Project Report : Single Image Haze Removal

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1 Introduction

Images of outdoor scenes are usually degraded by the turbid medium (e.g., particles, water-droplets) in the atmosphere. Haze, fog, and smoke are such phenomena due to atmospheric absorption and scattering. Haze removal1 (or dehazing) is highly desired in both consumer/computational photography and computer vision applications.

In this project, we experimentally examined approach proposed in [1], which could remove haze using single image.

2 Aproach

2.1 Haze model

The model widely used in describing the formation of haze image is as follows:

$$I(x) = J(x)t(x) + A(1 - t(x))$$

where x is a pixel, I is the observed intensity, J is the scene radiance, A is the global atmospheric light, t is the medium transmission describing the portion of the light that is not scattered and reaches the camera. The goal of haze removal is to recover J, A, and t from I.

2.2 Dark Channel Prior

Observation shows that, in foggy area of the image, the minimum RGB values of a pixel is higher than that in clear area. An intuition is that, foggy image tends to be whitish.

According to this, we can give an initial estimation of J:

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

where J^c is a color channel of J and $\Omega(x)$ is a local patch centered at x. In [1], it is called dark channel prior. A typical size of the patch is 15x15, and ω is arount 0.95.

As observation shows, nice property of J^{dark} is that, for a haze free image J, $J^{dark} \to 0$.

2.3 Estimate the Atmospheric Light

We pick the top 0.1% brightest pixels in dark channel, and pick the highest intensity in input image I as atmospheric light.

2.4 Estimate the Transmission

First assume that the atmospheric light A is known, By further assuming the transmission in a local patch $\Omega(x)$ is constant, the property of J^{dark}, after crunching equations, we get:

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

where $\widetilde{t}(x)$ is the estimation of true transmission $t(x)$. But even in clear days, atmosphere is not absolutely free of any particle, the haze effect may still slightly appears. The catch this observation, an constant parameter $\omega(0 < \omega <= 1)$. The equation above then becomes:

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

2.5 Transmission Refinement

In the original paper, the transmission is then refined using soft matting introduced in [2]. Rewriting $t(x)$ and $\widetilde{t}(x)$ in their vector form as t and $\widetilde{t}$, we minimize the following cost function:

$$E(t) = t^T Lt + \lambda(t - \bar{t})^T(t - \bar{t})$$

where L is the Matting Laplacian matrix proposed by [2], and λ is a regularization parameter.

The (i,j) element of the matrix L is defined as:

$$\sum_{k|(i,j)\in w_k}(\delta_{ij} - \frac{1}{|w_k|}(1 + (I_i - \mu_k)^T(\Sigma_k + \frac{\epsilon}{|w_k|}U_3)^{-1}(I_j - \mu_k)))$$

where I_i and I_j are the colors of the input image I at pixels i and j, δ_{ij} is the Kronecker delta, μ_k and Σ_k are the mean and covariance matrix of the colors in window ω_k, U_3 is a 33 identity matrix, ϵ is a regularizing parameter, and $|w_k|$ is the number of pixels in the window ω_k.

The optimal t can be obtained by solving the following sparse linear system:

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

where U is an identity matrix of the same size as L. Here, we set a small value on λ (10^{-4} in our experiments) so that t is softly constrained by $\widetilde{t}$.

2.6 Recover the Scene Radience

From equation aforementioned, it is direct that we can recover $J(x)$ by

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

where t_0 is the minimum transmission threshold, typically around 0.1.

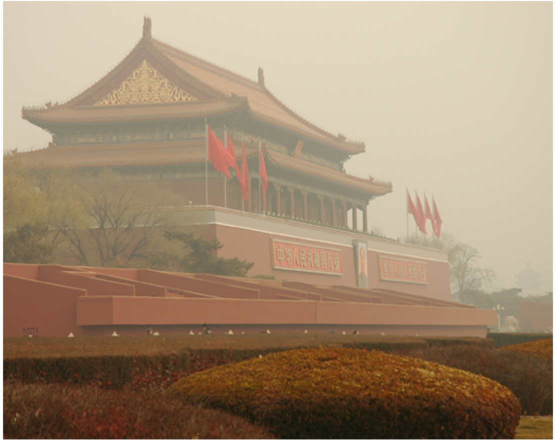
3 Result

See figures below.

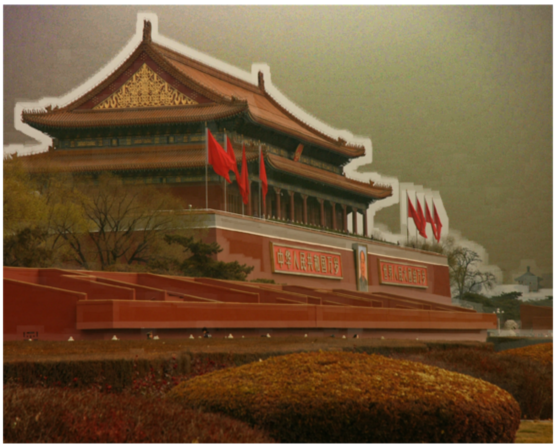
Reference

[1] Kaiming He, Jian Sun, and Xiaoou Tang. Single image haze removal using dark channel prior. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2009.

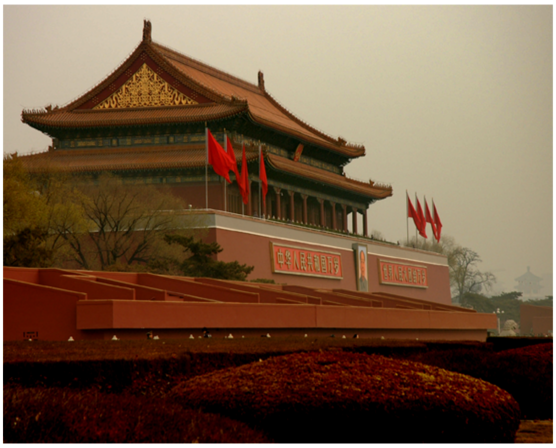
[2] Anat Levin, Dani Lischinski, and Yair Weiss. A closed form solution to natural image matting. In *Proceedings of the IEEE Conference on Computer Vision and Pattern Recognition (CVPR)*, 2004.



(a) input



(b) before soft matting



(c) output

Figure 1: Tiananmen

(a) input

(b) before soft matting

(c) output

Figure 5: Train