Single Image Dehazing with Varying Atmospheric Light Intensity

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Clear image

Beijing smog comparison August 2005 By Bobak, Wikimedia Commons, License CC-BY-SA 2.5

`https://commons.wikimedia.org/wiki/File:Beijing_smog_comparison_August_2005.png`

Effect of fog

Beijing smog comparison August 2005 By Bobak, Wikimedia Commons, License CC-BY-SA 2.5

`https://commons.wikimedia.org/wiki/File:Beijing_smog_comparison_August_2005.png`

Question

Can we “restore” the images by removing the atmospheric degradation ?

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Yes. But only to some extent.

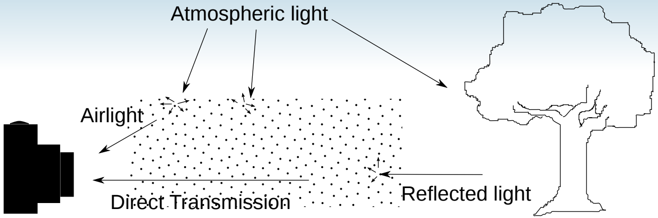
Goal

Given a hazy image we want to recover a its haze-free version.

(a) Hazy Image (b) Dehazed

Hazey image source: `http://research.microsoft.com/en-us/um/people/kahe/cvpr09/flag/flag.jpg`

Imaging model



In haze/fog the image formation equation is given by

$$I(\mathbf{x}) = \underbrace{J(\mathbf{x})t(\mathbf{x})}_{\text{Direct transmission}} + \underbrace{(1 - t(\mathbf{x}))A}_{\text{Airlight}}; \ \mathbf{x} = (x, y)$$

Where, $I(\mathbf{x})$ is the observed intensity.
$J(\mathbf{x})$ is the intensity of the reflected light before scattering.
$t(\mathbf{x})$ is scene transmission. It takes value between 0 and 1.
A is the atmospheric light.

Atmospheric light

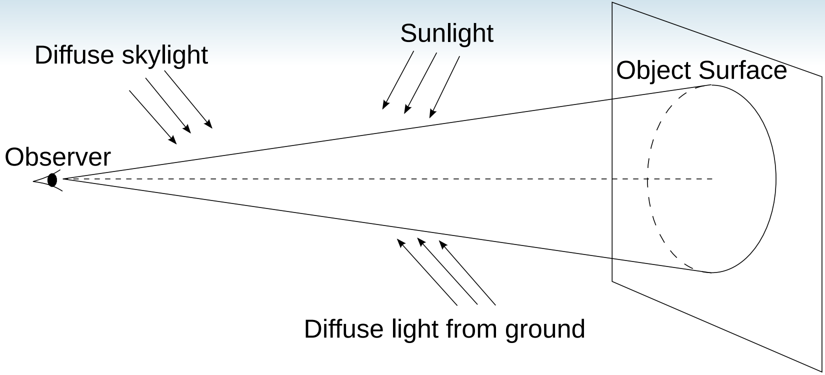


Figure: Contributors of airlight

Constant atmospheric light assumes the contribution of these lights is same in the whole image.

Atmospheric light

Figure: Atmospheric light is not constant

Relaxed Imaging Model

The imaging equation

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

is changed to

$$I(\mathbf{x}) = J(\mathbf{x})t(\mathbf{x}) + (1 - t(\mathbf{x}))m(\mathbf{x})\hat{A} \quad (2)$$

Where, $\hat{A}$ is atmospheric light vector direction(unit vector).
$m(\mathbf{x})$ is the magnitude of the atmospheric light at position $\mathbf{x}$.

We try to get $J(\mathbf{x})$ out of this relaxed equation.

Proposed method

Our proposed method can be broadly divided into these four steps.

1. Estimation of airlight direction ($\hat{A}$)
2. Estimation of magnitude of airlight component ($a(\mathbf{x}) = (1 - t(\mathbf{x}))m(\mathbf{x})$) at each patch
3. Interpolation of estimate for the patches without estimate
4. Haze free image recovery

Note that, our method builds upon the color line based dehazing by Fattal[1].

[1] R. Fattal, "Dehazing Using Color-Lines", ACM Trans. Graph., vol. 34, no. 1, pp. 13:1-13:14, Dec. 2014.

Color line prior

Considering colors as points in the RGB space, colors in a small patch of a natural image should lie on a line passing through the origin. But due to noise and camera related distortions they form elongated color clusters.[2] This holds if we consider within a patch

$$I(\mathbf{x}) = l(\mathbf{x})R \tag{3}$$

where, $l(\mathbf{x})$ is surface shading and R is surface reflectance. This won't hold if the patch contains an edge as R won't remain constant.

In case of haze images this line gets shifted by the airlight component $((1 - t(\mathbf{x}))m(\mathbf{x})\hat{A})$.

[2] I. Omer and M. Werman, "Color lines: Image specific color representation", CVPR 2004.

