Report

Name: Wang Heng Student No. :2019E8018461005

1. Dark Channel Prior

The dark channel prior is based on the following observation on haze-free outdoor images: in most of the non-sky patches, at least one color channel has very low intensity at some pixels. In other words, the minimum intensity in such a patch should has a very low value. Formally, for an image J, we define :

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

where J_c is a color channel of J and $\Omega(x)$ is a local patch centered at x. Our observation says that except for the sky region, the intensity of J_{dark} is low and tends to be zero, if J is a haze-free outdoor image. We call J_{dark} the dark channel of J, and we call the above statistical observation or knowledge the dark channel prior.

According to the paper, we can know :

$$J^{\text{dark}} \rightarrow 0.$$

2. Haze Removal Using Dark Channel Prior

2.1 Haze image

In computer vision and computer graphics, the model widely used to describe the formation of a haze image is as follows :

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

where I is the observed intensity, J is the scene radiance, A is the global atmospheric light, and 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 Estimating the Transmission

Assume we already know A, we can change the formation as follow :

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

Then, we take the min operation among three color channels on the above equation and obtain:

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

According to the dark channel prior, the dark channel J_{dark} of the haze-free radiance J should tend to be zero:

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

So we can get :

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

2.3 Recovering the Scene Radiance

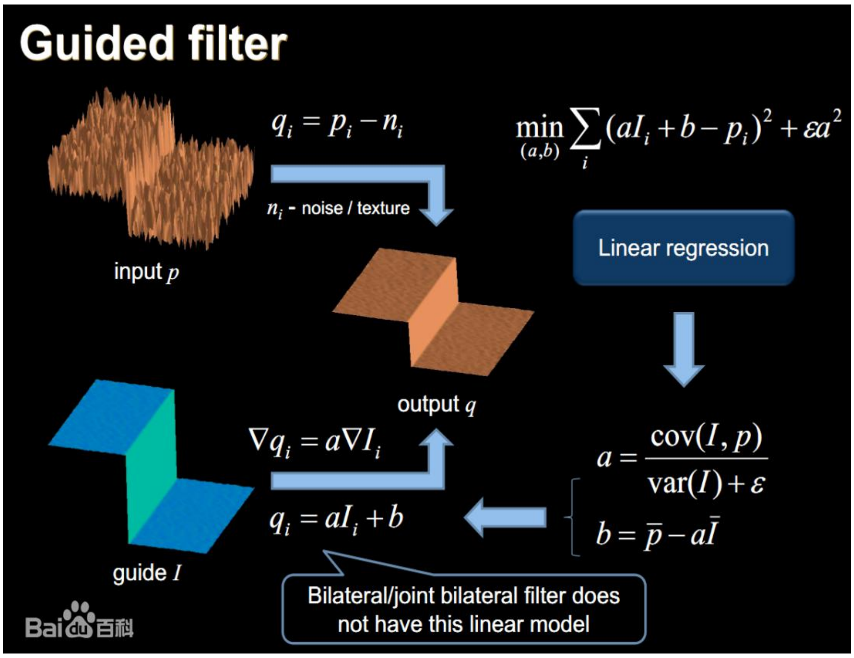
The final scene radiance $J(x)$ is recovered by :

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

2.4 Estimating the Atmospheric Light

We first pick the top 0.1% brightest pixels in the dark channel. These pixels are most haze opaque. Among these pixels, the pixels with highest intensity in the input image I is selected as the atmospheric light.

2.5 Guided Image Filtering



A general linear translation-variant filtering process, which in volves a guidance image I, an input image p, and an output image q. Both I and p are given beforehand according to the application. The filtering output at a pixel i is expressed as a weighted average:

$$q_i = \sum_j W_{ij}(I) p_j.$$

According to the paper, the kernel weights can be explicitly expressed by :

$$W_{ij}(I) = \frac{1}{|\omega|^2} \sum_{k:(i,j)\in\omega_k} \left(1 + \frac{(I_i - \mu_k)(I_j - \mu_k)}{\sigma_k^2 + \epsilon}\right)$$

From the figure, the key assumption of the guided filter is a local linear model between the guidance I and the filter output q. q is a linear transform of I in a window ω_k centered at the pixel k:

$$q_i = a_k I_i + b_k, \forall i \in \omega_k$$

where (a_k, b_k) are some linear coefficients assumed to be constant in ω_k. q has an edge only if I has an edge, because $\nabla q = a \nabla I$. Then we minimizes the difference between q and the filter input p. Specifically, we minimize the following cost function in the window:

$$E(a_k, b_k) = \sum_{i\in\omega_k} ((a_k I_i + b_k - p_i)^2 + \epsilon a_k^2)$$

The solution given by linear regression :

$$a_k = \frac{\frac{1}{|\omega|}\sum_{i\in\omega_k} I_i p_i - \mu_k \bar{p}_k}{\sigma_k^2 + \epsilon}$$
$$b_k = \bar{p}_k - a_k \mu_k.$$

Here, μ_k and $\sigma^2{}_k$ are the mean and variance of I in ω_k, $|\omega|$ is the number of pixels in ω_k, and $\bar{p}_k = \frac{1}{|\omega|}\sum_{i\in\omega_k} p_i$ is the mean of p in ω_k, in the paper, esp should be 0.001 or smaller.

