - \mu_k \bar{p}_k}{\sigma_k^2 + \epsilon} \quad \text{and} \quad b_k = \bar{p}_k - a_k \mu_k,$$

in which σ_k^2 and μ_k are the variance and mean of I in w_k, with $\bar{p}_k = \frac{1}{|w|}\sum_{i \in w_k} p_i$, and $|w|$ is the number of pixels in w_k. The final filtering output is given by:

$$q_i = \frac{1}{|w|}\sum_{k: i \in w_k}(a_k I_i + b_k) = \bar{a}_i I_i + \bar{b}_i,$$

Transmission Map before

Transmission Map after guided filter

Depth Map

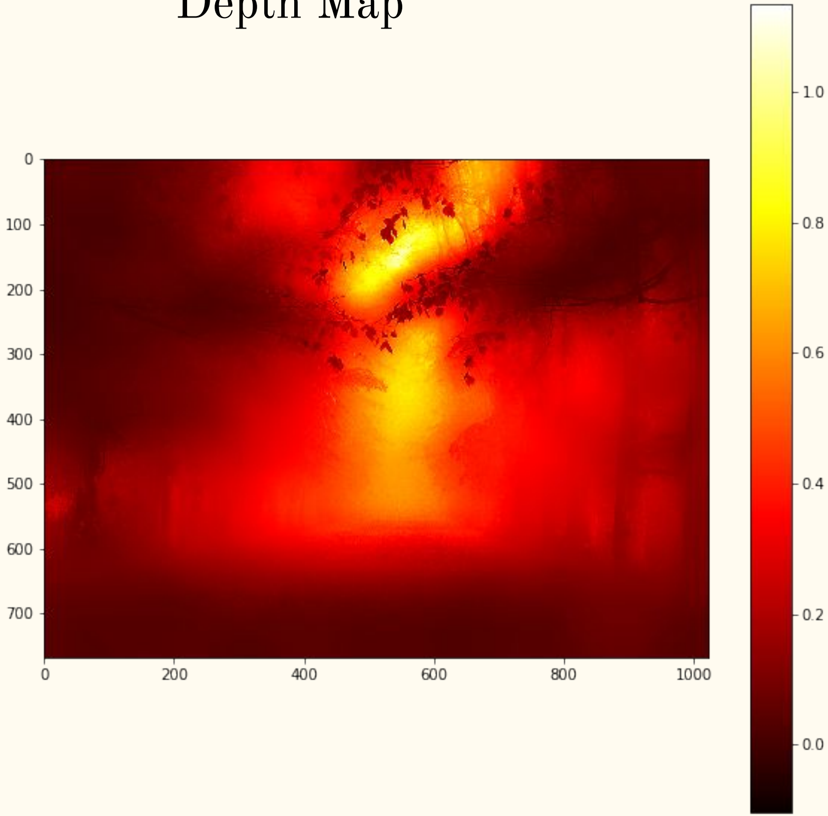
Using the transmission map, a depth map can also be constructed for the scene. When the atmosphere is homogenous, the transmission t can be expressed as:

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

where β is the scattering coefficient of the atmosphere. This equation indicates that the scene radiance is attenuated exponentially with the scene depth d

Transmission Map

Depth Map



Recovering the Scene Radiance

We use the haze equation model to recover the image scene. Since J(x)t(x) can be very close to 0 when the transmission t(x) is close to 0. We restrict the transmission t(x) to a lower bound t_0 to preserve some small amount of haze in very dense haze regions.

t_o is taken to be 0.1.