Color line

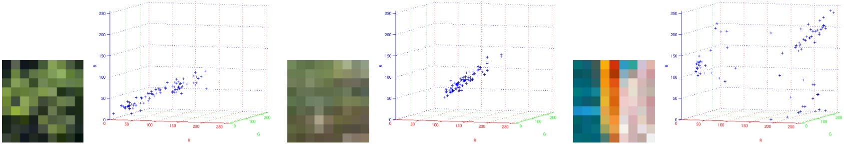
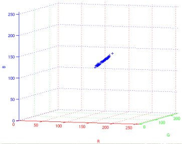
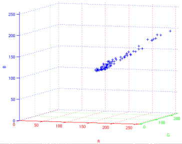


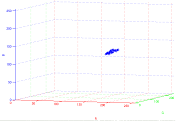
Image: Phi Phi Lay Island, Thailand by Diego Delso, Wikimedia Commons, License CC-BY-SA 3.0

https://commons.wikimedia.org/wiki/File:Isla_Phi_Phi_Lay,_Tailandia,_2013-08-19,_DD_04.JPG

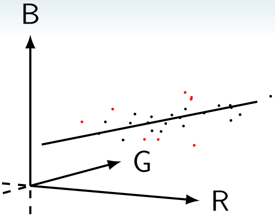
Color line in hazy images







Estimating $\hat{A}$

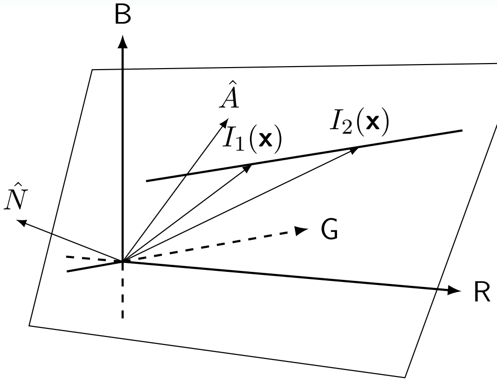


For each patch in the image

1. Apply RANSAC on the patch to compute the line ($\vec{P} = \vec{P_0} + \rho\vec{D}$). RANSAC returns a set of inliers and two points on the fitted line.
2. Compute the normal($\hat{N}$) to the plane containing the line and the origin.

Estimating $\hat{A}$

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



The plane containing the color line and origin will also contain the $I(\mathbf{x})$'s and $\hat{A}$.

Estimating $\hat{A}$

$\hat{A}$ is contained in all the planes formed by the lines of each patch and the origin. So, We can compute $\hat{A}$ as the intersection of those planes. This is computed by minimizing,

$$E(\hat{A}) = \sum_i (N_i \cdot \hat{A})^2 \tag{4}$$

which boils down to solving

$$\frac{\partial E}{\partial \hat{A}} = 2\Big(\sum_i N_i N_i^T\Big)\hat{A} = 0 \tag{5}$$

This requires non-trivial solution of the equation. So we use eigen vector corresponding to the smallest eigen value of the matrix $\sum_i N_i N_i^T$, as the solution.

Estimating $\hat{A}$

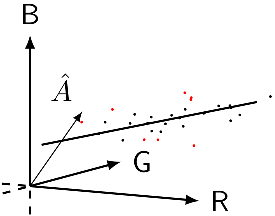
Test of estimate -

1. Number of inliers
2. All components of D is positive
3. Patch does not contain an edge (otherwise the assumption of a line in RGB space fails)
4. Not through origin

We discard the estimated line if test 1-3 fails and we discard the plane if test 4 fails.

Estimating $a(\mathbf{x}) = (1 - t(\mathbf{x}))m(\mathbf{x})$

Now, we have $\hat{A}$. $(I(\mathbf{x}) = J(\mathbf{x})t(\mathbf{x}) + (1 - t(\mathbf{x}))m(\mathbf{x})\hat{A})$
We can compute the shift of the estimated line.



The shift of the line from the origin is computed using,

$$E_{line}(\rho, s) = \min_{\rho, s} \|P_0 + \rho D - s\hat{A}\|^2 \quad (6)$$

where s will provide $(1 - t(\mathbf{x}))m(\mathbf{x})$.

Estimating $a(\mathbf{x})$

Test of estimate -

1. Intersection angle test (angle between $\hat{A}$ and D)
2. Intersection test (value of $\min_{\rho,s} \|P_0 + \rho D - s\hat{A}\|^2$)
3. Range test
4. Variability test (variation of the patch RGB values)

We discard the estimate if it fails these test.