We compute the filter output by :

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

3. Result&Analysis

3.1 Size of Dark Channel Windows:

Frame= 7

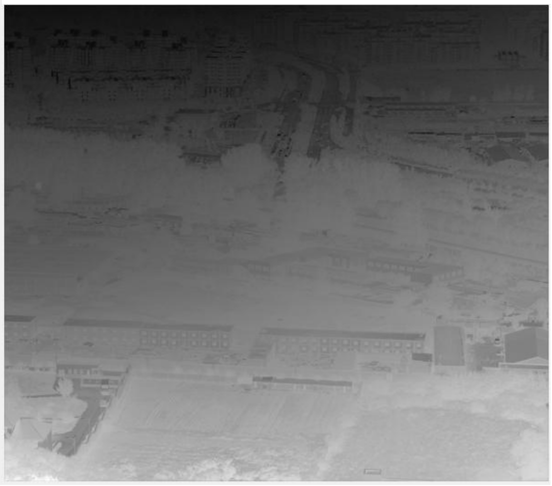
Frame=15

Frame=25

Frame=40

The frame of windows influence the results of dark channel. The more large the window is, the more blurry the image is. However it also need more time to compute. So, when we need more details, we should use small windows to process. If we wanted to compute faster, we need to choose large window.

3.2 Compare t with t_d

Output t Output t_d

Output t is computed directly by dark channel and airlight. Output t_d is computed by guide filtering. It's obvious that the output t_d is much better than output t. Output t_d's edge is more clear, the guide filter eliminate noise to make the edge clear.

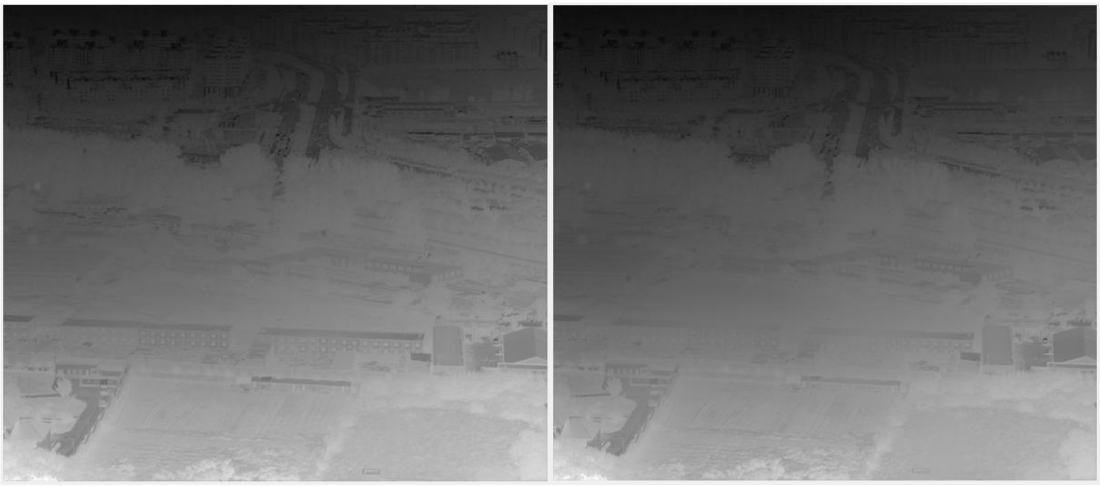
3.3 Compare Dark Channel with Dark Channel after Guide Filtering t

Dark Channel (both frame=15) Recover dark channel after guide filtering t

The dark channel result is much better after guide filtering t. I recover the new dark channel by guide filtering t. Guide filter recover input image and eliminate noise to make the dark channel more clear.

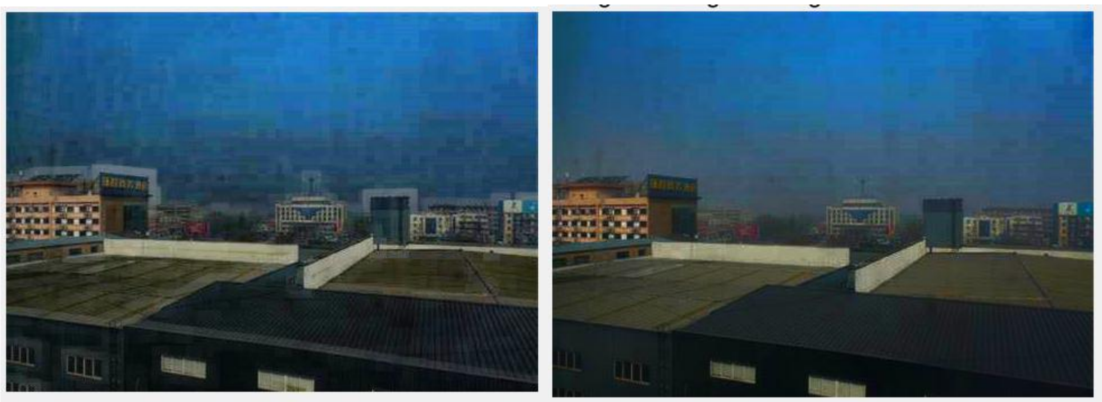
3.4 Guide Filter's Radius of Windows



r=60 r=40

When radius is 60, the output t_d has more detail than when radius is 40. Because when make guide filter, we need to do regression. When we choose a larger place, the “line” could classify more pixels, and make the noise small.

3.5 Final output



Output by using origin t Output by using t_d

Output by using t, the scene of buildings have more blurry edge, the details of output by using t_d are more clear than using t. When using guide filter, the t_d is linear with I, so when output J is that I divided by t_d. It is the input image that caused output.

3.6 Airlight

Airlight= Max(dark channel)=160

fix figure Airlight=170

Output by using max dark channel, the sky of picture are brighter than using fix figure airlight. But the sky is not smoothness. It is (I-A)/t and t<1, when I>A the output will be much large and the picture will be more bright, but if I near A, the output would not be much large, the picture will be normal. The reason why sky so different might be the original picture I.