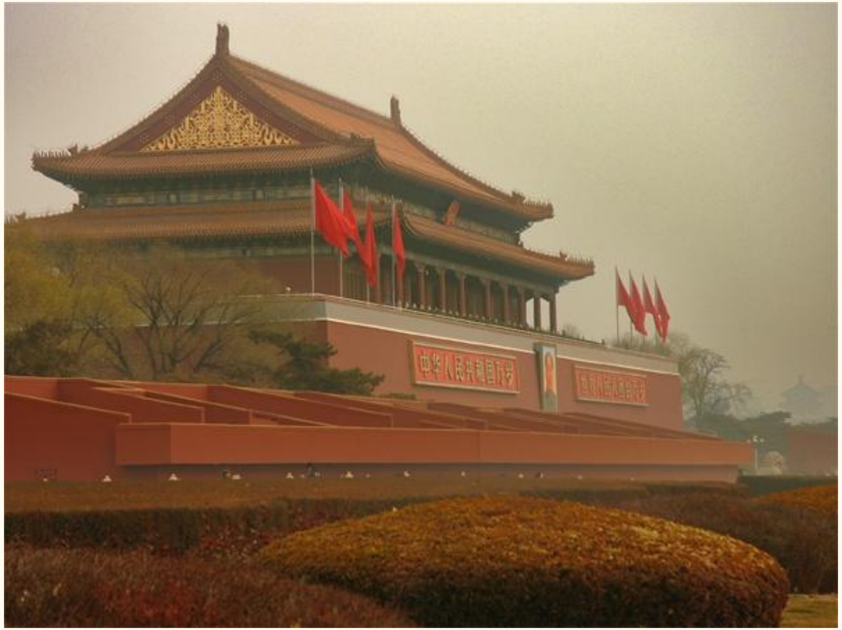
$$\mathbf{J}(\mathbf{x}) = \frac{\mathbf{I}(\mathbf{x}) - \mathbf{A}}{\max(t(\mathbf{x}), t_0)} + \mathbf{A}$$