Interpolating estimate

As we are discarding quite a few estimates all the pixels will not receive an estimate. So, we need to interpolate. This is done via minimizing the following,

$$\psi(a(\mathbf{x})) = \underbrace{\sum_{\Omega}\sum_{\mathbf{x}\in\Omega}\frac{(a(\mathbf{x})-\tilde{a}(\mathbf{x}))^2}{(\sigma_a(\Omega))^2}}_{\text{assuming the error as Gaussian}} + \underbrace{\alpha\sum_{\mathbf{x}}\sum_{\mathbf{y}\in L(\mathbf{x})}\frac{(a(\mathbf{x})-a(\mathbf{y}))^2}{\|I(\mathbf{x})-I(\mathbf{y})\|^2}}_{\text{Interpolates the estimate}} + \underbrace{\beta\sum_{\mathbf{x}}\frac{a(\mathbf{x})}{\|I(\mathbf{x})\|}}_{\text{varies } a \text{ with intensity}} \tag{7}$$

where is $\tilde{a}(\mathbf{x})$ is the estimated airlight component value, $L(\mathbf{x})$ gives neighborhood of $\mathbf{x}$ in the image and $a(\mathbf{x})$ is the airlight component to be computed.

Interpolating estimate

The previous equation(eq (7)) can be written in the matrix form as,

$$\Psi(a) = (a - \tilde{a})^T \Sigma (a - \tilde{a}) + \alpha a^T L a + \beta b^T a \tag{8}$$

where a and $\tilde{a}$ are the vector form of $a(\mathbf{x})$ and $\tilde{a}(\mathbf{x})$.
Σ is a covariance matrix of the pixels where estimate exists.
L is the Lapacian matrix of the graph constructed by taking each pixel as one node and connecting neighboring nodes. The weight of the edge between node $\mathbf{x}$ and $\mathbf{y}$ is $\frac{1}{\|I(\mathbf{x}) - I(\mathbf{y})\|^2}$.
Each element of b is $\frac{1}{\|I(\mathbf{x})\|}$ and α and β are scalar controlling the importance of each term.

The solution is obtained by solving,

$$(\Sigma + \alpha L)a = (\Sigma \tilde{a} - \beta b) \tag{9}$$

Recovery

We have $\hat{A}$ and $a(\mathbf{x})$. So, airlight is obtained at each pixel by computing $a(\mathbf{x})\hat{A}$. We recover the direct transmission as follows,

$$J(\mathbf{x})t(\mathbf{x}) = I(\mathbf{x}) - a(\mathbf{x})\hat{A} \tag{10}$$

As we don't have $t(\mathbf{x})$, we enhance the contrast using the airlight and try to recover $J(\mathbf{x})$. Let's say the recovered image is $J'(\mathbf{x})$, then

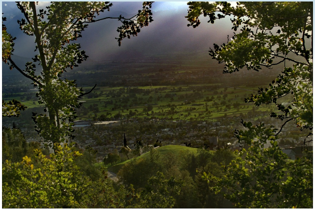
$$J'(\mathbf{x}) = \frac{J(\mathbf{x})t(\mathbf{x})}{1 - Y(a(\mathbf{x})\hat{A})} \tag{11}$$

$$Y(I(\mathbf{x})) = 0.2989 * I_R(\mathbf{x}) + 0.587 * I_G(\mathbf{x}) + 0.114 * I_B(\mathbf{x}) \tag{12}$$

$Y(\mathbf{x})$ is Rec. 601 luma

Result

(a) Original

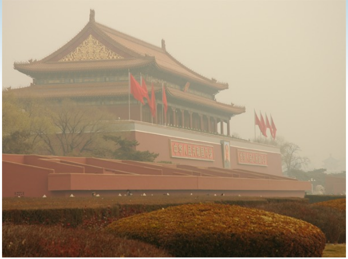


(b) Our method

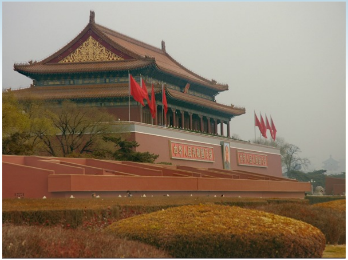
(c) Fattal color line

(d) He et al.

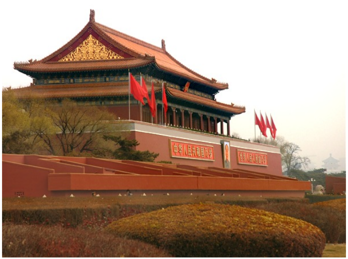
Result



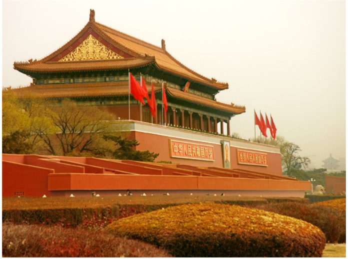
(a) Original



(b) Our method



(c) Fattal color line



(d) He et al.

Failure cases

(a) Original

(b) Our method

Figure: Sky becomes yellow after dehazing

Failure cases

(a) Original

(b) Our method

(c) Fattal color line

(d) He et al.

Conclusion

- Atmospheric light is not always constant throughout the image.
- That is why the relaxed equation handles atmospheric light better.
- Estimating the atmospheric light from multiple patches is more robust.

More results can be found from:
`www.isical.ac.in/~sanchayan_r/dehaze_ncvpripg15`

References

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Thank You