Image before Dehazing

Image after Dehazing

Input

Output



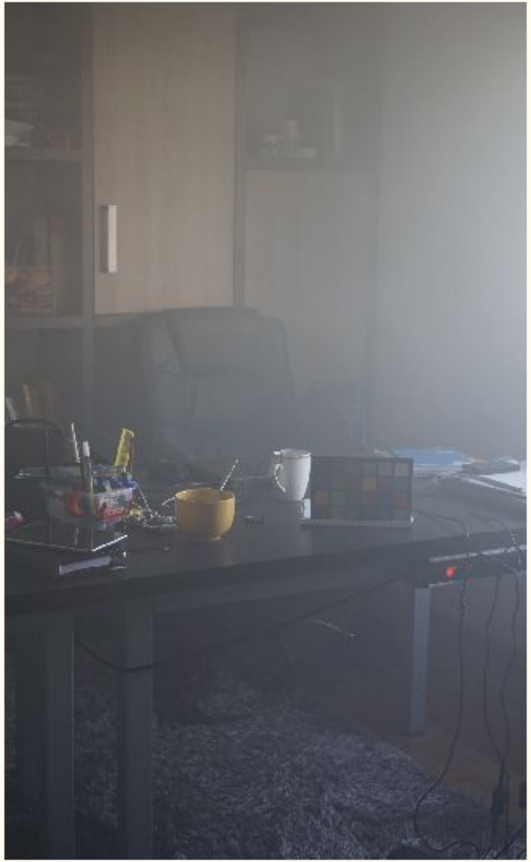
Input

Output

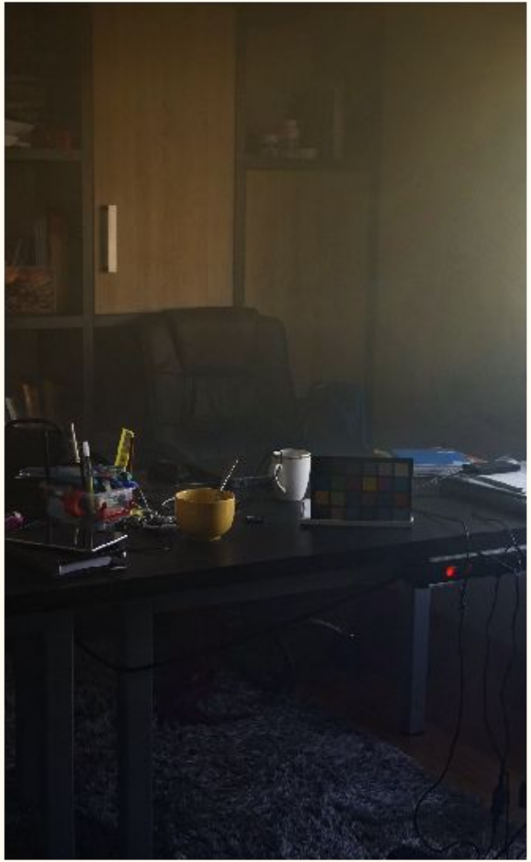
Input

Output

Input



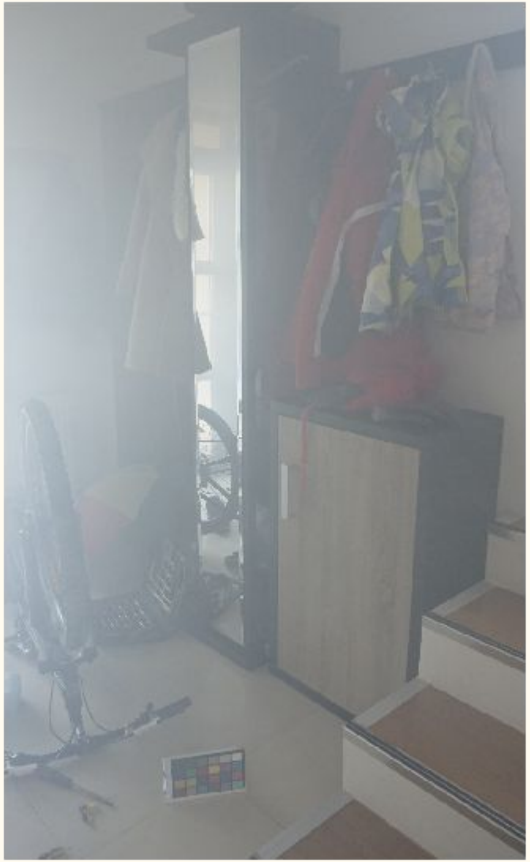
Output



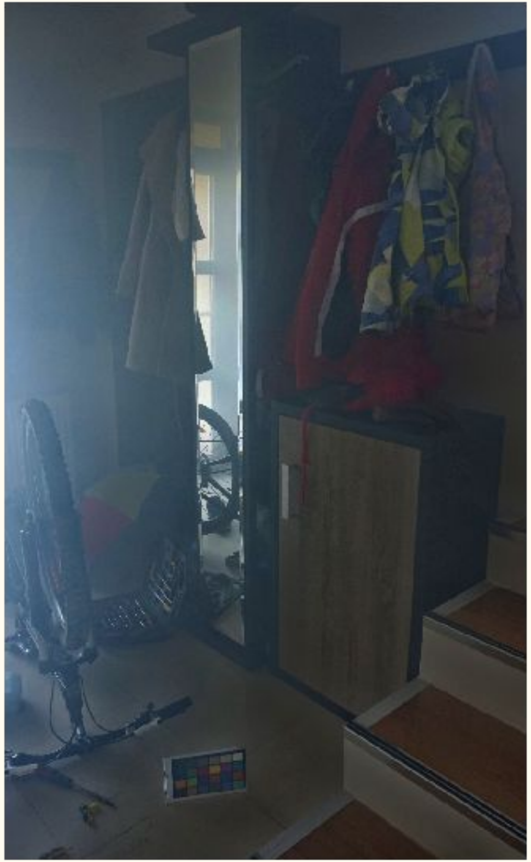
Failure Cases

When the scene contains light color patches like reflections, the airlight estimation becomes very poor. This happens most commonly in indoor images where there can be lights and reflections. Because of this, the result suffers from color shift in the hazy regions.

Input



Output



Ground Truth

Milestones Left

1. Compare with other methods (Fusion based, Enhancement based)
2. Explore applications like remote sensing images and night-time haze removal.

References

[1] K. He, J. Sun, and X. Tang, “Single image haze removal using dark channel prior”

[2] J. Pang, O. C. Au and Z. Guo, “Improved Single Image Dehazing Using Guided Filter”

[3] C. O. Ancuti, C. Ancuti, R. Timofte and C. D. Vleeschouwer, “O-HAZE: a dehazing benchmark with real hazy and haze-free outdoor images”

[4] C. O. Ancuti, C. Ancuti, R. Timofte and C. D. Vleeschouwer, “I-HAZE: a dehazing benchmark with real hazy and haze-free indoor images”